THE STEEL FOUNDRY

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BY

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ERRATA

In section A5, Chapter II, the method of estimating cost of steel *per ton of good castings* is incorrect, because the credit deducted for scrap value is that for .60 tons of good castings, not for 1 ton. For example, on page 19, lines 5, 6 and 7, the text should read:

"Estimating 60 per cent. good castings, 40 per cent. scrap, we have $19.28, less credit for .40 tons scrap at $14.00 per ton ($5.60) = $13.68, cost of metal for .60 tons good castings; $\frac{13.68}{.60}$ = $22.80 per gross ton of good castings."

Make corrections for this error as follows:

Page	Line of text	Table on Page 26, line	For	Read
19	7	1	$26.53	$22.80
20	7	2	29.92	26.45
21	7	3	36.33	32.87
22	6	5	38.18	34.72
23	7	6	49.23	45.50
25	8	8	96.87	93.40
26	6	7	61.50	58.03
26	8		1.2 cents	1 cent
26	9		4.3 cents	4.2 cents

Hall's, The Steel Foundry.

PREFACE

In this work the object has been to set forth the metallurgy of the steel foundry from the point of view of the engineer who keeps constantly in mind that his is a profession whose usefulness consists in prescribing the cheapest means of producing objects or structures of sufficient excellence for the purposes for which they are intended. The aim of the engineer in his work should be three-fold—to produce an article that will completely serve its purpose, to provide in the object the highest excellence that is justified by the use for which it is intended (and hence the price that can be paid for it), and to produce these objects at the least possible expense.

In the present volume are considered the classes of steel castings that are in demand in this country to-day, and their characteristics from a manufacturing point of view; the types of steel-making processes that are in use, and their characteristic features, such as relative cost of installation, relative cost and quality of steel produced, etc., that prescribe the use of one or another for manufacturing the sort of castings desired; and the procedure throughout the shop, such as moulding, pouring, annealing, etc., in the light of its influence on the quality and cost of the product. It is the hope of the author that this volume will prove of interest and benefit to steel foundry metallurgists and superintendents, and to the managers, officers and stockholders of existing or projected foundries; and to their judgment he submits these pages, hoping to be repaid for the labor of authorship by the knowledge that they have assisted to some degree the efforts of his co-workers in the great field in which we all labor.

The author wishes especially to thank Professor Joseph W. Richards, Professor Albert Sauveur, Professor Henry M. Howe, and Mr. Arthur Simonson for valuable advice and counsel; and Mr. A. H. Jameson and the David Williams Company for permission to reprint the article from the "Iron Age" on the building-up of impurities in steel. Certain of the micrographs and data in the chapter on heat-treatment have already been published in the author's papers before the American Institute of Mining Engineers and the American Society for Testing Materials; they are republished here with more detailed comment and explanation.

New York City, January, 1914.

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CHAPTER I

INTRODUCTORY

The function of the steel foundry is to produce by casting in sand or other moulds, steel shapes that cannot be rolled or forged; or that would require special equipment for rolling and forging, that is not justified by the number of the particular article wanted. Thus many steel articles that would be made by drop forging or press forging in dies, if wanted by the hundred or thousand, are made of cast steel when not enough are to be purchased to pay for the expensive dies required. The foundry, therefore, supplies the country with steel shapes often more costly than rolled or forged shapes; and herein lies one of the most vexatious features of the business.

In general, steel foundries may be roughly divided into three classes, according to the market in which they sell their castings. These are, first the Tonnage Foundry, that is the foundry supplying great numbers of castings from relatively few patterns, generally of shapes that can be made only of cast metal, and frequently bidding for long term orders on a flat rate per pound of steel. Such are the foundries furnishing draw bars and knuckles, bolsters, etc., for railroad cars, frames, driving wheel centers and other castings for locomotives, and other work of that general nature. The problem of these foundries in working to make a profit is similar to that of the rolling mills, and may be summarized as that of turning out a heavy enough tonnage of comparatively simple work at a small profit per pound, to return a dividend on the investment. The effort in these shops is concentrated on producing the greatest possible number of castings per day, and everything must be arranged to keep a constant flow of work passing through every department—delays are fatal. In many ways the problems in these shops are the easiest of solution to be met in the business, since the constant production of one class of castings lends itself naturally to the introduction of labor-saving devices suited to the particular sort of work being handled, and from the familiarity attained by constant repetition the men throughout the shop learn naturally the quickest ways of performing each detail of the operations. Raw materials, tools, equipment of every sort can be standardized, processes adopted or rejected according to how well they fit in with the primary object of keeping the output moving steadily through the shop, and the operation of the plant made almost automatic. The desired quality of the product is known, and improvements consist almost entirely in devising means of producing a superior article without interfering with the routine (and hence raising cost), in order that the salesmen may have an additional argument in favor of their goods and not be forced to shade prices to the last inch to get orders.

The second class is the Jobbing Foundry, a familiar name and a most expressive one, as shops of this class handle all the odd jobs that come along. Here are brought the miscellaneous machinery castings, automobile and truck castings, shapes that would be made by forging or rolling if wanted in quantity, and job lots of all sorts. The jobbing foundryman has a very different problem on his hands from that of the tonnage man, and his position is often an unenviable one. Frequently, one might almost say invariably, the number of castings to be furnished from each pattern is so small that a very few spoiled castings spell loss instead of profit on the order. The tonnage manufacturer has the opportunity to experiment with his patterns, change sections here and there, add fillets and brackets where needed, and generally get posted up by preliminary experiments on each pattern, and then start in and turn out finished work almost without thinking about details. The jobbing expert, on the other hand, must constantly foresee the difficulties to be encountered by the light that is in him, and must know almost by instinct the precautions to be taken in moulding and pouring to get a solid casting, the amount of metal that will be required for sink heads, gates, etc., and thus be able to fix a price that will yield him a profit. This price generally has to be so fixed as to cover the inevitable lost castings, which no human foresight or experience can entirely prevent; and the jobbing foundryman above all must have an unerring eye for the casting that from some peculiarity of design cannot be cast at all without a large number of "wasters," and must persuade the customer to alter the fatal features of the design, or turn the order down altogether. These are the cats and dogs of the business, and many are the wiles of the casting buyer in foisting them upon the unwary at prices that mean loss.

Another woe of the jobbing foundryman is the small casting that really should be a forging, on which he expends money for patterns, or for wasters made in experimenting on a small order, counting on subsequent orders produced without trouble to reimburse him—only to find that the machine of which his castings form a part is a success and is to be manufactured in quantity, justifying expense for dies to forge the parts and leaving the foundryman a sadder and a wiser man. The jobbing man's one really happy time is when business is so good that everyone is rushed to the limit, and orders are placed chiefly on quick delivery; then the overflow from the tonnage foundries comes to his shop and he waxes fat on standard work that can be easily and cheaply produced, and is paid his high prices because the work is wanted at once.

Our third class is composed of the foundries making a specialty of some alloy steel of particular excellence for certain purposes, or of some class of difficult castings especially suited to a particular steel-making process, and hard to make by any other. Almost as a matter of course the output of these foundries is a small one, and the profit per pound large. If the output were large, the tonnage foundries would gobble the work, especially when the specialty is in the shape of the casting rather than in the kind of steel; a large ouput in sight for a few difficult shapes of course justifying the installation of the special method of making steel needed, and the production of the work in quantity at a small profit per pound.

The Specialty Foundry, therefore, may partake of the characteristics of the jobbing foundry or of the tonnage foundry, according to the nature of the specialty—steel, or shape of casting. The foregoing remarks upon the two classes apply with equal force to this third class, and in the case of special steels the remarks upon the difficulties of jobbing work apply with even greater force, since to the difficulties of producing constantly varying shapes of work are added those of handling a steel frequently troublesome, for one reason or another, to produce even in simple shapes. Many an unwary foundryman has learned to his sorrow the difficulty of getting a share of the business of the manufacturer of special steels, who sells his product at a high figure because he must do so to make a profit, and is protected from competition by the smallness of his tonnage and the knowledge of the fine points of his process gained from years of experience. In the present condition of the foundry business, when there are perhaps more makers of castings than the demand justifies, so that price (and hence quality), are hammered down to the last possible inch, the payment of high prices for the output of a particular foundry means that that foundry has mastered a specialty that cannot be made on a "tonnage" basis, and competitors feeling around for business to fill up their shops in slack times should be very sure of their ground before going after a share of the specialty man's business, lest they get caught in the unforeseen difficulties of the specialty, and suffer considerable loss before they quite know how it happened.

Naturally, no hard and fast lines can be drawn between the three classes of foundry work into which the field is divided, and a particular shop may do business more or less along two or three of the general lines. Many a jobbing foundry has its specialties, which help to pay the profits of the business; many specialty foundries do a jobbing business to increase production and cut down overhead expenses; and either one may have standard lines that can be and are handled by methods similar to those of the tonnage shop. The management of a projected foundry, or of a foundry which is not paying the profits it should and is being reorganized, will do well to scrutinize their market closely and ascertain definitely the class in which they belong, in order to determine the direction in which their efforts should be directed to develop the business to the best advantage. For instance, the producers of a special steel, of which they have long enjoyed a monopoly, may find competition springing up and cutting seriously into their volume of sales. Investigation will probably show that they are in the habit of accepting orders only for such work as can be easily turned out; that methods of handling raw material and keeping product moving through the shop are archaic; and possibly that cheaper methods at various points of the process can be adopted to the betterment as well as cheapening of the product. The shop has been a pure specialty maker, and has neglected much of the jobbing work that it might have handled at a profit, and has not adopted the more modern methods that enable tonnage work to be produced cheaply. By improved handling methods, much of the output can be made at considerably reduced costs, and by accepting a wider range of orders for micellaneous work which can be obtained at high figures, output will be increased and the cost of steel correspondingly decreased.

New companies should be particularly cautious in entering the field without sure knowledge of the conditions to be faced. The tonnage shop, of course, is seldom started up except by large interests backed by ample capital, and often closely allied with consuming industries, so that the organizers have an assured tonnage in sight and are perfectly cognizant of the nature of their problem. Not so the small companies organized to carry on a jobbing or specialty business, often attracted by the supposedly fat profits of established companies, and incautiously entering the field with only sufficient capital to build a plant and carry on operations for a few months. The profits counted upon to carry on the business are in too many cases not forthcoming, due to losses arising from inexperience in fixing prices and handling odd castings in a jobbing business, from the unexpected difficulties encountered in the manufacture of special steels in complicated shapes, or what not. The troubles of many of the small foundries in the first few years of their life, which so often result in the closing down of the shop, arise in most cases from bad judgment on the part of the promoters in going into the business with only a half knowledge of the conditions to be faced. Without technical knowledge of steel making, and often without experience in the foundry business, they make mistakes in the selection of a steel-making method, of a plant location, of a type of furnace, or some such matter, that are too often fatal to the success of the shop.

CHAPTER II

GENERAL CONSIDERATIONS GOVERNING THE CHOICE OF A METHOD OF STEEL MAKING

The foundry is divided into the following departments, not all of which are included on the premises of every shop, although with the occasional exception of the last, the functions they perform are a necessary part of the production of the castings.

1. Steel making and raw material handling.
2. Pattern making.
3. Sand mixing.
4. Moulding and core making.
5. Casting.
6. Cleaning.
7. Annealing and heat treatment.
8. Finishing, straightening, welding, etc.
9. Laboratories.

In this chapter are set forth the general considerations governing the choice of the steel-making method to be adopted, the processes of steel making available, and the characteristic features of those processes which must be considered in making a choice among them. The processes that can be used are:

1. Crucible.
2. Open-hearth, acid or basic.
3. Bessemer, bottom blown or side blown.
4. Electric.
5. Open-hearth, or Bessemer, and electric.

In the crucible process, puddled iron, or open-hearth scrap low in carbon, is melted in small closed pots with sufficient charcoal or washed metal (iron containing about 3 per cent. of carbon), to produce a steel of the desired carbon content. The pots contain about 100 lb. of metal each, and are heated by coal, coke, gas or oil. The process is one of pure melting, and as no impurities are eliminated from the steel, pure steel is produced only by the use of pure materials. Oxidation of the metal by the gases of the furnace is, however, largely avoided, since the steel is protected from the flame by the pot and its cover.

In the open-hearth process a shallow bath of pig iron and steel scrap is melted down in a large furnace of the bath type, in which the metal is continuously exposed to the oxidizing gases of the furnace, as the flame plays over the metal at all stages of the operation. From a bath comparatively high in silicon, manganese and carbon, these impurities are removed to the desired degree by oxidizing them, both by the action of the oxidizing gases of the furnace, and by that of a slag made oxidizing by additions of iron ore. In the acid process, sulphur and phosphorus are not removed, so that freedom from these harmful impurities is obtained only by using very pure materials. The basis process, on the other hand, does eliminate phosphorus and sulphur, but the slags necessary for this are more oxidizing than those used in the acid process, so that the steel is constantly exposed to severely oxidizing conditions. The open-hearth furnace in foundry work is generally of about 5 to 25 tons capacity.

The Bessemer process, in American practise, removes no phosphorus or sulphur from the steel, as only acid methods are used. By this process, a molten bath of pig iron and scrap high in carbon, silicon and manganese, is converted to nearly pure iron by blowing air through the metal or upon its surface, in a cylindrical vessel containing a narrow deep bath. Carbon, silicon and manganese are oxidized and removed by the oxygen of the air blast, and the composition is then adjusted by proper additions to the molten bath. The conditions in the process are violently oxidizing, especially toward the end of the "blow," when much iron is burned by the air blast. The size of a charge, in foundry work, is from ½ to 3 or 4 tons.

The electric furnace heats a bath of metal by means of the electric arc in a furnace much like an open-hearth furnace, or by means of the resistance of the metal itself to the passage of an electric current through an annular bath of small cross-section. As no oxidizing gases are introduced into the furnace, the metal is not exposed to oxidizing conditions; indeed, by proper manipulation of slag and bath, neutral or even reducing conditions are attained. Not only can carbon, silicon, manganese, phosphorus and sulphur be eliminated from the steel, but the metallic oxides are almost entirely reduced from the steel and slag. In particular, sulphur and oxides are eliminated much more thoroughly than in any other steel-making process.

The electric furnace may be used to both melt and refine the charge, but owing to the high cost of electric melting, and of removing carbon, silicon and manganese while the metal is kept hot by the electric current, it is frequently advisable to use the furnace only as a means of purifying open-hearth or Bessemer metal. Furnaces are built in capacities of from ½ to as high as 25 tons.

The detailed discussion of these processes is reserved for the following chapters, and here we shall consider them only in the light of their availability for our purposes, as influenced by the considerations governing the choice of a steel-making method, which may be summarized as follows:

A. Market:
  1. Class, *i.e.*, alloy steels, very pure ordinary steel, or just plain steel.
  2. Variability, *i.e.*, number of kinds of steel.
  3. Size of average casting, and of largest and smallest.
  4. Intricacy of castings.
  5. Price—largely governed by the above 1–2–3–4.
  6. Yearly tonnage in sight.

B. Raw material and fuel most available.
C. Capital available.
D. Competition to be faced.
E. Labor available.
F. Intermittent or steady operation.

A1. Quality.—Taking first the quality of the steel produced, the processes may be grouped as follows, in order of decreasing excellence, by which is meant the inherent good quality of the steel itself, unaffected by conditions of casting, or what not.

1. Electric—alone or in connection with Bessemer or open-hearth.
2. Crucible.
3. Acid open-hearth.
4. Basic open-hearth.
5. Bessemer—bottom blown.
6. Bessemer—side blown.

This classification is perhaps open to challenge, and the author is far from believing that it is a hard and fast one, or that it is necessarily correct under any and all circumstances. So much depends upon the raw materials used, the care and skill exercised in handling the work, the degree of refinement to which the different processes are carried, the personal equation of the operating force and the ideal of perfection adhered to by the management and held up to the men for attainment, that the excellence of the steel produced by any one method in a particular shop may be so far above or below the average for this process as to upset the classification in their case completely. In this discussion, however, are given the reasons for the above classification of the processes, assuming that in every case the maximum possible degree of excellence is kept clearly in mind, worked for, and as nearly as possible attained.

The electric furnace clearly leads, since by electric furnace refining the most injurious impurities found in steel, phosphorus and sulphur, can be removed far more completely than by any other process; and at the same time the steel can be almost perfectly freed from dissolved or suspended oxides. In the electric furnace, and only in this process, it is possible to cover the steel with a slag of almost pure silicate of lime (and in arc furnaces treat this slag with fine coke), and work the steel with ferrosilicon, so that the conditions in steel and slag are strongly reducing, instead of oxidizing as in the other processes, and the last traces of oxides are converted into the metallic form. At the same time the gases which molten steel generally holds in solution are largely eliminated, and a steel is produced that is as nearly pure as we can possibly make it. The ease with which electric furnace steel containing low carbon and only small amounts of silicon and manganese can be poured into small and intricate castings, flowing smoothly like milk, setting perfectly quietly in the sink heads, and producing castings with hardly a trace of blow holes even in the hands of comparatively inexperienced steel makers, is largely due to its great purity.

The crucible process produces excellent steel, the finest that could be made, up to the date of the introduction of the electric furnace. Some authorities may even deny that the electric product excels that of the crucible. The excellencies of crucible steel are due to the protection of the melting and molten steel by the pot and is cover from the oxidizing gases of the furnace, so that after the oxygen of the air in the pot is exhausted by the burning of charcoal used as a source of carbon, or of the carbon, silicon and manganese of the metal, the steel under its layer of slag is exposed to a practically neutral atmosphere. Moreover, silicon added purposely, or absorbed from the clay of the pot, deoxidizes the steel. Thus an excellent product is obtained, even if the raw material is merely steel scrap from the open-hearth process. If the raw material be puddled iron, for reasons which will be set forth at greater length later, a much better steel is the result. But whatever be the raw material, the excellence of the steel is due to the refining in the neutral or slightly reducing atmosphere of the pot, of metal that has previously been subjected to strongly oxidizing conditions, either in the puddling furnace, the open-hearth furnace or the Bessemer vessel.

Though there is evidence tending to show that the metal is freed from oxides to a considerable extent in the puddling furnace, and that the puddled metal is further improved in crucible melting; yet it is impossible to conceive that with the surely moderately reducing conditions in the pot, even puddled metal, much less open-hearth steel, can be freed from oxides to as great an extent as is possible in the electric furnace. We believe that with the greatest care used in both processes, electric steel will excel crucible steel, and that on the average electric steel far outstrips the crucible steel generally made for castings, using open-hearth steel scrap as raw material.

That crucible steel is superior to open-hearth steel is widely accepted, and some of the reasons for that superiority are suggested by the foregoing discussion. In the open-hearth furnace the metal is subjected to strongly oxidizing conditions throughout the process, and the means at the disposal of the steel maker for reducing the oxides of iron absorbed by the steel are insufficient to carry this deoxidation to anything like completion. Hence the quality of the steel produced is inferior to that of crucible or electric furnace steel.

In acid open-hearth practice, no phosphorus and sulphur are removed from the steel, and there is even a slight gain in these impurities, while in the basic furnace the conditions are such that phosphorus and sulphur are largely eliminated; yet more strongly oxidizing slags are used in the basic furnace, and in order to facilitate the removal of phosphorus and sulphur the steel is often refined down to a very low content of carbon, which makes it more easily oxidized, and hence promotes the absorption of oxides. Add to this the fact that very impure grades of scrap are largely used in the basic furnace, and that the deoxidizing additions are generally so used that their effect is much less complete than in acid practice, and we have an array of considerations that point clearly to the superiority of acid over basic open-hearth steel. In some shops it has been found that this superiority can be measured roughly in terms of strength, and that for equal strength basic steel must have 5 "points" more carbon than acid steel.

We now come to the discussion of the excellence of Bessemer steel, and its classification relative to open-hearth. Here the author confesses he is in doubt, and hesitates to classify Bessemer steel as made for castings, below basic open-hearth. After long deliberation, the following discussion appears to him reasonable.

In Bessemer steel making air is blown through a bath of iron containing much carbon, silicon and manganese, or a blast of air is projected strongly upon the surface of such a bath. By the oxidizing action of the air, the carbon, silicon and manganese are converted to CO (gas), and to SiO_2 and MnO, the first escaping, the last two going to form slag. That much iron must at the same time be oxidized where the excess of air is great, especially at the end of the blow when the iron is no longer protected from such oxidation by carbon, silicon and manganese, is axiomatic, and is conclusively proved by the considerable loss of iron in conversion. That the oxidation by the blast is greater than the oxidation in the open-hearth furnace by the gases and the oxidizing slag, is undeniable. At the end of the blow, after the maximum oxidation of iron has taken place, the vessel is at once turned down, containing a steel very rich in oxides and gases (as shown by its "wildness," if we try to pour it at once), and we add ferrosilicon and ferromanganese to reduce the oxides. In the open-hearth process the oxidizing conditions grow less severe as the process proceeds, and we allow the steel to boil for some time, during which it undoubtedly frees itself from part of the oxides absorbed in the earlier stages of the process.

Open-hearth steel is, therefore, purer than converter steel, before the deoxidizing additions are made; and if these additions are used in such a way that their effect is as complete in the one case as in the other, the superiority of the open-hearth steel will be maintained. Since open-hearth steel in foundry work is generally poured into larger ladles than is Bessemer steel, solid additions in the ladle have longer to act, and hence do their work more thoroughly, in open-hearth practice. When the additions are made to the open-hearth furnace, they deoxidize the steel more completely than similar additions made to the Bessemer converter, because they have longer to act. But liquid additions to the Bessemer vessel or ladle probably do their work more thoroughly than solid additions to ladle or furnace. It is, of course, possible to use liquid additions in open-hearth practice, but it is seldom done, and in fact the additions are quite generally made in the ladle. Bessemer foundrymen, on the other hand, usually prefer to make their additions to the vessel, and many of them use melted material.

Open-hearth metal, therefore, can be made superior to Bessemer, but there is no doubt that owing to the more complete deoxidation often attained in Bessemer practice, much of the open-hearth steel poured in foundries is actually inferior to the best Bessemer steel made for similar purposes.

That bottom-blown Bessemer steel should be ranked above side-blown may surprise many readers, since it would seem at first glance that air blown through the metal must oxidize more iron than air blown upon the surface of the metal. However, partly because the higher temperature of side-blown steel promotes oxidation of the iron and absorption of the oxide by the steel, partly because in the bottom-blown vessel, the iron oxide formed is largely reduced again by the carbon of the overlying bath, actually the loss of iron is considerably greater in the side-blown vessel than in the bottom-blown. It would appear, therefore, that the metal must be less pure where the greatest oxidation has occurred and the greatest opportunity given for absorption of the oxide, and that other things being equal the superior position should be assigned to bottom-blown steel. The side-blown vessel, it should be said, is almost exclusively used in the steel foundry, and in numerous shops steel of very high grade is produced.

Before leaving the subject of the quality of the steel produced by the different processes, it is well to add that there are few castings used in this country to-day that call for steel of any grade higher than crucible steel made from open-hearth scrap, and that the choice of a process is largely governed by other considerations than the quality of the steel produced. Well-designed steel castings, made by any of the old processes carefully conducted, when free from flaws and blow holes and properly annealed or heat treated are excellently adapted to the uses to which they are put and will show by tests that they possess strength and ductility far beyond what they ever will be called upon to exhibit. That there is a market to-day for crucible castings made from high-grade puddled iron or for electric furnace castings, with regard to quality alone, is open to serious question, and the foundryman who makes them will certainly find it difficult to market his goods simply because of the inherent excellence of the steel from which they are poured.

A2. Variability of Product.—This demands flexibility in the steel-making process. By this is meant the ability to produce readily steels of widely differing analyses to take care of orders for small lots of steel of special composition. Such orders form a very inconsiderable proportion of the steel foundry business, and in almost no case can be counted upon as a steady source of income-producing work. As in some special cases this may be a consideration worth taking into account, it must be touched on briefly here.

In order of decreasing flexibility, the processes are:

1. Crucible.
2. Electric.
3. Bessemer.
4. Open-hearth.

The flexibility is, of course, determined by the weight of metal in each lot melted and by the difficulty of dividing a lot into parts. On the score of weight of lots, the flexibility is therefore in the order of capacity; but the capacity in the case of crucible melting is not that of the whole furnace, but that of a pot. In crucible melting, of course, each pot is a law unto itself, so that within limits as many different steels may be melted at once as there are pots in the furnace. Indeed, as we shall see, the difficulty in crucible work is just the other way around, and great efforts must be made to produce uniform steel. There are certain sorts of steel, such as very low carbon, that are hard to produce from crucibles, but the process is out and away the most flexible.

The contents of an electric furnace may be brought to a certain composition, enough steel of this sort poured off for the purposes in hand, and the composition of the bath then changed to suit other requirements. It is easy to see that only the small furnace lends itself to such treatment, as the expense of so handling 10 or 15 tons would be prohibitive. Or, we may produce steels of different compositions from a uniform bath by making our additions in the ladle. There are two objections to this method, which are first, that it sacrifices the benefit of thoroughly mixing our steel in the furnace, and second, that it is difficult to weigh accurately the amount of steel poured out, and so to secure correct composition.

In Bessemer work, after the steel is blown no further heat is added to it, and it begins to cool as soon as the vessel is turned down. Therefore, the only method of making different compositions of steel from one heat is to do the mixing in the ladle. The same considerations apply to this as to doing the same thing with an electric furnace, and in practice the method is rather unsatisfactory. The chief difficulty is the slag, which, if fluid, cannot be held back in pouring, and makes it practically impossible to pour the proper quantity of metal into each ladle. As the metal cools quite rapidly, it must be handled without much delay. For this reason, not over two kinds of steel can be made from one heat. The Bessemer process is, therefore, less flexible than the electric.

In open-hearth work, it is almost out of the question to make more than one kind of steel at a time. The furnaces being of large capacity it is not commercially practicable to make different compositions successively in the furnace; and the steel rushes so rapidly from fixed furnaces that even with a bifurcated spout the accurate proportioning of steel to each of two ladles is extremely difficult. Should the furnaces be tilting, not fixed, more can be done in this line, but even then we have the slag to hamper us and very little flexibility is practicable. To transfer steel of low carbon from one ladle to another of smaller capacity and so produce two steels at one tap is somtimes practicable, but the limit of such procedure is soon reached by the cooling of the steel.

A3-4. Size and Intricacy.—The processes in order of decreasing suitability for pouring small and intricate work can be tabulated as follows:

1. Crucible.
2. Electric.
3. Side blown Bessemer.
4. Bottom blown Bessemer.
5. Acid open-hearth.
6. Basic open-hearth.

This classification is a difficult one to fix arbitrarily, since there are many factors in the problem to be taken into consideration, which in particular cases may shift the relative positions of the processes.

To take a single instance, electric steel, owing to its great purity and freedom from gas, and to the high temperature at which it may be poured, is eminently suited to pouring castings of the very lightest weight and of very thin section. Many excellent castings that have been regularly poured of electric steel would be almost impossible to produce by the older processes. Should the electric furnace that is being used be of small size, therefore, especially if the steel is taken from the furnace in small ladles or shanks, the electric furnace may well handle work that even the crucible foundryman would hesitate to tackle.

On the other hand, the crucible process is pre-eminently one of small units. The average pot contains from 90 to 100 lb. of steel, and it has never proved economical to melt in larger crucibles. The steel can be made exceedingly hot, fluid, and free from gas, runs well in very light sections, and is kept hot by the hot pot, a very poor conductor of heat and so shaped as to present a very small surface of liquid steel compared to its mass. When the practice of pouring from the pots is followed, the steel can be brought to the moulds very hot, and all poured before it has an opportunity to chill. It would have to be a very small electric furnace indeed that would make it economical to shank off the steel in such very small lots that it would all be poured in light castings at the maximum temperature, and if the steel be poured directly from a large ladle it is impossible to do good work with very small castings, besides which the steel in the ladle would soon chill, at the very slow rate at which it would be disposed of. To "shank" from the large ladle manifestly would not bring the steel, especially that from the last of the ladle, to the moulds at as high a temperature as that of the pots kept hot in the crucible furnace until wanted. Lastly, the cost factor enters into this question very strongly, since the smaller electric furnaces cost very much more to operate per ton of steel than the large ones, the cost increasing in inverse ratio to the size. Hence to pour exclusively light work, using a number of small electric furnaces, considerably increases the cost of the steel in the ladle over what is possible with furnaces of 5 to 10 tons. In the crucible process, on the other hand, the unit of weight per pot is fixed and does not enter into the problem of cost of steel which is determined by the size and style of furnace used. The cost per pound of steel decreases with the increase in number of pots melted per day, and the process is as well suited to a large production of very light work as to a small tonnage. The leading position is, therefore, given to the crucible process, with the qualifying statement that other considerations may in particular cases put the electric furnace in the lead.

Again, the advocates of the small Bessemer converter, especially of the side-blown vessel of about 2 tons capacity, point out that their process is in many ways excellently adapted to the production of the very lightest work. The temperature of the metal can be made very high, the total tonnage of steel to be disposed of per blow is low, and by keeping the steel hot in the vessel and pouring from shanks, or pouring from a ladle with a number of shanks, extremely light castings can be poured. To this we may answer that as compared with the electric or crucible furnace of equal daily tonnage, the steel will undoubtedly chill faster in the unfired, although hot, vessel or ladle, than in the furnace, so that the last of the heat will often be colder in Bessemer practice than in the other processes, in spite of its initial extreme heat. Coupled with this is the fact that Bessemer steel is necessarily very full of oxides and gases, and hence "wild," when the vessel is turned down, and the time allowed for the action of the deoxidizers being short, the steel is never as pure, gas free and smooth flowing as crucible or electric steel. We are compelled, therefore, to conclude that in its nature the Bessemer process is less suitable to the production of a large tonnage of very light work than either the crucible or the electric process.

The side-blown Bessemer vessel as a general rule produces much hotter steel than the bottom-blown, and hence can be used for the manufacture of lighter castings. The higher temperature of the metal is perhaps offset to a certain extent by its greater sluggishness, due to the larger amount of oxides absorbed. This, however, is not proven, and is suggested as a possibility rather than stated as a fact. In some shops, where the bottom-blown vessel is run by men of exceptional skill and experience, it has been successfully used for extremely light work. As commonly handled, however, the side-blown vessel does better work on light castings than the bottom-blown.

The open-hearth furnace is not at all suited to light work. This is due to the generally large tonnage produced at a heat, and to the fact that the whole heat is from the necessities of the case commonly poured at once. Both of these factors militate against the pouring of large numbers of small castings, since the steel would be seriously chilled before all of it could be run into light work. The use of nozzles to pour with, and the necessarily large and violently flowing stream involved, prevents the proper pouring of small castings. Moreover, the steel is not so hot as that produced by the other processes and is less pure and well killed than crucible or electric steel. For castings averaging over 50 or 100 lb., on the other hand, the open-hearth furnace is the most suitable of the processes, especially as this heavy work commonly requires only a good average grade of steel and there is no incentive to the use of higher grade materials.

That basic open-hearth steel is less well killed, more oxidized, and contains more gas, and is therefore "wilder" and more difficult to pour into light work than acid open-hearth steel, is in the opinion of the author widely accepted, and certainly is in line with theoretical considerations of the case.

Recently a special design of small open-hearth furnace (W. M. Carr's combined furnace and ladle), has come into notice, and exceedingly good work has been done with these furnaces in pouring very pure metal into light castings. We doubt, however, if there is sufficient evidence at this time of the economy of these furnaces on light work to justify a rearrangement of this classification in the case of the open-hearth furnace.

A5. Price of Castings.—The price paid for castings of a given sort of steel is largely governed by the size and intricacy of the castings, since this involves the amount of moulding and core making time spent upon the mould per pound of casting, the difficulty of securing good castings, etc. Though special prices are paid for alloy steels, that of ordinary carbon steel castings does not at present depend upon quality as such. The desideratum is a casting as free as possible from blow holes, cracks and flaws and other defects, of a steel well enough made and annealed to pass the usual specifications. Since the tests commonly specified are intended to exclude only badly made and annealed steels, they are comparatively easy to pass with steel made by any of the commercial processes. With a comparatively few exceptions, therefore, superior quality, whether due to the steel-making methods used, or to the heat treatment put upon the steel, will not ensure higher prices and the more costly processes should be adopted only when they are absolutely needed to produce sound castings from the patterns to be handled. It should be remembered, however, that the cost of the steel is not the only factor in the cost of the castings.

The processes are grouped as follows, in order of increasing cost of steel, the estimates being based upon prices of raw materials in the Philadelphia market as given in the *Iron Age* for Nov. 27, 1913.

1. Basic open hearth.
2. Acid open hearth.
3. Bottom-blown Bessemer.
4. Basic open-hearth and electric furnace.
5. Side-blown Bessemer.
6. Electric furnace.
7. Gas crucible furnace, 30 pot.
8. Crucible furnace, coal holes or oil melting.

The variations in the price of raw material, fuel, power, etc., from time to time and from place to place, and the effect of fluctuating output, make these figures of value chiefly to illustrate the factors governing the costs of production. Some of the estimates, for instance that for the electric furnace, are considerably higher than many that have been published. In figuring these costs, an effort has been made to adhere as closely as possible to the conditions of practice in a small foundry, where it is not possible to secure the economies easily attained in large shops equipped with a number of furnaces, and not subject to delays, wide variations in output, etc. The figures here given are intended to represent conservative estimates of cost, that will not often be exceeded, rather than the much lower figures that can be attained when the process is being run under more nearly ideal conditions.

Costs of steel per gross ton in a 15-ton basic open-hearth furnace, burning producer gas and making 15 heats per week, or 225 gross tons.

RAW MATERIAL, assuming a conversion loss of 5 per cent., and using 40 per cent. pig, 30 per cent. purchased scrap, and 30 per cent. shop scrap.

Fifteen tons÷.95=15.79 tons, of which .135 will be ferros, leaving 15.655 tons, of which

6.262 tons will be pig,
4.6925 tons will be purchased scrap,
4.6925 tons will be shop scrap.

6.262 tons basic pig at $15.00,	=	$94.00
4.6925 tons purchased scrap at $10.00	=	46.93
4.6925 tons shop scrap at $14.00,	=	65.70
.075 tons ferromanganese at $50.00	=	3.75
.06 tons ferrosilicon at $75.00,	=	4.50
		$214.88 or for 15 tons
		$14.33 per ton

LABOR PER WEEK

2 melters at $150 per month,	=	$69.23
2 second helpers at $2.50 per day,	=	35.00
2 ladle men at $3.00 per day,	=	36.00
2 gas makers at $2.50 per day,	=	35.00
4 common laborers at $2.00 per day,	=	48.00
		$223.23

Production per week 15×15=225 tons. $\frac{223.23}{225}$ =$.99 per ton

SUMMARY

	Per ton steel tapped
Raw material	$14.33
Labor	.99
Coal, 700 lb. at $3.00	.94
Yard labor	.15
Repairs and maintenance	.75
Supplies and miscellaneous	.75
Management 50 per cent. of labor	.47
	$18.38

Interest and depreciation, 15 per cent. on $65,000 = $9750 per year. At 225 tons per week, 48 weeks per year, we produce 10,800 tons of steel. This item then amounts to about $.90 per ton, bringing our total cost to $19.28 per gross ton.

Estimating 60 per cent. good castings, 40 per cent. scrap, we have $\frac{19.28}{.60} = \$32.13$ per ton of good castings, less credit for .40 ton scrap at $14 per ton = $5.60, or $~~26.53~~ 22.80 per gross ton of good castings.

W. M. Carr gives in his book, "The manufacture of open-hearth steel castings," the following figures on the cost of installation of open-hearth plants, on which the above estimate is based.

ITEM	Cost of installation per ton of steel
Basic furnace	$1200
Gas producers, etc	600
Power, machinery, cranes, etc	2300
	$4100

On this basic, a 15-ton furnace will cost $61,500, not including buildings.

Costs of steel per gross ton in a 15-ton acid open-hearth furnace, burning producer gas and making 16 heats per week or 240 tons.

RAW MATERIAL, assuming a conversion loss of 4 per cent., and using 20 per cent. pig, 30 per cent. shop scrap and 50 per cent. purchased scrap.

Fifteen tons ÷ .96 = 15.63, of which .22 tons will be ferros, leaving 15.41 tons, of which

3.08 tons will be pig,
4.63 tons will be shop scrap,
7.70 tons will be purchased scrap.

3.08 tons low phosphorus pig at $22.00	$67.76
4.63 tons shop scrap at $13.00	60.19
7.70 tons low phosphorus scrap at $14.00	107.80
.09 tons ferrosilicon at $75.00	6.75
.13 tons ferromanganese at $50.00	6.50
	$249.00 or $16.60 per ton

LABOR

$223.23 ÷ 240 = .93 per ton

SUMMARY	Per ton steel tapped
Raw material	$16.60
Labor	.93
Coal	.94
Yard labor	.15
Repairs and maintenance	.60
Supplies and miscellaneous	.60
Management 50 per cent. of labor	.47
	$20.29

Interest and depreciation, 15 per cent. on $60,000 = $9000 per year. At 240 tons per week, 48 weeks per year, we produce 11,520 tons of steel. This item then amounts to $.78 per ton, bringing our total cost to $21.07 per ton of steel in ladle.

Estimating 60 per cent. good castings, 40 per cent. scrap, we have $\frac{21.07}{.60} = \$35.12$ per ton of good castings, less credit for .40 tons scrap at $13.00 per ton = $5.20, or $~~29.92~~ 26 45 per gross ton of good castings.

W. M. Carr (*loc. cit.*) gives cost of installation of acid open-hearth plants, not including buildings, as follows:

ITEM	Cost of installation per ton of steel
Acid furnace	$1000
Gas producers, etc	600
Power, machinery, cranes, etc	2300
	$3900 or for a 15 ton furnace, $58,500

Costs of steel per gross ton in a 3-ton bottom-blown Bessemer vessel, making 15 heats per day or 45 tons.

RAW MATERIAL, assuming a melting and conversion loss of 12 per cent., and using 60 per cent. pig, 30 per cent. shop scrap, 10 per cent. purchased scrap.

Three tons ÷ .88 = 3.41 tons, of which .05 tons will be ferros, leaving 3.36 tons, of which

2.016 tons will be pig,
1.008 tons will be shop scrap,
0.336 tons will be purchased scrap.

2.016 tons low phosphorus pig at $22.00	$44.35
1.008 tons shop scrap at $13.00	13.10
0.336 tons low phosphorus scrap at $14.00	4.70
0.024 tons ferrosilicon at $75.00	1.80
0.026 tons ferromanganese at $50.00	1.30
	$65.25 or $21.75 per ton

Labor	Per day
Charging cupola and yard, 4 men at $2.00 per day	$8.00
1 cupola tender at $3.00 per day	3.00
1 cupola tender helper at $2.00 per day	2.00
4 vessel men at $2.50 per day	10.00
1 blower at $5.00 per day	5.00
	$28.00 or $.62 per ton

Summary	Per ton of steel in ladle
Raw material	$21.75
Labor	.62
Fuel, ⅕ ton coke at $5.00	1.00
Repairs and maintenance	.40
Supplies and miscellaneous	.25
Power	.20
Management 50 per cent. of labor	.31
	$24.53

Interest and depreciation, 15 per cent. on $35,000 = $5250 per year. At 300 days per year, 45 tons per day, we produce 13,500 tons of steel. This item then amounts to $.39 per ton, bringing our total cost to $24.92 per gross ton of steel in ladle.

Estimating 60 per cent. good castings, we have $\frac{24.92}{.60}$ = $41.53 per ton of castings, less credit for scrap, .40 tons at $13.00 = $5.20, giving us $~~36.33~~ 37.87 per gross ton of good castings.

Costs of steel per gross ton in two 2-ton side-blown Bessemer vessels, making 10 heats per day, or 20 tons.

Raw Material, assuming a melting and conversion loss of 16 per cent., and using 50 per cent. pig, 30 per cent. shop scrap and 20 per cent. purchased scrap.

Two tons ÷ .84 = 2.38 tons, of which .034 tons will be ferros, leaving 2.346 tons, of which

1.173 tons will be pig,
.7038 tons will be shop scrap,
.4692 tons will be purchased scrap.

1.173 tons low phosphorus pig at $22.00	$25.81
.7038 tons shop scrap at $13.00	9.15
.4692 tons low phosphorus scrap at $14.00	6.57
.016 tons ferrosilicon at $75.00	1.20
.018 tons ferro manganese at $50.00	.90
	$43.63 or $21.82 per ton

LABOR	Per day
Charging cupola and yard, three men at $2.00 per day	$6.00
1 cupola tender at $3.00 per day	3.00
1 cupola tender helper at $2.00 per day	2.00
2 vessel men at $2.50 per day	5.00
1 blower at $5.00 per day	5.00
	$21.00 or $1.05 per ton

SUMMARY	Per ton of steel in ladle
Raw material	$21.82
Labor	1.05
Fuel ⅕ ton coke at $5.00	1.00
Repairs and maintenance	.50
Supplies and miscellaneous	.25
Power	.25
Management 50 per cent. of labor	.53
	$25.40

Interest and depreciation, 15 per cent. on 25,000=$3750 per year. At 300 days per year, 20 tons per day, we shall produce 6000 tons of steel. This item then amounts to $.63 per ton of steel, bringing our total cost to $26.03 per gross ton of steel in the ladle.

Estimating 60 per cent. good castings, we have $\frac{26.03}{.60}$ = $43.38 per ton of castings, less credit for scrap, .40 tons at $13 =$5.20, or 34.72 ~~$38.18~~ per gross ton of good castings.

Costs of steel per gross ton in a 5-ton electric furnace, melting cold scrap, working double turn and making 15 heats per week.

RAW MATERIAL	
.60 ton high phosphorus scrap at $10.00	$6.00
.40 ton shop scrap at $14.00	5.60
	$11.60 per ton

LABOR	Per week
2 melters at $150 per month	$69.23
2 helpers at $4.00 per day	48.00
2 helpers at $2.50 per day	35.00
	$152.23 or for 75 tons $2.03 per ton

SUMMARY	Per ton of steel in ladle
Raw material	$11.60
Labor	2.03
Power, 900 kw.-hr. at .015	13.50
Electrodes	1.50
Repairs and maintenance	1.00
Supplies and miscellaneous	0.75
Yard handling	0.25
Management 50 per cent. of labor	1.02
	$31.65

Interest and depreciation, 15 per cent. on $30,000 = $4500 per year. At 75 tons per week, 48 weeks per year, we produce 3600 tons of steel. This item then amounts to $1.25 per ton, bringing our total cost to $32.90 per gross ton of steel in the ladle.

Estimating 60 per cent. good castings, we have $\frac{32.90}{.60}$ = $54.83 per ton of good castings, less credit for scrap, .40 ton at $14.00 per ton or $5.60, giving us $~~49.23~~ 45.50 per gross ton of good castings.

Costs of steel per gross ton in a 5-ton electric furnace, refining molten Bessemer or open-hearth metal, and making 55 heats per week or 275 tons.

LABOR	Per week
2 melters at $150 per month	$69.23
2 helpers at $4.00 per day	56.00
	$125.23 or for 275 tons, $.46 per ton

SUMMARY	Per ton of steel in ladle
Labor	$ .46
Power, 300 kw.-hr. at .015	4.50
Electrodes	.35
Repairs and maintenance	.25
Supplies and miscellaneous	.50
Management 50 per cent. of labor	.23
	6.29

Interest and depreciation, $4500 per year. At 275 tons per week, 48 weeks per year, we produce 13,200 tons of steel. This item then amounts to $.34 per ton, bringing our cost to $6.63 per ton. This is to be added to the cost of open-hearth or Bessemer metal in the ladle.

In the case of Bessemer metal, the credit for shop scrap, and also the value of scrap charged to the vessel, should be taken on a basis of about $14.00 per ton of scrap, because low phosphorus steel will be made in the electric furnace.

Costs of steel per gross ton in a 20-pot crucible steel plant, using coal holes and making 2 heats per day. Pots containing 100 lb. of steel each, bringing our output to 4000 lb. of steel per day. Pots will average 3 heats each.

Raw Material

59 lb. low phosphorus boiler plate punchings at $13.00	$.3424
1 lb. washed metal at $25.00	.0112
40 lb. shop scrap at $13.00	.2321
½ lb. ferromanganse at $50.00	.0112
½ lb. ferrosilicon at $75.00	.0167
	$.6136 or $.006136 per lb.

Labor

	Per day
1 melter at $5.00 per day	$5.00
1 pot puller at $3.75 per day	3.75
1 helper at $2.75 per day	2.75
1 helper at $2.00 per day	2.00
	$13.50 or $.003375 per lb.

Pots

1 pot worth $2.00 makes 300 lb. of steel. Pots, therefore, amount to .006666 per pound of steel.

Summary

	Per pound of steel
Raw material	$.006136
Labor	.003375
Pots	.006666
Repairs and maintenance	.001000
Management 50 per cent. of labor	.01678
	$.018855 or $42.24 per ton

	Per ton of steel
Items above	$42.24
Fuel, 4 tons hard coal at $4.00	16.00
Supplies and miscellaneous	1.00
Power	.60
	$59.84 per ton of steel in pot

Interest and depreciation, 15 per cent. or \$5000, amounts to \$750 per year. At 4000 lb. of steel per day, 300 days per year, we shall produce 536 tons per year. This item therefore amounts to about \$1.40 per ton, bringing our total cost to \$61.24 per gross ton of steel in the pots.

Estimating 60 per cent. of good castings, we have $\frac{61.24}{.60}=\$102.07$ per ton of good castings, less credit for scrap, .40 ton at \$13.00 per ton, \$5.20, bringing our total cost to \$96.87 per gross ton of good castings.

Costs of steel per gross ton in a 30 pot regenerative crucible furnace, burning producer gas, and making 6 heats per 24 hours. Production 18,000 lb. per day. Pots will average 3½ heats each.

LABOR

	Per week
2 melters at \$5.00 per day	\$60.00
4 pot pullers at \$3.75 per day	90.00
2 helpers at \$2.75 per day	33.00
2 gas men at \$2.50 per day	35.00
2 gas men at \$2.00 per day	28.00
	\$246.00 or for

108,000 lb. of steel, \$.002277 per lb.

POTS

1 pot worth \$2.00 makes 350 lb. of steel. Pots, therefore, amount to \$.005714 per pound.

SUMMARY

	Per pound of steel
Raw material (as before)	\$.006136
Labor	.002277
Pots	.005714
Management 50 per cent. of labor	.001139
	\$.015266 per pound or \$34.20 per ton

	Per ton of steel
Items above	\$34.20
Repairs and maintenance	1.00
Fuel, 1500 lb. gas coal at \$3.00 per ton	2.00
Supplies and miscellaneous	.75
Power	.20
	\$38.15

Interest and depreciation, 15 per cent. on \$30,000, amounts to \$4500 per year. At 18,000 lb. per day, 300 days per year, we shall produce 2410 tons of steel. This item therefore amounts to about $1.87 per ton, bringing our total cost to $40.02 per gross ton of steel in pots.

Estimating 60 per cent. of good castings, we have $\frac{40.02}{.60}=\$66.70$ per gross ton of good castings, less credit for scrap, .40 ton at $13.00 per ton, $5.20, bringing our total cost to $61.50 per gross ton of good castings.

SUMMARY

	Per ton molten steel	Per ton good castings
Basic open hearth	$19.28	~~$26.53~~ 22.80
Acid open hearth	21.07	~~29.92~~ 26.45
Bottom-blown Bessemer	24.92	36.33 32.87
Basic open hearth and electric	25.91	....
Side-blown Bessemer	26.03	~~38.18~~ 34.72
Electric—cold scrap	32.90	~~49.23~~ 45.50
Crucible—30-pot gas furnace	40.02	~~61.50~~ 58.03
Crucible—coal holes	61.24	~~96.87~~ 93.40

Thus we see that the cost of the steel will run from about 1.~~2~~ cents to about 4.~~3~~2 cents per pound of good castings. As casting prices range from about 3½ cents on large tonnages of simple work to 12 or 15 cents for what is generally considered average light work, it will be seen that the costly crucible process can be used only for the latter class of material, and that on the cheaper grades of castings generally produced in bulk, it is impossible to figure a profit with Bessemer or electric furnaces. The open-hearth foundries producing in bulk can shade the price the small amounts necessary to attract purchasers of heavy tonnages, and live.

A 6. Tonnage.—The yearly tonnage to be produced affects rather the size and number of the furnaces to be installed than the choice of a process, as a little consideration of the foregoing discussion will show.

Production per week for the different processes is about as follows:

3-ton bottom-blown Bessemer	90–120 heats,	270–360 tons (single turn)
15-ton open-hearth furnace	15– 18 heats,	225–270 tons (double turn)
Two 2-ton side-blown Bessemer	72 heats,	144 tons (single turn)
One 5-ton electric furnace, melting and refining	15 heats,	75 tons (double turn)
One 5-ton electric furnace, refining only	55 heats,	275 tons (double turn)
30-pot gas crucible furnace	36 heats,	48.2 tons (double turn)
20-pot coal hole crucible furnace	12 heats,	10.7 tons (single turn)

The crucible process, of course, can be used only for high-priced castings, and no possible increase of production can bring the costs down so that with this process we can compete with the others on tonnage work. In the case of the open-hearth furnace, tonnage determines only size and number of furnaces. Though an increase of tonnage would somewhat reduce the cost of Bessemer metal, the small vessels can never be brought in direct competition with open-hearth foundries, as the cost of steel does not decrease with the tonnage produced in the same proportion as in open-hearth shops. The Bessemer foundries therefore compete with crucible shops and with the best of the acid open-hearth steel makers.

The position of the electric furnace is as yet indeterminate. As a melter and refiner in small units, it is at a disadvantage compared to Bessemer shops, yet can compete with them. To run large units, melting and refining cold stock, considerably decreases the cost of the metal, but leads to a state of affairs in which, owing to the bulk of steel to be handled per heat, the production of small castings is far from easy; and the production of tonnage work is not economical since the cost of the metal is much higher than that of open-hearth steel, and the margin of profit on this cheap work too small to permit of successful competition. By refining basic open-hearth metal, the electric furnace can be brought into competition with Bessemer shops, and therefore, as an adjunct of a steel foundry handling heavy work, can do effective service in allowing the shop to get into the small casting or specialty field. Habit is compelling, however, and the tonnage shop trying to handle the small casting business frequently fails because the management will not pay the minute attention to detail necessary to success in this field.

To refine open-hearth metal in a large electric furnace and produce heavy castings is not economical, since the steel still costs some 4 or 5 dollars per ton more than open-hearth metal, and the position of a large electric furnace refining open-hearth metal and producing heavy castings of a grade of steel too good for the market is thus a poor one strategically.

In electric-furnace installations, therefore, the indications seem to point to the advantage of using the largest units that can be employed and still pour small castings; taking advantage of the comparatively large size to reduce costs of metal as much as possible, and selling in a specialty or jobbing market to obtain good prices for the output.

B. Raw Material and Fuel most Available.—In the older iron-making centers raw material for any of the processes is readily available, and hence is a secondary consideration in the choice of a process. Fuels may not be readily obtainable at a price to allow of the use of a process in a particular locality, especially where competing shops are already intrenched. This is especially the case with the electric furnace, whose fuel is electric power which it uses most uneconomically as compared with many of the other processes, in places where power must be generated from coal. The raw materials and fuels used in the processes are as follows:

Process	Fuel	Raw material
Crucible	Anthracite coal or coke Producer gas (soft coal) Natural gas Oil	Puddled iron. Charcoal iron. Open-hearth scrap. Washed metal (or charcoal).
Bessemer	Coke (in the cupola) Power to drive blowing engines and compressors obtained from coal, gas, oil, water, etc.	Low phosphorus pig. Low phosphorus scrap.
Electric	Electric power, obtained from coal, natural gas, blast-furnace gas, coke-oven gas, oil, water.	(Basic pig), and High phosphorus scrap, or Bessemer or open-hearth metal, or (Low phosphorus pig), and Low phosphorus scrap.
Basic open hearth	Producer gas Natural gas Oil (Coke-oven gas), etc	Basic pig. High phosphorus scrap.
Acid open hearth	As above	Low phosphorus pig. Low phosphorus scrap.

It is apparent that only in exceptional cases will the fuel and raw material available be the chief determining factor in the choice of a steel-making process. So many fuels can be used for each process that only in comparatively rare cases will only one be available, and even then this fuel will almost always be capable of use for several processes.

Electric power is frequently available at comparatively low figures in districts where mineral fuels are costly, as for instance on the Pacific coast of the United States and Canada. In such cases the disadvantage under which the electric furnace labors in more favored districts may be entirely eliminated, and conditions point conclusively to the necessity of adopting this process to the exclusion of any other, on considerations of fuel alone. When it is remembered that for Bessemer practice the only fuel needed is the comparatively small amount of coke or coal used to melt pig iron in the cupola, or oil to melt it in a separate furnace or in the vessel, it will be seen that the mineral fuel must be very expensive and power very cheap, for this to be the case. The open-hearth furnace is so easily handled with oil, a very concentrated fuel, that it is rare for electric-furnace steel to be cheaper than open-hearth.

Again, where pig iron is extremely costly and scrap abundant and cheap, pig-iron consuming processes are at a disadvantage. This generally affects only the Bessemer process, leaving the choice among the other three open.

Even here, however, the problem can frequently be rendered soluble with the Bessemer process by melting almost all scrap in the cupola, and obtaining the silicon necessary for the process from small amounts of ferrosilicon melted with the charge in the cupola, or melted separately and added before charging the mixture into the vessel. In this way, by paying freight on the silicon necessary for producing heat in the vessel, in very condensed form, the Bessemer process may be made applicable in the face of great scarcity of pig iron.

At least one process exists for adding carbon to steel scrap in the open-hearth furnace in the form of coke or some such substance, and thereby greatly reducing the amount of pig iron needed in the pig and scrap process. Thus, on our Pacific coast, advantage is taken of abundant oil fuel and cheap scrap to conduct the manufacture of open-hearth steel quite cheaply. With cheap oil and electric power and abundant scrap, the coast should in a very few years make itself independent of the East in steel castings.

C. Capital Available.—This is a question, of course, of first cost of plant, and is too often the cause of disaster with companies started with insufficient knowledge of the conditions to be faced. The processes, in order of their first cost of installation, the cheapest first, are as follows:

1. Crucible—coal holes.
2. Side-blown Bessemer.
3. Electric—(not counting power-house).
4. Crucible—gas furnace.

5. Bottom-blown Bessemer—(including engines, boilers, etc.).
6. Open hearth.

From the point of view of the installation costs per ton of steel, however, as the figures already given show, this order is quite different. For convenience, the processes are again tabulated below, in order of installation cost per ton, as estimated above.

PROCESS	Interest and depreciation per ton
Electric furnace, refining hot metal	$ .34
Bottom-blown Bessemer	.39
Side-blown Bessemer	.63
Acid open-hearth	.78
Basic open-hearth	.90
Electric furnace, melting cold scrap	1.25
Crucible, coal holes	1.40
Crucible, gas furnace	1.87

While there is much to be said in favor of starting a specialty or jobbing business on a small scale, especially when the men in charge are not thoroughly familiar with the work to be handled, it is easy to overdo this and start with so little capital that before the difficulties are all understood and overcome the management finds itself embarassed from lack of funds. Thus if we mean to run a gas crucible steel furnace of 30 pots, and start our business with four or five coal holes, it is necessary to figure on a largely increased cost of metal at the start, and we may find it takes very much longer than we had expected to accumulate the earnings counted on to build the larger plant. As a general rule, however, the safest plan is to start with the same process we intend to use ultimately, since each process has its peculiarities that must be mastered, and the experience gained with the small plant is useful with the larger one.

D. Competition.—A very few words must dispose of this heading, since it is too much a matter of plain business sense to need exposition.

Frequently, in a field already covered by tonnage foundries a good deal of business in small jobbing work can be picked up. To start a small plant to take care of such business is frequently profitable, since the work is generally high priced. It must be remembered, however, that it is "turned down" by the tonnage foundries because it is hard to make, hence it will not be plain sailing to turn out the castings. Moreover, the field will seldom be a large one and therefore the business can be handled only with a small tonnage equipment.

It is almost unnecessary to point out, after what has preceded, that to enter into competition with a firm well intrenched in a particular line, with a more expensive process than the competitor is using, is almost always suicidal, since extra prices are not commonly paid for superior steel, if the established firm makes good sound castings. The new concern will get chiefly the "cats and dogs" turned down by the older shop, on which it is difficult to make a profit; and to try to get business by price concession is fatal, since the other fellow with his cheaper process can stand more than the newcomer in that line. Should one find that his shop has inadvertently got into such a situation, there are generally but three things to do—take the scrapings of the business, which if the controlling shop in the field carries on a tonnage business will often support a small concern; get some good specialties; or shut up shop.

E. Labor Available.—In districts where steel making is new, it is as easy to train men to one steel-making method as to another. Experienced men must be imported to start operations, but generally will not stay. The management must count, therefore, on training the local labor as rapidly as possible.

In the older steel-making districts, labor will frequently be available that understands one or two processes, but not the others. This is especially true of the electric furnace and of special designs of old types, as for instance the Krupp type of crucible furnace; trained labor for either is hard to get. Should the case for two processes be otherwise about even, a lack of men that understand one of them should at once put that process or special design of furnace out of the running. At times the difficulty of obtaining men to handle a process unfamiliar to the labor of the locality will even be found to convert a supposed superiority of a special design of furnace into a decided inferiority from the point of view of economical production of steel.

F. Intermittent or Steady Operation.—If the furnace can be kept going steadily, with no shut downs, any process may be used. Regenerative gas-fired furnaces (open hearth and crucible) cannot be shut down and started up again without great expense, and must be kept constantly hot. They are, therefore, best suited to double-turn operation at their maximum capacity. Operated single turn, the cost of steel will be greatly increased—and short shut downs will be costly, both because the furnace must be kept hot, and because to keep an expensive furnace idle runs rapidly into money.

The Bessemer converter is well suited to intermittent operation, and lends itself readily to very considerable fluctuations in the daily tonnage produced. The side-blown equipment being cheaper than the bottom-blown is less affected by shut downs.

Oil or coal burning crucible furnaces can be operated intermittently as easily as continuously, and their installation cost is so low that shut downs are relatively inexpensive.

Electric furnaces can be operated intermittently, but had far better be kept constantly hot, since the power consumed in heating them up is considerable, and the wear and tear on the furnace due to heating and cooling is severe. That shut downs of large (and hence costly) electric furnaces greatly increase the cost of metal, goes without saying.

SUMMARY

Process	Quality	Flexibility	Suitability for small work	Cost of steel	Tonnage	Cost of installation	Cost of installation per ton
	1 best	1 most flexible	1 most suitable	1 lowest	1 highest	1 lowest	1 lowest
Crucible	2	1	1	6	5	1	6
Electric	1	2	2	5	4	3	5
Acid open-hearth	3	4	5	2	1	5	3
Basic open-hearth	4	4	6	1	1	5	4
Side blown Bessemer	6	3	3	4	3	2	2
Bottom blown Bessemer	5	3	4	3	2	4	1

Note.—Electric furnace refining basic open-hearth steel stands between No. 3 and No. 4 in cost of steel.

Note.—Gas-fired crucible furnace stands between 3 and 4 in cost of installation.

Note.—Electric furnace refining hot metal stands No. 1 in cost of installation per ton.

CHAPTER III

THE CRUCIBLE PROCESS

The crucible process is the oldest of the steel-making methods now extensively used, and like practically all our modern processes is "indirect"; that is, steel is produced from some other product derived from the iron ore.

In very early times, both steel and iron were produced directly from the ore in open forges. These consisted essentially of an open basin or hearth in which very pure iron ore was heated in contact with a large excess of charcoal, the fires being blown with bellows or other primitive means of producing blast. Part of the ore was reduced by solid carbon, according to the usual formula,

$$FeO+C=Fe+CO,$$

while a considerable amount of the FeO combined with the silica, lime, etc., of the gangue of the ore to form a fluid or pasty slag. The metal obtained from these forges was in the form of a coagulated mass of small particles, much like a puddled "ball," and was hammered to squeeze out the slag contained in the interstices, cut into pieces, heated to welding and rehammered, until a fairly pure and uniform bar was obtained. If the metal absorbed much carbon from the charcoal a steel of varying degree of hardness was obtained. As a rule, however, soft, carbonless iron was the product desired, and in order to convert this into steel it was heated in a bed of charcoal out of contact with the air until it was cemented or case hardened to the center.

Later, the soft iron used for cementation was produced from the new product, pig or cast iron, by melting a bar of pig iron with a charcoal fire in an open hearth, and allowing the slowly melting iron to trickle down through the air blast used. By the oxidizing action of the blast, the carbon, silicon, manganese, sulphur and phosphorus of the pig were eliminated and nearly pure iron was obtained in a sponge of coagulated particles and slag, which was worked up as before. By this method also either iron or steel could be obtained, but iron was the usual product. This is the principle of the Walloon hearth and other like methods, by which Swedish charcoal iron is still made to-day.

The practice of cementation (or total case hardening, as it might be called), gradually developed as time went on, and as used in England to-day has made great strides in the furnaces employed, though in principle it is still the process of Tubal Cain. In the modern cementation furnaces, bars of soft iron are packed in long cast-iron boxes, each bar well bedded in pulverized charcoal, and two or more of the boxes are heated to full red heat in a conical topped, coal-fired furnace. After full heat is reached, it is maintained from 7 to 11 days, the progress of the absorption of carbon being watched by occasionally taking out a test bar through holes in the ends of the pots and when the desired degree of carburization has been reached the furnace is allowed to cool slowly. These "blister bars," as they are called, are broken when cool, the "temper" (or carbon content) estimated by the appearance of the fracture, and are then hammered out into longer bars, a product known as "spring steel." Cut, piled, heated, welded, and hammered out into bars once or twice, the product is "single-shear" or "double-shear" steel. These steels are still extensively used in Sheffield for cutlery and many tools in which a steel edge is welded to an iron back.

About 1740, Huntsman, a watchmaker of Sheffield, dissatisfied with the far from uniform steel of his day, hit on the scheme of melting blister bar in clay pots or crucibles, and made the first crucible steel produced in England. Naturally this steel was a great improvement on "double-shear" and at once largely displaced all other steels for high-grade requirements. With characteristic conservatism, Sheffield steel makers adhere to-day to Huntsman's methods, and for high-grade tool steels melt only blister bar of uniform temper, made from Swedish charcoal iron. Puddled iron, they maintain, will not make as fine a steel as the charcoal product, and is used in Sheffield only for poorer grades of steel.

It is hard to see the special virtue of spending two weeks soaking carbon into the iron in the solid state and then melting the product, when the two operations can be carried out simultaneously in a few hours. American steel makers pack soft iron and charcoal (or washed metal), into pots, melt down the iron, which absorbs the charcoal or the carbon of the washed metal, and obtain a steel of the desired "temper" in four or five hours. Our precedent for this practice is found in the ancient steel-making industry of India, Arabia, and other parts of the East, where for untold centuries steel has been made by remelting in clay pots with wood or charcoal, iron produced directly from the ore in crude hearths similar to those already described. The pots are luted tightly, packed in a charcoal fire, and the contents melted as in American practice, the soft iron absorbing carbon from the wood or charcoal and becoming hard steel. By this process were produced the long famous blades of the Orient, of which we have all heard perhaps as much as we can stand, and which must be our justification for claiming that as good steel can be made by cementing and melting in one step as by the slow and costly methods so largely followed in Sheffield.

Puddled iron, invented by Cort about 1784, is the raw material chiefly used to-day in America for fine tool steel and when carefully made, with low sulphur and phosphorus we claim that it will produce a tool steel as good as any. Indeed, except that it is made with soft coal as fuel instead of charcoal, and out of a fluid bath not in contact with the fuel, instead of out of a succession of drops of fluid iron running through the air blast, it is hard to see wherein the metallurgical features of the process differ from those of the Walloon hearth. The claim is made that we do not so thoroughly work the slag out of our puddled bar as is the case in charcoal iron practice, but since in remelting in pots practically all slag floats out of the puddled iron, it is not easy to see the advantage of working the slag out of the solid iron by rolling and hammering. To suppose that the mechanical working imparts a "quality" or "body" to the iron that persists in the molten steel is too great a strain on our credulity to warrant serious consideration.

The crucible process has been used for so many years that tradition and superstition have gathered upon it like moss on an old wall, and this discussion is purposely made explicit and rather long in order to set forth the matter in what appears to the author its true light. Purchasers of castings so frequently state that after years of unsatisfactory experience with makers using other processes, they at last adopted crucible steel, and never had any more trouble, that it is as well to state clearly and at once that their relief from their troubles is chiefly due to the ease with which small and intricate castings of crucible steel are poured solid and free from blow holes, cracks and flaws, and to the pains that makers specializing in small castings habitually take with their product, and not to mysterious, cure-all virtues of the process itself.

Let us then consider for a moment the reasons for the excellence of crucible steel, and the practice generally followed for the production of crucible steel castings, in order to see to what extent great excellence of steel is usually striven for and actually obtained. To begin with, as crucible steel making is a pure melting process, no removal of phosphorus and sulphur is possible, and the content of these elements even increases slightly, because the loss of metallic iron reduces the total weight of the molten steel as compared to that of the iron charged; and in the case of sulphur, because some sulphur is absorbed from the coke, coal or gas used in melting. For this reason low sulphur and phosphorus have to be obtained by the use of very pure raw material, either "low phosphorus" charcoal or puddled iron, or basic open-hearth scrap. If acid open-hearth or Bessemer scrap is used, the phosphorus and sulphur will be relatively high, and quite often by the indiscriminate use of plate-steel punchings whose origin is not known or whose analysis is not obtained, crucible steel is produced much higher in these objectionable elements than good practice should allow.

Excellence of the steel is further due to the fact that by melting in a closed pot with a cover either luted on, or soon sealed fast by the "running" of the pot and cover with the heat, the steel is protected from the oxidizing gases of the furnace, so that it does not oxidize and absorb its own oxides, nor absorb great quantities of harmful gases. There is, to be sure, air in the pot at the beginning, but the oxygen of this air is soon exhausted in the oxidation of charcoal in the pot, or of carbon, silicon and manganese of the iron, so that a neutral atmosphere is soon attained. This is, of course, lost when the cover is slid off to examine the steel, but the advantage from this source is well known and beyond dispute. Further, silicon, either absorbed from the clay of the pot by the reduction of silica, (SiO_2), to silicon, by the carbon of the steel, or added as ferrosilicon, reduces much of the oxides present in the metal, and renders it much "quieter" when poured, either by freeing the steel from gas, or by increasing the capacity of the steel to hold the gas in solution. Thus in crucible melting, open-hearth scrap is considerably improved in quality, and if hard tool steel be the product, it is better than open-hearth steel as such.

Tool steel practice, however, which tries the steel very high, has demonstrated to the satisfaction of the steel makers and steel users that crucible steel made of open-hearth scrap, however low in phosphorus, sulphur and manganese, is not as good as crucible steel made from puddled iron. The English makers and users, as already noted, carry this even further and will use only charcoal iron for the finest steels, and cement it before melting at that. As this superiority of tool steel made from wrought iron seems to be established beyond dispute, there must be some inherent excellence of wrought iron, not shown by the analysis for silicon, manganese, sulphur and phosphorus, which renders it superior as a raw material for crucible steel to open-hearth scrap of equivalent or superior analysis.

This excellence must be due to the method of manufacturing wrought iron, and to get an idea of what causes it, we must compare carefully the methods used for producing puddled iron and basic open-hearth steel of equal purity, as shown by the usual analysis.

In both the puddling furnace and the basic open-hearth steel furnace, a bath of molten iron high in carbon, silicon, manganese, sulphur and phosphorus is subjected to the action of iron ore in a highly basic slag, and of an oxidizing flame, in order to oxidize their impurities, and remove them either as gases (CO), or by sending them into the slag as oxides (SiO_2, MnO, etc.). The final product of both is nearly pure iron; but the temperature of the puddling furnace is so low that the metallic iron becomes solid as fast as it forms, a molecule or a tiny particle at a time, and by the gradual coagulation of these small masses a sponge of pasty iron particles is formed, whose interstices are filled with liquid slag; whereas the open-hearth furnace is maintained at so high a temperature near the end of the process that the metal is kept molten, poured into a ladle and thence into large ingots, where it cools relatively rapidly. The puddling process corresponds to the early stages of the basic open-hearth process, and it is owing to the lower temperatures that the slag, which is not very high in lime (CaO), and is very high in iron oxide (FeO), is able to retain phosphorus as phosphate and largely eliminate this impurity. In basic open-hearth practice, though considerable phosphorus is held in the slag when the metal is first melted, much of this phosphorus is reduced again from the phosphate by the action of iron and carbon at high temperature, and a very limey slag has to be made after the richly ferrous slag has performed its function of removing carbon, silicon and manganese, in order to hold phosphorus in solution and thus eliminate it from the steel by oxidation.

As in both processes the metal is exposed to highly oxidizing slag and gases, the difference must be chiefly in the lower temperature and the relatively slower and particle by particle solidification of the metal in the puddling furnace. It has always seemed probable that at the lower temperatures of the puddling furnace the metal absorbs less oxide and gases, especially since the very pure iron formed near the end of the process at once freezes, instead of being long exposed to oxidizing conditions when it has no silicon and manganese to protect it from oxidation, as in the case of the open-hearth furnace; and that the particle by particle solidification of wrought iron gives an opportunity for throwing dissolved gases and oxides out of solution that is largely denied to open-hearth steel frozen rapidly in large masses. To be sure, ferrosilicon and ferromanganese are added to remove a great part of the oxides, in open-hearth practice; yet they are often added in the ladle, and that their cleansing effect is far from complete is too well known to require argument.

From this discussion it is plain that crucible steel as such, is not necessarily a product of the highest excellence. If made of very pure materials properly melted, it is better than any other steel except the electric steel of to-day. If made of basic open-hearth scrap, even of very low phosphorus and sulphur, it is not a great deal better as steel than the scrap of which it was made. And if scrap is used indiscriminately without analysis, a very poor product may be the result. We have already set forth briefly in the introductory chapter our reasons for assigning superior quality to electric steel, and will dwell upon the matter more at length in the chapters devoted to the electric process. It is sufficient to point out here that the very moderate quality of crucible steel as generally made for castings is not at all as high as that of fine brands of tool steel, and cannot conceivably be called equal to the quality of well made electric furnace steel. It is just as well to state again, however, that for the great bulk of castings made by the crucible process, it is poor policy to use expensive puddled iron or charcoal iron in order to give the steel the fine quality of best tool steel. No casting is ever called upon to show the excellence of steel needed to make a tool stand up to long-continued metal cutting, and castings properly made of crucible steel, using basic open-hearth steel scrap as raw material, will exhibit physical properties that show that they are amply able to endure the stresses to which they are to be subjected in service. More especially is this the case when the castings are annealed by simply a short heating and slow cooling to relieve strains and somewhat improve the grain. We make our tools of the very finest steel in order that they may take the best possible temper when carefully hardened and temper drawn. If we similarly heat treat our castings so as to give them the very highest strength and greatest toughness they can be made to possess, and find we need still finer steel than we can obtain from remelted scrap, we naturally will turn to high-grade irons as raw materials. But if we only roughly anneal our castings, and do not nearly bring out the best that is in them, there is no need of using such very costly raw materials.

Castings are generally desired of mild steel, .25 per cent. carbon being the average content for most purposes. Many makers of crucible steel castings have difficuly in producing mild steels, as will be explained presently when we consider the control of analysis, and produce a great deal of steel that for most uses is too hard and brittle for the best results. This is a disadvantage of the process that frequently gives the steel maker trouble.

The real advantages that make the crucible process well suited to the manufacture of castings, especially light and intricate castings, and alloy steels of certain kinds, have already been touched upon in the introductory chapter. They are:

First, the low cost of installation of the process for starting a small shop.

Second, the high temperature of the steel, and the fact that it can be kept hot in the furnace until needed. Moreover, when pouring small castings, the steel can be poured directly from the hot pot, which being a poor conductor of heat with a small exposed surface of metal keeps the steel hot and fluid very well indeed. This is the more true because the steel is not chilled by pouring in a stream into the pot, as in the case of filling small "shank" ladles from a larger ladle. In addition to this, the steel is very free from gas, is smooth running and if well "killed" or purposely made high in silicon, feeds down exceedingly well in the risers, "sets" quietly in the moulds, and produces very sound, clean castings. This advantage, coupled with cheapness of installation, are the two chief reasons for the use of the process, in spite of the high cost of the steel produced, for the manufacture of small, intricate castings.

An advantage of less weight in the majority of cases is the flexibility of the process, as already explained in the introductory chapter. Naturally, as each pot is a separate lot of steel, many different kinds of steel can be made at one heat in quantities to suit the requirements of the shop. The only limits to this are the number of pots melted, and the ability of the melter to attend to a number of different kinds of steel at once. We shall see further on that the difficulties of producing at will just the analysis desired, limit the possible number of sorts of steel that a melter can be expected to produce sucessfully at one heat. There is not a very great demand moreover, for castings of special analysis, at least of steels that can be economically produced in crucibles, so that this flexibility is not often taken advantage of.

THE FURNACES

The furnaces used are the old-fashioned anthracite coal or coke hole, the oil-fired furnace, and the regenerative gas furnace of the pull-out (American), and side drawing (Krupp), types.

The coke hole is very little used in America, though coke is often used with anthracite in our practice in this country. The general style of hole used here for anthracite and in Sheffield for coke is about the same, and can be briefly described as a set of oblong melting holes lined with clay brick, with a flue at the back into which a small flue leads from each melting hole. One stack provides draught for a number of melting holes, and in America forced draught in the ash pits is universally used. The melting holes are sunk so that their top is at the working floor level, and there is a space provided in front of the ash-pit doors, so that the grate bars can be readily drawn from the holes for straightening, and the ashes easily shoveled out. This space is generally covered by a grating at the working floor

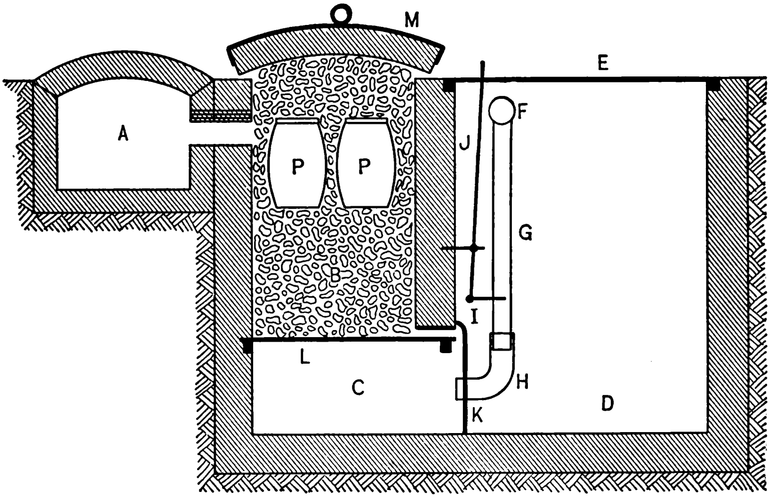

FIG. 1.—Anthracite coal melting hole. Vertical section. A, Flue; B, coal fire; C, ash pit; D, cellar; E, grating; F, G, H, blast pipe; K, ash pit door; I, J, blast damper; L, grate bars; M, cover; P, pots.

level, which serves the double purpose of giving light for the men to see what they are doing when removing ashes, and allowing any spilled steel to drop through without getting under the workmen's feet. The holes generally contain four pots, leaving room around the sides for fuel, and are deep enough to provide a bed of fuel from 18 in. to 2 ft. deep under the pots, when the tops of the latter are a few inches below the edge of the floor level. The covers of the holes are generally made in three sections so that they shall be light enough to handle easily.

The lay-out of such a shop is simple. The melting holes are generally lined up against one wall (or two walls) of the building, and the space in front of them covered with steel plates for piling plate scrap, heads, gates, and washed metal, for shoveling material and for packing pots. There should be room enough to pack at least one heat of pots comfortably, and have another heat packed ready for charging. A storage place for new pots, used pots waiting to be recharged, etc., is needed, and a small room with bins and grocer's scales for storing and weighing the alloys, such as nickel and ferrochrome, needed for alloy steels, and the cracked ferromanganese and ferrosilicon weighed into manila envelopes and tied up to throw into the pots. It may in some cases be best to have the melting holes in a single or double row in the center of the shop, so that pots can be carried both up and down the pouring floor to get them rapidly out of the way. For ladle work, a small pit is provided, in which to set the ladle when it it is being filled, and a small coal hole or a gas or oil burner is used for drying out the ladle. If a bottom pour ladle is used, stoppers, nozzles, stopper rods and sleeve bricks for the same require a storage room, where stoppers and sleeves can be put on the rods and a few kept ready for use. Since plants of this sort are generally very small, the exact lay-out is largely governed by the sort of building used, and common sense must govern the placing of furnaces, etc., so that the material can be brought to them and the steel carried away with the minimum of confusion.

For a furnace of five holes, four pots in a hole, two heats per shift, the crew will be one melter, one pot puller, one moulder (as he is called in the tool steel shops), and perhaps one helper to shovel coal and ashes, help pack pots, and do odd jobs.

Sheffield Coke Holes.—In the Sheffield crucible steel industry, where fine steel is produced, clay pots are generally used and coke used for fuel. Clay pots are generally somewhat smaller than graphite pots, since they are weaker, and when first used are brought up to heat in the fires very slowly and then filled by means of a long iron funnel. In any case, whether first packed hot or not, they must be heated with extreme care and slowness, and after one heat has been melted are at once recharged hot and returned to the fires. If allowed to cool they will crack. Less steel is usually charged in the pot at each successive heat, owing to the deep cutting of the pot at the slag line. The coke holes often contain but two pots, but otherwise are much like the common anthracite melting hole.

The advantages of the coal or coke hole furnace, are its low first cost, and its suitability for intermittent operation. The chief disadvantage is the high cost of the steel, which is due to the low tonnage produced, the heavy wear on pots, which do not last as long as in gas-furnace practice, the high fuel consumption, and the high labor cost. The pot pullers have more to do than on gas or oil furnaces, so that more of them are needed to handle a given tonnage, and the great amount of coal and ashes that have to be wheeled necessitates the employment of extra men. Another disadvantage is that in making very low carbon steel, which is very hard to melt, the fires, especially on the second heat of the day, often give out completely before the steel is melted; and as it is not possible to raise the pots and shovel coal under them more than twice, it is sometimes impossible to melt this sort of steel on the second heat.

The Oil-fired Furnace.—The direct-fired oil furnaces are very simple in construction and comparatively inexpensive to build. In some furnaces of this type, there is a combustion chamber alongside the melting hole, in which the oil is burned, and the hot gases enter the melting chamber over a bridge. Many styles of oil burners are used. In some of them the oil overflows in a series of shallow pans and is carried into the furnace by a draught of air. In others steam or compressed air is used to atomize the oil. Whatever be the style of burner, the important thing is to secure complete combustion of the oil and proper distribution of the hot gases in the melting chamber.

As there are no coal and ashes to wheel, the crew of an oil furnace is smaller than that of a coal hole plant of equal capacity. One melter and one pot puller, with one or two men to pack pots, can take care of a set of furnaces melting 40 pots a day.

The wear and tear of pots in oil melting is rather severe, yet the small crew and low fuel costs make these furnaces very economical when cheap fuel oil can be obtained. They have been extensively used in our middle West, where, however, the recent jump in the price of oil has considerably altered conditions. The cost of installation of oil furnaces is higher than that of coal holes, but lower than that of regenerative gas fired furnaces. Oil furnaces are well suited to intermittent operation, as they can be heated up very rapidly, and if built of good clay brick will withstand the heating and cooling involved. The melting is more rapid than in coal holes, and of course the pot pullers have to handle the pots but twice, as they do not have to be raised as in coal hole melting; and as there is no bed of coal to hamper them, the men are able to grasp the pots more easily, and can be surer of avoiding weak places in old pots.

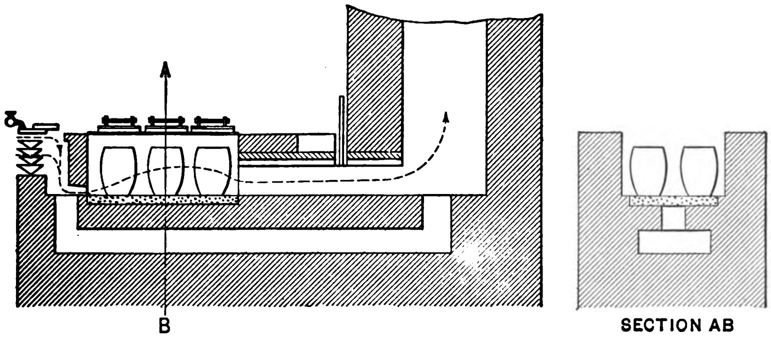

FIG. 2.—Milwaukee type oil furnace. Longitudinal and cross-sections. From "The Iron Trade Review."

The Siemens Regenerative Furnace.—Regenerative gas fired furnaces, using either producer gas or natural gas, are of two types, only one of which (the melting hole design), is extensively used in America. These furnaces are built very much like gas fired soaking pits, with, of course, a smaller chamber, and work on the regenerative principle, which is too well understood to require extended description here. In regenerative furnaces the gas and the air necessary for the combustion enter and leave the furnace through fire brick chambers filled with brick checker work, which alternately are heated by the outgoing gases, and give their heat to the incoming air and gas. In natural gas furnaces only the air is preheated, and both sets of checkers are used for air, or only one set is provided.

The furnaces are sunk below the working floor, generally enough so that the floor of the furnace (level with top of the melting holes), is 2 or 3 ft. above the general level of the shop. The melting holes are covered with covers or "bungs" which are larger than those of coal holes, and therefore cannot easily be lifted off by hand with

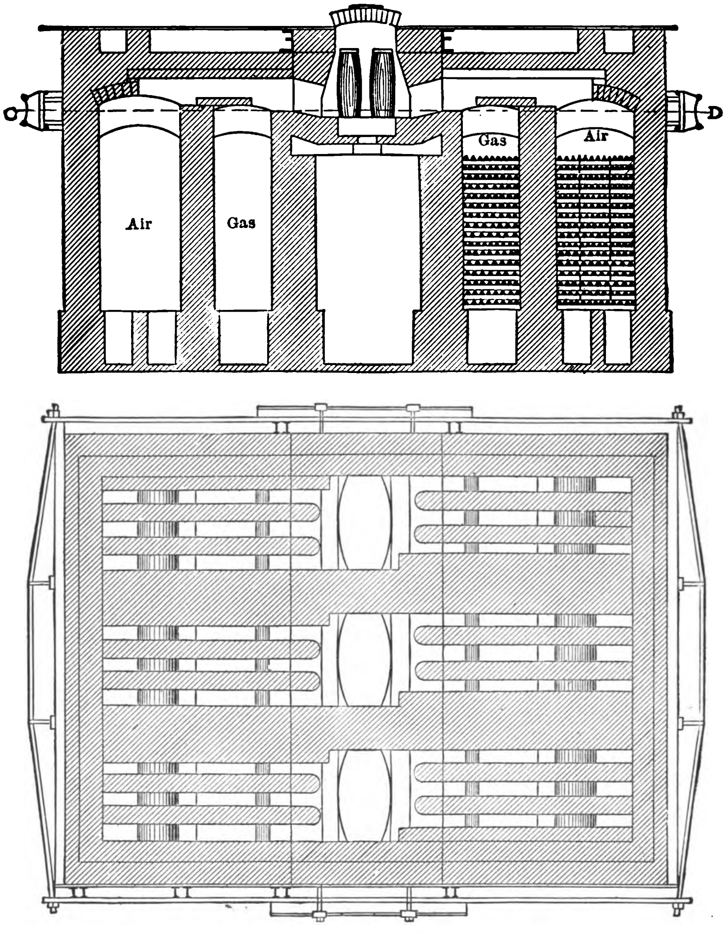

Fig. 3.—Siemens regenerative furnace. Vertical and horizontal sections. From Stoughton, "The Metallurgy of Steel."

a hook, but are swung by a lifting bar suspended from an overhead trolley. Three covers to a hole is the usual and the most convenient arrangement. The holes may be lined with clay brick, especially if the furnace is to be run "single turn" and cooled off considerably at night to save fuel. In this case the resistance of clay brick to repeated heating and cooling is taken advantage of. Clay brick furnaces last on the average only six months, and then require extensive repairs. Generally, silica brick are used, and the furnace lasts 12 to 18 months.

The bottoms of the holes are covered two or three inches deep with coke breeze, to keep the pots from sticking to the bricks, and to soak up the runnings from the outside of the pots and any steel spilled from cracked pots. Openings about 5 in. wide are provided in the bottoms of the melting holes, which are closed with the bottoms of old pots. After a heat has been melted, these holes are opened, any slag or spilled steel poked through, the holes closed up again and a little more coke breeze shoveled in and leveled to make up for what has been poked out.

Reversing Valves.—The reversing valves used for regenerative crucible steel furnaces are the same as those provided for open-hearth furnaces. For the air, of course, the plain "butterfly" flap valve is generally employed and gives satisfaction. The gas valve is frequently a butterfly, and should be water cooled. There is not the same objection to this style of valve for the gas in crucible furnaces that there is in open-hearth practice. Being smaller, the valves have less opportunity to warp; and as the waste gases going to the stack are somewhat cooler than in open-hearth practice, the warping is considerably less. The more complicated gas valves so valuable in open-hearth work are not often used for crucible steel furnaces.

Producers.—The scope of this book does not permit of a discussion of the types of producers for soft coal that can be used. Great progress is being made in the design of gas producers, with a view both to minimizing the hand poking needed in the old types and to increasing the economy of the producer. Good gas makers will keep almost any producer well poked down to prevent holes in the fire and consequent lean gas, but with the older designs the labor is severe. Many types should be regarded with a wary eye until their success in practice has been demonstrated, because some designers persist in giving great wind box area so distributed that after some months' operation the wind boxes get covered with chilled clinker, which spreads and chokes the whole fire and is very hard to poke out. Such producers give beautiful results on a short run, but kill the gas men after they begin to choke up. Water-sealed producers are thought by some furnace builders to be unsuitable for crucible furnaces, because the gas obtained from them wears out pots more rapidly than that made in dry-sealed producers.

In the lay-out of a shop using one of these furnaces, care should be taken to see that the melting shop and gas house can be thrown open on all sides in hot weather. The space for storing iron, scrap, etc., and packing pots, should if possible be on a level with the furnace floor so that pots can be "buggied" to and from the weighing space on a continuous floor. The pit between the regenerators into which the slag from the holes is poked should be easily accessible, at each end if possible; and at least should be so arranged that a good current of air can sweep through it. Otherwise it will get so hot in the pit as to make it impossible to clean out the accumulation of slag and coke without shutting down the furnace.

Ready access to all parts of the gas mains, valves, etc., is absolutely essential and manhole openings in the gas and air flues between valves and checker works will be found of great advantage in facilitating cleaning out and minor repairs. Checkers, if possible, should be accessible front and back, as when the furnace has been long in operation the checker works become clogged with dust and have to be blown out with compressed air through openings in the end walls. This can best be done if access is to be had from both ends, but when the furnace is deeply sunk only one end is commonly accessible.

If producer gas is used the gas house should be provided with easy means of getting out the great quantity of ashes that have to be handled. If possible, the bottoms of the producers should not be in a pit of small dimensions, as it is in that case uncomfortably hot for the men to work in getting out ashes in hot weather. The ashes have to be removed as they accumulate. With water-sealed producers this can be done at any time; with dry-sealed producers it is customary to do it on Wednesdays and on Saturdays during the general clean-out. On Wednesdays, during the cleaning out of ashes, it is well to open the gas mains and burn out the accumulated soot as much as possible. Saturday afternoon, after the last heat is drawn, is the time for general clean-out and any repairs to brick work that are needed. The top holes of the producers are opened and the gas allowed to burn, all doors in gas mains are opened, the soot is burned out of the mains and valves as completely as possible, and the rest dragged out with wooden scoops. This is the time to give the neighborhood a wide berth unless your duty compels you to boss the job; and in hot weather, all hands especially welcome the feature of an open-sided shop during cleaning out. The floating soot is bad enough even in such a shop.

Starting the Regenerative Furnace.—In starting a new producer, it should be filled up with ashes well over the tuyéres or wind boxes, and the fire kindled upon the ashes, coal being dumped in as soon as the wood fire is burning well, and the blast used only as needed. No gas should be turned into the furnace until good gas is being made.

While the producers are being started, the furnace is dried out with a coke or anthracite fire in each hole. The stack damper is raised, the valves are set on center, the covers of the holes are opened a little, and the draught is taken in the top of the holes, through all checkers, through the flues to the valves, and out the stack flue and stack. In a couple of days the furnace will be hot enough to light, when the valves are thrown over, the covers of the holes swung further apart, and gas carefully admitted, then a little air. Care should be exercised in not turning on gas too rapidly, or too much air, or air first, as a strong "kick" frequently occurs in any case, and a bad one may damage the furnace. After an hour or so the valves are thrown over; it is as well on the first two or three reversals to shut off gas and air before throwing the valves, to avoid strong "kicks." After a few reversals the valves can be thrown over without this precaution and when the furnace has become hot the reversal should take place without any kick at all. As the furnace heats up, the reversals are made at shorter intervals, and when it has reached working heat should be reversed every 15 or 20 minutes.

The crew of a 30-pot gas furnace consists of one melter, two pot pullers, one or two moulders, and when producer gas is used, two gas men per shift. The moulders help pack pots, wheel them to and from the holes and do odd jobs, and one of the gas men is used to swing the covers of the melting holes when pots are being charged or drawn. If the pots are poured one at a time, the moulders wheel them to the edge of the furnace and wipe the slag from them; the pouring gang from the foundry then carry them from the furnace. In pouring into a ladle, speed of drawing is essential; in this work the melter pours the pots as fast as they are brought to him, the moulders run them to him with buggies, and the pot pullers draw as fast as they can, one man pulling six pots while the other gets his breath and wets down his clothes again. In this way 30 pots can be drawn and dumped into the ladle in four or five minutes. Three heats should be melted per shift.

Advantages of the Gas Furnace.—The gas furnace has the advantage of clean and easy handling of pots already mentioned in the description of oil furnaces, and like the oil furnace, gives the melter almost complete control of the temperature at all times. The stack damper, air supply and gas supply valves enable the heat of the furnace to be closely controlled, and in addition by opening the covers of the hotter holes a little, they can be held back when melting too fast and getting ahead of the others. There is, however, no means of controlling the admission of gas and air in each hole, as the whole furnace is handled with one set of valves. Further advantages of this type of furnace are low fuel cost, low labor cost, and speed of melting. The only disadvantages are high cost of installation, and the fact that single turn operation is far from economical. If no steel is melted at night, one or two men have to be kept on to make gas and reverse the furnace every 20 minutes or one-half hour, and though the furnace is not kept up to full heat, fuel is burned and labor paid without return, resulting in a considerable increase of cost, to say nothing of the overhead cost of keeping an expensive furnace idle half the time. The necessity for the employment of pot pullers has been referred to as a disadvantage of these furnaces which does not apply to the Krupp type, in which the pots are lifted out with long suspended tongs and regular pot pullers are not employed. However, melters and pot pullers in this country are clannish and much inclined to stick together, so that a shop using the Krupp furnace often finds it difficult to secure competent melters. This offsets the advantage of pulling pots with cheaper labor.

The Krupp Furnace.—The Krupp furnace, used in one or two shops in this country, is built a great deal like a side-drawn annealing furnace. The pots are set in the furnace and pulled out through doors in the side by means of a long pair of horizontal tongs suspended from a trolley. The bottom of the furnace is nearly flat and commonly slopes toward a tap hole in the back through which slag and spilled steel are run out. The bottom is made of silica sand fused on in thin layers. Except that the bottom is flat and the port construction not at all the same, the furnace resembles in its general appearance a small open-hearth furnace. Its advantages are those of the other type of regenerative furnace. Its disadvantages are, that to see into the pots it is necessary to go up on the top of the furnace and peep through six or more small holes in the furnace roof; that spilled steel exposed to the gases of the furnace soon is "puddled," or in other words the carbon is oxidized out of it and carbonless iron formed, which will not run out the tap hole and has to be pried off the bottom, often taking part of the bottom with it; and that as the furnace is a "freak" in this country, men have to learn to run it instead of going right in and handling the furnace well from the start. The disadvantage that gave the author the greatest trouble when handling one of these furnaces was the spilled steel, which worked its way into the bottom, because the scale formed on it cut out the sand. The "skull" that accumulated often had to be burned out of the furnace from the tap-hole side with an air blast. In Germany, clay pots are used in these furnaces, the pots are never worked to the limit, and few break; but in America we work so constantly to get the last possible pound of steel out of a pot, that some break in almost every heat of old pots, and trouble results.

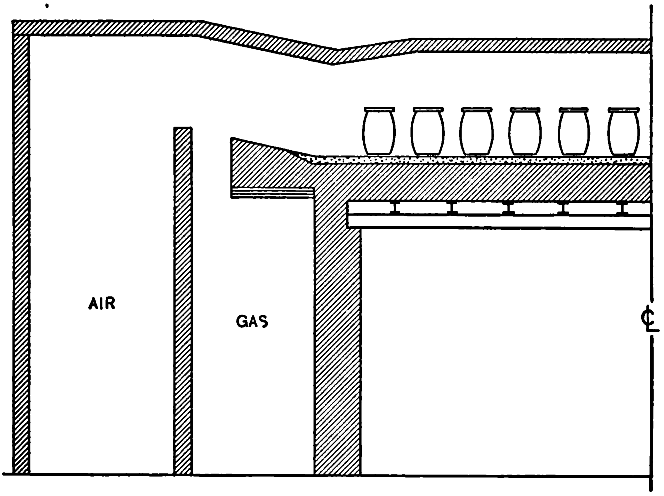

FIG. 4.—Regenerative crucible furnace—Krupp type. Half longitudinal section.

The Pots.—Pots are made either of clay, or of graphite and clay in about equal parts (the common graphite pots). The disadvantages of clay pots already mentioned are so pronounced that graphite pots with a clay lining about ¼ in. thick are often used in place of them. These clay-lined pots do not have to be handled so carefully as those made entirely of clay. The reason why in some instances clay, or at least clay-lined, pots are indispensable in good foundry practice will be taken up later, when the control of analysis of crucible steel is considered. Clay pots seldom make over three heats, while graphite pots will sometimes make five or six in foundry practice. Graphite pots should be stored in a dry, and, if possible, warm place; should be dried out on a furnace top for a week or two before using, and when new should be heated around the melting holes before charging. When hot they will stand pretty rough usuage, and can be dropped from the furnace to the ground without breaking if let fall on their butt ends and rolled out of the way. In the rapid work of ladle pouring this generally has to be done. When cool, the pots are examined for thickness, and tested for cracks by tapping them with an iron rod. If all right they ring clear like a bell, if cracked they will not ring. If not cracked, and thick enough for further use they are taken to the packing floor for repacking. If they are cracked or worn out, the bottoms are cut off with a coarse saw, or the sides smashed away with a heavy blunt knife, and the thick bottom parts are used as covers for the pots.

Melting.—In coal holes, a good grade of anthracite coal is used for fuel, and about two heats can be melted per shift. When operating single turn, the fires are lighted early in the morning, and blown up until a good bed of glowing coals about a foot deep is provided. About 6 in. to 1 ft. of coal is then dumped in, and the pots set directly upon it. The pot puller sets each pot firmly into the bed of coal, and when all are in, the moulder fills up around them with coal, heaps it up about 8 in. over the tops of the holes, and puts on the covers. Care must be taken to keep the coal out of the pots, as the steel absorbs carbon and sulphur from it very rapidly. The melter then puts the forced draft on the fires and urges them. At first the fires should be blown rather gently, especially if new pots are being used, because if the pots are heated up too rapidly they will spall and crack.

The melter should not be allowed to rush his fires up to full heat at the very first, because the sides of the pots are a poor conductor of heat, and through them must be driven the total amount of heat necessary to bring the steel up to the melting point, and to melt it; and if the outsides of the pots are brought to white heat very rapidly, leaving the contents of the pots comparatively cold, the heating up of the steel is not greatly hastened, but the pots themselves are exposed to extreme temperatures much longer than necessary, and are melted and slagged away on the outside very rapidly.

After about two hours the fires and pots settle down in the holes, so that it is necessary to get more fuel in under the pots to keep them off the grate bars. The pot puller goes over the holes and raises each pot with his tongs, while the melter pokes the coal well in under them, and the moulder shovels in more fuel. For this purpose coal is generally used, though sometimes part or all of this extra fuel is coke, which burns up more rapidly and makes a more intense heat than coal but does not last so long. The fuel is bedded up about level with the tops of the pots and well poked in, the covers replaced on the holes, and the fires urged again. In from one to three hours more the steel will be melted.

The melter examines the pots by separating the covers of the holes a little with his poker, and sliding the lid off each pot in succession. If the steel is melted, he thrusts his poker to the bottom of the pot to ascertain the condition of the metal. When first melted the steel boils quite freely and is "cold," so that a layer of it sticks to the poker. The boiling gradually subsides, and when the steel has been held in the pots a sufficient length of time, the bubbles in the slag will be large, and burst lazily, forming the so-called "cats-eyes." When the steel is hot enough not to stick to the poker and is quiet, the melter tosses in the additions of ferrosilicon and ferromanganese in envelopes and after a few minutes the covers are removed from the holes and the pots drawn. The adhering coal is rapidly scraped from the sides of the pots, the lids removed, and the slag wiped off. This is done with a slag "mop," or ball of slag formed on the end of an iron rod, with a ring at the end to start the formation of the slag ball. By wiping around the pot with the mop, at the same time turning it in the hand, a layer of sticky slag is caught on it which is spun off by rapidly whirling the mop along the floor. In a very few moments the steel is wiped clean and is ready to be carried to the moulds. In pouring into the moulds any remaining slag or scum is held back with a skimmer, or "flux-stick."

When a ladle is used the melter rapidly dumps the pots into it without wiping off the slag, which forms a blanket over the steel and protects it from chilling. For this practice, the more slag the better.

In oil and gas furnaces the melting is carried out very much in the same manner as in coal holes, with the exception that the pots naturally do not have to be raised to put extra fuel under them, and that the melting is more rapid. When using the Krupp type of furnace, it is not possible to make final additions to the pots in the furnace, and ferrosilicon, etc., must either be charged with the other stock, or in the ladle if one is used.

In both oil and gas furnace melting, the remarks already made on the dangers of too rapid firing at the first apply with even greater force than for coal hole melting, as it is easier to obtain extreme temperatures soon after the pots are charged. With bad handling, too hot a flame at first, and too much air admitted with the gas or oil, new pots are sometimes completely used up in one heat; properly handled, pots should average in a gas furnace three or four heats in steel foundry practice. When high carbon steel is melted, they will last much longer.

THE RAW MATERIAL

The raw materials used in crucible steel foundries are:

Puddled iron.
Charcoal iron.
(Basic) open-hearth scrap, especially boiler plate punchings.
Washed metal.
Charcoal.
Ferrosilicon, generally 50 per cent.
Ferromanganese, generally 80 per cent.
Nickel, ferrochrome, metallic chrome, tungsten, molybdenum, etc.
(Heads, gates and scrap castings.)

Specifications for the first four on the list should be carefully drawn so that the phosphorus and sulphur of the steel shall be within the limits desired. If castings are made to recognized specifications, a top limit of .08 per cent. of phosphorus and sulphur will be demanded for those on which no tensile tests and bend tests are made, and .05 per cent. where these tests are called for. In any case the phosphorus and sulphur for good castings should never be allowed to exceed the upper limit of .08 per cent.

In order to keep within these limits, the phosphorus and sulphur in the raw material have to be somewhat lower than this, since there is some loss of iron in melting, and the impurities therefore increase; some phosphorus comes from the ferromanganese, etc., used; and a little sulphur is picked up from the flame; and as it is necessary for good economy to remelt the scrap made in the shop the increase works up to a limit.[1]

Assuming that we melt in each pot 30 lb. of our own scrap, 69½ lb. of iron (or boiler plate punchings) and washed metal together, and ½ lb. of ferromanganese; that the loss in melting is 2

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[1] See Chapter 12.

per cent.; that the ferromanganese contains .3 per cent. of phosphorus; and that the maximum percentage of phosphorus we can allow in our steel is .05 per cent.; we can figure the maximum allowable percentage of phosphorus in our iron and washed metal as follows:

Let x equal this allowable percentage; then,

$$.05=\frac{69.5(x)+30(.05)+.5(.3)}{98}$$

whence, x equals .046 per cent.

Practically, it is better to keep below this figure. Swedish (charcoal) iron and puddled iron can be bought at .012 per cent. or .02 per cent. in both phosphorus and sulphur, though .03 per cent. is a safe limit, and cheaper material can be bought at this figure. Washed metal can easily be purchased below .02 per cent. or .025 per cent. in these impurities, and had better be kept to this figure, since the expense is generally not greater than for material analyzing .03 per cent. Open-hearth scrap can be bought below .03 per cent., and .035 per cent. is the highest that can safely be allowed, since the determination of the exact analysis of an entire lot is impossible, and some of each shipment may run higher than the average. Ferro-silicon and the other alloys, except ferromanganese, are commonly low enough in phosphorus and sulphur not to need attention. Ferromanganese frequently runs high in phosphorus, and the German product especially should be taken only on guarantee of its phosphorus content, as it runs higher in that impurity than English ferro. The average contents in other constituents can be taken about as follows: those to be specified are in parentheses.

Material	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	W, %	Mo, %	Slag %
Puddled and Swedish iron	.10	.10	.10	(.012)	(.012)	......	......	......	......	1-3
Basic open-hearth scrap	.10 to .30	.08 to .20	.40 to .80	(.03)	(.03)	......	......	......	......	......
Washed metal.	about 3	.10	.10	(.025)	(.025)	......	......	......	......	......
Ferrosilicon.	2.00	(10)	3-4	.03	.1	......	......	......	......	......
Ferrosilicon.	.08 to 2	(50)	......	.03	.03	......	......	......	......	......
Ferromanganese	6.00 to 7.00	.20 to .50	(80)	.03	.30	......	......	......	......	......
Ferrochrome	(1 to 8)	.1 to 1.0	......	.08	.04	......	(70)	......	......	......
Tungsten...	(.03 to .5)	.05 to .5	......	(.01 to .3)	(.008 to .02)	......	......	(90-98)	......	......
Molybdenum	(up to .5)	.2 to .4	......	(.03 to .3)	(.003 to .02)	......	......	......	(90-98)	......
Nickel......	.5	.1	......	.02	.02	(98)	......	......	......	......

THE CONTROL OF ANALYSIS

In figuring the analysis of crucible steel, nearly everything is fairly easy to estimate, except the carbon. While part of the carbon is contained in the alloys added and the iron and washed metal (or charcoal) melted, a considerable amount is absorbed from the graphite of the pots. This amount will vary from .15 or .20 per cent. to .40 per cent. according to the following factors:

1. Scrap and iron high in manganese absorb more than those low in manganese.
2. Heats hard to melt (puddled iron or steel scrap and a little washed metal) absorb more than heats easy to melt (all our own scrap for instance).
3. New pots contribute more than old.
4. Heats held long after melting pick up carbon rapidly.

Just how much will be gained can only be learned by experience and experiment, and mixtures frequently have to be changed to keep analysis correct. As a gas furnace grows old it melts more slowly, and commonly the steel then absorbs more carbon. Pots melted in gas and oil furnaces do not pick up as much carbon as those melted in coal holes.

For melting soft steels, below about .25 per cent. carbon (or even higher in the case of alloy steels), a clay or clay-lined pot must be used, to prevent the absorption of carbon. In fact, there is a loss of from .15 per cent. to .40 per cent. carbon in clay pot melting, which varies as follows:

1. Heats hard to melt lose more than those easy to melt.
2. Heats held long after melting lose more.

The clay lining of these pots is sometimes cut through to the graphite by the slag, especially if the slag formed is high in MnO, and then the steel absorbs carbon and the analysis obtained is not what was expected. This seldom happens on a new pot, or a pot used the second time on steel easy to melt. After the second heat there is not often enough of the lining left to use the pot again for making low carbon steel, unless the steel that has been made was very easy to melt. When the lining is cut through, the pot can be used for high carbon steel, allowing for a smaller absorption of carbon than for a regular graphite pot as long as any considerable amount of lining remains.

Silicon and manganese, when added in the form of 50 per cent. ferrosilicon and 80 per cent. ferromanganese, frequently come out lower than expected, if the alloys are charged in the pots with the iron and scrap. They are best added cracked fine and weighed into manilla envelopes, which are tied up with twine and tossed into the pots about five minutes before drawing. This procedure greatly shortens the time formerly allowed for "killing" or "dead melting" (allowing the steel to absorb silicon from the clay of the pot), which was once from ½ to 1¾ hours. Dead melting is now seldom practised, and the steel is not held long in the pots after it has become quiet.

The alloys used, such as chrome, tungsten, molybdenum and nickel, are charged with the iron or scrap. The metallic nickel on the market is nearly pure, and should generally be figured as containing 98 per cent. nickel. Molybdenum and tungsten are best used in the metallic (powdered) form and can be figured, if of about 98 per cent. purity, as containing 95 per cent. metal. Ferrochromes generally contain 70 per cent. chrome, and can be figured as containing 65 per cent. Carbon, silicon and manganese in all materials charged, if of sufficient quantity to affect the results, should be carefully figured in, not omitting to figure the carbon in the ferrosilicon and ferromanganese used as final additions.

If charcoal is used as the source of carbon, the amount it will contribute is variable, according to the difficulty of melting the steel. Easily melted charges absorb most carbon from charcoal. It is a safe rule to figure the charcoal as containing 85 per cent. carbon on heats of all high carbon scrap, and as low as 70 per cent. or even 65 per cent. in all puddled iron (or plate scrap) heats of low carbon content.

Without close co-operation between steel maker (figure man), and melter, the control of analysis, especially of carbon, is impossible. The pots never melt at a uniform rate, and, as already stated, the rate of melting affects the amount of carbon absorbed from the graphite very greatly. The pots nearest the ports in a Krupp furnace will melt first; in regenerative hole furnaces, generally the hole nearest the gas valves leads; in coal holes, the fires draw better in one hole than in another; and in any hole the middle pots generally lead the end pots. Hence some pots will melt more slowly than others, and since it is commonly not practicable to draw the pots as they melt, some will be held fluid after melting longer than others. In hole furnaces it is, of course, possible to draw all the pots in one hole as soon as they are melted, and even in Krupp furnaces this can be done to some extent. The furnace crews, however, naturally do not relish being kept about in their wet rags very long, and it is seldom good policy to start drawing until all pots are far enough along so that they can all be pulled without much delay. Another reason why intermittent drawing is bad practice is that in drawing the furnace cools off considerably, which retards the melting of the laggards; and that the melter being busy bossing the job of drawing cannot give his attention as he should to the steel being melted.

In hole furnaces, the melter has an opportunity to slow down the holes that are melting too fast, either by shutting off the forced draught on coal holes, or by opening the covers on gas holes. On oil furnaces, the flame can be cut down for the same purpose. The good melter watches his steel carefully, and by noting the rapidity of melting, the boiling of the steel, the depth of cutting at the slag line, etc., can gauge with surprising accuracy the progress of absorption of carbon, and draw his heat at such a point that the majority of the pots will give steel close to the desired composition. But inevitably there will be variations, frequently quite wide, between the analyses of individual pots.

The same is true, with a reverse sign, of melting in clay pots or clay-lined pots; indeed, it is seldom possible in clay-lined pot practice to obtain the same nicety of control that is characteristic of higher carbon steel making in graphite pots.

THE USE OF LADLES TO PROMOTE UNIFORMITY

Here we see in greater detail one of the disadvantages already mentioned of crucible steel making, the auto flexibility, so to speak, of the process, which often causes wide variations in the analysis, and hence the physical properties, of the castings produced. In tool steel practice, mixing the steel in large ingots by pouring a number of pots through a common funnel, one after the other, or pouring three pots into two and then into the ingot mould, has proved but a partial corrective of this evil. The large ingots, say of eight or ten pots, so poured, have proved very far from uniform along their length and cross-section, as there is not time in the moulds for thorough mixing of the steel from the different pots; and the same will commonly be true of steel castings poured by dumping pots successively into a casting. The corrective for this trouble is mixing the steel in a ladle. Necessarily, in ladle pouring, all the pots have to be melted before any are drawn, but a good melter will often draw some pretty cold ones, balancing them with hot steel from other pots, when he feels that the average of the heat has reached the analysis desired, and will turn out steel of surprising uniformity from heat after heat. It is never, however, possible to guarantee the same exactness of composition that is possible for instance in acid open-hearth practice, and a leeway of 10 "points" at the least, as .30 per cent. to .40 per cent. when .35 per cent. is desired, is the closest control of carbon that can be expected for a number of heats.

There is one disadvantage in ladle pouring, however, in that it sacrifices some of the heat of the metal. Thus, although the steel can be got quickly into the ladle and is protected from cooling by the blanket of slag (which is purposely made abundant for ladle work by putting about a cupful of brick dust in each pot), yet it naturally does not keep as hot as if left in the furnace till needed. Hence, in pouring very small work, even if the steel after mixing in the ladle is promptly distributed about the shop in shank ladles, more difficulty will be experienced than in pouring directly from the pots. It is, therefore, a question of judgment how far to go toward securing uniformity of composition by ladle mixing at the sacrifice of the high temperature so necessary for running small and intricate work. We are more or less between the devil and the deep sea: to leave pots too long in the furnace because the pouring gang is small and few pots can be handled at a time, increases heterogeneity; to draw them all and mix the steel in a ladle often means lost castings or metal poured into scrap because it has grown too cold to run thin sections. Again, a large pouring gang can handle the pots rapidly from the furnace, if they are poured direct, or can handle a number of small shanks at once if the steel is mixed in the ladle, but a large gang costs money. Moreover, to pour small castings over the lip of a large ladle, or through a nozzle, is out of the question, as the stream is too large and there is no chance to pour the casting at the rather gentle rate often necessary. Perhaps the ideal condition would be to have enough heavy work on hand to take the cooler metal from the ladle after about half the heat had been poured into light castings by means of small shanks filled from the ladle. The whole subject is a nice question of judgment, and is discussed at some length here, because though similar conditions exist in pouing steel in the other steel-making processes, they do not to any extent involve the non-uniformity of composition so hard to deal with in crucible steel making.

As the troubles of the melter in securing steel of proper composition from a whole heat are many and various, it is clear that to require him to produce more than three or four different kinds of steel in one heat so multiplies the chances of error as to practically insure a good deal of steel of faulty composition.

Packing Pots.—In packing pots, a little iron (or plate scrap) is first laid on the bottom, then the charcoal, nickel, ferrochrome, etc. (brought in weigh pans from the "physic" room), then the rest of the iron and scrap. Washed metal is frequently charged in good-sized lumps on the very top, leaving the cover raised some inches—in the opinion of the author this is poor practice, as some of this metal is apt to run down the outside of the pot and cut it badly. Pots should never be charged more than level full, and though putting the washed metal on the top facilitates melting because the high carbon washed metal melts first and in running over the iron and scrap helps carburize and melt them, yet in the process some carbon is inevitably oxidized which would not be lost if the washed metal were covered with a good layer of iron or scrap.

Examples of Charges.—In figuring crucible steel charges, the author has found the most convenient method is to work entirely in ounces, a 90-lb. pot containing, of course, 1440 oz. This is a comparatively easy number to divide by, especially since one soon learns its multiples; and the larger figures so involved will be found easier to handle than fractions or decimals of a pound, which must afterward be reduced to the nearest ounces in weighing out the charges. For the benefit of the steel maker who may be interested in this method of figuring, and for the elucidation of some of the remarks already made on gains and losses in melting, the following typical cases are appended.

The lime in these examples is to help form a slag, by uniting with the iron oxide of the rust and scale on the iron and some silica from the clay of the pot. The black oxide of manganese is added with the idea that manganese will be reduced from it by the carbon of the steel, resulting in the better deoxidation of the metal. Its use in conjunction with ferromanganese is of doubtful value.

The "Base" is the estimated weight of the steel, from which the percentages of carbon, silicon, etc., are calculated.

(1) High-speed Tool Steel—Graphite Pots—Coal Holes

CHARGE

Lime	½ oz.	
80 per cent. ferromanganese	1 oz.	= 1 oz.
70 per cent. ferrochrome	4 lb. 8 oz.	= 72 oz.
Tungsten	8 lb. 12 oz.	= 140 oz.
Molybdenum	2 lb. 14 oz.	= 46 oz.
Wrought iron	75 lb.	= 1200 oz.
Ferromanganese in package,		= 1 oz.
		1460 oz.
Base		= 1440 oz.

CARBON

Ferromanganese	2 oz. at .06	= .12 oz.
Ferrochrome	72 oz. at .07	= 5.04 oz.
Tungsten	140 oz. at .01	= 1.40 oz.
Molybdenum	46 oz. at .015	= .69 oz.
Iron	1200 oz. at .001	= 1.20 oz.
		8.45 oz. = 59 per cent.

CHROME

Ferrochrome	72 oz. at .65	= 46.8 oz.	= 3.25 per cent.

TUNGSTEN

Tungsten	140 oz. at .95	= 133 oz.	= 9.24 per cent.

MOLYBDENUM

Molybdenum	46 oz. at .95	= 43.7 oz.	= 3.03 per cent.

MANGANESE

Ferromanganese	2 oz. at .75	= 1.50 oz.
Iron	1,200 oz. at .001	= 1.20 oz.
		2.70 oz. = .19 per cent.

ANALYSIS OF STEEL

C	Cr	W	Mo	Mn	P	S	Si
.87	3.39	9.31	2.92	.19	.02	.014	.12

(2) High-speed Steel—Clay-lined Pots—Coal Holes

CHARGE

Lime	½ oz.	
80 per cent. ferromanganese	3½ oz.	= 3.5 oz.
70 per cent. ferrochrome	4 lb. 8 oz.	= 72.0 oz.
Tungsten	8 lb. 12 oz.	= 140.0 oz.
Molybdenum	2 lb. 14 oz.	= 46.0 oz.
Wrought iron	74 lb.	= 1184.0 oz.
Ferromanganese in package,		= 2.5 oz.
		1448.0 oz.
Base		= 1440.0 oz.

CARBON

Ferromanganese	6 oz. at .06	= .36 oz.
Ferrochrome	72 oz. at .07	= 5.04 oz.
Tungsten	140 oz. at .01	= 1.40 oz.
Molybdenum	46 oz. at .015	= .69 oz.
Iron	1184 oz. at .001	= 1.184 oz.
		8.674 oz. = .60 per cent.

Chrome, tungsten and molybdenum same as (1).

MANGANESE

Ferromanganese	6 oz. at .75	= 4.50 oz.
Iron	1184 oz. at .001	= 1.184 oz.
		5.684 oz. = .39 per cent.

ANALYSIS OF STEEL

C	Cr	W	Mo	Mn	P	S	Si
.40	3.21	9.01	3.25	.10	.013	.014	.09

(3) High Per Cent. Nickel Steel—New Clay-lined Pot—Coal Holes

Melting Time 4 hr. 51 m.

CHARGE

Lime	½ oz.	
Black oxide of manganese	2 oz.	
Charcoal	4.5 oz.	= 4.5 oz.
Nickel	17 lb. 4 oz.	= 276.0 oz.
80 per cent. ferromanganese	1.5 oz.	= 1.5 oz.
Iron	73 lb.	= 1168.0 oz.
Ferromanganese in package		= 5.0 oz.
		1455.0 oz.
Base		= 1440.0 oz.

CARBON

Charcoal	4.5 oz. at .70	= 3.15 oz.
Nickel	276 oz. at .005	= 1.38 oz.
Ferromanganese	6.5 oz. at .06	= .39 oz.
Iron	1168 oz. at .001	= 1.168 oz.
		6.088 oz. = .42 per cent.

NICKEL

Nickel	276 oz. at .98	= 270.48 oz.	= 18.78 per cent.

MANGANESE

Ferromanganese	6.5 oz. at .75	= 4.875 oz.
Iron	1168 oz. at .001	= 1.168 oz.
		6.043 oz. = .42 per cent.

ANALYSIS OF STEEL

C	Mn	P	S	Si	Ni
.15	.30	.01	.018	.044	19.17

(4) Hard Chrome Steel—Graphite Pot—Coal Holes

Melting Time 4 hr.

CHARGE

Lime		½ oz.	
Black oxide of manganese		2 oz.	
80 per cent. ferromanganese		1 ½ oz. =	1.5 oz.
70 per cent. ferrochrome	2 lb.	2 oz. =	34.0 oz.
Charcoal		3 ½ oz. =	3.5 oz.
Ferrosilicon		3 ½ oz. =	3.5 oz.
Iron	88 lb.		= 1408.0 oz.
Ferromanganese in package			7.5 oz.
			1458.0 oz.
Base			= 1440 oz.

CARBON

Ferromanganese	9 oz. at .06	= .54 oz.
Ferrochrome	34 oz. at .07	= 2.38 oz.
Charcoal	3.5 oz. at .70	= 2.45 oz.
Iron	1408 oz. at .001	= 1.408 oz.
		6.778 oz. = .47 per cent.

CHROME

Ferrochrome	34 oz. at .65	= 22.1 oz. = 1.53 per cent.

MANGANESE

Ferromanganese	9 oz. at .75	= 6.75 oz.
Iron	1408 oz. at .001	= 1.408 oz.
		8.158 oz. = .57 per cent.

SILICON

Ferrosilicon	3.5 oz. at .50	= 1.75 oz.
Iron	1408 oz. at .001	= 1.408 oz.
		3.158 oz. = .22 per cent.

ANALYSIS OF STEEL

C	Mn	P	S	Si	Cr
.79	.39	.01	.02	.175	1.47

(5) Hard Nickel Steel—Graphite Pots—Coal Holes

Melting Time 4 hr.

CHARGE

Lime		½ oz.	
Black oxide of manganese		2 oz.	
80 per cent. ferromanganese		3 oz.	= 3.0 oz.
Charcoal		11.5 oz.	= 11.5 oz.
Nickel	2 lb.	15.5 oz.	= 47.5 oz.
Iron	87 lb.		=1392.0 oz.
			1454.0 oz.
Base			=1440. oz.

CARBON

Ferromanganese	3 oz. at .06	= .18 oz.
Charcoal	11.5 oz. at .70	=8.05 oz.
Nickel	47.5 oz. at .005	=0.238 oz.
Iron	1392 oz. at .001	=1.392 oz.
		9.86 oz. = .69 per cent.

MANGANESE

Ferromanganese	3 oz. at .75	=2.25 oz.
Iron	1392 oz. at .001	=1.392 oz.
		3.642 oz. = .25 per cent.

NICKEL

Nickel	47.5 oz. at .98	=46.55 oz. =3.23 per cent.

ANALYSIS OF STEEL

C	Mn	Ni
.87	.24	3.42

(6) Soft Nickel Steel—Clay-lined Pots—Coal Holes

Melting Time 5 hr. 20 m.

CHARGE

Lime		½ oz.	
Black oxide of manganese		2 oz.	
80 per cent. ferromanganese		1 oz.	= 1.0 oz.
Charcoal		5.5 oz.	= 5.5 oz.
Nickel	2 lb.	10.5 oz.	= 42.5 oz.
Iron	72 lb.		=1152.0 oz.
Ferromanganese in package			4.5 oz.
Ferrosilicon in package			9.0 oz.
			1214.5 oz.
Base			=1200 oz.

CARBON

Ferromanganese.......	5.5 oz. at .06	=0.33 oz.
Charcoal.............	5.5 oz. at .70	=3.85 oz.
Nickel...............	42.5 oz. at .005	=0.213 oz.
Iron.................	1152 oz. at .001	=1.152 oz.
		5.545 oz. = .46 per cent.

MANGANESE

Ferromanganese.......	5.5 oz. at .75	=4.125 oz.
Iron.................	1152 oz. at .001	=1.152 oz.
		5.277 oz. = .44 per cent.

SILICON

Ferrosilicon.........	9 oz. at .50	=4.50 oz.
Iron.................	1152 oz. at .001	=1.152 oz.
		5.652 oz. = .47 per cent.

NICKEL

Nickel...............	42.5 oz. at .98	=41.65=3.47 per cent.

ANALYSIS OF STEEL

C	Mn	Si	P	S	Ni
.19	.31	.367	.015	.023	3.84

(7) Steel Castings—Graphite Pots—Krupp Furnace

CHARGE

Black oxide of manganese	3 oz.	
Boiler punchings........................	75 lb. =	1200.0 oz.
Heads and gates.........................	25 lb. =	400.0 oz.
Washed metal	10 lb. =	160.0 oz.
80 per cent. ferromanganese.............		1.5 oz.
60 per cent. ferrosilicon...............		10.0 oz.
		1771.5 oz.
Base..............................		=1760. oz.

CARBON

Punchings............	1200 oz. at .002	=2.40 oz.
Gates................	400 oz. at .0075	=3.00 oz.
Washed metal.........	160 oz. at .03	=4.80 oz.
Ferromanganese.......	1.5 oz. at .06	= .09 oz.
		10.29 oz. = .58 per cent.

SILICON

Ferrosilicon	10 oz. at .55	= 5.5 oz.
Gates................	400 oz. at .002	= .8 oz.
Punchings............	1200 oz. at .001	= 1.2 oz.
		7.5 oz. = .43 per cent.

MANGANESE

Ferromanganese.......	1.5 oz. at .75	= 1.125 oz.
Punchings............	1200 oz. at .002	= 2.400 oz.
Gates................	400 oz. at .003	= 1.200 oz.
		4.725 oz. = .27 per cent.

MELTING TIMES AND ANALYSES OF HEATS

Time	C	Si	Mn
5 hr. 45 m...............	.71	.26	.34
5 hr. 45 m...............	.61	.25	.27
5 hr. 30 m...............	.75	.28	.29
5 hr. 55 m...............	.62	.29	.29
4 hr. 45 m...............	.67	.30	.28
6 hr. 15 m...............	.68	.34	.30
5 hr. 35 m...............	.80	.33	.38
5 hr. 35 m...............	.80	.27	.36
Average.............	.71	.29	.36

(8) SAME AS (7), EXCEPT THAT FERROMANGANESE = 3 OZ.

FIGURED ANALYSIS

C	Si	Mn
.59	.43	.33

MELTING TIMES AND ANALYSIS OF HEATS

Time	C	Si	Mn
....	.84	.28	.31
6 hr. 40 m...............	.66	.29	.32
5 hr. 40 m...............	.77	.31	.35
4 hr. 50 m...............	71	.31	.34
Average..............	.75	.30	.33

(9) THE ANALYSES OF 25 HEATS OF CHARGES (7) AND (8) GAVE RESULTS AS FOLLOWS:

	P	S
Lowest....................	.019	.016
Highest....................	.062	.088
Average....................	.033	.063

Three points of crucible steel foundry practice are illustrated in these figures—the use of washed metal and open-hearth scrap as raw materials, the high carbon carried to make the charge melt easily, and the high sulphur and phosphorus content of some of the steel made.

ALLOY STEELS

The crucible process is well suited to the manufacture of ordinary carbon steels, except those very low in carbon; and of nickel, chrome, nickel-chrome, tungsten and molybdenum steels. Examples of most of these are shown in the tables above.

Manganese steel can be produced in crucibles, by charging a mild steel mixture that will melt at about .20 to .25 per cent. carbon in clay-lined pots, and mixing this steel with proper amounts of ferromanganese, melted separately in graphite pots. It is not possible to melt the whole charge together, because, as already noted, mixtures high in manganese cut deeply into crucibles and absorb a great deal of carbon. When an attempt is made to melt wrought iron, or soft steel scrap, and ferromanganese together in a graphite pot, the absorption of carbon is so great as to result in a steel containing 2 or 3 per cent. of carbon, quite useless for the purposes for which manganese steel is made. Even in clay-lined pots, the cutting action is so severe as to eat through the clay lining and cut deeply into the graphite, so that the carbon of the steel will be far too high.

For the same reason manganese steel sink heads, gates and other scrap cannot be remelted in graphite or clay-lined crucibles, so that the scrap has to be sold or used up in open-hearth furnaces. Clay crucibles could be used for making the steel and remelting the scrap, but clay crucibles as already noted are awkward to handle, and the cutting action of the scrap is so severe as to wear out pots very rapidly.

The cost of manganese steel made by the crucible process is so high that it is not practicable to produce the steel in this way, except for certain special products of small size—and even for these castings other processes are more suitable.

CHAPTER IV

THE BESSEMER PROCESS

The Bessemer process for converting pig iron or its equivalent into steel was invented by Sir Henry Bessemer in the 1850's, and was the first method ever developed for the production of steel in large heats and at a low price. It is an indirect method—that is, it converts pig iron, the first product made from the ore, into steel—and owes its cheapness to the tremendous tonnage that can be turned out with a comparatively inexpensive installation.

The process consists in blowing air through a molten mass of pig iron, high in carbon, silicon and manganese, contained in a cylindrical vessel lined with refractory material and open at the upper end for the escape of the gases. The oxygen of the air oxidizes the silicon, manganese and carbon very rapidly, the silicon and manganese forming SiO_2 and MnO, which unite with FeO produced by the oxidation of some of the iron to form a slag; the carbon escaping into the air as CO and burning at the vessel's mouth to CO_2, producing an intensely bright flame. In from 8 to 15 minutes the impurities in the steel are all oxidized, and iron begins to burn rapidly, producing a great deal of FeO, some of which is absorbed by the metal, the rest going into the slag.

The combustion of the silicon to SiO_2, and to a less degree that of manganese to MnO, produces a great amount of heat. That of carbon to CO adds only slightly to the heat of the steel. The heat produced by the combustion of these elements raises the temperature of the molten iron the amount necessary to maintain it fluid when the impurities are all removed and a bath of metallic iron remains.

It was the FeO absorbed by the steel at the end of the blow that hampered the early experiments of Bessemer, and for a time rendered the success of the process doubtful. The metal when tapped from the stationary vessels first used, was so heavily oxidized and full of gas that it was "wild" in the moulds, full of blow holes, weak, and generally worthless. Nevertheless, plants were built to produce Bessemer steel and constant efforts made to overcome this difficulty.

In Sweden, the process was a success practically from the start, and many plants were erected that produced excellent steel without difficulty. Upon investigation, it was found that the Swedish pig iron used for the process was so high in manganese that much of this element remained unburned till near the end of the process; and that as the Swedes had adopted the procedure of stopping the blow when about the amount of carbon was left in the metal that was desired in the finished product, much manganese remained in the blown steel. It was thought, rightly as it proved, that this manganese counteracted the injurious effects of the oxidation of iron, and that in blowing pig iron low in manganese, the addition of spiegel (pig iron containing 10 to 20 per cent. of manganese) might overcome the difficulties that were being experienced in English practice. The surmise proved correct, the low manganese pig iron blown as usual and then treated with molten spiegel to add manganese (and at the same time the desired carbon), was found to produce excellent steel, and from that time on the success of the process was assured. In 1856 Sir Henry Bessemer read his paper on "making wrought iron and steel without fuel," and acknowledged the necessity of manganese—Mushet obtained a patent on the use of manganese the same year.

The development of the process for making steel of all grades from soft structural steel to medium hard steel for rails, and even high carbon steel for tools, was very rapid. Inventors in all countries vied with one another in improving the mechanical devices used in the process, and increasing the size of the vessels and the output. The vessel was mounted on trunnoins, whereby the speed of handling was greatly increased; in place of melting the pig iron in cupolas, the fluid pig from the blast furnaces was kept hot for use in the Bessemer plant in a "mixer" (a tilting furnace of large capacity); the spiegel necessary for deoxidizing and recarburizing was melted in cupolas instead of reverberatory furnaces; and the cranes, casting pits and other apparatus for getting the steel into the ladles and thence to the moulds were greatly improved. At the same time the size of the vessels was increased, until in place of the 2- and 3-ton vessels first used, the standard steel works size in America to-day is from 10 to 2c tons.

In the manufacture of castings, the large bottom-blown vessel has been used to a certain extent from the first, but the application of the Bessemer process to the steel foundry soon involved the design of small units, and was hampered by the difficulty of producing steel in small heats that was hot and fluid enough to be run into light castings. In the efforts that were made to overcome this difficulty two lines were followed. The first was to retain the bottom-blown type of vessel and find means to produce higher temperatures by changes in the volume of air blown through the metal, that is, speeding up the process; by changes in the amount of heat-producing elements contained in the pig iron; and by adding heat-producing elements at some stage or stages of the blow. The second was to utilize the principle soon invented for warming up cold heats in the ordinary vessel, of blowing at or over the surface of the bath and attaining extra temperature by the combustion of iron and the burning of CO to CO_2 within the vessel. This led to the perfection of the side-blown vessel.

It was soon found that of the manganese added to Bessemer steel, a part was found chemically combined in the steel, a part disappeared. Moreover, within limits, the more manganese was added, the greater was the actual weight of manganese lost. As we now know, the manganese reduces the FeO in the steel by the reaction

$$FeO+Mn=MnO+Fe,$$

and the manganese oxide goes largely into the slag. Part of it is retained in the steel, but its influence is not so harmful as that of FeO.

A second function of the manganese is to unite with the sulphur of the steel, which normally exists as sulphide of iron, FeS, to produce sulphide of manganese, MnS. Owing to its existing in the steel as more or less rounded globules, instead of in strings between the crystals, MnS does not make steel "red short" (*i.e.*, weak and brittle when hot) to anything like the same degree as does FeS; and as iron does not dissolve the sulphides of other metals readily, some of the MnS floats out of the steel. These two functions of manganese are the basis of modern steel making.

A point to be clearly remembered in this connection is that, as already stated, more actual weight of manganese added increases the weight of manganese lost, that is the manganese converted to MnO and slagged. This means that the reaction between manganese and oxide of iron does not readily complete itself, owing to the tenacity with which metallic iron retains its own oxide in solution; and that in order to force the maximum amount of FeO to react with the manganese, we must have a considerable excess of the latter present. It is almost as if the manganese were a weight, the iron a sponge, and the FeO the water held in the interstices of the sponge. By setting a 4-oz. weight on the sponge we force out part of the water, putting on 4 oz. more expels still more water, and so on. We never can force all the water from the sponge by pressure; and by the reducing action of manganese alone, especially in the Bessemer process in which the manganese has but a short time to act, we can never expel all the FeO from the steel. A proportion remains, which depends largely upon the amount of manganese added, and the time allowed for it to act. It is to this residue of dissolved FeO, as well as to the gases absorbed and never completely expelled, that the inferiority of Bessemer steel is attributed.

The advantages of the process for the production of light castings are:

1. Cheapness of installation.
2. Cheapness of steel produced.
3. Large output per dollar invested.
4. High temperature of steel.
5. Suitability for intermittent operation.
6. Small heats at short intervals.

The installation costs of a small Bessemer plant are low, especially if a side-blown vessel is used, as the chief items of expense for the side-blown plant are vessel, cupolas, positive pressure blowers and motors to drive them. No very expensive foundation work is required, and the equipment is quite simple. The bottom-blown shop requires, instead of positive pressure blowers, a blowing engine of considerable size and boilers to supply it with steam, making the equipment more costly than that of the side-blown shop.

In the introductory chapters, figures have been given that show the comparatively low cost of the steel per ton, and the great output per dollar invested. The side-blown vessel falls somewhat below the bottom-blown in these respects, owing to the heavier loss of metal in blowing, and to the lower output resulting from slower blowing.

The side-blown vessel produces metal that is considerably hotter than that of the bottom-blown, but either if properly handled can be counted on to turn out steel that will pour into light castings without undue difficulty.

Intermittent operation of a small Bessemer plant is the rule rather than the exception. If the cupolas are run every day, and in the case of the bottom-blown vessel, if the vessel is run every day, the operation of the shop will be more uniform. The fuel required to heat up the vessel and cupolas does not cost much, however, and as the installation costs, especially of small side-blown shops, are quite low, many such shops are regularly run only part time.

For a foundry making small castings, the light heats of the Bessemer vessel, coming at frequent intervals, are an advantage in pouring for two reasons. First, the metal can be brought very hot to the moulds and all poured before it cools off. Second, the work of the moulders is not greatly hindered by the pouring, since only part of the shop is invaded by the pouring gang at each heat and the men elsewhere can go on moulding undisturbed.

The disadvantages of the small vessel in steel foundries are: 1. Quality—the steel not being as good as crucible or electric steel, with which it competes, nor on the average as good as acid open-hearth steel. 2. Small heats—the pouring of castings of over four times the gross weight of the steel that can be produced at one heat is extremely difficult with a bottom-blown vessel, and over twice or three times the weight of a heat with a side-blown. This disadvantage, however, is more apparent than real, since it affects only the production of heavy work and the small converter is seldom able to compete successfully with the open-hearth foundries in heavy carbon steel castings. In some kinds of specialty work, where the specialty is an alloy steel made in castings of all weights from a few ounces to 10 to 12 tons, this disadvantage becomes a real one, and makes it probable that the ideal shop of this kind would have both open-hearth and Bessemer equipment, using the latter for the special steel in small sizes, and the former for the heavy special steel orders and for a miscellaneous trade in machinery castings of the better class. 3. Flexibility, by which is meant the ability to produce readily several different kinds of steel in small lots. In Bessemer practice, the only way to make several kinds of steel from one heat is to put molten recarburizers in two or more ladles and add a weighed amount of the soft metal from the vessel. When a very sticky slag is made (in the Bessemer process the slag is sometimes semi-solid), it is not difficult to hold back the slag with a skimmer, and thus get the correct amount of metal in the ladle. When a fluid slag is made, it becomes well-nigh impossible to weigh the metal accurately.

This practice, moreover, cannot be carried very far in Bessemer work because the chilling of the steel in the vessel is so rapid that not more than two compositions of steel are readily made, and if the heat has been blown too cold, not even two.

The Bottom-blown Vessel.—The bottom-blown converter of small size is not widely used in this country, so that there is but one general type made. This is a plain cylindrical vessel, generally of about 3 tons capacity, with tapered nose, built all in one piece except the bottom and wind box, which are arranged to be readily removed from the body of the vessel. The vessel is mounted on trunnions, is revolved by a hydraulic cylinder with a rack working on a pinion on one vessel trunnion, or by an electric motor. The blast main enters through one trunnion, goes down the side of the vessel, and is attached to the wind box through a coupling readily broken when the bottom is removed. The bottom and wind box are permanently fastened together, and clamped to the body of the vessel in such a way as to be readily taken off when a new bottom is needed.

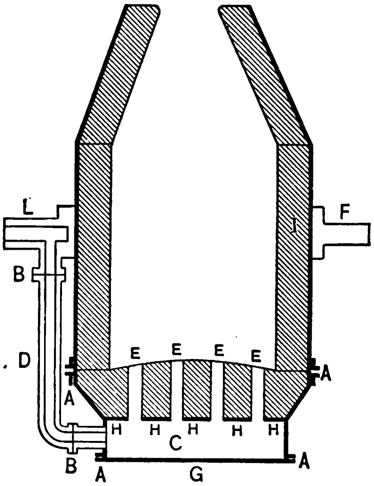


FIG. 5.—Bottom-blown Bessemer converter. Vertical section. A, Clamping lugs; B, joints in blast pipe; L, F, trunnions; D, blast pipe; G, wind box cover; C, wind box; H, bottom plate; E, tuyères; I, lining.

The vessel proper is generally lined up with flat slabs of so-called mica schist or of silica rock, beginning at the nose and working upward (the vessel being swung into position with nose down), until the whole is filled. The lining in the main part of the vessel is made about 10 in. to a foot thick, the slabs are wedged tightly in place, breaking joints carefully, and the whole well plastered with siliceous ganister (old silica brick or silica sand and pebbles ground up with enough clay to make the mass plastic). The bottom of the converter is provided with holes between wind box and lined space, on which the clay tuyères are set. These are bricks some 2 or 3 ft. long, each pierced with a number of small holes about $\frac{1}{2}$ in. in diameter through which the air passes. The outside of the bottom is lined with mica schist or rock of the same sort as that used in the body of the vessel, the space around the tuyères is partly filled up with large bricks set on end, and the remaining space is then packed with ganister ground very dry, shoveled in a few inches at a time, and tamped down with moulders' rammers. The whole is brought to a slightly convex surface, and is then dried out in an ordinary flask oven. The tuyères, bricks and ganister used for bottoms should be selected with care, as the life of bottoms is short enough at the best, and to use tuyères that melt or slag away rapidly greatly shortens this life.

The number of tuyères used for a 3-ton vessel is such that the total tuyère area is about 6 to 10 sq. in. If each tuyère has seven holes $\frac{3}{8}$ in. in diameter, and nine tuyères are used, this gives 6.95 sq. in. tuyère area. By varying the size of holes in one or more of the tuyères, and sometimes by omitting one tuyère, this area can be varied to meet the requirements. In general, with a given equipment, to reduce the tuyère area means slower blowing and less "slopping." The pressure of the blast can be changed to accomplish the same ends. The blast ordinarily used is supplied at a pressure of from 15 to 30 lb. per square inch.

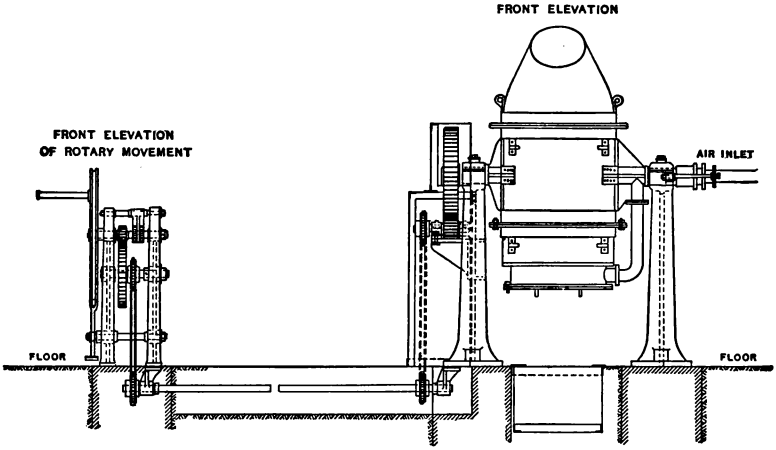


FIG. 6.—Walrand-Lègenisel converter. Front elevation. From Journal of the Iron and Steel Institute.

The life of a vessel lining should be from six months to a year. The composition of the metal charged in the vessel, by its influence on the slag produced, affects the life of linings, and especially of bottoms, very considerably. A high silicon, low manganese mixture produces a very siliceous, sticky slag, which cuts the linings hardly at all, while higher manganese produces a slag rich in oxide of manganese, fluid, and greedy for silica, which cuts linings and bottoms severely. In general, it is better to proportion the ganister used to give the greatest possible life of linings and bottoms with a given iron mixture, rather than to suit the mixture to the lining. This is especially the case where scrap can be used as a substitute for part of the pig, resulting in a considerable saving, though at the expense of linings on account of manganese in the scrap. It costs so little to line a vessel that the decreased life of lining is much more than offset by the saving in materials.

Bottoms will last from 15 to 40 heats—the latter figure is a high one. Frequently, on account of the delay incident to changing bottoms in the middle of a day's run, and the cold steel inevitably blown in the first one or two heats on a new lining, a bottom which would make several more heats is removed at the end of a day's run, rather than leave it on for the first few heats the next day.

Between heats the nose of the vessel is scraped out with an iron bar to remove loose slag, and places in the sides that are cutting out are plastered with ganister. Before starting up in the morning the cut places are similarly patched, if the lining is tending to cut itself out. With very siliceous slags the tendency is sometimes to build up the lining, and slag occasionally has to be cut away from the sides of the vessel with bars and sledges.

When a bottom is nearly used up and one or more tuyères are getting short, it is necessary to blank off a few holes in the tuyères, or sometimes a whole tuyère, by ramming the holes full of ganister. For this purpose the cover plate of the wind box is made readily removable, so that between heats the plate can be taken off and tuyères blanked off from the bottom. Holes in long tuyères that get stopped up are at the same time poked out with small bars.

Bottoms are put on by turning the vessel upside down, shoveling a good layer of ganister on the lining where the joint comes, setting on the bottom and tightening up the bolts, at the same time ramming the ganister tight with moulders' rammers.

Before blowing steel, the vessel has to be brought up to a good yellow heat. This is generally done by building a wood fire in it, turning on a gentle blast, and then dumping in lumps of soft coal. The fire is kept going three or four hours, and serves very well. The same thing can of course be done with an oil burner or other form of torch.

It is hardly possible to give the crew needed to handle the shop, as this varies considerably with the tonnage made, furnaces used for melting recarburizers, etc. Omitting the firemen on the boilers, and the engineer of the blowing engine, the men needed are:

Blower—generally foreman of the whole shop. He works, when blowing, in the "pulpit" where he can see the flame of the vessel and as much as possible of the shop. In the "pulpit" are the levers controlling the blast and the revolving mechanism of the vessel, engine-room push buttons or whistle cord, etc.

Vessel foreman—in charge of vessel and ladles.

Ladle man and two or three helpers, who also assist on the vessel.

One (or two) men on vessel charging platform, who may be part of ladle gang.

Cupola tender and helper.

One cupola charger—if mechanical charging be used.

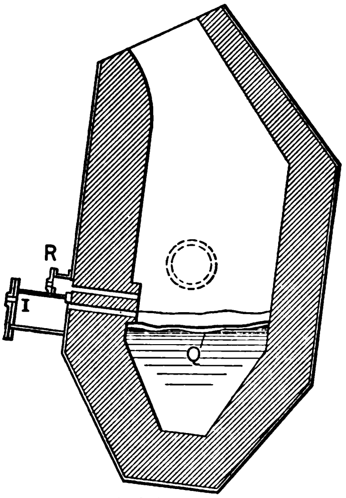
Yard gang, who handle raw materials for cupolas, and charge the latter in many shops.

Physic furnace foreman and helpers.

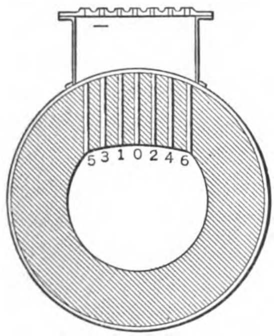
For vessel, ladles, etc., and cupolas, eight or nine men should be able to take care of 15 or more heats a day, including loading slag on small cars. If the slag is wheeled out in barrows, extra men must be provided for this job.

The Side-blown Vessel.—The side-blown vessel, which is the type almost universally used in steel foundries in America, differs from the bottom-blown chiefly in the construction of the vessel, and the pressure and method of application of the blast. It can be successfully used in smaller sizes, 2 tons being the most common capacity. In the original type of side-blown converter, the tuyères were placed around the sides of the vessel, somewhat below the surface of the metal. In consequence, a fairly high-blast pressure was required. These vessels may be considered as merely a modification of the bottom-blown type. The heavy wear on the lining at the tuyères, coming on the sides instead of on the removable bottom, is a great disadvantage because it renders necessary repairs to the lining itself every 20 to 30 heats. These converters are now little if at all used in America and will not be considered in this work.

The true side-blown vessel is one in which the blast is introduced through tuyères in one side of the vessel, above or *at the surface of the bath.* The Tropenas vessel was one of the first of this design to be widely used in America. In its original form it was provided with two rows of tuyères, the upper being designed to introduce extra air and burn CO to CO_2 more advantageously than by blowing an excess of air through the lower set. The extra set, however, proved to be difficult to manipulate and are now seldom used. To prevent undue oxidation of iron, the bath in this vessel has been made very deep. In placing a tamped lining in the Tropenas vessel, a collapsible form is used. The tuyères, which are commonly of brick, are comparatively short, and are said to require replacing every 20 heats or so.

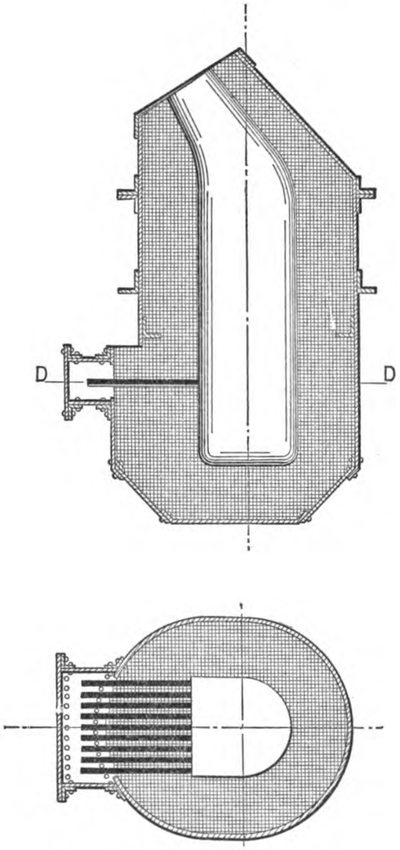


VERTICAL SECTION



HORIZONTAL SECTION

FIG. 7.—Tropenas converter. From Transactions of the American Institute of Mining Engineers.



SECTION ON DD

FIG. 8.—Stoughton long-tuyere converter. Vertical and horizontal section. From Transactions of the American Institute of Mining Engineers.

In recent years, several designs of two-piece vessels have been placed upon the market, in which either the top or the bottom half is made removable and is clamped on much as are the bottoms of bottom-blown vessels. The Stoughton converter is of this type, the bottom half, with the tuyères and wind box, being removable. This feature facilitates relining, as a solid wooden form is used for each part in placing tamped linings, and is said to allow of the use of a single vessel for continuous operation. Further features of this converter for which advantages are claimed are the use of iron or steel pipes for tuyères, held in place by a casting on the side of the vessel, in which they have a long bearing, some 9 in.; the thickening of the lining at this point, whereby longer tuyères are used; and increased height of vessel, whereby slopping is minimized. The placing of the tuyères is much simplified by the use of the solid bearing for them, and as they burn off they can be pushed forward a little and the lining patched around them. By the use of a thicker lining at the tuyères it is claimed that 25 to 30 heats can be made without putting in new tuyères. The removable bottom allows of extensive repairs to the lower half of the lining without disturbing the upper half.

The linings used in these converters are of three types: silica rock, (ganister rock), or mica schist slabs set in the converter in the same manner as the lining of a bottom-blown vessel; silica brick linings made up of special shapes; or a mixture of silica sand (and pebbles) and clay tamped in place around a wooden core to give the shape of the inside. When brick linings are used, the tuyères are generally in the form of special bricks. In stone or tamped linings the tuyères are made by moulding the lining round wooden forms (which are afterward pulled out), by the use of brick tuyères, or by using iron or steel pipes for the purpose which are left in place. In making a tamped lining one course of brick is generally used next to the shell, and the bottom is built up of brick for one or two courses.

The tuyères are generally arranged in fan shape, in order to cover every part of the converter with the blast. Minor repairs in the way of patching the lining, especially at the tuyères, have to be made for every run. The vessel is used only every other day, making from 7 to 12 heats, and the patching done on the idle days. The lining at the tuyères is generally patched from the outside by cutting it away at this point and replacing tuyères and lining through the wind box opening. For this reason it is commonly necessary, in order to blow steel every day, to have two or three vessels, since the converter cools off too slowly to enable the men to work at it and have it ready for use every day.

To overcome this difficulty, the Tropenas Company has introduced, in small sizes, a drop-bottom converter. In this design, the bottom is closed by a swinging door, such as those used on cupolas, which is dropped after the day's run, and the bottom punched out. With both ends of the vessel open it cools quite rapidly, and repairs can be made to the lining each morning without difficulty.

The top section of the lining of two-piece vessels lasts several months with only a little patching. In one shop, running a vessel every other day, making about 8 heats a day or 24 a week, a ganister lining is said to last about 9 months.

The side-blown vessel is heated up every day before steel is blown, sometimes with a coal fire, but more often by means of an oil burner introduced through one of the tuyères.

The blast used in these converters is at a pressure of 3 to 4 lb. per square inch, occasionally 5 lb. In order to furnish blast at this pressure in the necessary quantity, a positive pressure blower is required.

Special Types of Converters.—Two special designs of small converter deserve notice here, before the general description of Bessemer practice is taken up. The first of these is the Stock converter, in which the pig iron and scrap are charged cold and melted with oil burners introduced through the tuyères, after which the vessel is turned up and the metal blown. During the melting period the hot gases from the oil burners are taken off through an "economizer" or brick chamber containing iron pipes, which is opposite the nose of the converter while oil is being burned. When the metal is melted, the vessel is turned up to blowing position and the blast is taken through the pipes of the economizer, whereby its temperature is considerably raised. By the use of hot blast a very high blowing temperature is said to be attained. The advantages of this type of vessel are the high temperature of the metal, and the fact that in oil melting there is no absorption of impurities from the fuel, whereby the increase of sulphur in the iron, which is often so troublesome in regular practice, is avoided. This vessel has a distinct field of its own—the production of a very small tonnage of small steel castings as an accessory to shops not contemplating the production of steel in quantity, in localities where coke is costly. For this field its cheapness of installation commends its use. To attempt to compete with users of regular types of converters in localities where coke is cheap is quite another matter. To begin with, the melting of the metal will be considerably more costly by this process than by cupola melting, when enough steel is to be made to give the cupola a good run. In the second place, the Stock vessel will turn out steel at the rate of only about 1 heat every two hours. Compared with the regular vessel which produces 2 or 3 heats an hour, therefore, the Stock converter is at a disadvantage, as it would require from four to six of these vessels to equal the production of one converter of equal size supplied by a cupola. As the economy in installation is confined to cost of cupola and its blowers, we can readily see that for considerable tonnages this saving will vanish, since one cupola with blower or fan can be installed more cheaply than three to five extra vessels.

The field for the Stock converter will therefore be found in places where coke is costly and oil cheap. Under such conditions oil melting may be cheaper than cupola melting, but even then the disadvantage of being obliged to use a number of vessels to attain high output will remain. To take advantage of cheap oil and costly coke under these circumstances it might be more economical as far as melting costs go, for the production of a considerable tonnage of small castings, to install oil-burning melting furnaces and use them to supply a single converter of the usual type. The first cost of such an installation, however, would be greater than that of a battery of Stock converters, and if a regenerative furnace were used it could not be run intermittently, as converter plants can.

Bessemer Electric.—The second special type of vessel is the combined Bessemer converter and electric furnace, in which metal is first blown and afterward refined with electric current. The discussion of this type properly belongs with that of electric furnaces in general, and both this design and the open-hearth electric furnace will be described in the chapter devoted to electric furnace melting.

LAY-OUT OF BESSEMER SHOP

The lay-out of a shop depends so much upon the conditions in each case that it is not easy to give more than the general rules that apply to the subject, and many of them are rather negative than positive, stating rather what not to do than what to do. For convenience we will assume that our shop is of fair size containing say a 3-ton bottom-blown vessel or two 2-ton side-blown vessels, and that we shall produce about 8 to 15 heats per day. This comparatively large production is taken as a basis, since a shop making but a few heats a day, or a few heats a week, does not involve the problems in economical handling of material that demand attention in laying out the plant.

The shop will consist of

1. Engine room.
   - Bottom blown
     - Blowing engine and boilers
     - Pump for moving vessel by hydraulic power
     - Fan or compressor for cupolas (and for melting furnaces for recarburizers)
   - Side blown...
     - Compressor for vessel
     - Fan or compressor for cupola (and for melting furnaces for recarburizers)
2.
   - Cupolas
   - Vessel
   - (Melting furnaces for recarburizers)
3.
   - Ladle handling and heating fires (or oil burners)
   - Extra bottom handling and oven (bottom blown)
4. Yard for storage of..
   - Coal for boilers—bottom blown
     - and for recarburizer furnaces, if crucible coal holes are used
   - Coke for cupolas
   - Pig iron
   - Purchased scrap
   - Shop scrap
   - Ferromanganese, ferrosilicon, etc.

In the general arrangement of the shop, care should be taken in the first place to see that the units are so placed that they will not be in each other's way when the increasing output of the shop calls for extensions. In a bottom-blown shop, with its bulky installation of boilers, blowing engine, etc., this heavy machinery cannot readily be moved to allow for errors in original placing, and care should be exercised to locate it so that the other units of the plant can readily be extended without being interfered with by a badly placed engine room. At first sight this seems a simple matter, but when it is considered that the blowing engine must be fairly close to the vessel (because the engineer must see what is going on), the problem becomes more difficult. As the large blowing engine of the bottom-blown vessel is generally steam driven it will frequently be economical to install steam-driven pumps and to provide hydraulic power to rotate the vessel, and other small steam equipment.

The engine room equipment for a side-blown vessel is so much less bulky that it is far easier to place to advantage. The compressors are generally driven by electric motors, and occupy relatively little space. The vessel is most often turned over by an electric motor, and this still further reduces the total of equipment.

The cupola or cupolas for melting the vessel charge should be so placed as to most easily transfer the metal from them to the vessel. Though in small shops the cupolas are generally tapped near the ground and the metal brought to the vessel by lifting the ladles with the overhead crane, the economy of time and labor necessary where many heats are to be made points strongly to the desirability of placing the cupolas with their tapping level above the charging level of the vessels. This is especially desirable when several consecutive heats are to be blown for one casting, as delays in crane service may then retard the rapid production of the heats so essential to success. It may be objected that the extra height to which the pig iron and coke have to be hoisted is a disadvantage; but they have to be hoisted anyway, and if an elevator is to be used a few feet of extra lift do not materially affect the cost of hoisting. If the material is to be delivered to the cupola charging platform by an overhead crane in the stock yard, the extra height of crane runways needed for the higher cupolas would be a more serious matter, but in the majority of small steel foundries other means of yard handling are generally cheaper than an overhead crane so that this objection will not often be a valid one.

It is, therefore, generally most advantageous to have the cupolas at a higher level, discharging into a ladle on a vessel charging floor. This ladle may be swung with a crane, or mounted on trunnions (often on a platform scale, in order to weigh the amount of metal for each heat), and turned by a wheel with gear and pinion, running the metal through a spout into the vessel.

To facilitate the use of cupola metal for recarburizing high carbon heats, a swinging cupola spout will be of great advantage. By this means small ladles on a platform scale can be filled from the cupola with the proper amount of metal, and their contents poured into the vessel; or if the recarburizing is done in the ladles, the latter can be set upon the scale and filled direct from the cupola. Either arrangement would be more convenient than taking metal from the ladle used to weigh vessel charges.

The bottom-blown vessel is swung into a horizontal position for charging, and generally is charged when turned over in one direction, and poured when turned the other way. This necessitates the use of two spouts if recarburizing is to be done in the vessel, one to run in the blowing charge, and one to run in recarburizer. The side-blown vessel, on the other hand, generally is charged and poured on the same side. Hence if the recarburizers are to be added to the vessel, they can be run in by means of the same spout as that used to pour in the blowing charge.

Melting furnaces may or may not be installed for premelting "physic" (that is recarburizer), depending largely upon the grade of steel to be produced. If much hard steel, or steel containing a high percentage of alloys, is made, they are frequently a necessity, though at times the use of fluid metal from the main cupolas is all that is necessary.

The melting furnaces used for recarburizers should be of a type that can be operated intermittently, because of the generally intermittent, or at least single-turn operation, of the shop as a whole. Depending largely upon the kind and quantity of metal to be melted, we may use:

1. Small cupola.
2. Air furnace (coal or oil fired).
3. Crucible furnace.
4. Electric furnace.

The question of choice among these methods of melting is discussed in the section on the use of recarburizers.

If furnaces are used for melting recarburizers they should be placed so that they can readily pour their metal into the steel ladles, set on scales; or into a small ladle that can be poured into the vessel. When cupolas are used, they can be placed in such a way as to tap on the same level as those used to melt the vessel metal. In small shops where speed of operation is not particularly essential, the cupolas used for recarburizers are generally set at the general level of the foundry, and the metal taken to the vessel by cranes.

The main working floor should be as roomy as circumstances allow. Nothing is more fatiguing and exasperating to the men than a crowded shop where they have no elbow room and no place to jump to when the vessel "slops." As has already been pointed out in discussing crucible steel foundries, the greatest pains should be taken to provide means of throwing open in summer all places where men have to work—main floor, vessel platform, cupola tapping and charging platforms, physic furnaces, etc. Neglect of this important feature of design frequently adds considerably to the labor cost of shops when they grow to a good size and handle metal in bulk, since a hot stuffy working place simply means that the amount of work each man is physically able to accomplish per day is reduced and working forces are artificially enlarged.

Working space for lining and drying out ladles, fixing up stopper rods, etc., should be ample. Ladles may be dried and heated up with hard coal or coke fires, or oil or natural gas burners. The choice will be largely a matter of the relative cost of the fuel. In bottom-blown shops several extra bottoms are kept on hand, and one or two are always ready, lined up and dried out in a flask oven located conveniently to the melting shop. Storage space for tuyères, ladle nozzles and stoppers, sleeve brick for stopper rods, etc., should be conveniently located.

In order to keep the vessel at a low level, a pit is often placed in front of it, in which to set the ladle when it is being filled. The same thing is sometimes done in the case of physic furnaces. There are several drawbacks to such a lay-out. One is that if a ladle burns through and the steel goes into the pit, it is quite a job to get the resulting skull out, especially if the pit is deep and provided with concrete walls. Another is that such an arrangement makes it inconvenient to approach the vessel to fill shanks, or to pour in recarburizer from a small ladle. Moreover, men have a way of falling into such pits.

On the other hand, the pit can sometimes be made deep enough to hold the accumulated slag from a day's work, so that the job of removing slag between heats is dispensed with, and the whole cleaned out at once when the vessel is idle. In bottom-blown shops running to capacity, there is so much slag to take care of that it would not be advisable to make the pit deep enough for this purpose.

If, however, a shallow depression is provided in front of the vessel, the job of shoveling out the slag is easier, and especially when a car running on a small track is used in place of wheelbarrows to carry away slag, it is rather easier to remove it after each heat than to shovel a day's accumulation out of a deep pit.

Storage Yard.—The storage yard and raw material handling generally force themselves unpleasantly upon the attention of the management as soon as the shop begins to turn out a large tonnage. Too often it is then found that the whole shop has been so located that changes in methods of storing and handling material are difficult to make, when a little forethought in the beginning would have taken care of the whole matter. Means are generally provided to dump coke for the cupolas, and coal for the boilers (and pot furnaces), from trestles, and to get them to the places where they are wanted without too much expense. It is in the handling of pig iron, scrap and alloys that the trouble generally comes. A small shop as a rule cannot afford to use an overhead crane or a locomotive crane with a magnet for unloading raw material, and depends upon hand labor for this work. This is quite right and proper, but the error is too frequently made of failing to forsee that eventually crane handling must take the place of hand labor and to make provision for the time when this is to take place. However the yard be arranged, everything that can be dumped from cars into bins or piles, such as coal, coke, ferromanganese (in quantity), etc., should eventually be so handled; and pig iron and scrap should be unloaded with a magnet, either with an overhead crane or with a locomotive crane.

Though the materials for the cupola charges, as well as coke, generally have to be loaded on cupola charging cars by hand, nevertheless the number of times they are handled should be the smallest possible. In certain shops some of the pig iron is picked up seven times by hand before it goes down the cupola, owing to inadequate and badly arranged storage space, which necessitates piling the pig iron, and sometimes moving piles about, instead of allowing it to lie in heaps as unloaded from the cars. Though generally the cars or lots of pig iron are kept separate, to facilitate control of cupola "mixtures," nevertheless the greatest economy will result from providing ample space to allow of leaving the lots in heaps, from which the iron is picked up and loaded on charging cars. Whether these cars, and the coke and limestone, be brought to the cupola charging platform by elevator, by overhead crane or by rope tramway, the practice of hand charging of the cupolas, when many heats are made, is to be condemned as a waste of money. In place of the old-fashioned practice of storing coke and limestone (sometimes also pig and scrap) in heaps on the cupola charging floor, weighing them there and charging into the cupola by hand, which involves several rehandlings, some system should be adopted by which weighed lots of coke, limestone and metal are sent to a single man at the top, who dumps them into the cupola by mechanical means. The objection to this method has always been that the material is not evenly charged; but by using two or three charging doors in the cupola, and properly piling the materials on the cars, there is no doubt that as good work can be done in this respect as is generally done by a charging gang. In a well-arranged shop pig iron and scrap are handled only three times—once off the cars, once on to the charging cars, once down the cupola.

Handling the Cupola.—A word as to the handling of the cupola in Bessemer foundry practice will not be amiss. No one who has not assisted in turning out a long day's run, heat after heat, in a Bessemer foundry, quite realizes the prime importance of hot cupola metal, tapped exactly when it is wanted. The efforts of the metallurgist and blower are set at naught, the advantages of carefully adjusted composition of the vessel charge are lost, and heat after heat of cold steel turned out, when the cupola gets behind and throws down cold metal. To assure the production of hot steel, heats should be tapped from the cupola smoking hot, and not held more than 5 or 10 minutes in the receiving ladle. Small cupola charges with properly proportioned coke are advisable, and every effort should be made to keep the cupola running uniformly.

Blowing—Bottom-blown Vessel.—The usual procedure in bottom-blown Bessemer shops is to charge heats of pig and scrap that will tap out of the cupola at about 1.60 to 1.80 per cent. silicon, and about .50 to .80 per cent. manganese, or even less. In blowing such a heat, the first period or silicon flame lasts from three to even six minutes, and after some four minutes blowing the resistance to the passage of the blast considerably increases and the blast pressure rises, probably owing to the very pasty slag formed. At this stage of the blowing there is practically no flame at the mouth of the vessel, because the oxygen of the blast is all used in the combustion of silicon and manganese, which form slag, and only the inert nitrogen of the air issues from the vessel.

For a bath of given composition, this period of the blow will be the shorter, and the carbon flame will appear the sooner, the hotter the steel is allowed to grow—because as the temperature rises a point is reached where carbon is oxidized in preference to silicon and manganese. Therefore, if the bath is allowed to grow hot undisturbed, carbon will begin to burn before silicon and manganese are completely eliminated, whereas if the temperature is held down by additions of cold scrap or washed metal, silicon and manganese will be nearly all gone before carbon starts to burn.

When the silicon is nearly eliminated the carbon flame begins to appear, and soon the full long flame, of an intense white color, plays from the vessel, and showers of sparks are thrown out. By the intensity of the light of this flame the blower judges the temperature of the metal, and takes steps to make the blow hotter or colder, according to the methods that are used in the shop. About 8 to 12 minutes after the vessel is turned up, the flame shortens in or "drops" (quite rapidly in the case of a low-manganese mixture), which means that the carbon is practically eliminated, and to prevent the oxidation of iron that begins when the carbon gets low, and increases rapidly as the carbon drops to the final amount of about .08 to .10 per cent., the vessel should be turned down at once, and the blast shut off.

The recarburizers are now added. If used solid, they are preferably thrown into the vessel and a proper time allowed for them to melt, though they may be thrown into the steel as it runs from the vessel. When melted additions are used, they are sometimes poured into the vessel, though often they are poured into the large ladle and the blown metal then run in from the vessel.

The engineer of the blowing engine keeps the pressure up to the full amount of about 25 lb., unless he gets the signal from the blower to slack off. When the vessel is turned down, either at the end of the blow or because anything goes wrong, the engineer at once slows his engine, and stops it when the vessel reaches the horizontal, to avoid blowing out slag and steel. It is for this reason that the engine must be placed where the engineer can see the vessel.

Before taking up the various methods in use for heating or cooling the bath, a few words must be said about the supposed dangers of allowing the metal to become too hot, either before or during the carbon flame period. The nature of the process is such that there must inevitably be great oxidation of iron at all stages of the blow, since at the mouths of the tuyères the oxygen is in such great excess that not enough silicon, manganese and carbon are at hand to satisfy this oxygen, and some iron must be burned to FeO. But most of this FeO is at once reduced to iron again by carbon, silicon or manganese, as long as there is any considerable amount of these elements present, though some of it unites with the SiO_2 and MnO formed and the SiO_2 of the lining, and is lost in the slag. During the first period of the blow nothing comes through the bath (and the rapidly increasing mass of slag) except the inert nitrogen of the air, and probably a little oxygen that has passed through the bath uncombined. When the carbon begins to burn, CO is formed in the metal by the union of carbon and oxygen, escapes in bubbles, and rises rapidly, carried upward by its own heat and by the rush of nitrogen being blown through the vessel. Upon reaching the outside air this CO begins to burn to CO_2, with a flame that will be hotter or colder, more or less luminous, according to the temperature of the metal in the converter; because the hotter the metal, the hotter the gas that is forced through it and the hotter the CO formed in it. The flame itself, of course, is formed *at the mouth* of the vessel, exactly as a flame is formed when we apply a match to a mass of combustible gas escaping from a pipe.

As the process proceeds, there are fewer and fewer carbon, silicon and manganese molecules to meet the molecules of FeO formed near the tuyères, rob them of their oxygen and return the iron to the bath. Hence, the formation of FeO increases rapidly toward the last of the blow, and when the vessel is turned down there is a great deal of it in the metal, besides the far larger part that has found its way into the slag when it met slag particles brought in contact with it by the violent bubbling of the bath. Since the formation of large amounts of this FeO cannot be prevented, the only question to be considered in this connection is whether the attainment of extreme temperatures increases the formation of FeO, and its retention by the steel.

This question probably must be answered in the affirmative, since it is known that the solubility of FeO in iron increases with increasing purity of the iron, and with increasing temperature. It is theoretically possible, even, that such extreme temperatures can be reached at the first part of the blow that the iron will dissolve FeO and hold it so tenaciously that even the carbon, silicon and manganese will not reduce it. In practice this is probably never true to any appreciable extent; but in the later stages of the process there is little doubt that with great increase of temperature the power of iron to dissolve its own oxide becomes so great that the affinity of carbon for oxygen is insufficient to reduce the FeO as rapidly as at lower temperatures, and therefore more FeO is formed and held dissolved in the metal.

Moreover because the solubility of the FeO in iron rises with rising temperature, in very hot heats the reduction of this FeO by the manganese of the recarburizers is more difficult. If, therefore, from the exigencies of our business we have to make our metal extremely hot in order to pour very small castings, we face a difficulty due to the greater retention of FeO by our steel, which is then probably more prone to chill rapidly and form blow holes in the castings. If the reasoning we generally depend upon is correct, the remedy is plain. We know that the more FeO we wish to remove the more manganese we must add to the steel; therefore, if the steel tends to form and hold more FeO than normal because we are blowing very hot, we must, in order to attain our usual grade of purity, increase our manganese additions. By so doing, we kill two birds with one stone, since the part of the extra manganese that is used up in removing more FeO promotes fluidity and sound setting by increasing purity; and the part that remains in the steel increases fluidity by lowering the melting point of the steel, and perhaps also by its direct influence on the fluidity at a given number of degrees above the melting point.

The experience of the author has been that if there is no chemical analysis specification upon the castings being made, it is advisable to blow steel for small castings as hot as it is possible to make it; and though no doubt more FeO is formed and held in solution in the steel than in colder heats, yet by increasing the manganese addition to say 1.30 or 1.40 per cent., the extra oxidation is more than counterbalanced by the extra elimination of FeO, and a steel made that will run better and show fewer blow holes than can be produced in the converter in any other way.

Cooling the Metal.—The means adopted to cool heats that are too hot are first, to blow steam through the bath with the air by means of a steam pipe (with valve under the blower's control), admitting steam to the wind box. Second, to use cold scrap, pig iron or washed metal, thrown into the vessel before turning up, when it is thought the heat will be too hot, or shoveled in during the blowing. Third, to allow the heat to stand after blowing. The use of steam is not advisable, for though information is not in existence to show positively that it injures the steel, yet the concensus of leading authorities is that the steel is better when no steam is used. Scrap does the steel no harm, as its only effect is to cool the metal because it is itself cold and therefore in warming up and melting it reduces the temperature of the bath. It is best to get it in before the heat is turned up. If one or two heats have blown very hot, and the next one also runs smoking hot from the cupola, and must be blown at once without cooling off in the receiving ladle, from 50 to 300 lb. of cold scrap in a 3-ton heat will reduce the temperature of the steel considerably. Of course good scrap should be used. Heads or short pieces of gates from the foundry are best, as they can be dropped into the vessel easily. Should the heat blow too hot in spite of the scrap added, or a heat unexpectedly blow very hot, scrap can be dropped into the vessel from a long suspended shovel provided for the purpose.

Because of its purity, washed metal is sometimes used for this purpose, but it is a great waste of money to use it, as it is no more efficient a "cold metal" than scrap. It is no colder than scrap, and therefore absorbs no more heat in warming up; and as its melting point is lower than that of scrap it probably is really less efficient as a cooler, because it melts at a lower temperature and hence takes less heat from the bath in warming up and melting.

Probably the simplest way to handle heats that have blown hotter than necessary is simply to allow them to stand in the vessel or ladle until their temperature has fallen to normal. As the metal cools, the iron retains its oxide less tenaciously, and the oxide is reduced by the carbon and manganese of the recarburizers; and the extra time allowed for this reaction tends to make it more complete.

Warming up the Metal.—A heat whose composition is already fixed may be warmed up in a number of ways. By shoveling 30 or 50 per cent. ferrosilicon into the vessel in lumps, or in pasteboard cans full of fines, silicon is added to the bath and the temperature greatly raised by the heat produced in oxidizing this extra silicon to SiO_2. Generally, this material is added during the carbon flame period, when the blower is able to judge by the appearance of the flame, and the behavior of previous heats, whether or not his steel needs warming up.

The use of ferrosilicon for this purpose is mentioned in a patent on the use of manganese as a vessel addition, granted to R. A. Hadfield,[1] dated 1903; and is the subject of a later patent issued to A. Tropenas[2] in 1908. The Tropenas patent calls for the addition of the ferrosilicon when the carbon flame appears. Hadfield does not specify the exact stage when it should be added. In the Walrand process it was customary to add ferrosilicon quite early in the blow. This process, the invention of Walrand and Légenisel,[3] which has been used more abroad than in America, is to blow nearly to the "drop of the flame" without additions of any kind; pour into the vessel a certain amount of molten ferro-silicon, containing generally 10 per cent. of silicon; turn up and blow until this silicon is eliminated; then turn down and proceed as usual. The iron is protected from oxidation during this "after blow" by the silicon, so that extra loss by oxidation is slight or non-existent, and very hot steel is produced.

Particulars of this method are given in two papers by Mr. G. J. Snelus, in the *Journal of the Iron and Steel Institute.*[4] In the first article, it is stated that blowing small heats containing a high percentage of silicon, or adding ferrosilicon to the blow during the car-

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[1] U. S. Patent No. 743715, dated November 10, 1903.

[2] U. S. Patent No. 354694, dated February 25, 1908.

[3] U. S. Patent No. 503816, dated August 22, 1893, reissue No. 11570, dated 1895.

[4] Vol. 1, 1894, page 26, and Vol. 2, 1896, page 104.

bon flame period, had been tried prior to Walrand's invention and had proved a failure, because the gases evolved from the burning carbon carried away much of the heat produced by the combustion of the silicon. Mr. Snelus attributes the success of the Walrand method to the fact that the heat of oxidation of the silicon is rapidly evolved, and that there are no gases (except of course nitrogen), to carry away that heat.

In the second article the statement is made that in an English shop using this method, the vessel was turned down for the addition of ferrosilicon when the bath contained about 1.30 per cent. of carbon. The object of turning down before the complete elimination of carbon was to secure the presence of carbon during the after-blow to provide a flame, that there might be a "drop" to show when the added silicon was eliminated from the bath. In most of the shops using the method, the "drop" was determined by the vanishing of the carbon lines in the spectrum of the flame.

These methods are expensive, as they call for considerable amounts of ferrosilicon. Probably the simplest and cheapest way to accomplish the results desired is to turn the vessel slightly forward so that one or more of the tuyères are at or above the surface of the bath, and blow awhile in this position, slacking the blast to avoid blowing metal and slag all over the shop. By this means CO is burned to CO_2, within the vessel, by the free oxygen from the exposed tuyère openings; and iron is oxidized to FeO and goes into the slag in considerably increased amounts, resulting in a further gain in temperature. Though this procedure results in decreased output, owing to greater loss of iron, yet it is cheaper to burn twenty dollar pig iron to get extra heat than to burn seventy dollar ferrosilicon (equivalent to $140 silicon.)

Effect of Varying the Silicon and Manganese.—To increase the temperature of the steel by changing the composition of the metal charged to the vessel is the remedy for persistent cold blows, and is the method to be followed as far as possible. To add heat-producing elements is of course the only way to secure additional heat, and this can be done without extra cost by varying the silicon and manganese in the metal charged.

The heat of combustion of silicon is much greater than that of manganese, while that of carbon (to CO) is inconsiderable. At first sight, therefore, it would seem a simple matter merely to increase the percentage of silicon in the vessel charge and thereby make the steel blow very much hotter. But with mixtures containing some 2 per cent. silicon and .60 to 1.00 per cent. manganese, the first period of the blow is very long, sometimes 6 minutes, without any shortening of the carbon flame period, so that a blow requires from 12 to 14 minutes. The pressure of the blast during the silicon-burning period becomes very great and the engine works hard and slows down. The steel produced is not as hot as would be expected. This result agrees with the statement of Walrand and Légenisel that it is difficult to secure hot steel in the bottom-blown vessel by the use of mixtures containing high percentages of silicon.

By the use of mixtures containing rather less silicon than in the above case, and in addition considerable amounts of manganese (the manganese often considerably exceeding the silicon), very good results have been attained. The first period of the blow lasts but one or two minutes, the carbon flame comes up very soon after blowing begins, and the total time of a blow is from 8 to 10 minutes. The metal is much hotter than that obtained from the high silicon mixture.

Complete data are not at hand to calculate the total amount of heat contributed to the charge by each of the above mixtures. From a rough estimate, however, it seems that the high silicon charge contributes more total heat than the high manganese metal. The latter appears to require somewhat less air to burn the metalloids than the former, but not enough to account for the greatly diminished blowing time; and a smaller proportion of the total heat produced would appear to be carried away in the gases, but not enough to account for the hotter steel produced, if the gases in each case are assumed to be heated to the same temperature.

In blowing the high silicon mixture, evidently no carbon is oxidized till silicon and manganese are largely eliminated, while in the case of the high manganese mixture the temperature at which carbon is oxidized in preference to manganese is soon reached, so that the burning of carbon begins while considerable amounts of manganese (and probably some silicon) remain in the metal. This speeds up the blow, because when carbon is being burned to CO, the bubbling produced by the escaping gas causes the bath to froth up in the vessel and offer greatly decreased resistance to the passage of the blast. That this is so is shown by the lowering of the pressure of the blast in a high silicon heat when carbon begins to burn, with accompanying speeding up of the engine; and by the fact that with the high manganese mixtures the pressure remains low from the first.

Thus the amount of air passing through the bath per minute is increased and the operation shortened. The difference in the two cases, in the amount of heat lost by radiation, and in heating the entering air and the departing nitrogen and CO, is difficult of calculation; but that the air passing in greater volume and at greater speed through the freely boiling high manganese bath has less opportunity to absorb heat from the metal, and hence carries away much less heat, volume for volume, is quite probable. Thus the loss of heat to the gases in the case of the high manganese charge is probably much less than that in the high silicon charge, partly because less air in all is blown through the metal, and partly because the escaping gases are not heated so hot.

At the same time radiation losses are decreased, since the total time of the blow is so much shortened, and the radiation per minute is probably constant; and thus the mixture which gives probably less total heat actually produces much hotter steel.

In addition to their effect upon the heat of the steel, these high manganese mixtures cause marked changes in the slag, because the great amount of MnO produced makes the slag extremely fluid and watery. This is in some respects desirable, because a fluid slag of low melting point doubtless separates more completely from the metal in the ladle than the very gummy slags made with low manganese mixtures. This is because the fluid slags more easily form large globules by the union of small droplets, and these large globules float out of the steel far more rapidly than very finely divided particles. Moreover, the highly manganiferous irons do not pick up so much sulphur in the cupola as lower manganese irons, and if the cupola metal is allowed to stand 10 or 15 minutes in the receiving ladle, some of the sulphur floats out as sulphide of manganese.

The disadvantage of the high manganese mixtures are: first, that a slag rich in MnO corrodes the linings, and especially the bottom of the vessel severely, and second, that the fluidity of the slag sometimes results in explosive "slopping" of the vessel. This is in part due to the reaction between FeO of the slag and carbon of the steel. The first difficulty is much more than offset by the advantages secured; the second sometimes becomes a great nuisance. The easiest way to stop slopping appears to be to throw a few pounds of 50 or 60 per cent. ferrosilicon into the vessel. This probably acts by temporarily reducing the proportion of MnO and FeO and increasing the SiO_2 in the slag, and thereby rendering it less fluid and active; and if only a sufficient amount of sand or ground bricks could be got into the slag, it would probably have the same effect. The slopping, however, takes place during the carbon flame period when the volume of gas coming from the vessel is so great that only very heavy materials can be dropped in; even a brick will not fall through the ascending current of gases, and if it would the chances are it would not melt and go into the slag quickly enough to stop the slopping.

The easiest and cheapest way to deal with this slopping is to allow plenty of room in the top of the vessel to take care of the bubbling slag, and to slack down the air pressure by slowing the engine when the vessel gives signs of trouble. When the vessel is newly lined, extra space can be secured by cutting down the weight of the heats, and making up for it by blowing one or two more heats a day; and as soon as the lining is cut away by the slags, there will be room enough to blow full-sized heats. This method has been found to work very well in practice, and the author has seen as many as sixteen or eighteen heats of high manganese metal blown in one day without the use of any vessel additions whatever to prevent slopping, many of the heats being poured into very small castings.

Published details of German Bessemer practice suggest the use of vessel mixtures running very high in silicon, even up to 3 per cent., with manganese around 1 per cent. The possibilities of this method have not to the author's knowledge been investigated by the users of small bottom-blown vessels in America. The experience with high silicon irons already mentioned would appear to show that the blowing time would be very long with such mixtures, and the gain in heat not as great as could be desired.

Blowing—Side-blown Vessel.—The metal generally charged to the side-blown vessel contains from 1.75 to 2.00 per cent. silicon, and .30 to .50 per cent. manganese. The vessel is tipped forward and the molten pig iron charged in the proper amount. The weight of the charge varies somewhat from day to day, as the lining of the vessel cuts away or builds up, and is fixed by the fact that the level of the metal must be such that it is just even with the bottom edge of the tuyères, when the vessel is tilted forward at an angle of some 7 or 8 degrees. The converter is tipped back to this angle after charging by means of a hand wheel, until the metal reaches the tuyères. If too little metal has been charged, so that the vessel is not inclined forward enough when the metal is at the tuyère level, more is charged till the angle is about right. The blast should strike well out toward the middle of the converter, so that it is important to have this angle correct.

When the correct amount of metal has been charged, the vessel is tipped forward one or two degrees, and the blast is turned on, at a pressure preferably of about 3¾ or 4 lb. At first, only sparks come from the mouth of the vessel; and as the metalloids are eliminated from the bath and the volume of the metal decreased, the vessel is gradually turned toward the vertical, so that the blast shall continue to impinge upon the bath at the correct spot. After about 3 or 4 minutes blowing, a faint flame appears at the mouth of the vessel, which soon increases in size; on thus "getting a light," as it is called, the vessel may be tipped back a little, which will assist in bringing up the full flame, and the blast may be reduced a little.

The flame at this stage of the blow is short and rather thin, looking much like the ordinary Bessemer flame when it first appears. After some 5 to 15 minutes blowing (the vessel meanwhile being gradually turned nearer and nearer the vertical), the flame begins to lengthen out and grow brighter, and a "boil" takes place. This is accompanied by a flame much like a full ordinary Bessemer flame, and often by the throwing out of a good deal of slag and frequently of metal. In order to keep the charge in the vessel during a boil, the blast is slacked down as low as possible, without filling the tuyères. It is not possible to lower the blast below about 1¼ lb., without allowing the metal or slag to run into the wind box. The long flame of the boil seldom lasts much over a minute or possibly two, and the flame quickly goes back to its former dimensions. Frequently, there are several boils, at intervals of from 3 to 10 minutes, not all of which are well marked. As many as four or five may occur.

Should the volume of the metal become so low that the blast cannot be made to strike the bath at the proper point, so that the flame goes out, pig iron or ferrosilicon is charged cold, or the vessel is turned forward, the blast taken off, and more fluid metal charged to make the volume right.

It is important in blowing to keep tipping the vessel up so that the blast shall impinge upon the bath at the correct point, and the tuyerès be the proper distance above the surface of the metal. If the tuyères get too high above the metal, the tubes of slag that form at the noses of the tuyères by the chilling of the slag will get so long as to interfere seriously with the blast, partially shutting it off and allowing it to strike at improper points. The result is frequently great oxidation of the metal, and violent slopping.

After one or more boils, followed by the subsidence of the flame to its former size, the "final flame" appears. This is long, intensely white, and feathery at its upper edge, and is the only long flame the vessel gives that lasts more than about a minute. Frequently, slag or metal is thrown out during this stage of the process, but the experienced blower seldom fails to recognize the final flame. The "drop" is much like that of the regular Bessemer flame, and when it appears the vessel is turned down and the blast shut off. The total time of a blow will be from 14 to 25 or 30 minutes.

If the blower is uncertain whether or not he has had a final flame and drop, the vessel is turned down and the bath inspected. If the final flame has occurred and the carbon is eliminated, the metal and slag lie quiet and flat in the vessel without bubbling; whereas if there is still carbon in the metal, the slag boils fairly strongly.

It will be seen from the foregoing that the burning of silicon, manganese, and especially carbon, progresses slowly in the side-blown vessel, with one or more periods of sudden increase in the rate of elimination, accompanied by strong boiling of the slag and consequent slopping. Evidently as the blast rushes over the surface of the bath, silicon, manganese, carbon and iron are oxidized, and a slag formed which grows progressively richer and richer in FeO as the carbon, silicon and manganese are eliminated from the surface metal, leaving the iron unprotected and hence more free to oxidize. The circulation of the bath is not sufficient to reduce this FeO by the action of carbon, silicon and manganese to anything like the same extent as is possible in the bottom-blown vessel, where FeO is formed at the bottom of the bath and is largely reduced by the metalloids before it can swim to the surface and enter the slag.

As the oxidation of the metalloids progresses, a point is reached where the slag becomes very high in FeO available for reaction with carbon, and at the same time the fluidity of the slag reaches a maximum. Doubtless the action of the blast is largely confined to the upper layers of the metal, reducing its contents of carbon, silicon and manganese to a very low point, and oxidizing much of its iron to FeO, especially as the surface soon grows so hot and the carbon so low that the oxidation of iron is very rapid. Then the effect of the slag on the metal begins to be more violent, probably assisted by diffusion of carbon into the upper layer from below; the metal and slag begin to boil, the FeO oxidizing silicon, manganese and carbon from the metal rapidly, and soon the boiling becomes very violent. A long flame is thrown out because the CO is evolved so rapidly that it burns to CO_2 largely at the vessel's mouth. Upon the exhaustion of the available FeO of the slag this reaction subsides, and the bath, well mixed by the strong boil, is again subjected to slow oxidation, followed by renewed boilings when the slag reaches the proper composition.

If vessel mixtures are blown that contain from .75 per cent. to 1 per cent. of manganese with the usual silicon, the boiling and slopping are very violent and result in a great loss of metal. This is no doubt due to the fact that the MnO formed by the combustion of the manganese makes the slag very watery and promotes the reaction between the carbon of the bath and the FeO of the slag.

Ferrosilicon is thrown into the vessel to discourage boiling, as well as to provide extra heat. It probably acts on the slag in the same way as in the bottom-blown vessel, by increasing the SiO_2 and reducing the FeO, thereby rendering the slag less fluid, and postponing its reaction with the carbon of the bath.

So far as the author is aware, the addition of pig iron, washed metal, or scrap in order to cool the steel when it gets too hot is not often resorted to in side-blown practice. The same additions can be used as for a bottom-blown vessel when it is desired to keep the temperature down, as for instance, for a large casting; but as in bottom-blown practice it is probably the best and most economical practice to simply let a hot heat cool off, and if necessary increase the manganese additions to more thoroughly reduce FeO from the steel.

Recarburizing in the vessel is very common practice in side-blown foundries. This is owing partly perhaps to the inviting angle at which the vessel stands when "turned down," with its open throat conveniently disposed to throw or pour the recarburizers down into the metal, unlike the bottom-blown vessel which has to be turned into a horizontal position in order that the metal may clear the tuyères when the blast is shut off.

The size of heats and hence the amount of recarburizer varies from day to day, as has been already explained, according to the condition of the lining of the vessel. Generally it will be sufficiently accurate to estimate the increase or decrease in capacity each day and proportion the recarburizer to be added accordingly; but of course if greater accuracy is required, the first heat of the day can be weighed in the ladle and any error in the estimate corrected.

The weighing of melted recarburizer is to be recommended, though if it is melted in crucibles, weighing before melting is generally sufficiently accurate for small additions. Cupola metal can be measured fairly accurately by volume instead of by weight, by using small ladles of known capacity to take off the desired amount. For heavy additions and rapid working, however, platform scales on which the entire addition is weighed in one ladle are essential.

A bottom-blown vessel easily turns out three heats per hour, so that from 18 to 25 heats can be blown per day, running single turn. This rate can be maintained every day in the week. A side-blown vessel takes so much longer to blow each heat that the production is only about two heats per hour, or 9 to 12 heats per day. On account of the necessity for repairing the lining, a single side-blown vessel can rarely produce more than 40 heats per week. Side-blown plants, however, generally use two or three vessels, so that a production of 12 heats per day, or 72 per week, can be regularly obtained.

These rates of production can be considerably increased, if the cupola capacity is available to provide metal. As a bottom-blown vessel seldom requires over 12 minutes to blow a heat, and a side-blown 20 to 25 minutes, it is of course possible by driving to turn out steel at a rate greatly exceeding that given, especially for a short time. Thus in bottom-blown shops, when three or four heats are required for a large casting, one heat is charged in the vessel and held until the next heat is tapped from the cupola into the receiving ladle. By the time heat one is blown, heat three is ready to tap from the cupola, again filling the ladle, and heat four is tapped from the cupola soon after blowing starts on heat three; thus four heats are turned out as fast as the vessel can take care of them. Since the third and fourth heats are charged into the vessel almost as soon as tapped, they are so hot when charged as to need less silicon than the first and second heats, especially as the steel for a large casting need not, generally must not, be too hot. The average blowing time is reduced by cutting the silicon and manganese in the later heats, and thus it is possible to blow four heats in about 40 to 45 minutes.

The methods of pouring Bessemer steel vary somewhat with the size of the castings that are being made, and with the preferences of the man in charge. In some shops the whole heat is poured into a large ladle, and castings poured directly from this, or from "shanks" filled from the large ladles. In others, the shanks are filled directly from the vessel. In the latter case recarburizing in the vessel must be the practice adopted, in the former it may be. Again some shops use a stopper and nozzle in the large ladles, some pour "over the lip." The discussion of the relative advantages of these methods properly belongs in the chapter on moulding and pouring, and is given there in some detail.

THE RAW MATERIALS

The raw materials of the baby Bessemer process for steel foundries are:

1. Low phosphorus pig.
2. Low phosphorus scrap.
3. Ferromanganese, ferrosilicon, etc.
4. Heads, gates, and "wastered" castings.

The fuel is coke for the cupolas, oil, hard coal, etc., for physic furnaces other than cupolas, and coal or oil for the boilers of the blowing engine of the bottom-blown vessel.

The increase of phosphorus and sulphur, resulting from the remelting of scrap, is greater in the Bessemer process than in any other, both because the loss of iron in converting to steel is greater, and because a great deal of sulphur is "picked up" from the coke in the cupolas. In order to make steel within the limits of standard specifications, therefore, the greatest care must be taken in the selection of raw materials. In order to keep the phosphorus and sulphur content of the steel below .05 per cent., both pig iron and scrap must contain well under .03 per cent. of those impurities. There is a very limited supply of "low phosphorus" iron, and the price is necessarily very high, consequently the greatest possible amount of low phosphorus steel scrap should be worked into the cupola mixture. This scrap is generally used in the shape of plate trimmings, and in that form is cheaper than the standard "low phosphorus heavy melting scrap" sold for open-hearth use. For open-hearth furnaces this plate scrap is so light that a great loss is encountered in melting it, but it is well suited to cupola melting. Heavy steel scrap is very hard to melt in the cupola, and should be used sparingly, if at all.

The furnaces smelting the iron ores of Cornwall, Pa., produce a low phosphorus and sulphur pig iron, that contains from .40 per cent. to .90 per cent. or so of copper. For many years even slight amounts of copper in steel have been considered deleterious, and consequently this pig iron has been sold considerably cheaper than standard low phosphorus pig. The researches of late years have shown clearly what has long been known in some shops, viz., that copper below .50 per cent., or even .70 per cent., is not at all harmful to steel if the sulphur be kept low; and the use of this copper-bearing pig is greatly increasing.

Because the absorption of sulphur from the coke is very considerable, a limit for sulphur in coke has to be made, and none should be used with over 1 per cent. of this impurity. It is just as well to draw the specifications to cover the content of ash at the same time, and refuse coke with ash over 10 or 12 per cent. Good foundry coke will conform to these figures, but the choice of a coke should be governed also by its texture and hardness. Too hard a coke that shatters badly in handling is in general not a good fuel for cupola melting; no specifications, of course, can be drawn for physical characteristics, and the best way to find out if a coke is suitable is to try a carload or so of it, always bearing in mind the natural conservatism of the average workman, who has an inveterate habit of getting used to one brand of coke, or one shape of scrap, and moving heaven and earth to prevent the purchase of any material other than what he has been using.

The proportion of purchased scrap that can be used is governed by the amount of heads, gates and "wastered" castings that the shop produces and has to melt up. Roughly from 30 to 50 per cent. of the metal in the ladle finds its way to scrap, so that at least 30 per cent. of the cupola charges has to be shop scrap. This remelting of scrap causes an increase of the phosphorus and sulphur content of the steel of successive heats, which, as Mr. Jameson has shown us, works up to a limit by progressively decreasing increments.

Taking his equations,[1] let us see what are the limits of phosphorus, sulphur and copper content that we shall attain in our steel, using a mixture of 30 per cent. of our own scrap, 10 per cent. of purchased plate scrap and 60 per cent. pig iron, of which two-thirds is iron containing .70 per cent. copper, one-third standard low phosphorus iron. Phosphorus and sulphur in purchased pig and scrap, .03 per cent. Converting loss, 12 per cent. (a good average for bottom-blown vessels). "Pick-up" of sulphur in melting, .01 per cent. Then, for the limits of phosphorus, sulphur and copper reached by our steel, using the formulæ,

$$X=\frac{(100-a)c}{100-(a+b)}\text{ and }X=\frac{(100-a)c+100d}{100-(a+b)}$$

Where X = per cent. of element in question after maximum is reached.
a = per cent. of scrap remelted = 30 per cent.
$100-a$ = per cent. of new material melted = 70 per cent.
b = converting loss = 12 per cent.
c = per cent. of element in question in pig and plate scrap = .03 per cent.
d = "pick up" (.01 for S).

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[1] See Chapter XII

FOR PHOSPHORUS[1]

$$X = \frac{70(.03)}{58} = .036 \text{ per cent.}$$

FOR SULPHUR

$$X = \frac{70(.03)+100(.01)}{58} = .053 \text{ per cent.}$$

FOR COPPER

$$\frac{40(.70)}{70} = .40 \text{ per cent. copper in new material}$$

$$X = \frac{70(.40)}{58} = .48 \text{ per cent.}$$

Since the ferromanganese used as recarburizer contains considerable amounts of phosphorus, generally averaging .30 per cent., it is necessary to take this factor into account in figuring out our X or maximum phosphorus that we will attain in our steel. To show clearly the influence of this factor in the problem, the following examples are appended, giving actual calculations made on several steels in which varying amounts of ferromanganese are used, depending on the amount of manganese desired in the finished product. From these figures it will be seen that the ferromanganese has a considerable effect on the phosphorus content of the steel. This effect, of course, increases with the amount of ferromanganese used per heat.

ORDINARY STEEL WITH 1.30 PER CENT. MANGANESE

$$\left.\begin{array}{rl} \text{80 lb.} & \text{ferromanganese at .3 per cent. phosphorus} \\ \text{22 lb.} & \text{ferrosilicon at .1 per cent. phosphorus} \end{array}\right\}\text{physic}$$

$$\left.\begin{array}{rl} \text{1400 lb.} & \text{foundry scrap at } X \text{ per cent. phosphorus} \\ \text{4600 lb.} & \text{new pig and scrap at .03 per cent. phosphorus} \end{array}\right\}\text{charged to cupola}$$

5350 lb. steel produced

$$X = \frac{80(.3)+22(.1)+1400X+4600(.03)}{5350} = .042 \text{ per cent.}$$

ORDINARY STEEL WITH .60 PER CENT. MANGANESE

Using the same mixture, but only 40 lb. ferromanganese for physic.

$$X = \frac{40(.3)+22(.1)+1400X+4600(.03)}{5300} = .039 \text{ per cent.}$$

Figuring Cupola Charges.—To illustrate the methods of figuring cupola charges for Bessemer work, a few typical examples are here

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[1] Sometimes phosphorus as well as sulphur may be picked up from the coke in the cupola. When this is the case, the second formula should, of course, be used for this calculation.

introduced. In this connection it is as well to state definitely that "mixing" has to be done wholly by analysis, and for that reason the use of several "brands" or makes of pig iron is not at all necessary. It will be found advantageous, nevertheless, to use at least four lots of pig iron for mixtures, because it is quite out of the question to obtain pig of uniform silicon content, and in order to keep the composition of the successive heats as nearly constant as possible from day to day, without constant figuring of new charges, several lots of iron must be used. Generally two lots will give out nearly together, and then two more can be selected and used, whose average silicon content is the same as the average of the two replaced. With four lots of pig and two kinds of scrap, composition can be kept fairly even for weeks by judicious selection, without the necessity of refiguring mixtures.

$$\text{Desired}\left\{\begin{array}{l}\text{Si 2.10 per cent.}\\ \text{Mn low}\end{array}\right.$$

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P	3.00	.30	0	1000	30.0	12.6
Pig 2 Std. low P	2.20	.30	0	800	17.6	
Pig 3 Cornwall low P	3.30	.30	.60	1400	46.2	
Pig 4 Cornwall low P	2.50	.30	.50	1000	25.0	
Foundry scrap	.40	.60	.65	1800	7.2	10.8
				6000	126.0 2.10%	23.4 .39%

$$\text{Desired}\left\{\begin{array}{l}\text{Si 2.00 per cent.}\\ \text{Mn 1.50 per cent.}\end{array}\right.$$

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P	3.00	1.80	0	1000	30.0	18.0
Pig 2 Std. low P	2.20	2.20	0	1100	24.2	24.2
Pig 3 Std. low P	3.30	1.60	0	900	29.7	14.4
Pig 4 Std. low P	2.50	1.90	0	1200	30.0	22.8
Foundry scrap	.40	.60	.65	1800	7.2	10.8
				6000	121.1 2.02%	90.2 1.50%

Desired { Si 1.80 per cent.
Mn low

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P............	2.00	.30	......	700	14.0	2.1
Pig 2 Std. low P............	2.50	1.50	......	800	20.0	12.0
Pig 3 Lebanon low P.......	2.90	.30	.60	1000	29.0	3.0
Pig 4 Lebanon low P.......	3.40	.30	.50	1100	37.4	3.3
Foundry scrap.............	.40	.60	.65	1800	7.2	10.8
Plate scrap................	.10	.60	......	600	0.6	3.6
				6000	108.2 1.80%	34.8 .58%

This work is so much a matter of arithmetical juggling that it is not worth while to give more than these few examples. Low phosphorus plate scrap can be used in greater or less amounts to balance variations in silicon in the pig iron. If there is a shortage of foundry scrap, plate scrap should be worked in to take its place and save pig iron, the most costly raw material used. If much scrap is to be melted (it is generally best to melt at least 40 per cent.), the pig irons bought have to be correspondingly high in silicon; and the man in charge of this work has to keep close watch of his stocks of raw material in order to specify the silicon content of his pig iron to suit his future requirements. The use of 10 per cent. ferrosilicon and steel scrap to take the place of part of the pig iron is perfectly possible, though it will be hard to make the scrap and ferrosilicon melt at a sufficiently even rate in the cupola to give heats of the uniform composition so essential for good blowing. Even in melting pig iron and scrap, the unevenness of composition of successive heats, due to the more easily fusible materials of the charges melting first and running ahead of the other stock, sometimes gives the blower trouble. A large proportion of plate scrap can be melted in the cupola charge, and the shortage of silicon made up by adding 50 per cent. ferrosilicon melted separately. Generally there is no financial advantage in using these materials, as it is cheaper to use pig iron. As mentioned in the introductory chapters, in places where pig iron is costly and scrap cheap, the use of these materials in large percentages may be advantageous.

The silicon and manganese in the metal run from the cupola will be somewhat lower than in the metal charged, on account of oxidation in melting, some 20 per cent. of the silicon being so lost. Of the two, the manganese suffers the greater loss, when it is present in considerable amounts. The exact composition of the metal tapped will vary somewhat from heat to heat.

When a given charge is used, the silicon and even more the manganese content of the metal run from the cupola tend to fall off, toward the end of the day's run. This can be taken care of by changing the mixture used for the later heats, but one should be careful not to go too far in this direction, since the cupola metal toward the last of the run is often hotter than that tapped earlier, so that in these heats less manganese and silicon are needed for the production of hot steel.

Figuring Recarburizers.—The figuring of additions to the steel is so simple a matter that a very few words must suffice to illustrate it. The materials available for this purpose are:

Material	Source of
1. Cupola metal	C (Si) (Mn)
2. 80 per cent. ferromanganese	C Mn
3. 20 per cent. spiegel	C Mn
4. 50 to 60 per cent. ferrosilicon	Si
5. 10 to 12 per cent. ferrosilicon	C Si
6. Silico-spiegel	C Si Mn
7. Pig iron	C (Si) (Mn)
8. Hard coal, coke, etc	C
9. Carborundum	C Si
10. Nickel	Ni
11. Ferrochromes	(C) Cr

The choice among the many materials that can be used depends largely upon three considerations, as follows:

1. Are additions to be melted or solid?
2. If melted, by what method?
3. Is the steel to be of high or of low carbon content?

If solid additions are to be used, naturally the choice falls upon materials as high in the desired elements as can be obtained, unless too high a melting point results from great purity. Eighty per cent. ferromanganese, 60 per cent. ferrosilicon, etc., are then used, and extra carbon, if needed, obtained from additions of coke or of cupola metal.

If much hard steel, or steel high in various alloys, is to be made, the recarburizer generally has to be melted. As far as possible, metal from the main cupolas should be taken to make up recarburizer for hard steel heats, since it saves the melting of large separate lots of recarburizer.

The melting furnaces that are used are generally of a sort suited to intermittent operation, because a Bessemer plant is seldom run continuously. The furnaces that can be used are:

(1) Small cupola.
(2) Air furnace, or oil-fired furnace of some kind.
(3) Crucible furnace, generally oil or coal fired.
(4) Electric furnace.

The choice is governed by

(1) Nature of material to be melted.
(2) Amount of material to be melted.
(3) Cost of melting.
(4) Continuous or intermittent operation.

The cupola is suited to melting low percentage ferro alloys, and melts large quantities cheaply. Ferros such as 80 per cent. ferromanganese and 50 per cent. ferrosilicon lose too much by oxidation when melted in cupolas, and are generally handled in crucibles or a small electric furnace. The air furnace or some type of non-crucible oil melting furnace may be used in some cases as a substitute for the cupola, for instance, in places where coke is costly. The electric furnace can be substituted for the crucible furnace under some circumstances; it will in some cases give cheaper melting.

Whenever possible, the recarburizers should be used molten, as there is no doubt that they purify the steel far better when so added. When the additions are but a small fraction of the weight of the heat, especially if the steel is hot enough to melt them readily, and time is allowed for them to melt and act on the steel, quite good work can be done with solid recarburizers. But molten metal would do better.

Summarizing this question, the methods used in adding recarburizers are as follows:

1. Adding solid in ladle—least effective.
2. Adding solid in vessel—better.
3. Adding liquid in ladle—better yet.
4. Adding liquid in vessel—best.

If low carbon steel high in silicon and manganese is to be made, the choice must fall on high percentage silicon and manganese alloys because, as the following figures show, the low percentage alloys contain too much carbon per unit of silicon or manganese. For instance, a steel of silicon .40 per cent., manganese .80 per cent., using 20 per cent. spiegel and 10 per cent. ferrosilicon, would figure out as follows:

Kind	C, per cent.	Si, per cent.	Mn, per cent.	Wght.	C, lb.	Si, lb.	Mn, lb.
Spiegel................	4.5	......	20	35.4	1.59	......	7.08
Ferrosilicon...........	1.8	10	......	30.8	0.55	3.08	....
Blown metal..........	.10	.10	.10	934.0	.93	.93	.93
				1000.2	3.07 .30%	4.01 .40%	8.01 .80%

These alloys thus contain too much carbon for our purposes, if we desire steel below .30 per cent. carbon.

Using 80 per cent. ferromanganese and 50 per cent. ferrosilicon, we figure as follows:

Kind	C, per cent.	Si, per cent.	Mn, per cent.	Wght.	C, lb.	Si, lb.	Mn, lb.
Ferromanganese.......	6	......	80	8.8	.528	......	7.04
Ferrosilicon...........	.5	50	......	6.0	.030	3.0	....
Blown metal..........	.10	.10	.10	985.0	.985	.985	.985
				999.8	1.543 .15%	3.985 .40%	8.025 .80%

To make steel of .20 per cent. carbon, the extra half pound of carbon needed can be added as coke, in which case we add 1 lb., allowing for a loss of 50 per cent.; or better we use cupola metal. If this contains 2 per cent. silicon, .50 per cent. manganese, 3.5 per cent. carbon, we have to cut our ferrosilicon and ferromanganese accordingly, thus,

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
50 per cent. ferrosilicon.	5.5	.0275	2.75	....
80 per cent. ferromanganese...............	8.7	.5220	....	6.96
Cupola metal...........	12	.4200	.24	.06
Blown metal...........	975	.975	.975	.975
	1001.2	1.9445 .19%	3.965 .40%	7.995 .80%

On the other hand, for steels above .34 per cent. carbon or so, the spiegel and ferrosilicon will not contain enough carbon for our purposes, and we must either melt pig iron with them, or use cupola metal to make up the deficiency as before. Whichever we do, allowance must be made for the silicon and manganese in the pig iron or the cupola metal. Even in this case, however, it is not by any means necessary to use the low percentage alloys, melted in the cupola, as it may sometimes be cheaper to use the higher percentage ferros added solid, or even melted. For steel of .45 per cent. carbon, .40 per cent. silicon, .80 per cent. manganese, we have the following four methods open to us.

1. Using 20 per cent. spiegel, 10 per cent. ferrosilicon, and pig iron (carbon 3.5 per cent., silicon 1 per cent., manganese .50 per cent.).

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
10 per cent. ferrosilicon	27	.486	2.7	
20 per cent. spiegel	35	1.575		7.00
Pig	43	1.505	.43	.215
Blown metal	900	.900	.90	.900
	1005	4.466	4.03	8.115
		.45%	.40%	.81%

2. Using 20 per cent. spiegel, 10 per cent. ferrosilicon, and cupola metal (3.5 per cent. carbon, 2 per cent. silicon, .50 per cent. manganese).

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
10 per cent. ferrosilicon	23	.414	2.3	
20 per cent. spiegel	35	1.575		7.00
Cupola metal	46	1.610	.92	.23
Blown metal	900	.900	.90	.90
	1004	4.499	4.12	8.13
		.45%	.41%	.81%

3. Using 50 per cent. ferrosilicon, 80 per cent. ferromanganese, and cupola metal.

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
50 per cent. ferrosilicon	3	.015	1.50	
80 per cent. ferromanganese	8.5	.510		6.80
Cupola metal	91	3.185	1.82	.455
Blown metal	900	.900	.90	.900
	1002.5	4.610	4.22	8.155
		.46%	.42%	.82%

4. Using 50 per cent. ferrosilicon, 80 per cent. ferromanganese and pig iron. This calculation will be very much like number 3.

As we have already set forth at some length in the introductory chapters, Bessemer metal is more overoxidized than open-hearth steel, and even when the deoxidizers are added molten in the converter, the removal of oxides is never complete. Nevertheless, if both ferromanganese (80 per cent.) and ferrosilicon (generally 50 per cent.) are added as deoxidizers, and especially if they are used molten, steel can be produced that is comparatively free from oxides and gases, and castings are poured that are quite free from blow holes, etc. The difficulty of deoxidizing the steel sufficiently to prevent blow holes increases greatly as the carbon content of the steel produced is reduced. Thus some shops that add enough ferromanganese, ferrosilicon and pig iron (or metal from the cupola), to produce steel of .50 per cent. carbon with the usual silicon and manganese, pour castings of this metal without great difficulty; but ask them to pour .20 per cent. or .15 per cent. carbon steel and they get into trouble with blow holes and misrun castings.

To examine this question a little more closely, we may take an example from practice. At one shop it was found that composition (A) (below) would run well, and gave castings with few blow holes; composition (B) soon became pasty in pouring, ran badly and gave castings with many blow holes; this trouble was corrected by substituting composition (C) for composition B.

	A	B	C
C	.40 per cent.	.20 per cent.	.20 per cent.
Si	.30 per cent.	.30 per cent.	.30 per cent.
Mn	.60 per cent.	.60 per cent.	1.30 per cent.

In explanation of this, it is suggested that steel B becomes sticky sooner than A or C, for the following reasons.

1. Carbon and manganese both lower the melting point of steel, therefore B's melting point is highest.

2. Carbon and manganese both increase the fluidity of molten steel, especially just before freezing. Steels low in carbon, silicon and manganese go through a longer period when they are sticky than those high in one or all of these elements. Therefore B soon became sticky.

3. The purer the iron, the more tenaciously it holds its oxides. Therefore B is probably less well cleansed of oxide than A, because it is more nearly pure iron, and therefore the same amount of silicon and manganese less thoroughly removes the oxide; and less well than C because the lower manganese less thoroughly removes the oxide.

4. The lower the temperature of the iron, the less tenaciously it holds its oxides, and the greater the tendency of carbon, silicon and manganese to reduce them. Therefore B is probably less well freed of oxide than A or C, because it freezes at a higher temperature.

5. Probably oxides both raise the melting point of the steel, and decrease its fluidity, hence B will be less fluid and have a higher melting point than A and C from this cause also. This follows from considerations 3 and 4.

The stickiness of steel of composition B rendered it a difficult matter to run such a steel into small sections. A 3-ton heat soon became too "mushy" to run into light work, and many of the castings poured of metal approaching the mushy state were full of blow holes.

There are many ways in which the greater abundance of blow holes in steel B than in A or C may be explained, the most probable being that owing to the higher melting point of B, less time is allowed for the escape of gases from this steel, which are therefore carried over in considerable quantity into the mushy stage just before freezing, when their escape is greatly hindered by the resistance of the mushy steel to their egress. It may be added that additions of aluminum, silicon-calcium and other deoxidizers improved the pouring qualities of steel B, but as the same additions were used for steels A and C, the relative ease of handling was not affected by these additions; and as steel C was found to be superior in physical properties to either A or B, it soon displaced them both in the foundry. It was as strong or stronger than A, and as tough or tougher than B, without being in any way too hard for common use. This foundry had for years had difficulty in pouring steel of as low as .20 per cent. carbon and had been deterred from trying composition C by the opinion, long commonly held, that more than 1 per cent. of manganese rendered the steel brittle. No doubt harder steels, containing from .45 per cent. of carbon up, such as are used for the manufacture of rails, are rendered brittle by such high percentages of manganese. At any rate, the rail mill men formerly held that 1 per cent. was about the maximum content of manganese that it was safe to add to their steel. But in the case of soft steels, much more manganese can be used not only with safety, but even with great benefit to the steel. This is perhaps because the functions of manganese and of carbon in steel are much alike, so that it is the sum of their percentages, or the sum of some multiple of the percentage of each, that cannot exceed a certain figure without producing a brittle steel.

Using coke or coal in the ladle as a source of carbon is a practice to be avoided whenever possible. To sum up this subject, the composition of typical recarburizers and the methods of using them are given in the following table.

Material	C, %	Si, %	Mn, %	Ni, %	Cr, %	Used	In	Melted in
Cupola metal	3–4	1-2	.5-3	......	......	Molten	Vessel or ladle	C
Ferromanganese	6–7	.30	80	......	......	Molten, solid	Vessel or ladle	Cr-E
Spiegel	4–5	.30	20	......	......	Molten	Vessel or ladle	C-A
Ferrosilicon	0.5	50	......	......	......	Molten, solid	Vessel or ladle	Cr-E
Ferrosilicon	1.8	10	......	......	......	Molten	Vessel or ladle	C-A
Silico-spiegel	1.9	10	20	......	......	Molten	Vessel or ladle	C-A
Pig iron	3–4	1–3.5	.30-3	......	......	Molten	Vessel or ladle	C-A
Hard coal, coke	50	......	......	......	......	Solid	Ladle	....
Nickel	.50	......	......	99	......	Molten	Vessel or ladle	Cr–E
Ferrochrome	7–8	......	......	......	70	Molten	Vessel or ladle	Cr–E
Ferrochrome	.50–2	......	......	......	70	Molten	Vessel or ladle	Cr–E

C = cupola. Cr = crucible. E = Electric furnace. A = Air furnace.

ALLOY STEELS

The composition of Bessemer steel may be varied within wide limits with comparative ease, since the blown metal is practically pure iron, containing only about .10 per cent. of carbon, silicon and manganese, and therefore by properly proportioning the recarburizers, the chemical content may be made almost anything we please. In this connection, however, it should be remembered that if heavy additions are to be made to the steel, in order to secure high carbon content, or a high content in manganese, nickel, chrome, or other alloy, it is often essential to melt these additions. If this is not done, the steel will be so chilled that it will be impossible to pour it; indeed, in the case of some of the alloy steels now made in great quantities, to attempt to use solid additions would result in practically solidfying the steel in the ladles or vessel.

The limitations of the Bessemer process in the production of alloy steels are chiefly confined to chrome, tungsten and molybdenum steels. These alloys often have to be added molten, and ferrochromes are very hard to melt alone, ferrotungsten and ferromolybdenum even more so, while metallic tungsten and molybdenum cannot be melted alone. With sufficient amounts of ferromanganese or pig iron, ferrochromes can be melted, but if crucibles are used for melting, low carbon ferrochromes will absorb carbon from the graphite of the crucibles very rapidly, so that the production of low carbon chrome steels of high chrome content is not at all easy. Tungsten and molybdenum steels of high alloy content and low carbon are almost impossible to produce by Bessemer methods.

In the manufacture of nickel-chrome steel, the Mayari pig irons can be used to great advantage, as almost all of the nickel remains in the metal after blowing. The chrome is reduced by oxidation losses from about 2 per cent. to some .50 to .70 per cent.

Similarly, if nickel and chrome, or nickel-chrome steels are manufactured in quantity, it will pay to keep the scrap from these heats separate and use it in the manufacture of the alloy steel, because much of the chrome and nearly all of the nickel can be counted upon to remain in the metal and reduce the consumption of nickel and ferrochrome proportionately.

The Bessemer process is particularly well suited to the manufacture of manganese steel, for the following reasons.

First, Bessemer blown metal and ferromanganese, mixed together in such proportions as to give the manganese content desired, result in a steel of correct composition in carbon and silicon.

Second, manganese steel is poured largely into comparatively small castings; hence the very hot Bessemer metal, made in small heats at frequent intervals, is well suited to the pouring problems presented.

Third, the enormous dose of ferromanganese added to the blown metal deoxidizes it to an extent that is quite sufficient to make the quality of the steel as high as is needed.

The special problems presented in the manufacture of this steel are the melting of the ferromanganese, which is used in such great quantities that it cannot be added solid, and the working up of the scrap.

The ferromanganese is commonly melted by one of the processes suitable for high percentage alloys, as, for instance, the crucible furnace or the electric furnace. In spite of the cost of these methods of melting, they generally will do cheaper work than any others, as by their use heavy losses of manganese by oxidation in melting are avoided. Efforts are being made with varying success to substitute cheaper melting methods.

The scrap problem is a hard nut to crack, because in remelting and blowing this metal the manganese is necessarily all oxidized and lost. By using as much of the scrap as possible in the cupola charge, and by using it in place of spiegel for recarburizer in the manufacture of ordinary steel, the accumulation is greatly cut down.

What cannot be used is sold to the open-hearth shops, who do not save the manganese the metal contains. Electric furnace melting will save the manganese, but considerations of cost have so far prevented its adoption for this purpose.

Crucible or cupola melting of the scrap for use direct is not feasible, because of the great absorption of carbon that necessarily occurs in the process.

The Basic Bessemer Process.—We have seen that in the Bessemer process, as carried on in the United States, no phosphorus or sulphur is eliminated from the steel; in fact, owing to the loss of carbon, silicon, manganese and iron in blowing, without any loss of phosphorus and sulphur, the percentage of these impurities somewhat increases. In the case of sulphur, and to some extent phosphorus, an actual increase in the total weight of the impurity occurs, because some is absorbed from the fuel in the cupola. Because the lining of the vessel, and therefore the slag, is acid, *i.e.*, siliceous, any phosphorus oxidized to P_2O_5 is at once reduced by iron and carbon, with the formation of FeO,CO, and metallic phosphorus, since iron and carbon have a greater affinity for oxygen at these high temperatures than has phosphorus; and in the absence of any base such as lime (CaO) to hold the P_2O_5 in the slag as phosphate of lime, permanent oxidation of the phosphorus is impossible. Phosphate of iron, if formed, will at once be broken up by SiO_2, as SiO_2 has a greater affinity for FeO than has P_2O_5, at these temperatures. Thus no phosphorus can be eliminated in acid-lined vessels.

The basic Bessemer process was designed to overcome this difficulty, and give a rapid process of steel making that should at the same time be a dephosphorizing process. The first requisite being a basic slag, lime is added to the charge in the vessel before blowing begins. Since this lime would at once attack a lining of silica (SiO_2) or any acid material, eating into it until enough SiO_2 was dissolved out to unite with the CaO to form a siliceous slag, the lining of the basic Bessemer vessel has to be of either neutral or basic material. On account of its cheapness, a basic lining of burned dolomite (double carbonate of lime and magnesium) is used. Though in fact this lining is partly eaten away by each heat and contributes material to the basic slag, this contribution is not necessary, is indeed an evil, for if not thus cut into the linings would last much longer.

In order to keep the amount of lime needed to produce a basic slag, and hence also the volume of slag produced, at a minimum, pig iron low in silicon is blown; in practice the silicon should not be over .50 per cent. Since this takes away the greater part of the heat-producing element utilized in ordinary Bessemer work to warm up the charge, some substitute has to be found, and that substitute is phosphorus, the very element the process is designed to remove. This apparent paradox is easily understood when the details of the process are considered. At the beginning of the blow, SiO_2 and MnO, as fast as formed from the oxidation of silicon and manganese, unite with the CaO (lime) to form a double silicate of lime and manganese (and of course iron); and since lime is in large excess, a highly basic slag, capable of holding phosphorus in solution as phosphate of lime, is formed from the start. When silicon, manganese and carbon are eliminated and the flame drops, the blowing is continued long enough to oxidize the phosphorus, which is not rapidly removed as long as carbon, silicon and manganese are present, since the affinity of those elements for oxygen at high temperatures is greater than that of phosphorus. The combustion of of this phosphorus to P_2O_5 produces a great deal of heat, and the iron is protected from oxidation by the phosphorus as long as any considerable amount of the latter is present, just as in the acid process the iron is protected by silicon, manganese and carbon. Upon completion of the necessary length of "after blow" to remove phosphorus, the vessel is turned down, and the steel handled as usual.

As phosphorus is the source of much of the heat necessary to maintain the carbonless iron fluid at the end of the blow, there must be a considerable amount of it in the pig iron used. Actually from 2.5 per cent. to 3 per cent. is needed to produce sufficient heat; and as the highly phosphoric slag produced is a valuable by-product, being sold for fertilizer, the amount of phosphorus in the pig is kept as high as it is possible to have it without too much prolonging the blow.

The removal of sulphur in the basic process is only partial and rather erratic, so that the pig iron required is not very high in this impurity.

In America, there are no iron ores so far opened up that will produce pig iron suitable for carrying on the basic Bessemer practice at a profit; no ores being mined that can be used for the manufacture of low silicon—high phosphorus pig at a sufficiently low cost. Some of the Alabama ores come the nearest to it, but the phosphorus in the pig iron smelted from them is not high enough for the basic Bessemer process, nor is the silicon low enough. Indeed, these ores produce a pig difficult to work even in the basic open-hearth process, as the pig contains too much silicon, which is a handicap in basic open-hearth practice, for the same reason as in basic Bessemer; namely, because it requires a great deal of lime to slag the SiO_2 produced, and the heavy blanket of slag makes it difficult to work the heats. "Duplexing" has successfully handled these pigs; the silicon, manganese and carbon being removed in an acid Bessemer converter, and the carbonless steel then purified of phosphorus and sulphur in a basic open-hearth furnace.

As the basic Bessemer process has been several times attempted in this country, and uniformly proved a financial failure, we shall not again refer to it in these pages.

CHAPTER V

THE OPEN-HEARTH PROCESS

The open-hearth or Siemens-Martin process for making steel was developed in England about 1867 by Sir William Siemens, and independently in France by Martin. The process consists essentially of the melting down of steel scrap and some pig iron in a furnace of the bath type, oxidizing out the carbon, silicon and manganese of the metal by means of additions of iron ore, and adjusting the composition by proper additions.

In order to maintain in a fluid condition the nearly pure iron produced by the elimination of the metalloids from the bath, a high temperature has to be attained in the furnace, much higher than can be secured by the direct combustion of coal. To meet this essential condition, the regenerative principle was invented. By the use of checker chambers such as have been described in the chapter on the crucible furnace, producer gas, resulting from the partial combustion of coal in a gas producer, is fed very hot to the hearth of the furnace, meets sufficient preheated air for its combustion, and heats the furnace chamber and bath to a very high temperature. So intense a heat can be attained that when a furnace is "hot," the operator has to be constantly on his guard lest the brickwork be melted away.

Besides producer gas, other fuels can be used. Natural gas, when obtainable, is excellent for the purpose and does not have to be preheated, but is piped directly into the hearth, only the air passing through regenerators. Fuel oil is used in the same way. On the continent of Europe, coke-oven gas has been tried, and of late experiments are being made with powdered coal.

Whatever the fuel, and whatever the method of working, conditions in an open-hearth furnace are pretty much the same. The reasoning that has already been given in discussing basic Bessemer steel making shows us that a basic lining and a basic slag are necessary, if dephosphorizing of impure material is to be attempted. As in Bessemer work, therefore, we have to consider both acid and basic methods; and as both are used in the steel foundry to a large extent, a somewhat extended consideration of each is necessary.

In the acid open-hearth process, pure materials have to be used in order to produce pure steel. Low phosphorus pig and scrap are melted down in the furnace, losing part of their carbon, silicon and manganese (and some iron) in melting, and forming a slag of FeO, MnO and SiO_2. There is a very slight gain in phosphorus as in the other acid processes due to loss of iron, etc., and when producer gas is used as fuel, there is also a gain of from about .01 per cent. to .03 per cent. in sulphur, which is picked up from the gas. When the metal is all melted and covered with the fluid slag, iron ore is thrown into the furnace in proper amounts, and a slag very rich in FeO is the result. The excess oxygen of the flame, and the oxygen of the iron ore, oxidize carbon, silicon and manganese in the bath, the last two entering the slag, the first boiling out as CO. The bubbling produced by the evolution of CO keeps the bath in circulation, and aids in heating up the metal. As a bath must boil vigorously in order that it may readily be heated up, some pig iron to provide carbon is essential. The silicon and manganese of the pig are also an advantage, since they tend to protect the iron from excessive oxidation in melting down. The ore is added in amounts sufficient to run the carbon down to about what is desired in the finished steel (the silicon and manganese having been first removed), and the good melter does not add so much ore to his heat that the carbon "races" down, but brings it to what he desires by progressively slower steps. In this way the last 10 or 15 "points" of carbon are removed very slowly, and probably are oxidized mostly by the excess oxygen of the gases. By this procedure the available iron oxide of the ore is largely used up, and as much of the oxide as possible boiled out of the steel. If the bath is hot enough, the usual recarburizers are then added, and the heat tapped and poured.

In basic practice, limestone is charged with the pig and scrap, and lime is used freely with the ore, whereby a basic slag is maintained throughout the process, and phosphorus largely eliminated. Sulphur is also removed to some extent, but this action is erratic and not as much sulphur is removed as phosphorus. If very low phosphorus and sulphur are desired, the steel is generally run down to very low carbon, about .06 to .08 per cent., and subjected to the action of a very limey slag for some hours. In making steel of ordinary grade, the heat is tapped soon after the desired carbon is reached. In any case, however, the slag in the basic furnace contains a great deal of FeO throughout the process, and hence is strongly oxidizing. The steel, therefore, is never so well cleared of oxide as in acid practice. Moreover, in order to avoid "rephosphorizing," the recarburizers are generally added in the ladle, so that they have less time to act in reducing oxides than in the best acid practice.

Open-hearth steel, therefore, especially basic steel, contains oxides to quite a large extent; but probably not as much, even in the case of basic open-hearth, as Bessemer converter metal. The quality of the steel produced, is therefore, generally intermediate between that of electric or crucible steel, and that of Bessemer metal.

The comparative freedom of open-hearth, especially acid open-hearth steel, from gases and oxides, would make it suitable for the production of small, intricate castings. But, as we have stated in the introductory chapters, the rather low initial temperature of the metal, and the size of the heats, which in ordinary practice are tapped out in one lot and have to be poured off before the metal has time to chill, forbid the use of the process for any but heavy castings. For light work, the process as generally carried out is at a prohibitive disadvantage as compared to Bessemer, crucible or electric methods.

For castings averaging over 50 lb. each, the advantages of the open-hearth process far outweigh its disadvantages, and make it the most suitable process for such work. The quality of the steel is quite high enough for the castings desired, and it will pour them readily; the cost of the steel is low; the output is very large, so that the total profit on a year's output of comparatively cheap castings is considerable; and the process can be worked with a variety of fuels and raw materials.

The disadvantages of the process are the lack of flexibility in making different kinds of steel at one heat, which has already been discussed; the heavy installation expense; and the fact that the furnace must be kept going at full capacity day and night. These disadvantages tend to make the process unsuitable for the foundry producing light castings, but for the tonnage foundry they are either unimportant, or positive advantages. For such work, the lack of flexibility is of little moment; the heavy installation expense is distributed over a great tonnage; and continuous operation is a necessity in a tonnage shop in order that the interest and depreciation cost of the plant may be spread over the largest possible output.

THE FURNACES

The scope of this work does not permit of an extended discussion of the design of furnaces now in use, but a few general remarks upon this head must suffice.

The essential parts of a regenerative furnace are the enclosed working chamber, or hearth, with a bottom lined with refractory material, where the flame is produced and heats the charge; the four regenerative chambers (sometimes only two, when only air is preheated), filled with the brick "checker work," where the heat of the products of combustion leaving the hearth is absorbed, to be returned to the incoming gas and air when the direction of flow is reversed; proper passages or flues connecting the hearth with the regenerators, and the latter with the gas producers; throttling valves to control the amount of gas and air admitted to the regenerators; reversing valves to admit air and gas to each pair of regenerators alternately; and a stack of sufficient size and height to carry off the cooled gases leaving the regenerators. The general arrangement of the component parts is too well known to require extended description.

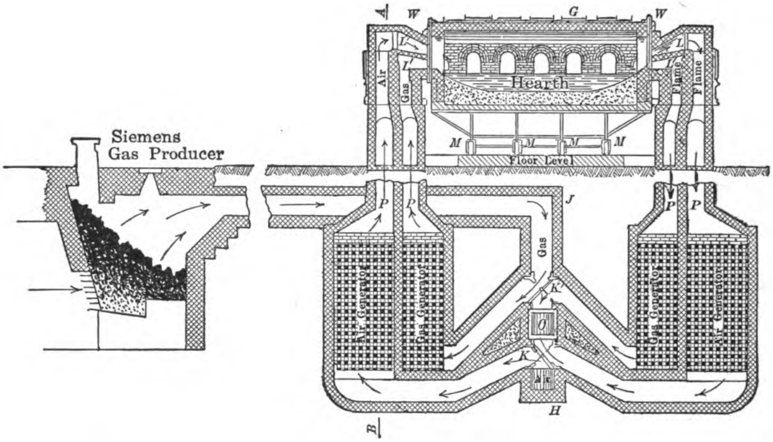


FIG. 9.—Diagram of open-hearth furnace. From Howe, "Iron, Steel and Other Alloys."

The principal changes that have been made in the building of furnaces since they were first introduced are the increase of size and capacity, the moving of the regenerators back from under the ends of the furnace, the design of special gas reversing valves, the measures that have been taken to protect door frames, ports and other parts from burning out (water cooling), and the use of tilting furnaces. Furnaces are now built up to 60 tons capacity for ordinary practice, and for the special Talbot process 200-ton furnaces are in use. The regenerators, when placed directly under the ends of the furnaces with the uptakes leading vertically from them, fill up rapidly with dust, slag, etc., and require frequent cleaning and renewal. By placing open chambers at this point, called "slag pockets," and setting the regenerators back of them, the dust and slag are collected in a convenient place where they can easily be removed, and the life of the checker works is greatly increased.

A few of the essential points that should be insisted upon in the design of a furnace are as follows:

Man holes should be provided for each flue, gas as well as air, between the reversing valves and the checkers; and a man hole in the stack flue, between the reversing valves and the stack, or a door in the base of the stack—if the latter is far from the valves, both will be desirable. There should be ample space around the valves so that they are easily accessible. The checker chambers should be amply tied together; insufficient bracing results in a checker chamber roof so leaky that no amount of grout poured into the cracks will stop the leaks.

In the superstructure of the furnace, the roof should be entirely separate from the side walls; some builders will practically rest the roof on the walls, either by setting the "skew backs" directly on the walls, or by supporting on the walls the channel irons that hold the skew backs. The result is that the wall cannot be cut away to patch it when worn thin without danger of bringing down the roof. The channels that hold the skew backs should be clamped to the buck stays of the furnace so that the roof is supported entirely by the framing.

It is well to avoid "dry" door frames; water-cooled frames much more than pay for themselves in less frequent renewal of frame and doors and in the comfort of the men. The door frames should be so designed as to be readily replaced. Some builders, if allowed, will hold them in place with the buck stays. Water-cooled "ports" (or, more properly, the space between gas and air flues where they enter the hearth), if properly designed, are well worth while; if badly designed, for instance by merely running water pipes through from front to back of the furnace, they are not worth their expense. The pipes will protect but a very small thickness of brick, so that the port cuts back to them as rapidly as if not water cooled at all. Then the bricks above and below each pipe cut away, leaving a sort of shelf of hanging bricks. This shelf soon falls and exposes the pipe, which then burns away in a very few moments and is of no further service.

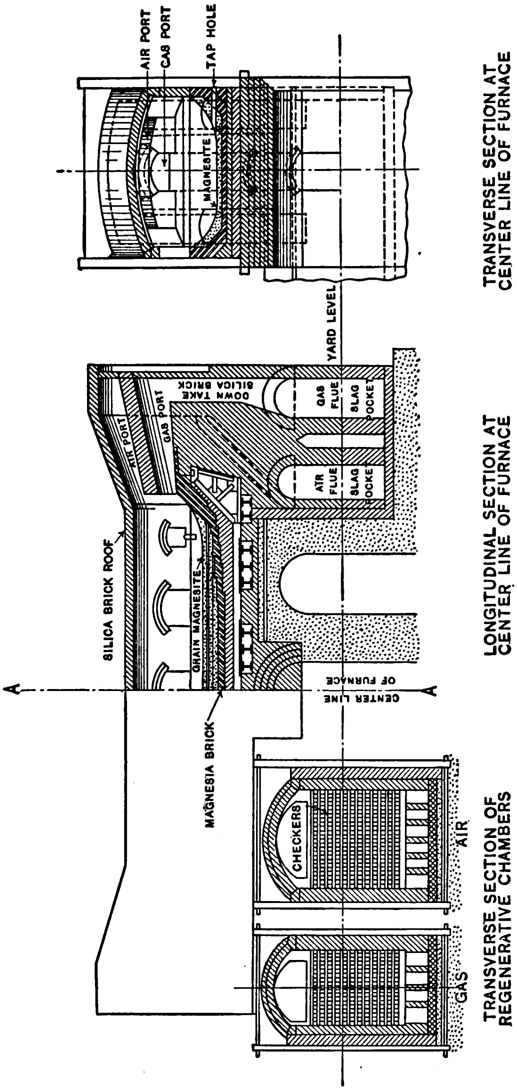
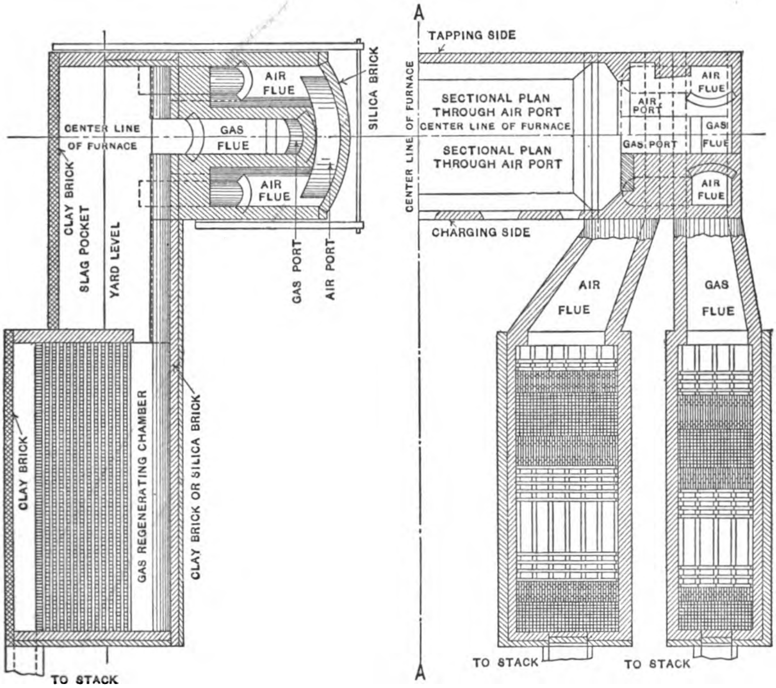


FIG. 10.—Typical basic open-hearth furnace. From Harbison and Walker, "A Study of the Open Hearth".

If possible, even in a very small furnace, there should be one or more doors on the tap hole side. Even if kept bricked up and opened only when making bottom, these doors are a great convenience, and make it possible to be sure of the condition of the banks under the charging doors. Without them, the sand used to patch the front banks has to be rolled down with a sand spoon, and the men cannot see whether the holes are properly filled or not. Under such circumstances, many holes will not be filled as they should be and break outs will be unpleasantly frequent.

The tap hole should not be placed so low that when the bottom



SECTION THROUGH PORTS AND REGENERATIVE CHAMBER SECTIONAL PLAN OF REGENERATIVE CHAMBERS

FIG. 10*A*.—Typical basic open-hearth furnace. From Harbison and Walker, "A Study of the Open Hearth."

is made the slope to it is very steep. If placed too low, it is well-nigh impossible to scrape it clean after a heat has been tapped, and the slag and drainings of metal running into it will result in the freezing of the hole and numerous "hard taps." It should, of course, be so placed that practically everything will run out when the heat is tapped, but should be so located that when the furnace is empty the last drainings do not run to the hole, but have to be splashed out with a rabble.

The height of the furnace from hearth to roof should not be too great; the working of some furnaces is greatly improved by taking off a foot at this point. The "head," or opening where the air comes into the furnace, should be ample to take waste gases down through the air checkers as well as the gas checkers. It is essential that the hot gases should go down through both sets of checkers, and contracted passages prevent this. If the air checkers are too cold it is impossible to get the furnace hot.

Too much iron or steel plating outside the front and back walls is a nuisance, as it renders it almost impossible to get at the walls to patch them when they grow thin. Bare walls as far as possible are to be preferred.

Double jambs and arches for the charging doors are essential, especially double arches. When a single arch burns out and falls, it brings the wall over the door with it; a double arch, when the lower course falls, leaves the walls supported, and a new arch can be put in at the end of the week.

The beams supporting the working floor should never come close past the front of the furnace, or near the buck stays. If the main floor beam is close to the furnace, the metal running from a break out may cut into it seriously and, worse still, may form a great chunk of cold steel welding floor beam and buck stays into an inextricable tangle. There should be an open space in the floor, below the front of the furnace, large enough so that a break out may run into the pit under the hearth without striking obstructions. This hole can be kept covered with loose plates.

The throttling valves controlling the admission of gas and air generally consist of a simple "saucer" lowering into a seat, and require no description. Reversing valves, which were originally of the "butterfly" type, are now made in numerous styles, some of which are very complicated. The butterfly valve, especially if provided with a water-cooled seat, does very well for the air, but its strong tendency to warp and leak make it unsuitable for the gas. Of the many designs of gas reversing valves, some are open to the criticism that they warp and stick, while others give trouble from accumulations of soot. The rule that the simplest design is the best cannot be followed in the case of these reversing valves, since those that give the least trouble are generally rather complicated.

The gas mains, valve chambers of regulating valves, and gas reversing valves, should be provided with clean-out doors of ample size for the removal of soot.

Tilting Furnaces.—There are two types of tilting open-hearth furnaces, known as the Wellman and the Campbell, in both of which the hearth portion of the furnace tips up for pouring. In the former, the furnace is tipped forward upon rockers like a rocking chair, while the latter is revolved by means of rollers under the rockers, the center of the gas port opening being the center of rotation. As a result of the motion of the Wellman furnace, the gas port is brought out of line with the gas flue in the stationary end of the furnace, so that while the furnace is tipped forward gas has to be shut off, and the furnace is greatly cooled down. This cooling off wracks the brickwork severely. The Campbell furnace, on the other hand, can be left tilted over and fired as long as necessary, and the furnace is not cooled off in tilting.

Firing the furnace while it is tilted over is resorted to chiefly in continuous processes, where molten pig is poured into a bath containing a great deal of hot ore or scale. The violence of the resulting boil makes it necessary to tip the furnace in order to keep the bath from running out the doors, and in some cases it is an advantage to be able to fire the furnace while a strong boil is going on. If the tilting furnace be used in the ordinary manner, or if the tilting feature be taken advantage of only to pour successive small lots, it is not so essential to be able to fire while the furnace is tilted.

Tilting furnaces are more expensive to install and maintain than stationary furnaces, and should not be used except when there is good reason for incurring the extra overhead and operating expenses. The fact that occasional small lots of steel of special composition have to be made does not justify the installation of a tilting furnace, as should there be enough of such work to make it worth going after, a special small furnace can be installed to take care of it. Continuous working to take off small lots from a large furnace for small castings (generally with an electric furnace to refine and warm up the steel), or pouring a heat in successive small lots, can best be carried out in a tilting furnace, as the use of a stationary furnace with several tap holes at different levels is not very convenient and involves the tapping of the slag each time, while with a tilting furnace a skimmer in the spout can be used to hold most of the slag back.

For a furnace of 15 to 20 tons capacity, the crew on each shift consists of two or three furnace men, generally known as first, second (and third) helper, a gas man and helper (if producers are used), and a melter, who may have charge of five or six furnaces. When there are several furnaces, a ladle man and one or two helpers take care of the ladles; for a single furnace, the furnace men can do this work. When the furnace is charged by hand, the crew naturally has to be larger than when a charging machine is used. A 5-ton gas furnace, charged by hand, can be run with six men, who will charge the furnace in from 20 to 40 minutes. The floor crane is then, of course, used to swing the piel for charging heavy chunks. Such a crew would consist of a melter and two helpers, two gas men, and a ladle man, on each shift.

Lay-out.—The lay-out of an open-hearth shop, involving the handling of great quantities of materials, must be considered carefully in building the plant. If gas producers are used, the coal cars should if possible be able to dump their coal directly to the place where it is wanted, without any hand shoveling. Furnace space and gas producer space should be arranged so that in hot weather the sides can be thrown wide open to let in all the air possible. The open-hearth building should be high and airy, and plenty of floor space in front of the furnaces should be provided. If a charging machine is used, the wide track necessary compels the designer to make this space ample.

Accessibility of all parts of the furnace, valves, flues, etc., is an essential feature of the general lay-out. In view of the fact that checker works have to be frequently blown out to get rid of accumulated slag and dust, and that when the furnace is being repaired many of the checker brick are taken out and replaced, it seems superfluous to state that the checkers should be entirely above ground. So arranged, and with a shop that can be thrown open to the air, checkers can be cooled off rapidly, so that the time consumed in top repairs and changing checkers is reduced to the minimum. Yet in numerous instances furnaces are built in a sunken pit like a crucible furnace, and to make matters worse, in many such cases only a very small free space is left at the front and sides of the checkers.

The floor should be commanded by a crane of ample capacity to handle any lifts needed. Generally it is better not to span both pit and charging floor with the same crane.

The ladle should never be down in a pit; if the furnace is built with checkers all above ground it will not be necessary to have it so, and the ladle will even have to be raised above the casting floor level on a car or a saddle. With this construction the space provided for the slag that slops over the ladle, and for catching slag or steel boiled out of the doors by incautious oreing, or resulting from a break out or a leaky ladle, is easily got at and cleaned out; and any skull from a break out or leaky ladle can be hooked to the pit crane and dragged out. The dragging of a heavy skull out of a steep-sided pit is a job that few care to undertake a second time.

Yard arrangements for an open-hearth shop are generally quite easy to make, if ample space is available. The straight-line plan is of course the most desirable. Either a locomotive crane or overhead cranes may serve the yard, preferably the latter. Magnets should be used for unloading pig and scrap, and for loading furnace charges on the narrow gauge cars sent to the furnaces. If the furnaces are machine charged all material will be loaded in charging boxes and the open-sided "piels" used for charging ingots and heavy crop ends. The magnets can load these very handily. For hand-charged furnaces small flat cars serve the same purpose, and are readily loaded with magnet and crane. Generally, unless a favorable difference of level can be taken advantage of, the furnace charging floor is considerably above the yard. Elevators or the cranes can be used to lift cars to the furnace floors if only one or two furnaces of small capacity are installed, but for any considerable tonnage they will prove rather slow, and it will be better to run the cars up an incline to the floors.

Starting a Furnace.—Operations of course begin with a new furnace, and the first thing is to get the furnace heated up and set a bottom. It is especially important to heat up a new furnace carefully and slowly, to guard against the spalling and cracking of the silica brick of which it is built. First throw the reversing valves on center and close the air and gas inlet valves; then build a wood fire in the hearth and feed it constantly (or use a hard coal fire in a stove). Build a second fire at the base of the stack to create the necessary draught. Have a pile of sand ready for use, and if the fire gets too lively and the flames touch the roof (before the roof has became hot), shovel in sand to deaden the fire. Keep the fire going night and day till the furnace walls and roof are thoroughly dry and hot.

A better and quicker way to warm up a furnace is to use oil burners introduced through the doors, or through the gas ports. If natural gas or oil be the fuel, the main burners of the furnance can be used for warming up; they can best be lighted by means of a small wood fire in the hearth. In heating up with oil or gas burners, care must be taken to bring the furnace up very slowly, turning on the fuel sparingly at first.

In one or two days the furnace will be hot enough to light producer gas with a wood fire; oil burners will reduce this, or get the furnace up to much greater heat in the same time. Have the producers making good gas before any attempt is made to turn gas into the furnace. Throw the reversing valves over, admit gas cautiously to the furnace and keep the wood fire going until the gas lights. When a furnace is not very hot it is well to open the doors when gas is first put on. At first there will be only a fitful dull red flame almost lost in the black gas. The first reversals should be made carefully, at intervals of about 1½ hours, preferably shutting off the flow of gas before reversing in order to avoid hard kicks. On the first few reversals, new fires may have to be made to relight the gas. After a half dozen reversals the gas burns freely, the furnace begins to pick up heat rapidly, and should be "thrown over" at shorter intervals. After about 24 hours air can be admitted and the reversals made every 20 minutes or half hour.

As the furnace heats up, the roof begins to expand. The longitudinal expansion is largely taken care of by the "slip joints" provided for the purpose, but the horizontal motion must be taken up by loosening the nuts on the tie rods a little at a time as the roof moves. The men go over every nut at intervals, and loosen them up enough so that they move easily, but not enough to loosen the roof and allow bricks to fall out. Here and there a few will slip out of the roof, and these must be replaced with others, held in place with wedges until the expansion is sufficient to hold them securely. When the furnace has reached full heat, the making of bottom begins.

The Acid Bottom.—In the acid furnace, the roof, walls and bottom are of silica brick and a lining or bottom of silica sand is set on the bottom brick. It is a saving of sand to bank a good layer of silica brickbats, left from the construction of the furnace, in the angles between sides and bottom. Over these a layer of sand about 2 in. thick is shoveled, and the furnace run up hot enough to partially fuse or sinter this sand into a solid mass. As soon as this layer is firm, another of the same thickness is added, and so on until the bottom is brought up to its full dimensions.

The tap hole can be broken through with bars from the outside after the bottom is made, or an iron pipe the size of the hole desired can be used as a form. In this case the tap hole is shaped with siliceous ganister and closed with coal and sand before bottom making begins.

The sand used for bottom making (and for patching the bottom after each heat) should be either a silica sand with just enough FeO and Al_2O_3 to make it "set" (or partially fuse), at the full heat of the furnace, without getting too soft, or preferably a pure silica sand mixed with an impure one containing a larger proportion of FeO and Al_2O_3. It is generally much easier to obtain a pure sand and an impure one to mix with it than to get just such a sand as is needed.

When the bottom is finished, a "wash heat" of acid slag may be melted on it; or a light heat of pig iron and scrap melted down, and the slag made bulky with iron ore and sand. In any case, the slag should be thoroughly splashed up on the banks in order to soak the bottom full of it. The furnace is then ready for melting steel.

The tap hole is closed with fine anthracite coal mixed damp with a little sand. The men on the charging side run a rabble or splash hook into the furnace and block the inside of the hole, while two men do the closing from outside. Coal and sand are thrown up into the hole and packed firmly in place with a rammer until it is full. Sand is then banked over the coal on the outside and a few shovels of "seal" (coal ashes and sand in about equal parts) are thrown over the hole on the inside. Great care should always be taken to scrape the hole clean of slag, and especially of metal, before closing, as the penalty for carelessness is a "hard tap."

Needless to say, the tap hole of a tilting furnace is easily closed and not subject to hard taps. Unless it is intended to roll the furnace very far over to keep metal and slag from boiling out the doors, the hole is very lightly plugged.

The Basic Bottom.—The bottom bricks of the basic furnace are of magnesite, since acid (silica) bricks would react with the basic bottom material and produce slag. One or two courses next to the steel shell may be of clay, or chromite, bricks. The walls and roof are of silica brick, and to prevent their slagging the magnesite of the bottom bricks at their contact, an action which would be increased by the iron oxide and manganese oxide of the furnace slag which spatters upon the walls, one or two courses of chromite brick are commonly used to separate the bottom and the wall bricks. Chromite brick are sometimes also used to pave the bottom of the gas port. These bricks are made of chromic iron ore, a double oxide of iron and chromium which is almost absolutely neutral, and hence are not slagged by either the silica wall brick or the magnesite bottom.

The bottom of the basic furnace may be made of either calcined dolomite (CaO MgO), or calcined magnesite (MgO), or both.

Magnesite is greatly to be preferred, as it makes a much denser bottom that can be confidently relied upon to stay in place when once set in and soaked full of slag, while dolomite bottoms frequently give trouble by coming up in patches, or cutting through. Whichever is used, it should be mixed with sufficient basic slag (generally from 5 to 15 per cent.) to make it sinter at the full heat of the furnace, and placed a layer at a time as an acid bottom is set. Sometimes a little tar is mixed with the magnesite and slag. Magnesite brickbats can be used to help out in filling up the corners, before any lining is placed.

The patching of the slag line is done with dolomite or magnesite, frequently both, the former predominating. Holes in the bottom that have to be splashed out and patched are best repaired with magnesite. The tap hole is closed with either one, mixed with coal, but magnesite is preferable, as a dolomite hole is very uncertain, frequently taps itself, and nearly always makes the men jump lively in tapping.

Week-end and General Repairs.—On Saturdays, the furnace is gone over and minor repairs and patching done for the week. Generally the ends of the furnace are opened, the accumulation of slag chipped out of the gas flues back of the ports, and the slope of the gas port filled up with sand (in acid furnaces) or magnesite (in basic). New doors may be required, or patches in the walls, door jambs and arches, etc., when the brickwork begins to get old. Accumulations of dust in the flues between reversing valves and checkers, or in the stack flue, may have to be removed; and in general things are made ship-shape for the next week. At the same time the ashes are cleaned out of the gas producers and the gas mains and valves burned and scraped free of soot.

When a producer gas furnace of the usual type has been used for some time, and the brickwork has grown thin, the gas often begins to leak through the roof arch of the gas port, generally where it joins the gas uptake, and to mix with the air in the "head." This condition can usually be detected by the flame playing out where the roof and the end wall of the furnace join, and must be attended to immediately or the brickwork will be cut away rapidly and the furnace put out of business. The end wall is partly taken down to get at the trouble, and the holes in the brickwork that are making the trouble are plastered up. The best material for this purpose is chrome ore ground fairly fine and mixed with water and a little fire clay to form a stiff mud. The leaks must be thoroughly stopped, but of course when a furnace gets to this point it is a question of only a short time until a new top is needed.

When the walls have worn too thin to admit of further patching and the ports have cut back until the furnace no longer heats properly, a short shut-down is necessary. If the roof is fit to outlast another set of walls and ports, it can be left standing, or sometimes part can be repaired. As soon as the furnace is cold enough to work on, often before it has grown black, the walls are knocked out and removed, the brickwork of the ports and ends is dug out as far as necessary, and the bricklayers begin rebuilding as soon as it is humanly possible to do so. At the same time the slag pockets are cleaned out, and the checkers examined. The latter may have to be removed altogether, or part of them taken out, down to good bricks. Checker bricks that are thoroughly glazed are very inefficient and should not be put back in place. A shut-down for this partial repairing keeps the furnace idle altogether about a week. Gas is put on again as soon as possible and operations resumed.

If the roof has fallen in while a heat was molten, as sometimes happens when the furnace is run close to the limit of the top, it is not necessary to get the metal out. The new walls and roof can be put up as if the furnace were empty, and the skull melted out when gas is turned on again. It will, of course, take the furnace a bit longer to become cool enough to approach, under these circumstances.

Break Outs.—A break out is a mean thing to contend with, yet if possible it should be fought. An approaching break out can often be foreseen by the violent boiling of the bath over the spot where the bottom is being cut through. Frequently, if at the front of the furnace, the first warning is the reddening of the hearth plates at the threatened spot.

As the bath heats up and grows comparatively quiet, one spot should maintain a steady slight boil—the spot right over the tap hole. If this boiling ceases, a hard tap is to be expected. If it becomes violent, the bath is cutting its way out the tap hole and will soon be running down the spout, "self-tapped." A break out when the heat is about ready, is best fought by tapping the heat and taking chances on analysis, adding silicon and manganese largely on rapid calculations, frequently made in the head of the melter as he hastens to the scene of action. An approaching break out in the flat part of the bottom cannot be fought, and the only remedy is to tap at once before the steel goes into the pit and renders it impossible to approach the tap hole. Small break outs through the banks, at or near the surface of the bath, are fought by shoveling sand and bricks (in the basic furnace, dolomite, bricks, etc.) into the opening with the sand spoon, and turning the hose on the plates on the outside to chill the metal. With all hands from several furnaces on the job, a very mean looking break out can be stopped, but it is hard work and men play out left and right.

A break out, of course, is caused by an improperly closed tap hole or a badly repaired bottom. To guard against break outs in the bottom, large holes should be splashed clear of metal after the heat is tapped, and filled up with sand (in the basic furnace, magnesite), well set in, a layer at a time. Break outs through the front banks are more easily guarded against when the furnace has doors in the tap hole side, through which the front is repaired properly and its condition examined.

Tapping.—In order to get the heat out in a lively stream from the first, the tapping of an open-hearth furnace should be done carefully. Two men are required at the hole, one armed with a narrow shovel and one with a tapping bar. The banked-up sand should be removed cleanly and the filling of the hole dug out over the whole cross-section, until a large red-hot patch is exposed. A vigorous punch of the bar into the center of the filling will then bring the steel quickly, and the stream will almost at once cut out the whole hole. In some cases the bar may have to be driven through with a sledge. At times the steel comes almost of itself, and the men have to work fast and be nimble in getting out of the way as the stream breaks out. The men tapping should have a clear floor left and right to give them space to get away at once in case of too lively a tap. Of late several ingenious tap hole guards have been devised and described in the technical press, for the protection of the men tapping a furnace from the showers of sparks when a heat "taps itself," and their use is strongly to be recommended.

If the tap hole does not at once cut itself out, the melter or man in charge gives the word to "punch her out," whereupon the men on the charging side, who have a heavy bar ready for the purpose, slide this bar in through the peep hole of the door and punch out the hole with a few vigorous strokes.

A hole that cannot be punched through by hand must be opened with the heavy tapping bar, sometimes called the "snot bar." This tool is made of about 1½-in. round steel, and is provided with a handle which can be slipped over it and secured with a wedge. It is driven through the tap hole with sledges, the handle attached and wedged fast, and is then backed out of the hole by sledging on the handle. When the steel comes, quick work is necessary to save the bar.

If this procedure will not open the tap hole, it is because steel has run into the filling and frozen, and the chances of getting the heat out in time to use it are poor. Two methods of opening such a hole are possible, of which one is to bank charcoal against the filling, if the latter is red hot, cover it with sand, and blow up the fire with a gentle blast of air introduced through an iron pipe. This method is slow and uncertain, as it depends upon heating up the steel plug in the tap hole enough to melt it. This is facilitated by the absorption of charcoal by the steel, resulting in the lowering of the melting point of the steel by the increase in its carbon content.

A far better way is to go at the plugged hole at once with an oil or gas burner, and heat the steel up until it starts to melt and run. Then the oil can be shut off and a strong blast of air alone directed upon the melting metal. The air oxidizes enough of the iron to FeO to keep the steel at melting point by the heat of combustion of the metal itself, and with air alone a hole can be melted through the plug and back to the fluid bath behind. It is a lively job for the operator, as he is exposed to a shower of slag and scintillating particles of steel that pour from the hole and keep him dodging, and without his glasses he is in danger of having an eye badly burned.

Meanwhile, the charge in the furnace is, if possible, kept at the proper composition by additions of pig iron, ferrosilicon, etc., and sometimes the steel is saved as a heat; but, as already stated, a badly plugged hole frequently means a heat poured into ingots for scrap, and a furnace bottom deeply cut into; indeed, if the hole is not opened in an hour or so, the proceedings may be enlivened by a break out. Such a badly plugged hole means that it was not scraped clean and carefully closed after the preceding heat was tapped.

The Acid Process—Melting.—For the usual pig and scrap method in the acid furnace, the charge consists of from 20 to 35 per cent. pig and the rest scrap. Much less pig than this can be charged, but in order to get a bath composed largely of scrap, which necessarily melts very low in carbon, hot enough to tap, a good deal of pig iron has to be thrown in to make the steel boil.

As this is a discussion of the steel foundry, the all pig-iron process (either acid or basic) is automatically excluded from consideration, since we shall have to remelt in every heat from 20 to 40 per cent. of our own scrap, the proportion largely depending upon the size of our castings and the number and size of the heads used on them.

The high silicon content of the foundry scrap which we have to remelt greatly affects the calculation of the charge. It is in general the best practice to so proportion the silicon and manganese of the charge that these elements will be practically eliminated when the bath is melted. In a producer gas-fired furnace, we can assume a good composition for the charge as carbon 1.20 per cent., manganese 1.00 per cent., silicon .50 per cent. In an oil furnace, the silicon, manganese, and sometimes carbon, must be higher. Assuming that we have 30,000-lb. charges, one-third our own scrap (carbon .25 per cent., silicon .30 per cent., manganese .60 per cent.), pig iron at carbon 4 per cent., silicon 1.5 per cent., manganese 2.0 per cent., and low phosphorus scrap at carbon .15 per cent., silicon .10 per cent., manganese .40 per cent., let us see the proportions of pig we shall have to use.

Material	Weight	Weight, lb.		
		C	Si	Mn
Our own scrap	10,000	25	30	60
Purchased scrap	12,000	18.0	12	48
Pig iron	8,000	320.0	120	160
	30,000			
		363.0	162	268
		1.21%	.54%	.89%

Such a mixture will melt quite free from silicon and manganese, and probably at from .70 to 1.00 per cent. carbon. The consumption of ore should not exceed 6 per cent. of the weight of the charge, and on such heats will be found to average well below this figure. It is possible for quicker running to reduce the pig iron so that the carbon shall be about 1.00 per cent. as in the next example.

Material	Weight	Weight, lb.		
		C	Si	Mn
Our own scrap	10,000	25	30	60
Pur. scrap	13,500	20.25	13.5	54
Pig	6,500	260.00	97.5	130
	30,000	305.25	141.0	244
		1.01%	.47%	.81%

Pig iron very high in silicon and low in manganese may frequently cause embarrassment, as may be seen from the following calculation, based on pig of 3.0 per cent. silicon, .30 per cent. manganese.

Material	Weight	Weight, lb.		
		C	Si	Mn
Our own scrap	10,000	25.	30	60
Pur. scrap	13,500	20.25	13.5	54
Pig	6,500	260.00	195.0	19.5
	30,000	305.25	238.5	133.5
		1.01%	.79%	.44%

This condition may easily become complicated by the availability of purchased scrap consisting largely of cast steel averaging .30 per cent. silicon. The use of high proportions of this scrap, or of high silicon pig, will result in heats that melt high in silicon, with the result that much time is spent in the elimination of the silicon by means of ore. Confronted with such conditions we must cut down the proportion of pig iron so that the charge will be low in carbon, yet contain enough silicon, when melted, to protect the carbon from oxidation. Our bath will then melt at about the carbon content of the charge, and we can run it down with little or no ore; or if it melts too low in carbon and is hard to get hot because it will not boil, we can "pig" it to assist operations.

Many of the low phosphorus pigs that are available in the East to-day are very low in manganese also, averaging about .30 per cent. When these pigs are used, the proportion of manganese in the bath will be low, with the result that the amount of manganese oxide available for the slag will be small. Consequently the proportion of iron oxide in the slag will be high, and the loss of iron correspondingly increased. (Campbell[1] has shown that the figure $FeO+MnO$ in acid open-hearth slags is approximately a constant.) This may be offset by the use, when available, of manganese steel scrap as a part of the charge.

Charging ore with the pig and scrap is a possible method of hastening the elimination of silicon and manganese from the bath while melting, but is not often resorted to because of the effect on the bottom. The FeO of the ore takes up SiO_2 whenever it can get at the hearth, cuts the bottom severely and forms volumes of slag.

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[1] "The Manufacture and Properties of Steel," 2d Ed., p. 272.

In charging the acid furnace all the pig iron is placed upon the bottom, and the scrap on top of the pig. This method is followed to prevent the severe cutting of the bottom caused by the iron oxide formed on the melting scrap coming immediately in contact with the silica bottom and absorbing SiO_2, with consequent formation of slag and the loss of iron. By interposing a layer of pig, which melts first, a pool of molten metal is formed into which the melting scrap drops, and the slag floats on this bath from the first. By floating on molten pig, much of the FeO is reduced by the carbon, silicon and manganese of the pig, and the iron saved.

In some shops the scrap is charged first, with the idea that if the pig is on top it will melt first and flow over the scrap, whereby the iron of the latter will be protected from excessive oxidation by the carbon, silicon and manganese of the pig. This protection, however, is only partial at the best, and probably the advantage gained is more than offset by the increased loss of iron oxide formed on the scrap, which comes at once in contact with the bottom and unites with the SiO_2 of the sand to form slag, before the pig iron can melt and run down to head it off from the bottom.

Charging should if possible be completed at one operation. Sometimes when a great deal of light scrap has to be melted, it is impossible to get it all in at once, though much can be done by charging scrap into say the right-hand end of the furnace, with the flame entering from the left, then reversing the valves and filling up the left-hand end, reversing again and charging more scrap at the right. During the charging of the left side, the metal on the right is heated up and sinks down, making room for more. Too much light scrap is a great nuisance, as it not only increases the loss of metal but also delays charging and melting. Turnings are especially hard to melt, as they stick to the bottom in lumps and have to be poked off with a bar.

In handling the open-hearth furnace, heated with producer gas, it is desirable to use an even flow of gas, and as little of it as possible. When the charge is cold, the flame will be dark at the best, and a good supply of air will be needed to burn the gas. The gas valve should be opened to about the point at which it will be kept; the stack damper raised just enough to carry away the waste products, but not enough to draw the gases so strongly that the flame will "race" through the furnace; and air enough admitted to make the flame look as white as possible. If the gas is being fed so fast that a steady flame pours out of the peep holes in the doors, especially if raising the stack damper will not keep the flame in the furnace, too much gas is being fed and the furnace being "crowded." By keeping an eye on the top of the stack, waste of gas can be guarded against. The furnace operator and the gas man have to get used to each other; if the former keeps his supply of gas regular by using a constant opening of the valve, his gas man soon learns how often he has to dump coal in the producers to maintain even pressure, and things will go smoothly. A furnace man who constantly makes large shifts in the position of his gas valve, alternately draining the producers of gas and nearly blowing the tops off them by shutting down his valve, does not know his business and his gas man will hate him.

The flame should be regulated chiefly by shifting the stack damper and air-supply valve. As soon as the charge begins to get hot (and looks red through the blue glasses), the furnace man should begin to shut off the air supply a bit at a time, and try to make the flame roll through the furnace, hanging well down into the stock, and moving slowly. The flame should look as white as possible, free from dark spots and flickering; and neither a short flame reaching only part way into the furnace, nor a flame so long as to be still burning at the far end, should be carried. The former means either too little gas or too much air, and results in heating the charge mostly at one end and oxidizing it severely; the latter means too much gas, which will continue to burn quite uselessly in the checkers and waste fuel scandalously. Above all, the flame should roll slowly along, hugging the stock and playing through it, should be white, and long enough to heat the whole length of the hearth.

With such a flame, the melting stock will "honeycomb," and melt down rapidly and evenly; it will be clear at a glance that the metal is hot throughout, a thick section being nearly as hot in the middle as at the surface. A swift, short flame, dragged along by the draught of a wide open stack damper and fed with too much air, "glazes" the stock so that it melts chiefly in a thin layer at the surface, and largely at the top of the pile. Such melting oxidizes the metal badly, wasting iron and making the steel "wild" from excess of dissolved oxide.

At all times, the furnace man watches his roof, walls, and outgoing port closely, keeps the flame down to the bath (and so away from the roof), and slacks the temperature when he sees his brickwork giving signs of starting to melt. By shutting off the air, and lowering the stack damper, the temperature is kept down.

Natural gas or oil firing should be handled along the same lines, though changes in the fuel supply are not so undesirable.

When the charge is "down," and nearly all the floating pieces have melted, the first helper gets busy with his bar and pokes all scrap free from the bottom. It may take him some time to do this, especially if much light scrap and turnings have been charged, as these stick to the bottom like limpets.

When all is melted, the bath should be well stirred with the bar, and the "raise" noted. By this is meant the height to which the slag boils over the bar as it is moved about. The colder and "wilder" the metal, the higher this boil will be. The boiling produced by this rabbling has the effect of freeing the steel from oxides by bringing it into contact with the slag.

A test of the metal is then taken by means of the small test spoon, which should be first warmed in the furnace a moment, then well coated with slag, then dipped deep in the bath and rapidly withdrawn. A small test mould is filled, and the metal left over poured slowly from the spoon to judge its temperature. If it pours clean from the spoon to the last drop, it is very hot. The more of it freezes in the spoon, the colder and wilder the metal. A little of the slag adhering to the handle of the spoon is saved from each test; by its color the progress of the elimination of iron oxide is watched. When the steel is cold and wild, it scintillates and "rises" strongly in the test mould. Another means of judging the temperature of the bath is the manner in which it melts away the bar used for stirring it up; a hot heat cuts a bar off quite square, a cold one leaves the end "rat-tailed." The heat should be hot before oreing is started.

By the fracture of the test piece or by color carbon analysis, the melter estimates the carbon of the bath and the amount of ore needed to eliminate the carbon to the desired extent. The helpers throw in ore while the first helper swings doors and watches the behavior of the bath, which, unless still high in silicon, begins to boil violently as the ore is thrown in. If much ore is needed, it cannot be added all at once, or the bath will "boil over." The boiling increases in violence only slowly up to a certain point, when the addition of one or two more chunks of ore will bring the whole bath boiling up, and slag and metal will run out the door and all over the floor. At the same time, the great amount of CO suddenly evolved (and burning to CO_2) so fills the furnace with gas that the flame pours from all openings in volumes and the neighborhood becomes decidedly unpleasant. Should a "boil over" occur, the reversing valves should be thrown "on center" at once, to shut gas from the furnace, and if the boil does not subside, the gas should be shut off, the reversing valves thrown over again, and no more gas admitted till things quiet down. It does not do to leave the reversing valves on center long, as it generally heats them badly, but a "boil over" comes so quickly that to throw the valves on center is the only way to shut off the gas in time to do any good.

The boiling produced by the ore should be maintained by further additions, until in the opinion of the melter enough has been added to eliminate the carbon to the desired degree. When the first effect of the ore begins to wear off, the bath should be stirred with the bar and a second test taken. If enough ore has been charged, this second test should show greatly reduced carbon content; and a third taken half an hour after the second should show still lower. Should the second test show too little reduction of carbon, more ore must be added; the same is true after two or more tests if the carbon ceases to "slide down" fast enough, and frequently more ore will have to be added to keep up a proper rate of elimination. For the production of really fine steel, however, the effect of the ore should be pretty well worn off an hour or two before tapping, and ideal practice is to get it all into the furnace as soon as possible after melting, and have the carbon "slide down" rapidly at first, then less rapidly and then very slowly, taking an hour to make the last 8 or 10 "points." By this practice the FeO in the slag available for oxidizing silicon, manganese and carbon is practically all exhausted before the heat is tapped, and the FeO is largely eliminated from the steel and taken into the slag. As the effect of the ore wears off the "raise" becomes less, the slag grows less black and watery, and the metal pours more cleanly from the test spoon.

Should too much ore have been added, so that the carbon is "racing" down, the bath will be practically carbonless before it has had time to get hot, may even freeze up, if the melting has been done with a very short, oxidizing flame. To prevent this, pig iron or ferrosilicon must be thrown in until the carbon content is held stationary. Ferrosilicon is used when the bath is hot, but losing carbon too rapidly. The silicon uses up the oxygen of the ore without making the bath boil, and generally will prevent the carbon from dropping further. Pig iron is used when the bath has to be much heated up without further elimination of carbon. The boiling produced by the oxidation of the carbon of the pig greatly assists in getting the bath hot; and, of course, if enough pig is added the carbon of the bath will be kept up.

Should a heat freeze, which happens only if such a "sharp" flame has been used in melting as to oxidize most of the carbon, silicon and manganese before the furnace is hot enough to maintain the resulting low carbon metal fluid, pig iron and spiegel or ferromanganese, are thrown in and melted, and more added as necessary until the fluid bath of metal high in carbon, silicon and manganese has taken up the solid or semi-solid metal beneath. This is a long, tiresome job, eats into the bottom of the furnace tremendously, and results in a heat poured into scrap, as the cutting of the bottom compels the tapping of the metal as soon as it is liquid enough to run out.

The temperature of the steel is followed by the indications already described. When the carbon is low enough to tap the heat, the metal should be so hot that it will pour out clean or nearly clean from the test spoon. If it will not, the temperature should be increased, holding the carbon up if necessary by throwing in pig iron or ferrosilicon, until the steel will pour reasonably clean. If the ferrosilicon, pig, or ferromanganese used as recarburizers are added in the furnace, a last test after they are melted does not come amiss. This last test, if the silicon (or both silicon and manganese) have been added, should pour perfectly clean from the spoon, and the test should lie flat in the mould.

Some furnace men add ore till the carbon is racing down and the steel full of oxides, the tests skulling the spoon and scintillating and rising strongly in the mould, throw in ferrosilicon and pig iron to check the elimination of carbon, tap the heat as soon as these are melted, add their ferromanganese in the ladle and pour their steel. They melt their metal hot and keep it hot, so that it at least pours. But it is full of oxides, "raw" and "wild" in the moulds, and of poor quality. By heavy doses of manganese and silicon, and frequently of aluminum, the steel is quieted (freed of oxide and gases) enough to make fairly sound castings; but it is not good steel. These are the shops where the makers of "final deoxidizers" make a great hit, and they do it partly by the use of "final deoxidizers," but largely by so improving the practice that when the heat is tapped, the oxides are largely eliminated to start with.

The French metallurgists have worked out a method of deoxidizing the slag (and hence the steel), in acid open-hearth work, to an extent much greater than is possible by simply allowing ample time for the effect of the ore to wear off. This consists in sprinkling the slag, after the bath is sufficiently hot and the available oxide pretty well boiled out, with crushed bauxite or loam (containing alumina in considerable quantity), and crushed coke. The adding of these materials has to be carried out with great judgment and skill, the loam, and especially the coke, being spread evenly over the surface of the slag so that none falls in a mass at one point. This involves much dexterity with the shovel, as, of course, if coke falls in a mass at one point it is very liable to sink through to the bath and add carbon to it.

The action of these additions is to eliminate the oxides of iron and manganese from the slag by the reducing action of the coke, according to the usual reactions,

$$\mathrm{FeO+C} \text{ equals } \mathrm{Fe+CO}$$
$$\mathrm{MnO+C} \text{ equals } \mathrm{Mn+CO}$$

while the alumina replaces them in the complex silicate which is the slag. Carefully carried out, this procedure results in a slag nearly white, quite free from the brown color of FeO and nearly free from the green of MnO; though of course these oxides are not entirely eliminated. Yet skillful melters will make these additions until the slag (and hence the steel) is remarkably free from oxides; and the steel so made is of exceedingly high quality. Steel men in this country have, so far as the author is aware, never attempted (or at least never adopted) this procedure and many of them appear never to have heard of it. In these days of final deoxidizers, perhaps we shall see it used.

When the heat is tapped the furnace men scrape and close the tap hole, warm up the furnace a bit, and shovel sand all around the slag line of the hearth to repair the damage done by the slag. What can be reached by shoveling is so repaired, the out of the way spots in the corners are got at with the sand spoon. The furnace is made hot enough to "set" the sand and is then ready for the next heat.

Typical Heats.—In order to illustrate the procedure in handling an acid open-hearth furnace, the history of a few typical heats is shown in the tables that follow. In these, the charges weigh 30,000 lb., and a "Base" of 29,000 lb., is taken as the approximate weight of steel to be obtained. The analyses given are for the charge, the steel desired, and that obtained. The symbol $\overline{.04}$ signifies that .04 per cent. is the highest percentage of an element that will be accepted. The phosphorus and sulphur content obtained are in some cases lower than that given for the charge. This is explained by the fact that the latter is figured on known maximum contents of the pig iron and scrap used. The pig iron in this plant was kept in piles according to its phosphorus and sulphur, and each pile was known to be *below* such and such a figure. Similarly the different grades of scrap were known not to *exceed* certain figures.

The symbol R equals 1″, or R equals 2″, etc., signifies the height to which the bath boils when stirred, as already described. This shop was run for the production of steel upon which very close control of analysis was demanded, and a small laboratory for running "color carbons" on the tests was located in the open-hearth building. A color carbon analysis can be run in about 20 to 25 minutes, so that the men in charge are kept well posted on the analysis of the bath.

The symbol BR represents the last test taken before the recarburizer is added. The carbon of this test has to be estimated; "carbon estimated," in the tables, refers to it. Comparison with the analytical results, in the "history of heat," shows the very accurate judgment of the melters.

Heat (1) was chosen to illustrate a case in which not only was no ore added to decarburize the bath, but also, in order to get the steel hot without running the carbon down too far, a considerable amount of pig had to be added. The temporary rise in the carbon content after the addition of the pig, followed by renewed elimination of carbon, is well shown.

The slag of this heat was brown throughout. This refers to the color of the fracture of the cold slag, and is used as an indication of the degree of oxidation of the bath. When the bath is first melted the slag is nearly black, very thin and fluid, and consists largely of silicate of iron. The steel in contact with such a slag will be full of oxide. During the "working" of the heat, the black changes to a brown and this gradually to a greenish-brown or greenish-gray color. The green shades indicate the presence of MnO in the slag, and a much decreased oxidation of the bath.

The limestone added to this heat was for the purpose of thinning the slag. Frequently, especially on nickel-steel heats, the slag absorbs so much silica from the bottom of the furnace as to be almost infusible, and in these cases limestone is used to lower its melting point, and hence thin it. When, on the other hand, the slag is too thin and watery because it contains an excess of FeO, loam is added to thicken it.

Heat (2), made in the same furnace as (1), though quiet the first time it was rabbled (that is, there was no "raise" over the bar), became very wild, with a 3-in. raise, after the addition of the ore, and the slag was very thick and had a strong tendency to remain brown. These two conditions, pointing to a bath containing a great deal of oxide, grew less marked when the steel was ready to tap. The normal loss of manganese (and carbon and silicon) was to be expected, and was obtained. Thus .75 per cent. of manganese was added and dropped to .63 per cent., and the metal was raised to .32 per cent. carbon, which dropped to .27 per cent. Reference to heat (1), in which no ore was used, shows that there was a slight gain in manganese in that heat in spite of the 2-in. raise and the brown slag, which tend to show an oxidized heat.

Heat (3) went into the same casting as heat (2). The ore was evidently added before it was known that this heat was to wait for heat (2), and had the usual effect of sending the carbon down rapidly. In fact, too much ore was added for really good practice, as the carbon was already low and an accurate estimation of it would have dictated a much smaller addition, or none at all. Had it been known at the first that this heat was to wait for heat (2), it would have been run like heat (1), no ore at all added, and the heat allowed to run down slowly. As it was, a heroic addition of pig was needed to keep the carbon up, and it was considered advisable to use 12 per cent. ferrosilicon and charge it in the furnace, in order to counteract the oxidation resulting from the elimination of the carbon to such a low point. That the silicon had the effect of quieting the bath thoroughly is evidenced by the fact that no manganese was lost in recarburizing.

Heat (4) is in every respect a normal one. All the recarburizer was added in the furnace so that a heavy addition of manganese (1.01 per cent.) was needed, in order to obtain .75 per cent.

Heat (5) illustrates the practice of charging a certain amount of scrap (billets in this case), near the end of the run, after the steel is hot. The object of this is to produce vigorous boiling in the bath, exactly as the rod makes the steel boil, in order to facilitate the removal of oxides from the metal. In other respects the heat is not unusual, though the amount of ore required to eliminate the carbon is higher than in the first four heats. This was due largely to the higher silicon and manganese of the charge.

In heat (6), a great deal of ore was necessary to eliminate the carbon. In this heat, the steel melted high in carbon and vigorous measures were necessary to get things going. A heat made soon after this one, in the same furnace, contained a great deal of foundry scrap (high in silicon), lay flat and not boiling when melted (because the silicon was still present in considerable quantity and protected the carbon from oxidation), and though the steel melted at only 1.25 per cent. carbon, 2200 lb. of ore were required to bring the carbon to .19 per cent. Where much steel foundry scrap, with its comparatively high silicon, has to be melted, this condition will be faced daily unless provision is made for the high silicon in the scrap by using low silicon pig, or less pig than usual, as already described.

(1) 15-ton Acid Furnace—Producer Gas—Castings

CHARGE

Low phosphorus pig	6,000 lb.
Billets	12,700 lb.
Scrap	11,300 lb.
	30,000 lb.
Base	29,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	1.12	.90	.39	.035	.034
Aimed for	.40	.65/.70	.28/.32	.04	.04
Obtained	.40	.75	.33	.026	.033

Carbon estimated	.35
Carbon added	.085
Manganese added	.73
Silicon added	.352

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	200	4.24	....	100.00
Ferromanganese	265	16.59	212.0	1.33
Pig	100	4.00	.4	.80
		24.83	212.4	102.13
		.085%	.73%	.352%

HISTORY OF HEAT

Time	No. test	Item	Carbon
5.30 to 6.50 p. m.		Charged	
2.00 a. m.		Melted	
2.05 a. m.	(1)	R 1″	.75
2.20 a. m.		100 lb. limestone	
2.40 a. m.	(2)	R 2″	.55
3.10 a. m.	(3)	R 2″	.44
3.40 a. m.	(4)	R 2″	.37
3.55 a. m.		700 lb. pig	
4.15 a. m.	(5)	R 2″	.38
4.45 a. m.	BR	R 2″	.34
4.50 a. m.		100 lb. pig	
5.00 a. m.		Tapped	
		200 lb. ferrosilicon, 50%	in ladle
		265 lb. ferromanganese, 80%	
		Slag light brown throughout.	

(2) 15-ton Acid Furnace—Producer Gas—Castings

CHARGE

Low phosphorus pig	6,000 lb.
Billets	24,000 lb.
	30,000 lb.
Base	29,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	1.22	.86	.46	.042	.036
Aimed for	.25	.65/.70	.28/.32	$\overline{.05}$	$\overline{.05}$
Obtained	.27	.63	.32	.033	.039

Carbon estimated	.24
Carbon added	.073
Manganese added	.744
Silicon added	.37

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	210	4.45		105.0
Ferromanganese	270	16.90	216	1.35
		21.35	216	106.35
		.073%	.744%	.37%

HISTORY OF HEAT

Time	No. test	Item	Slag	Carbon
1.30 to 2.50 a. m.		Charged		
12.00 Noon		Melted		
12.05 p. m.	(1)	Quiet	Brown	.72
12.10 p. m.		600 lb. ore		
12.45 p. m.		200 lb. ore		
1.05 p. m.	(2)	R 3″	Greenish brown thick	.55
1.10 p. m.		5 shovels loam		
1.35 p. m.	(3)	R 3″	Yellowish brown.	.47
2.05 p. m.	(4)	R 2″	Yellowish green.	.36
2.55 p. m.	BR	R 1″	Yellowish green.	.25
3.00 p. m.		Tapped		
		210 lb. ferrosilicon, 50% 270 lb. ferromanganese, 80%	in ladle	

(3) 40-TON ACID FURNACE—PRODUCER GAS—CASTINGS

CHARGE

Low phosphorus pig	17,200 lb.
Scrap billets	13,300 lb.
Scrap	19,700 lb.
Turnings	7,900 lb.
Scrap ingots	27,900 lb.
	86,000 lb.
Base	84,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	1.22	.86	.46	.042	.036
Aimed for	.25	.65/.70	.28/.32	.05	.05
Obtained	.26	.69	.32	.032	.038

Carbon estimated	.09
Carbon added	.157
Manganese added	.689
Silicon added	.393

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferromanganese	650	40.69	520	3.25
Coal	100	50.00		
Ferrosilicon	2820	41.17	59.22	327.12
		131.86 .157%	579.22 .689%	330.37 .393%

HISTORY OF HEAT

Time	No. test	Item	Carbon
9.55 to 10.25 p. m.		Charged	
7.50 a. m.		Melted	
7.55 a. m.	(1)	R 2″	.65
Several lots		1000 lb. ore	
9.10 a. m.	(2)	R 3″	.37
10.10 a. m.	(3)	R 2″	.26
12.10 p. m.	(4)	R 2″	.12
1.10 p. m.	(5)	R 2″	.09
1.45 p. m.		1000 lb. pig	
2.10 p. m.	(6)	R 2″	.11
2.45 p. m.	BR		.10
2.50 p. m.		2820 lb. 12% ferrosilicon (hot)	
3.05 p. m.		Tapped	
		650 lb. ferromanganese (80%) 100 lb. hard coal } in ladle	

(4) 15-TON ACID FURNACE—PRODUCER GAS—NICKEL STEEL

CHARGE

Low phosphorus pig	4,800 lb.
Washed metal	3,600 lb.
Nickel-steel scrap	14,700 lb.
Scrap billets	900 lb.
Nickel plaquettes	356 lb.
	24,356 lb.
Base	24,000 lb.

ANALYSES

	C	Mn	Si	P	S	Ni
Charge	1.60	.79	.33	.028	.027	
Aimed for	.38/.42	.65/.75	.14/.18	$\overline{.03}$	$\overline{.03}$	3.50
Obtained	.38	.75	.11	.024	.04	3.29

Carbon estimated	.28
Carbon added	.159
Manganese added	1.01
Silicon added	.177
Nickel melted	2.44
Nickel added	1.06

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	310	4.52	6.51	35.96
Ferromanganese	285	17.84	228.00	1.43
Pig	350	16.00	7.00	5.25
		38.36	241.51	42.64
		.159%	1.01%	.177%

HISTORY OF HEAT

Time	No. test	Item	Ni	C
6.45 to 7.40 p. m.		Charged		
1.30 a. m.		Melted		
1.35 a. m.	(1)	R 1″	2.44	1.12
1.50 a. m.		200 lb. ore		
2.15 a. m.		200 lb. ore		
2.45 a. m.	(2)	R 1″		.55
3.00 a. m.		100 lb. limestone		
3.15 a. m.	(3)	R 3″		.41
3.45 a. m.	(4)	R 2″		.33
4.15 a. m.	BR			.25
4.16 a. m.		262 lb. Ni plaquettes		
4.27 a. m.		310 lb. ferrosilicon (12%)		
		350 lb. pig		
		285 lb. ferromanganese (80%)		
4.35 a. m.		Tapped		

Slag heavy—dark brown at first, then light greenish gray.

(5) 15-TON ACID FURNACE—PRODUCER GAS—FORGING INGOTS

CHARGE

Low phosphorus pig	6,000 lb.
Scrap	17,500 lb.
	23,500 lb.
Billets on floor	500 lb.
	24,000 lb.
Base	23,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charged	1.38	1.03	.53	.035	.047
Aimed for	.30/.35	.60/.70	.14/.18	.045	
Obtained	.34	.64	.14	.032	.047

Carbon estimated	.27
Carbon added	.075
Manganese added	.71
Silicon added	.18

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Si lb.	Mn lb.
Ferrosilicon	350	5.11	40.6	7.35
Ferromanganese	195	12.21	.98	156.00
		17.32	41.58	163.35
		.075%	.18%	.71%

HISTORY OF HEAT

Time	No. test	Item	Carbon
6.20 to 7.30 a. m.		Charged	
1.15 p. m.		Melted	
1.20 p. m.	(1)	Quiet	1.20
1.25 p. m.		400 lb. ore	
1.55 p. m.		200 lb. ore	
2.25 p. m.		200 lb. ore	
2.45 p. m.	(2)	R 3″	.93
2.50 p. m.		200 lb. ore	
3.15 p. m.	(3)	R 3″	.82
3.20 p. m.		100 lb. ore	
3.45 p. m.	(4)	R 2″	.59
4.15 p. m.	(5)	R 2″	.47
4.45 p. m.	(6)	R 2″	.35
4.50 p. m.		500 lb. billets	
5.15 p. m.	BR		.28
5.25 p. m.		350 lb. ferrosilicon (11%)	
5.35 p. m.		Tapped	
		195 lb. ferromanganese in ladle	

Slag light brown, greenish at end.

(5) 15-TON ACID FURNACE—PRODUCER GAS—FORGING INGOTS

CHARGE

Low phosphorus pig	4,800 lb.
Washed metal	3,600 lb.
Scrap	15,100 lb.
	23,500 lb.
Base	23,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	1.60	.79	.33	.028	.027
Aimed for	.24/.28	.60/.65	.14/.18	$\overline{.06}$	$\overline{.035}$
Obtained	.25	.61	.13	.029	.04

Carbon estimated	.17
Carbon added	.088
Manganese added	.716
Silicon added	.185

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	350	5.11	7.35	40.6
Pig	75	3.00	1.50	1.13
Ferromanganese	195	12.21	156.00	0.98
		20.32 .088%	164.85 .716%	42.71 .185%

HISTORY OF HEAT

Time	No. test	Item	Carbon
6.00 to 6.50 p. m.	....	Charged	....
1.00 a. m.	....	Melted	....
1.05 a. m.	(1)	Quiet	Test too hard to drill.
1.30 a. m.	....	700 lb. ore	....
2.00 a. m.	....	300 lb. ore	....
2.40 a. m.	....	200 lb. ore	....
3.15 a. m.	....	200 lb. ore	....
4.00 a. m.	(2)	R 4″	.62
4.30 a. m.	(3)	R 3″	.50
4.35 a. m.	....	300 lb. ore	....
5.00 a. m.	(4)	R 3″	.35
5.30 a. m.	(5)	R 2″	.27
6.00 a. m.	(6)	R 2″	.21
6.30 a. m.	BR	....	.15
6.37 a. m.	....	350 lb. ferrosilicon (12%). 75 lb. pig.	....
6.50 a. m.	....	Tapped	....
		195 lb. ferromangenese (80%) in ladle.	

Slag thin, dark green.

The Basic Process—Melting.—The charge in the basic furnace generally contains more pig iron (and cast iron scrap) than is used in the acid process, and up to 50 per cent. of pig is often charged in regular pig and scrap practice. It is not at all necessary to use such heavy percentages of pig, more especially when soft steel is being melted, since such heats frequently melt very high in carbon, and consequently require considerable amounts of ore. As in the acid process, it is best if possible to charge such a mixture that the bath when melted shall contain 1 per cent. of carbon or less, and very little silicon or manganese. The latter, however, seldom goes below .20 per cent. in basic practice. In order to secure this analysis in the molten bath, the carbon in the charge should be about 1.50 per cent., manganese about 1 per cent., and silicon .50 to .60 per cent. The examples of basic heats shown a little further on illustrate several typical charges, and it will be noted that in some cases a very high carbon charge will melt quite low in carbon.

The limestone charged commonly amounts to from 10 to 15 per cent. of the weight of the metal. As in acid practice, the ore consumption should not exceed 6 per cent. of the weight of the steel.

In basic practice it is essential, in order to effect the elimination of phosphorus and sulphur, that a highly basic slag be formed from the start. The limestone is, therefore, charged first. On top of the stone is placed the scrap, and the pig is put in last. Because the bottom is basic, neither the limestone nor the cinder from the melting scrap can attack it and form slag, so that this method of charging is quite safe and enables us to secure a basic slag as soon as melting starts. Moreover, the scrap is protected from excessive oxidation by means of the carbon, silicon and manganese of the pig iron, which melts first and soon partially buries the scrap. There is only one drawback to this order of charging, which is that when much light scrap, especially turnings, is melted, it sticks to the bottom and makes a good deal of work for the men, who are obliged to poke it loose with bars.

Iron ore, or mill scale, is sometimes charged with the limestone, especially when a high percentage of pig iron is melted, in order that as much silicon and manganese as possible may be eliminated during the melting. They, of course, cannot attack the bottom, for the same reason that the cinder cannot do so.

A basic heat, when melted, unless very hot, is commonly covered with a blanket of sluggish slag, in which many lumps of limestone float about. As the temperature rises, the stone melts, because the slag is able to absorb more and more lime (CaO) as it grows hotter, since the melting point of these slags is the higher the greater the proportion of bases to acid; and therefore the hotter the slag, the more lime it can absorb. When the heat is "down," the first helper rabbles up all scrap that sticks to the bottom, and when his metal is all melted takes the first test, as in acid practice.

If the slag formed on the melted bath is very basic and sluggish, as described above, the phosphorus in the steel generally will be largely eliminated when the bath is melted, and the efforts of the men must be devoted to bringing down the carbon of the bath by additions of ore without making the slag too irretentive of phosphorus. The fracture of the test piece and, in shops where very close control of analysis is desired, a quick analysis of the test, show the amount of carbon and of phosphorus that have to be eliminated, and the additions of iron ore and lime are proportioned accordingly.

Before any ore is added, the slag should be nearly all melted.

Though the ore assists in promoting the fluidity of the slag, additions of fluorspar may be needed to reduce its melting point, and enable the last of the limestone to melt. In case the slag is very thin, watery and black, indicating an excess of silica and iron oxide, and a deficiency of CaO, burned lime (or occasionally limestone) is shoveled in, to bring the composition and consistency to the desired point. Such a watery slag indicates that dephosphorizing during melting has been less complete than is desired, and extra pains must be taken to secure a limey slag.

Ore is added in sufficient amounts to oxidize the carbon and produces a vigorous boil, as in acid practice. When its effect begins to wear off, and the carbon approaches the desired point, additions of lime are made to keep the slag as basic (and sticky) as possible, in order to promote the elimination of phosphorus. The progress of this elimination is watched closely, and in many cases it is sufficiently advanced by the time the carbon is low enough, and the heat hot enough, to tap. If very low phosphorus content is desired, however, especially if the charge is very high in that impurity, the bath may have to be brought down to .10 per cent. in carbon or lower, and heavy additions of lime and fluorspar made. Meanwhile the carbon of the bath may, if desired, be kept up by additions of pig iron. This is the more to be recommended, as by the boiling produced it aids in keeping the bath hot and in bringing all the steel in contact with the dephosphorizing slag.

The elimination of sulphur is very erratic in the basic furnace, as the examples shown later well illustrate, and though in a general way it follows that of phosphorus, yet in some cases the sulphur can be eliminated to the desired degree only by bringing the bath to very low percentages of carbon and making heavy additions of lime. It will be noticed in these typical heats that the total amount of sulphur eliminated is much less than that of phosphorus.

The same precautions that have been described in the case of the acid furnace should be observed in basic practice. The ore should be got in early, and allowed to work until its iron oxide has been used up as far as possible in eliminating silicon, manganese, and carbon from the bath. By working heats for some time after the effect of the ore has worn off, the iron oxide is as far as possible eliminated from both slag and steel, resulting in the best possible metal. No heat should be tapped that is highly oxidized and "wild," but the process continued until the tests pour quite clean from the spoon. It is possible, and even in some cases common practice, to rush a heat, running the carbon down rapidly with ore, and stopping its elimination at the desired point with pig iron or ferrosilicon, but steel so made is of inferior quality. This is the more true because the basic slag is at the best rather high in iron oxide, and hence oxidizing, to the last.

In basic practice, the recarburizers, especially the manganese, are added largely in the ladle. One reason for this is that manganese, coming in contact with the slag, reduces more or less of the calcium phosphate and causes rephosphorizing of the steel; another is that much more of the manganese added to a basic furnace is lost by oxidation than in acid practice. However, in the manufacture of basic steel for very high-grade forging work, in one of the leading American shops, it is customary to add a part at least of the manganese, in the furnace. The alloy is charged in heavy chunks which sink through the slag and as it is largely immersed in the steel while melting it does not cause marked rephosphorizing, while its effect in eliminating the oxides from the bath and improving the quality of the steel is very marked.

The pig iron, if used solid, must be added in the furnace; coal or coke is often used in the ladle, though as a rule the best practice demands that as much of the carbon as possible be added in the metallic recarburizers. Ferrosilicon is generally added in the ladle.

In figuring recarburizers for basic heats, allowance has to be made for the considerable proportion of manganese, generally from .20 to .40 per cent., retained by the steel. The examples here given illustrate this point very well.

Typical Heats.—These typical heats were made in large furnaces for high-grade forging work, but serve very well to illustrate basic practice for the production of steel very low in phosphorus and sulphur. In all of them rather low phosphorus charges were melted, to make sure of attaining the great purity desired, and for the same reason the working of the heat was carried further than usual foundry practice requires. A special basic pig, containing only .3 per cent. of phosphorus, was used. Ordinarily, basic pigs contain from .6 to 1 per cent., and the charge from .3 to .5 per cent. of phosphorus.

Heat (1) was originally charged for making .48 per cent. carbon steel, and afterward changed over to .30 per cent. carbon. As it melted very high in carbon, 3000 lb. of ore were needed to run the carbon down, and great deal of lime and fluorspar to reduce the phosphorus, which also melted rather high, considering the requirements and the fact that the limestone charged amounted to 14 per cent. of the weight of the heat. The fluorspar is added to make the very limey slag fluid.

Heat (2) melted much lower in carbon, and pig had to be thrown in to keep the carbon up. The phosphorus was very obstinate after it had reached .03 per cent., and as will be seen, it would not go down to .012 per cent. until the carbon had reached very low figures.

Heat (3) melted very low in phosphorus, and staid down. While waiting for the carbon to reach low enough figures, lime was added to keep the slag basic.

Heat (4) is included to show a heat which melted very high in carbon, but low in phosphorus. The phosphorus content of this charge was purposely made lower than usual because very low phosphorus steel was to be made, with high carbon. Had the charge contained the usual amount of phosphorus, the heat would probably have melted too high in that element, and refused to go down to very low figures until the carbon had been largely eliminated. The objection to this was that a great amount of pig iron or spiegel would have been necessary as recarburizer to obtain the carbon needed, and this shop had no cupolas at its command for melting recarburizer. The large plants making basic rail steel commonly use hot metal in large amounts as recarburizer, and in this way are able to work high phosphorus charges down low in both carbon and phosphorus and recarburize to high carbon content without trouble.

Heat (5) is included to show a heat that dropped to very low phosphorus content without much working of the slag with lime. Evidently this slag was already very limey and thick, as fluorspar was added after the ore had done much of its work. The amount of limestone charged with this heat was practically the same as that in heat 1, but in this case its effect was pronounced.

Heat (6) melted a good deal like heat (2), though the carbon of the charge was much lower, but the phosphorus, probably because less had to be eliminated, proved much less obstinate, and went down to low figures while the carbon was still comparatively high. Evidently the slag was limey and thick early in this heat, though the amount of limestone used was but 9.4 per cent. of the weight of the charge, as fluorspar was added heavily soon after the bath was melted.

(1) 35-TON BASIC FURNACE—PRODUCER GAS—FORGING INGOTS

CHARGE

Basic pig	38,000 lb.
High phosphorus scrap	26,600 lb.
Low phosphorus skull	11,400 lb.
	76,000 lb.
Limestone	10,500 lb.
Base	74,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	2.25	1.05	.60	.199	.06
Aimed for	.26/.30	.50/.65	.14/.18	.015	.025
Obtained	.28	.73	.13	.029	.021

Carbon estimated	.25
Carbon added	.039
Manganese added	.37
Silicon added	.21

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	300	6.36		151.62
Ferromanganese	350	22.51	280.0	1.75
		28.87 .039%	280.0 .37%	153.39 .21%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn
8.10 to 9.15 a. m.		Charged			
5.15 p. m.		Melted hot			
5.20 p. m.	(1)	Quiet	1.92	.071	.37
5.30 p. m.		600 lb. ore			
6.30 p. m.		600 lb. ore			
7.00 p. m.	(2)	R 1"		.065	.35
7.15 p. m.		600 lb. ore			
7.30 p. m.	(3)	R 1"		.065	.34
7.45 p. m.		600 lb. ore			
8.15 p. m.	(4)	R 1"		.06	.30
8.30 p. m.		600 lb. ore			
8.55 p. m.	(5)	R 1"	.90	.05	.25
9.00 p. m.		400 lb. fluorspar			
9.25 p. m.	(6)	R 1"	.78	.05	.31
9.50 p. m.		400 lb. lime			
9.55 p. m.	(7)	R 1"	.61	.035	.34
10.00 p. m.		1200 lb. lime			

HISTORY OF HEAT (*Continued*)

Time	No. test	Item	C	P	Mn
10.25 p. m.	(8)	R 1"	.53	.035	.33
10.35 p. m.		600 lb. lime; 400 lb. fluorspar.			
10.55 p. m.	(9)	R 1"	.45	.03	.37
11.10 p. m.		400 lb. lime			
11.25 p. m.	(10)		.38	.02	.36
11.45 p. m.		400 lb. lime			
11.55 p. m.	(11)		.33	.018	.36
12.05 p. m.		700 lb. lime			
12.25 p. m.	B R		.25		
12.35 p. m.		Tapped	300 lb. ferrosilicon (50%). 350 lb. ferromanganese (80%).		in ladle.

(2) 35-ton Basic Furnace—Producer Gas—Forging Ingots

CHARGE

Basic pig	34,200 lb.
High phosphorus scrap	30,400 lb.
Low phosphorus skull	11,400 lb.
	76,000 lb.
Limestone	10,600 lb.
Base	74,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	2.08	1.01	.56	.189	.064
Aimed for	.26/.30	.60/.65	.14/.18	.015	.025
Obtained	.29	.61	.16	.014	.035

Carbon estimated	.10
Carbon added	.22
Manganese added	.58
Silicon added	.21

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	300	6.36		151.62
Ferromanganese	490	30.67	432.0	2.45
Coal	250	125.00		
		162.03 .22%	432.0 .58%	154.07 .21%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn
5.45 to 6.45 a. m.		Charged			
		Melted			
3.10 p. m.	(1)		.40	.03	.18
3.20 p. m.		300 lb. fluorspar			
3.40 p. m.	(2)		.28	.035	.21
3.50 p. m.		1000 lb. pig			
4.10 p. m.	(3)		.28	.035	.24
4.20 p. m.		400 lb. lime			
		200 lb. fluorspar			
4.40 p. m.	(4)		.24	.03	.28
4.50 p. m.		300 lb. lime			
5.10 p. m.	(5)		.15	.028	.28
5.20 p. m.		300 lb. lime			
5.40 p. m.	(6)		.09	.013	.26
5.50 p. m.		250 lb. lime			
		1000 lb. pig			
6.20 p. m.	(7)		.11	.012	.22
6.30 p. m.		450 lb. pig			
6.50 p. m.	B R	R 2″	.09		
7.05 p. m.		Tapped			
		300 lb. ferrosilicon (50%)	in ladle		
		490 lb. ferromanganese (80%)			
		250 lb. coal			

(3) 35-TON BASIC FURNACE—PRODUCER GAS—FORGING INGOTS

CHARGE

Basic pig	34,200 lb.
High phosphorus scrap	30,400 lb.
Low phosphorus skull	11,400 lb.
	76,000 lb.
Limestone	7,600 lb.
Base	74,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	2.08	1.01	.56	.189	.064
Aimed for	.26/.30	.60/.65	.14/.18	$\overline{.015}$	$\overline{.025}$
Obtained	.29	.71	.16	.022	.025

Carbon estimated	.22
Carbon added	.087
Manganese added	.50
Silicon added	.19

FIGURED AS FOLLOWS

Material	Pounds	C lb.	Mn lb.	Si lb.
Ferrosilicon	280	5.93		141.51
Ferromanganese	455	28.48	364.0	2.28
Coal	60	30.00		
		64.41 .087%	364.0 .50%	143.79 .19%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn	S
3.20 to 4.20 p. m.		Charged				
		Melted				
12.15 a. m.	(1)		.82	.01	.25	.032
12.20 a. m.		500 lb. ore				
1.00 a. m.	(2)		.53	.01	.26	
1.10 a. m.		300 lb. ore 200 lb. fluorspar				
1.45 a. m.	(3)		.47	.01	.26	
2.15 a. m.	(4)		.41			
2.20 a. m.		600 lb. lime				
2.45 a. m.	(5)		.34			
2.55 a. m.		350 lb. lime				
3.15 a. m.	(6)		.28			
3.20 a. m.		300 lb. lime				
3.55 a. m.	B R		.23			
4.10 a. m.		Tapped				
		280 lb. ferrosilicon (50%) 455 lb. ferromanganese (80%) 60 lb. coal	in ladle			

(4) 35-TON BASIC FURNACE—PRODUCER GAS—SPECIAL FORGING INGOTS

CHARGE

Basic pig	44,400 lb.
Low phosphorus scrap	29,600 lb.
	74,000 lb.
Limestone	7,400 lb.
Base	72,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	2.60	1.14	.83	.147	.053
Aimed for	.80/.95	.35/.50	.12/.16	.015	.03
Obtained	.95	.38	.13	.012	.021

Carbon estimated	.87
Carbon added	.017
Manganese added	.085
Silicon added	.163

FIGURED AS FOLLOWS

Material	Lb	C lb	Mn lb	Si Lb
Ferrosilicon	175	3.71	....	88.45
Ferrosilicon	245	4.31	5.15	28.42
Ferromanganese	70	4.38	56.00	.35
		12.40	61.15	117.22
		.017%	.085%	.163%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn	S
10.25 to 11.30 p. m.	....	Charged	....	....	....	....
....	....	Melted	....	....	....	....
6.30 a. m.	....	400 lb. fluorspar	....	....	....	....
7.00 a. m.	(1)	....	2.12	.012	.31	.029
7.10 a. m.	....	500 lb. ore	....	....	....	....
7.30 a. m.	....	500 lb. ore	....	....	....	....
8.00 a. m.	(2)	....	1.62	.012	.22	....
8.15 a. m.	....	300 lb. lime	....	....	....	....
8.30 a. m.	(3)	....	1.15	.012	.25	.023
8.45 a. m.	....	200 lb. lime	....	....	....	....
9.00 a. m.	(4)	....	1.03	....	....	....
9.15 a. m.	....	750 lb. lime 300 lb. fluorspar	....	....	....	....
9.35 a. m.	....	350 lb. lime 100 lb. fluorspar	....	....	....	....
9.50 a. m.	B R	R 1″	.85	....	....	....
10.00 a. m.	....	Tapped	....	....	....	....
		175 lb. ferrosilicon (50%) 245 lb. ferrosilicon (11%) 70 lb. ferromanganese (80%) } in ladle				

(5) 35-TON BASIC FURNACE—PRODUCER GAS—FORGING INGOTS

CHARGE

Basic pig	38,000 lb.
High phosphorus scrap	26,600 lb.
Low phosphorus scrap	11,400 lb.
	76,000 lb.
Limestone	10,600 lb.
Base	74,000 lb.

ANALYSES

	C	Mn	Si	P	S
Charge	2.25	1.05	.60	.199	.06
Aimed for	.46/.49	.50/.55	.15	$\overline{.04}$	$\overline{.04}$
Obtained	.52	.60	.115	.022	.027

Carbon estimated	.44
Carbon added	.063
Manganese added	.30
Silicon added	.15

FIGURED AS FOLLOWS

Material	Pounds	C lb	Mn lb	Si lb
Ferrosilicon	220	4.66	....	111.19
Ferromanganese	275	17.22	220	1.38
Coal	50	25.00	00	00
		46.88 .063%	220 .30%	112.57 .15%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn
7.35 to 8.40 a. m.		Charged			
4.10 p. m.		400 lb. fluorspar			
4.15 p. m.	(1)		1.70	.054	.49
4.15 p. m.		3000 lb. ore (in 1000-lb. lots)			
6.35 p. m.		200 lb. fluorspar			
6.40 p. m.	(2)		.75	.012	.30
7.10 p. m.	(3)		.58	.012	.30
7.50 p. m.	(4)		.50	.012	.28
8.15 p. m.	B R	R 1"	.42		
8.20 p. m.		Tapped			
		220 lb. ferrosilicon (50%) 275 lb. ferromanganese (80%) 50 lb. coal	in ladle		

(6) 35-ton Basic Furnace—Producer Gas—Nickel Forging Ingots

CHARGE

Basic pig	21,600 lb.
Cast-iron scrap	5,000 lb.
Nickel-steel scrap	53,200 lb.
Nickel plaquettes	655 lb.
	80,455 lb.
Limestone	7,600 lb.
Base	76,000 lb.

ANALYSES

	C	Mn	Si	P	S	Ni
Charge	1.60	.98	.54	.134	.043	
Aimed for	.27/.30	.60/.70	.14/.18	.035		3.50
Obtained	.31	.67	.15	.014	.025	3.45

Carbon estimated	.27
Carbon added	.053
Manganese added	.49
Silicon added	.21
Nickel added	.80

FIGURED AS FOLLOWS

Material	Pounds	C lb	Mn lb	Si lb
Ferrosilicon	175	3.71	....	88.45
Ferrosilicon	580	8.47	12.18	67.28
Ferromanganese	450	28.17	360.00	2.25
		40.35 .053%	372.18 .49%	157.98 .21%

HISTORY OF HEAT

Time	No. test	Item	C	P	Mn	Ni
9.20 to 10.20 p. m.		Charged	....	....	....	....
6.30 a. m.	(1)		.50	.029	.30	2.70
6.40 a. m.		400 lb. fluorspar	....	....	....	....
6.50 a. m.		200 lb. fluorspar	....	....	....	....
7.00 a, m.	(2)		.44	.014	.29	....
7.30 a. m.	(3)		.36	.012	.31	....
7.40 a. m.		300 lb. lime	....	....	....	....
8.00 a. m.	(4)		.31	....	....	....
8.10 a. m.		400 lb. lime	....	....	....	....
8.35 a. m.	B R	R1″	.27	....	....	....
8.40 a. m.		150 lb. lime; 621 lb. nickel plaquettes.	....	....	....	....
8.50 a. m.		Tapped	....	....	....	....
		175 lb. ferrosilicon, 50% 580 lb. ferrosilicon, 11% 450 lb. ferromanganese, 80%	in ladle.			

USE OF SMALL FURNACES

Among others, Mr. W. M. Carr has shown what can be done with very small open-hearth furnaces for pouring light castings, and with his portable furnace claims to be able to handle any work that can be made by the Bessemer or crucible process. His furnace is of very small capacity, some 2 tons, and is built with a barrel-shaped removable body or hearth, which is taken directly to the moulds and poured through a nozzle in one side, which takes the place of the tap hole. The slide for raising and lowering the stopper rod is fastened to the side of the furnace. When the metal is ready to pour, a stopper rod is inserted through the charging door, the furnace body is picked up with the crane, the end openings are closed by means of special doors provided for the purpose, and the steel is teemed directly from the furnace into the moulds.

Oil is used for fuel, though natural gas would probably serve as well. It is doubtful if producer gas would work well in such a short furnace.

The advantages of this design are easily seen. The first is the result of the removable feature; that the steel is kept hot longer in the hot furnace than it would be in a ladle. The second is the small size of the heats and the high temperature of the steel, which make it possible to pour very small castings. Third, in that its output is small, the furnace is quite well suited to the ordinary small foundry, which cannot command a large tonnage especially when first started up. Moreover, the installation cost is low, so that the loss by "overhead" in idle time is not great; and the furnace can readily be shut down and started up again at small expense. Oil-burning open-hearth furnaces in general can be shut down, with all doors and valves closed, on Saturday afternoon and left till the next day without growing too cold. The men can come out on Sunday morning, and have the furnace ready to charge by midnight. Though the small furnace will grow much colder in the same time, yet it will heat up more rapidly.

There are several disadvantages to this method of working. First, all recarburizing must be done in the furnace, and if the basic process is used this may involve rephosphorizing. Second, the castings all have to be poured through a nozzle, as it is not possible to fill shanks through a nozzle, and then pour from the shanks—the steel would be chilled too much. Nozzle pouring, even with a 2-ton heat, is not good practice for light work, as the stream has too much velocity which renders it impossible to fill the moulds at the nicely regulated rate so essential to fine work. This could of course be provided for by using a furnace with a spout instead of a nozzle, and shanking direct from the furnace; if this were done, recarburizing in the ladle would be feasible.

Third, the small furnace, though it enables us to pour small castings of open-hearth steel, which can be made considerably better than Bessemer metal, sacrifices some of the advantage of cost of metal that the open-hearth has over other processes, because labor, and some other charges, are distributed over so small an output.

Continuous Melting to Supply an Electric Furnace.—In the use of an open-hearth furnace to supply metal for a small electric furnace pouring light castings, metal must be available at short intervals. In order to use but one open-hearth and one electric furnace for this purpose, it is possible to use a tilting open-hearth furnace and run it on the continuous melting principle, tapping out a part of the heat every two or three hours, and adding more cold stock.

It is even conceivable that this method might be followed in an open-hearth foundry making rather light work, in order to distribute the pouring over the day instead of doing it all in two heats. Recarburizing in the ladle would be necessary in such work, since it would be very expensive to add silicon and manganese to the whole bath, tap but a fraction of the steel, and then lose the silicon and manganese in bringing down the carbon of the bath again after the next lot of pig and scrap had been melted. Moreover, it would slow down the process to follow this practice, as carbon cannot be eliminated readily from the bath in the presence of silicon and manganese, and hence after each ladle full was drawn and more metal melted to take its place, time and ore would have to be wasted in oxidizing the silicon and manganese added to the bath as recarburizer.

To use this method successfully for the production of steel at frequent intervals, but a small part of the heat should be tapped each time, unlike the usual continuous processes, in which a large part of the bath is taken off. Moreover, as hot metal from the blast furnace would not be available for operations on such a small scale, and the heats probably could not be drawn rapidly enough to justify the use of a cupola to melt the successive additions, cold pig and scrap would have to be charged, and it is not probable that the furnace would melt quite as fast under these conditions as when melting a whole heat at a time. We can, however, assume safely that the furnace would melt, and at least partially refine steel, at the rate of a heat in 15 hours, or one-fifteenth of its capacity per hour. With a 10-ton furnace, we should be able to tap off a 2-ton heat, which is about the handiest size for use in a small casting foundry, every 3 hours, or 8 heats a day.

With producer gas fuel, the acid furnace run in this manner cannot be used for the production of castings direct, because, as is shown in the section on raw materials, the increase of sulphur is too great. Either an acid or a basic furnace can be so run in conjunction with an electric furnace, since the latter can be provided with a basic lining, and made to do all the dephosphorizing. It will be more economical, however, to do the bulk of this work in the open-hearth furnace, since on account of the heavy expense for current, the electric furnace cannot compete with the open-hearth in dephosphorizing, and should whenever possible be used only for the final purification of steel.

It would be possible, even, to use a basic open-hearth and an acid electric furnace—but the latter has some important disadvantages that make such an arrangement a poor one.

This method of working involves getting the full capacity of the furnace ready as usual, taking off 2 tons for the electric furnace, charging and melting 2 tons of pig and scrap, adding ore to oxidize the carbon, silicon and manganese (and in the basic furnace lime and fluorspar to eliminate phosphorus and sulphur), and again taking out 2 tons. The slag should be held back in pouring, only enough being removed to make it possible to work the heat, and in the basic furnace, enough to keep the phosphorus content of the slag sufficiently low.

In a 10-ton basic furnace, if 2 tons of steel of .10 per cent. carbon, .05 per cent. silicon, and .20 per cent. manganese, are tapped out, and 1 ton of pig (carbon 3.5 per cent., silicon 1 per cent., manganese 1.60 per cent.), and 1 ton of scrap (carbon .15 per cent., silicon .20 per cent., manganese .60 per cent.), are added, the composition of the bath will be raised to carbon .45 per cent., silicon .16 per cent., manganese .38 per cent. To oxidize these impurities will not require much ore or time, as probably quite a part of the oxidation will be done by the gases of the furnace in melting. As the pig and scrap will be protected by the fluid bath, however, the work of the gases in eliminating the metalloids will be less than the 40 per cent. usually assumed as the basis for calculations in regular practice.

One problem presented by this method of working is the maintenance of the bottom and banks in good condition. The bottom itself is cut very little when the furnace is kept full of steel; but the banks at the slag line will require patching every two or three heats, and if only 2 tons out of 10 are drawn off, there will not be a good chance to do this work well. The front and back can of course be repaired by tipping the furnace, but the end banks will not be exposed by this method. In order to prevent break outs, therefore, it will probably be necessary at intervals to take off several heats successively without recharging. If the steel is being poured directly into castings this will not be a serious matter, as it is not necessary to pour at regular intervals. When the steel is being used to supply an electric furnace, however, the delay will cause the latter to lie idle while the open-hearth furnace is melting the larger charge put in to make up for the two or three heats tapped out. This idle time can be made up for in part by melting a heat of cold scrap in the electric furnace.

THE RAW MATERIALS

The raw materials for the open-hearth furnace may be summarized as follows:

ACID PROCESS

Specified Analysis

Material	P	S	Si	Mn
Low phosphorus pig	.03 to .035	.03 to .035	as desired.	as desired.
Low phosphorus scrap	.03 to .035	.03 to .035	....	....
Washed metal	.03 to .035	.03 to .035	....	....
Wrought iron	.03 to .035	.03 to .035	....	....
Iron ore	.03 to .035	.03 to .035	....	....

BASIC PROCESS

Basic pig	.60 to 1.00	.03 to .1	1 to 1.25	....

Scrap—miscellaneous unclassified cast iron, wrought iron and steel scrap—if the sulphur is too high, production of low sulphur steel will be difficult.

Iron ore and limestone low in silica.

The basic furnace of course does not need material low in phosphorus and sulphur, as these are eliminated in the process. The silicon, however, must be low, since limestone must be provided to flux the SiO_2 resulting from its oxidation, and therefore the more silicon there is in the bath the more lime is used up in fluxing it. For this reason, machine cast pig is preferable to sand cast, as it is free from adhering SiO_2 (sand), which consumes a good deal of lime. For the same reason, both ore and limestone should be low in silica.

The slight loss of metal in the acid process does not raise the phosphorus and sulphur in the steel enough to need figuring. An oil-fired or natural-gas-fired furnace will not pick up sulphur; but a producer gas-fired furnace will pick up at least .01 per cent. of sulphur per heat. For this reason, the stock melted must be lower in sulphur than the steel desired, and also the gas coal used in the producers must generally be bought to specifications, coal over .1 per cent. in sulphur being unsuited for many acid furnaces making fine steels. The amount of sulphur so picked up varies greatly in different furnaces, depending evidently somewhat upon the distance from producers to furnace; the greater this distance, the less the "pick up."

Using the equations with which we worked before on this head, and assuming that we melt 40 per cent. of our own scrap per heat, and that the pick up amounts to .01 per cent. per heat, we can figure the percentage of sulphur that we can allow in our raw materials as follows;

Let X equal the allowable percentage in raw material, including ore:

.05 per cent. equal the maximum percentage in our steel;

$$\left.\begin{array}{l}\text{6000 lb. of pig}\\ \text{8400 lb. of purchased scrap}\\ \text{9600 lb. of our own scrap}\end{array}\right\}\text{ be the weight of a charge;}$$

2300 lb. be the weight of metal obtained per heat;

The additions to the furnace be those of acid heat No. 5 in the list of typical heats already given;

then,

$$.05=\frac{\overset{\text{Pig}}{6000X}+\overset{\text{Scrap}}{8400X}+\overset{\text{Ore}}{1100X}+\overset{\text{Own scrap}}{9600\,(.05)}+\overset{\text{Ferrosilicon}}{350\,(.02)}+\overset{\text{Whole heat}}{24000(.01)}}{23000}$$

whence $X=.027$ per cent.

If the pick up be .02 per cent., and purchased pig and scrap each contain .03 per cent. we shall get, for the maximum sulphur in the steel,

$$X=\frac{14400(.03)+1100(.03)+9600X+350(.02)+24000.(02)}{23000}=.071\%.$$

If it be found, then, that our furnace picks up .02 per cent. let us see what must be the composition, X, of purchased pig, scrap and ore, in order that our steel shall not exceed .05 per cent.

$$.05=\frac{14400X+1100X+9600(.05)+350(.02)+24000(.02)}{23000}$$

whence $X=.012$ per cent.

We cannot afford to buy material of this analysis, even if we can get it, so that we must buy coal of lower sulphur content, in order to reduce the "pick up"; use some other fuel, such as oil or natural gas; dispose of all our scrap; or change over to a basic furnace. If we do not remelt our scrap, we calculate as follows:

$$.05=\frac{\overset{\text{Pig}}{6000X}+\overset{\text{Scrap}}{18000X}+\overset{\text{Ferrosilicon}}{350(.02)}+\overset{\text{Ore}}{1100X}+\overset{\text{Whole heat}}{24000(.02)}}{23000}$$

whence $X = .026$ per cent., the content of sulphur that we must have in our raw material in order to keep the sulphur in our steel below .05 per cent.

We can, of course, buy scrap, pig and ore of this analysis; but to be obliged to sell all our own scrap is out of the question.

If part of the capacity of a small tilting furnace is taken out every two or three hours and used for the production of castings direct, the furnace must be basic, if producer gas be the fuel; because, on account of the prolonged sojourn of part of the metal in the furnace in using this method, an acid furnace fired with producer gas will produce a much higher sulphur steel than the same furnace run on straight heats. This can be calculated by the method of figuring which we have used for regular practice.

Assuming that we use a 10-ton furnace and the furnace melts at the rate of a heat every 15 hours, then if

a equals original sulphur of stock charged,
b equals "pick up" of normal heat in 15 hours,
X equals sulphur of bath after an infinite number of heats.

Further assuming that 2 tons are tapped every three hours, and 2.10 tons more metal (allowing for loss), are charged; this metal to be 40 per cent. our own scrap, or .84 tons, and 1.26 tons pig iron and scrap of sulphur equals (*a*).

We can work this out on two assumptions, as follows:

A. That the "pick up" (*b*) is at a uniform rate over the 15 hours of a normal heat. Then the rate of "pick up" per hour is $\frac{b}{15}$, and for the three hours, $\frac{b}{5}$. On this assumption we have,

$$X = \frac{8\left(X+\frac{b}{5}\right) + .84\left(X+\frac{b}{5}\right) + 1.26\left(a+\frac{b}{5}\right)}{10}$$

That is, we have in our furnace after a tap and recharge, 8 tons of metal at sulphur X, and after three hours, at $X+\frac{b}{5}$, .84 tons of our own scrap at sulphur X, and after three hours at $X+\frac{b}{5}$, and 1.26 tons of new pig and scrap at sulphur (*a*), and after three hours at $a+\frac{b}{5}$, and this 10.1 tons will give us 10 tons of metal.

From this equation we get $X = \left(\frac{6.3}{5.8}\right) a + \left(\frac{10.1}{5.8}\right) b$

$$\text{Assuming } \left.\begin{array}{l} a \text{ equals } .03 \\ b \text{ equals } .015 \end{array}\right\} \text{ then } X \text{ equals } .059 \text{ per cent.}$$

(b) is taken as .015, on the assumption that a heat melted in 10 hours picks up .01 per cent. If (b) be .01, X equals .05 per cent.

B.—If the furnace melts its steel in 9 hours and holds it molten 6 and all the "pick up" takes place in the 6 hours. Further, if the same ratio of melting time and holding time applies to the additions, then $\frac{9}{15}\times 3$ or $\frac{9}{5}$ hours are spent in melting the additions and $\frac{6}{15}\times 3$ or $\frac{6}{5}$ hours in holding them fluid. Then a equals original per cent. of sulphur of steel, $\frac{b}{6}$ equals "pick up" per hour (all pick up occurring in the time the steel is held molten), and the "pick up" of the additions in $\frac{6}{5}$ hours is $\frac{b}{6}\times\frac{6}{5}$ equals $\frac{b}{5}$. The pick up of the 8 tons left in the furnace and held 3 hours is $\frac{b}{6}\times 3$ equals $\frac{b}{2}$.

Then we have,

$$X=\frac{8\left(X+\frac{b}{2}\right)+.84\left(X+\frac{b}{5}\right)+1.26\left(a+\frac{b}{5}\right)}{10}$$

Whence X equals $\left(\frac{6.3}{5.8}\right)a+\left(\frac{22.1}{5.8}\right)b$.

$$\text{and if } \left\{\begin{array}{l} a \text{ equals } .03 \text{ per cent.} \\ b \text{ equals } .015 \text{ per cent. (on the same assumption as before),} \end{array}\right.$$

X equals .089 per cent.

If (b) be taken as .01 per cent., X equals .071 per cent.

By figuring out a number of heats on assumption *B*, it can be shown that if we start with pig and scrap containing .03 per cent. of sulphur, and in the 2-ton additions use 60 per cent. of this new material and 40 per cent. of scrap from each preceding heat, the steel will contain over .05 per cent. of sulphur after four heats, and practically .07 per cent. sulphur after 32 heats have been made, if the "pick up" per heat be .01 per cent. Actually, of course, .071 per cent. sulphur is approached as a limit, never quite reached. If the furnace is emptied after 32 heats have been made, and recharged with 60 per cent. new material and 40 per cent. scrap of

.07 per cent. sulphur, it will take but one heat to pass .05 per cent., and 29 heats to reach .07 per cent. sulphur in the steel. Operated continuously, therefore, the furnace would produce steel of nearly .07 per cent. sulphur, on this assumption.

The exact amount of this increase in sulphur is not easy to predict, since the truth probably lies between the two extremes here taken. However, with a furnace that normally picks up .01 per cent., it is safe to predict an increase of at least .03 per cent., so that in order to produce steel of .05 per cent. we would have to use pig and scrap below .02 per cent., which would be out of the question. Therefore, with producer gas we cannot use the continuous process on an acid bottom, remelting our own scrap, for making steel very low in sulphur.

In some cases, for instance in a plant established in the Pacific coast states, pig iron may be very costly and scrap very cheap. The use of ferrosilicon or ferromanganese to contribute carbon, silicon and manganese to a bath of all scrap, following the expedient suggested for Bessemer practice, is not feasible in open-hearth work, as carbon is also essential. It is easy to show that if the ferro-alloys were used in proportions sufficient to give the required carbon in the bath, the resulting manganese or silicon would be many times too high.

In order to be able to handle a bath of all scrap, it has been proposed by Mr. Lash to use gas coke or other material of that sort, charged on the bottom of the furnace under the scrap. As the latter melts it absorbs the carbon of the coke. The carbonaceous material being under a heavy mass of scrap, is protected from oxidation sufficiently to ensure the absorption by the bath of the greater part of the carbon. Though this process is, or has been, used with success, it has its drawbacks (as any method involving a preponderance of scrap must have), in that there is nothing to protect the iron from oxidation in melting. This is not an insuperable obstacle, as in acid practice a good deal of loss from this cause always occurs, but it should not be lost sight of in figuring on the use of the process.

Perhaps the best solution of this problem, in cases where pig iron is at a prohibitive price, would be to melt the scrap, or some of it, in a cupola, and thence run it into the open-hearth furnace. A great deal of carbon would be absorbed by the scrap in the cupola, probably from 2.50 to 3.50 per cent., and by pouring this cupola metal upon a partially melted charge of scrap in the open-hearth furnace, a bath would be obtained high enough in carbon to be worked in the usual manner.

Because the cupola could not be run continuously, it would of course not melt as cheaply as in regular cupola practice. But the advantages secured should more than offset this drawback.

High Carbon and Alloy Steels.—The manufacture of high carbon and alloy steels in open-hearth furnaces presents some special features that should be considered.

For the production of high carbon steels, if the acid furnace is used, the method followed is to interrupt operations when the carbon of the bath is just below the content desired. This practice presents no special features, except that the bath must be of high carbon when melted, in order that it may be hot by the time it reaches the composition desired.

In the basic furnace, two methods are open to the steel maker. The first, of which one example is given in basic heat number 4 above, is to operate as in the acid furnace, tapping the heat when the carbon is just below the desired amount. To carry this method out successfully, the charge of the furnace should be comparatively low in phosphorus and sulphur, because, as we have already seen, it is not always easy to eliminate these impurities to the desired degree during the working of a bath that is kept high in carbon. The second method, which is more often used with charges high in phosphorus and sulphur, is to carry the carbon down below .10 per cent., in order to promote the elimination of the phosphorus and sulphur. This necessarily involves a very heavy addition of recarburizer, since to attempt to use coal or coke to bring heats of steel up from .08 per cent. to as high as .70 per cent. carbon, will almost inevitably result in the turning out of many heats of incorrect analysis. The ladle additions of ferromanganese and ferrosilicon will not contain nearly enough carbon to raise the carbon of the bath to the desired point, and we are thus forced to use pig-iron additions. For a 30-ton heat (say 66,000 lb.), of basic steel, containing say .10 per cent. carbon, to be brought to .80 per cent. carbon, .40 per cent. silicon, and .70 per cent. manganese, our additions will be about as follows:

	C, per cent.	Si, per cent.	Mn, per cent.
Ferromanganese at	6.00	.5	80.0
Pig at	4.00	2.0	.5
Bath at	.10	.05	.20

Item	Wght lb	C lb	Si lb	Mn lb
Pig	11,300	452	226	56.5
Ferromanganese	370	22.2	1.85	296
Bath	54,330	54.3	27.17	108.7
	66,000	528.5 .80%	255.02 .39%	461.2 .70%

Several considerations affecting the use of these heavy pig-iron additions present themselves immediately. To begin with, to add some 11,000 lb. of solid metal to a 54,000-lb. heat, will chill the bath to such a point that it will have to be heated up all over again, which can only be done by boiling out a large part of the carbon already added. It is essential, therefore, that the pig be added molten, and cupolas will be needed to melt it.

Moreover, if we add such quantities of molten basic pig, of the usual phosphorus content of at least .60 per cent., we shall raise the phosphorus of our steel to a prohibitive degree, as a little figuring will show:

54,000 lb. soft steel at .015 per cent. phosphorus, =	8.1 lb.
11,000 lb. pig at .60 per cent. phosphorus, =	66.0 lb.
	74.1 lb.
	or .11 per cent. phosphorus.

Even if a special low phosphorus basic pig (phosphorus .30 per cent.) is used, the phosphorus of the steel will be too high.

54,000 lb. soft steel at .015 per cent. phosphorus, =	8.1 lb.
11,000 lb. pig at .30 per cent. phosphorus, =	33.0 lb.
	41.1 lb.
	or .062 per cent. phosphorus.

Therefore, we are forced to use Bessemer or low phosphorus pig as recarburizer, in this method of working. The resulting content of phosphorus in the steel will be as follows:

54,000 lb. soft steel at .015 per cent. phosphorus......	8.1 lb.
11,000 lb. Bessemer pig at .10 per cent. phosphorus...	11.0 lb.
	19.1 lb.
	or .029 per cent. phosphorus.
54,000 lb. soft steel at .015 per cent. phosphorus......	8.1 lb.
11,000 lb. low phosphorous pig at .03 per cent. phosphorus..	3.3 lb.
	11.4 lb.
	or .017 per cent. phosphorus.

Of the alloy steels, nickel steel can be readily produced in an open-hearth furnace, either acid or basic The nickel is added in the form of plaquettes charged with the heat or thrown into the bath, and there is almost no loss in melting. In the manufacture of very high percentage nickel steel, a difficulty arises in making the additions without unduly chilling the bath. In either acid or basic furnaces, nickel steel scrap can be remelted with but slight loss of nickel, but to melt a bath containing over 5 per cent. of nickel is undesirable, because the estimation of the carbon content of steel so high in nickel, by either color carbon or fracture determinations, is impossible. The bath should be melted down, therefore, at from 4 to 5 per cent. of nickel, and the rest added in successive lots of plaquettes, which should preferably be preheated. To get the nickel all in and melted requires several hours, and in the meantime the bath continues to lose carbon. In the acid furnace, to prevent this elimination of carbon as far as possible, the silicon is generally charged before the nickel additions are begun. Owing to this loss of carbon while adding the nickel, the additions are commonly started when the heat is a little *above* the desired carbon content. Very close control of the carbon can be attained only by analysis of the samples by direct combustion in oxygen, since no other method of analysis can be used for the rapid determination of carbon in these heats.

Other alloys, such as chrome, tungsten, etc., are oxidized almost completely in remelting the scrap. Chrome in the basic furnace, starting at 1 per cent., will generally go down to .10 per cent. by the time the heat is ready to tap. Moreover, the chromic acid resulting from the oxidation of the chrome produces a very pasty slag, which, especially in the basic furnace, makes trouble by "building up" on the bottom to a serious extent. Plants remelting chrome steel scrap as a large part of their charge generally have to run one or two heats of carbon steel every little while to cut out these slag accretions.

Ferrochrome of 70 per cent. chrome should be added in the furnace and, at least in basic furnaces, a considerable proportion of the chrome is oxidized in melting. It has been found that the amount of chrome so entering the slag as oxide is greatest immediately after melting, and that by holding the heat from 20 minutes to ½ hour after the ferrochrome is melted, quite a considerable amount of the lost chrome will be reduced by the carbon of the bath and restored to the steel. The French metallurgists assist this action by spreading coke dust over the slag in the manner that has been described in the discussion of the French methods of deoxidizing acid slags.

Tungsten, molybdenum, etc., can be added to the bath as ferro alloys, or as metallic powder. In either case, it is generally best to put these expensive alloys in sheet metal cans which are then tossed into the bath. When so charging tungsten, it will sink to the bottom of the furnace, owing to its great weight, and generally nearly ½ hour will be necessary to melt it. If the ferrochrome or ferromanganese have been put in the same cans with the tungsten and carried to the bottom of the furnace, the usual loss in adding these alloys to the furnace will not occur, and much smaller additions are made, nearly as small, in the case of manganese, as when adding the alloy in the ladle. Heavy additions of these alloys must be heated to avoid chilling the bath, and will present the same difficulties that are met with in making high percentage nickel steels.

Manganese steel can be made quite easily of open-hearth metal, as of Bessemer metal, and by practically the same methods. In order to avoid heavy losses the large additions of ferromanganese have to be melted and added in the ladle. The scrap produced can be remelted and its iron saved, but in ordinary practice the manganese contained in it is lost. The large heats that have to be disposed of, and the rather low temperature of the metal compared to Bessemer steel, make the process unsuited to the production of much of the work that the makers of manganese steel castings are called upon to turn out.

CHAPTER VI

THE ELECTRIC FURNACE

The usefulness of the electric furnace in steel-foundry work (or other steel making, for that matter) is due almost wholly to the fact that it enables the steel-maker to carry the elimination of phosphorus, sulphur, and oxides and gases, to a point not possibly to be attained with any other steel-making process. This is especially true of sulphur and oxides. The ability to attain such a high degree of purification of the steel is due to the opportunity offered to expose the metal to conditions either oxidizing, neutral or reducing, at the will of the operator. By making an oxidizing slag with iron ore, lime, etc., we can expose our steel to oxidizing conditions. Then, as the atmosphere of the electric furnace can be made entirely neutral (or non-oxidizing), by scraping off this slag and making a new one of lime and fluorspar, and using reducing agents such as powdered coke and ferrosilicon, we can produce conditions almost as reducing as we please. Moreover, the very high temperature attainable enables us to melt slags composed almost wholly of silicate of lime and very free from metallic oxides, which deoxidize and desulphurize the steel almost completely.

The ideal finishing conditions for a heat of steel, a non-oxidizing atmosphere, and a slag (and therefore a steel) practically free from oxides of iron, can only be approximated in the open-hearth furnace. This is true, first, because the flame is always oxidizing, and second, becaus it is not feasible to melt slags very free from iron oxides and composed almost wholly of silicate of lime, on account of their high melting point. These ideal, but heretofore unattainable, conditions were put at our disposal by the development of the electric refining furnace, and at first sight it almost makes us expect the millenium.

Why, then, with the ideal steel-making furnace at last put at our disposal after working for centuries with what metallurgically considered are but make-shift methods, have we not at once abandoned the imperfect instruments and turned unanimously to the new way? The reason is not far to seek, and can be given in that single mighty little word "cost." Compared with other means of contributing heat to metal, either to melt it or to keep it melted and superheated, the electric current is expensive. True, we can make steel in an electric furnace somewhat more cheaply than by the old-fashioned crucible process, and the steel if properly made is as good, or better. But when we compare electric furnace steel made from cold stock with Bessemer or open-hearth steel, we see we are attaining high quality at great expense. To melt cold stock and refine it to good steel, all with the heat of electric current, requires from 750 to 1200 kw.-hr. of power per ton of steel, and with power at 1 cent per kilowatt-hour, that means a "fuel" charge of $7.50 to $12.00. Even keeping previously melted metal hot and refining it requires some 150 to 300 kw-hr. per ton. These considerations make it clear why the electric furnace has not been widely adopted by the steel foundries.

There are no limitations to the process from the point of view of the kinds of steel that can be made. We have seen that the crucible process is not strikingly adapted to the manufacture of low carbon steels; that the Bessemer process, on account of the fact that all carbon is eliminated, and the desired amounts restored in the shape of ferromanganese, pig iron, etc., demands fluid additions for high carbon and high alloy steels, and will not make certain steels easily; and that the same is true of the basic open-hearth process when very low sulphur and phosphorus are to be attained, since in this case we frequently have to eliminate nearly all the carbon before we can get the impurities down to the desired point. In the electric furnace, on the other hand, additions of alloys of any kind, in any desired amount, can be made to the furnace, the alloys melted, and the whole bath brought up to high temperature, not only without change in the composition of the bath to which the alloys are added, but even without great loss of the alloys. This is owing to the fact already mentioned, that we can hold our steel for an indefinite period in a neutral atmosphere, under a slag that does not act on the carbon, silicon, manganese, or added alloys of the metal.

Still another advantage of the electric furnace has already been mentioned in discussing manganese steel, and is to be inferred from the previous paragraph. This is its ability to melt steel scrap containing costly alloys, without the oxidation and loss of the alloys that occurs in working up the scrap by Bessemer or open-hearth methods, or the great gain in carbon so difficult to avoid in crucible melting. None of these troubles occur with the electric furnace; we can remelt our scrap practically without change of composition, correct the trifling change that does occur with suitable additions, and pour our steel. As we have seen already, however, we do this at a high price, since to melt with electric power is costly; and it may or may not pay to remelt alloy steel scrap in the electric furnace, depending upon the value of the alloy in question.

Summarizing the sunny side of the question; the electric furnace gives us metal of unsurpassed quality, which is very hot, and will run the lightest sections with ease. The price of these blessings is growing less as time goes by. The furnace can be run intermittently as it is not essential to its operation that it be kept continuously hot; but the cost of installation, especially when a source of power must be provided, and consequent overhead expense, make idle hours an expensive luxury. The process is flexible when small units are used, as has already been explained at length in the introductory chapters; in large installations flexibility is attained only at a sacrifice of some of the excellencies of the process. Steel of any sort can be produced at will.

Aside from the cost of the steel several considerations have retarded the progress of the electric furnace. These are, first, newness; by which is meant the inevitable handicap imposed upon any new process or apparatus by the lack of available men competent to handle it. This is but a temporary condition, and grows less marked every year. Second, the development of the electrical efficiency of the apparatus more or less at the expense of metallurgical efficiency. This condition is due to the fact that the electric furnace was developed, perhaps naturally, by electrical rather than metallurgical engineers. Lack of familiarity with the fine points of steel making on the part of the men developing the furnace was to have been expected, and has been shown in a number of details of design and operation. For instance, devices to increase the electrical efficiency of the furnace have in many cases been adopted without due regard to the limitations imposed by convenience of handling steel and slag; and sometimes these devices have made the furnace far from "fool proof," a fatal objection to a furnace which must be manned at least in part by unskilled labor. Another instance has been in the methods adopted for setting bottoms in the furnaces. Sometimes from lack of familiarity with the proper methods to pursue, sometimes because the furnace is so designed as to make long lining life impossible electric furnace bottoms have up to a few years ago made but a few heats. Open-hearth men soon learned to set a bottom a bit at a time, and make it a solid mass capable of almost indefinite life, and the electric furnace operators might easily have profited by their experience. Yet they had to learn all over again that a bottom set in one operation can never be satisfactory.

A third disadvantage that the electric furnace has had to contend with is really but a corollary to that of high cost of steel. This is that the very high quality of steel which the electric furnace produces, is not yet in general demand at a price that will yield a profit to the maker of steel castings. Better and better steel is being sought for a great many purposes, however, and when electric steel castings have been upon the market a few years the demand for them is sure to come. At the same time the costs of production cannot fail to grow less as metallurgical engineers and electrical engineers work together upon the problem, and a point must eventually be reached where the demand for really high-grade castings will create a price which will yield a good profit to the maker.

The cost of installation of an electric furnace is rather high compared to that of other processes, especially if the engine and generator to supply power have to be installed. Upkeep costs have in the past been very high, partly, it is to be supposed, owing to the above-mentioned lack of familiarity with good practice that has been shown by the men in charge of the furnaces. Electrode costs on arc furnaces are not so high now as they were only a year or two ago, as great improvements in the design and manufacture of electrodes have come very rapidly. The rapid wearing out of roofs of arc furnaces, due to the great heat radiated from the arc, is a problem that so far has defied the efforts made to solve it in a completely satisfactory manner.

TYPES OF ELECTRIC FURNACES

Electric furnaces may be divided into three general classes, determined by the manner of generating the heat and applying it to the bath. One or both of two means of converting electric current into heat are made use of in all the furnaces so far built, the first being to utilize the great heat of the electric arc; the second, to use the heat generated in the metal by its resistance to the passage through it, of a heavy electric current. Thus we at once have two types, the arc furnace and the resistance furnace, and the first type is subdivided into the arc furnace pure and simple, and the arc-resistance furnace.

A table of the principal makes of furnaces now on the market will be useful in considering this subject, and is presented below:

- Furnaces
  - Arc (Stassano)
  - Arc-resistance
    - Heroult
    - Girod
    - Nathusius
    - Keller
    - Gronwall
  - Resistance
    - Kjellin
    - Röchling-Rodenhauser
    - Colby
    - Frick
    - Hiorth

The following description of these furnaces has been purposely made as general as possible and an effort has been made to point out the merits or defects of a class only, not of a single design. The emphasis has been put on the metallurgical rather than the electrical features, and no attempt has been made to assign definite figures for current consumption to each furnace.

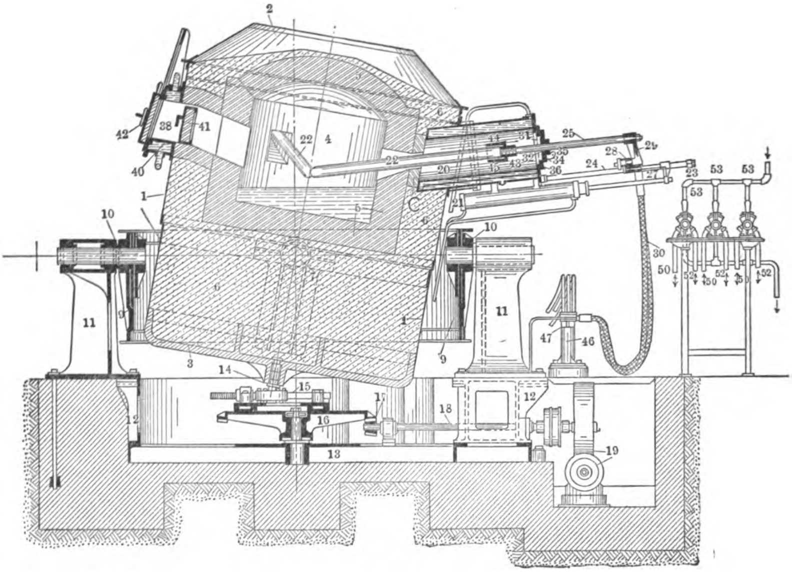

FIG. 11.—Stassano electric furnace. Vertical section. From "Metallurgical and Chemical Engineering."

The pure arc furnace of Stassano consists of a cylindrical vessel of steel plate, lined with refractory material, and mounted at a slight inclination, with means for revolving it about its major axis.[1] Three carbon electrodes are introduced through the side walls of the furnace near the top, inclined downward toward the bath, and with their tips separated a suitable distance, after the arc is struck. The current is carried to the electrodes from sliding contacts, and the arc plays between the extremities of the electrodes. The charge is thus heated entirely by the heat of the arc. When melting cold stock, however, the arc frequently jumps to one piece of scrap after another, and the fluctuations in the power consumption are then very considerable. The Stassano furnace requires rather more power per ton of steel than arc-resistance furnaces. The single chamber containing the metal in a bath, with working doors, is convenient for making additions to the metal.

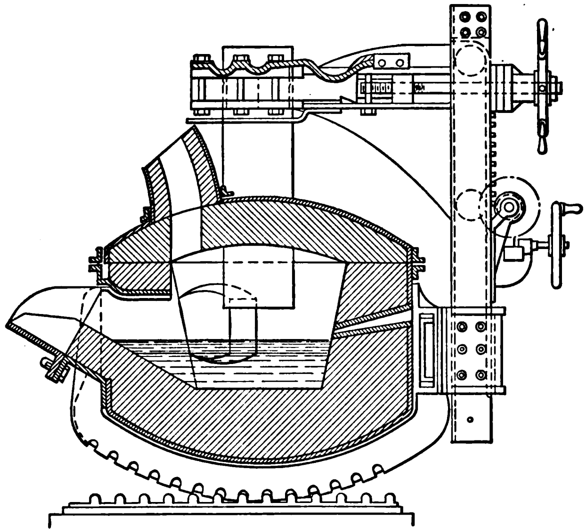

FIG. 12.—Heroult electric furnace with two electrodes. Transverse section. From "The Iron Trade Review."

The arc-resistance furnaces strike the arc between the ends of vertical electrodes and the metal being melted, or the molten bath. In the Heroult furnace, which is built much like the hearth portion of a tilting open-hearth furnace, all the electrodes are above the metal, and current travels from electrode to metal, through metal

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(1) In the newest design of the furnace, shown in Fig. 11 the furnace does not actually rotate, but oscillates. This construction much simplifies the connections to the electrodes and does away with sliding contacts.

(or metal and slag), to the next electrode and so out. The bath is thus heated both by the heat of the arc and by the heat produced by the resistance of steel and slag to the passage of the current through them.

Modifications of this type consist for the most part in having all the (carbon), electrodes above the bath positive, and the negative electrodes in the bottom, or banks of the furnace, so that the current is forced to pass through the whole bath. The Girod furnace is provided with a number of iron electrodes built into the bottom of the furnace; in the Nathusius, the bottom itself, which becomes a conductor of electricity when hot, conducts the current from the negative poles to the bath; the Keller is somewhat similar to the Nathusius, with a conducting bottom of iron rods and magnesite; the Gronwall has a carbon block next to the bottom plate, covered by the magnesite, which becomes a conductor when hot; and other modifications have been made.

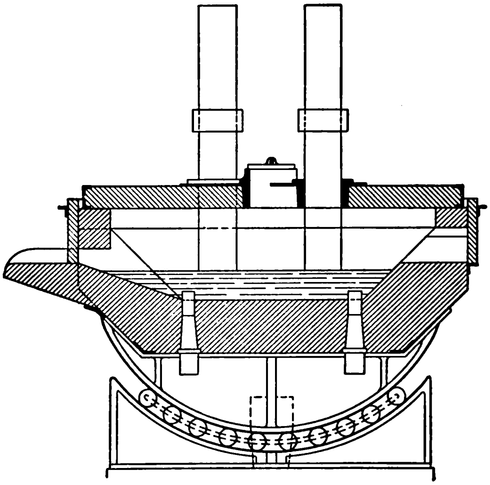

FIG. 13.—Girod electric furnace with four electrodes. Transverse section. From "The Iron Trade Review."

Almost all the arc furnaces are made tilting, to avoid tap-hole troubles; and in most cases the roof is readily removable, to facilitate replacement, which is necessary at intervals too frequent to suit the ideas of men who are used to open-hearth practice. The great heat from the arcs wears away the silica brick roof very rapidly, and so far no means have been found to prevent it.

Aside from their electrical efficiency, which is better than that of the pure arc furnaces, the advantage of these bath furnaces, as they may be called, is chiefly that by means of the doors in sides and ends, the bath can readily be got at in working the furnace. There are advantages claimed for the submerged electrode types, in that a greater proportion of the heat is obtained by resistance, and hence a more uniform heating of the bath secured; while in the Heroult type the heat is largely concentrated at and near the arcs, so that with every increase in the surface of the bath the number of suspended electrodes needed is increased. This matter of multiplicity of electrodes is not confined to the Heroult type, however, since in all arc-resistance furnaces of large size, a number of electrodes have to be used.

Since in working an electric furnace for the refining of impure metal the first oxidizing and dephosphorizing slag, and sometimes a second, has to be scraped off from the steel, the desirability of having the charge concentrated in a single space of simple shape, all parts of which are readily accessible, is obvious. This advantage is possessed by the arc and arc-resistance furnaces, and from the point of view of the metallurgist and steel maker these furnaces are the most like "real furnaces" of any.

All these furnaces take alternating current at a comparatively low voltage and high amperage; consequently transformers to step down the current to the proper extent form part of the equipment, and very heavy copper connections carry the current to the electrodes. The frequency of the current, however, is normal.

The electrodes are made movable, and are fed down as they burn away, sometimes by hand, sometimes by electrically controlled apparatus that keeps the arc at a given length. They are made of graphite, or of amorphous carbon.

In melting cold stock, the current during the first hour fluctuates violently, owing to the jumping of the arc from one piece of scrap or pig to another. Frequently the arc "goes out" altogether, and the furnace man has to "stand by" and manipulate the electrodes. During this lively first hour or so, the power consumption jumps wildly from zero to almost anything you please. This state of affairs puts a heavy strain on a power line that is supplying other machines, unless the demands of the furnace are but a small fraction of the total power carried by the line. Thus a 1-ton furnace that operates on a line carrying several thousand kilowatts does not affect other machines on the line; while a large furnace in a manufacturing city, which took power from a private company, upset the entire town when the owners tried to melt cold stock in it.

The resistance furnaces that have been brought to the attention of the steel maker are all of the so-called "induction" type. That is, the furnace and transformer are one, the bath of steel being the secondary circuit of the transformer. The original Kjellin furnace consisted of a circular trough, lined with refractory material, which contained the metal to be melted; a core piece of iron, of which one leg was at the center of the circle of the trough, and one outside; and a primary winding, inclosing the outer leg of the core piece. In such a furnace, by passing a high-voltage current through the primary, a current is induced in the metal in the trough, whose voltage will be to that of the primary current as one (the number of turns in the secondary) is to the number of turns in the primary. Thus a low-voltage, high-amperage current in maintained in the trough.

Cooling devices for the primary winding are necessary, and of course suitable covers for the trough, tipping mechanism and spout, etc. In starting the furnace, a ring of iron or steel is placed in the trough in order to make a closed circuit for the current, and when this is melted cold scrap is charged. After one heat is made, by leaving a part of the metal behind after pouring, a ring is left to start the current. In refining molten metal from another furnace, of course, this is not necessary.

Of the modifications that have been made in this type of furnace, most have two objects: increasing the electrical efficiency, and providing a working chamber more easily got at than the ring. The Röchling-Rodenhauser furnace was designed to provide for both these improvements. In this furnace, the electrical efficiency was increased by surrounding both poles with a ring of steel, thereby catching a greater proportion of the magnetic flux lines; a large central bath was provided at the intersection of the two rings; and in addition, electrodes were bedded in the bottom at each end of the central bath which transmit current through the bottom material (as soon as the bottom becomes hot), thereby increasing the available supply of heat. This furnace is an improvement in electrical efficiency over the original single ring type; though the metallurgist feels a natural dread of the thin bit of bottom over the two end electrodes, lest a careless workman cut away the lining at that point in charging a chunk of metal, and expose the bare electrode.

Considered as a class, the induction furnaces have several dis-

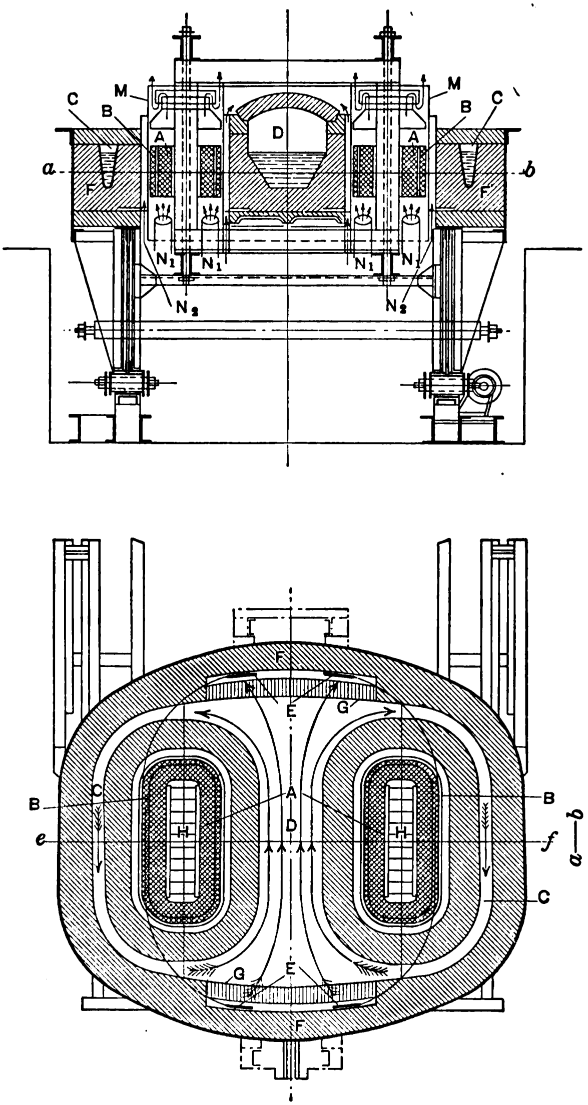

FIG. 14.—Röchling-Rodenhauser electric furnace, double ring type. Vertical and horizontal sections. From D. Carnegie, "Liquid Steel."

advantages, and one advantage, over the arc furnace. The first disadvantage is what has been dubbed the "pinch effect," and consists in the drawing in of the ring of metal at some point in its cross-section, as the current density is increased, resulting in breaking the circuit momentarily. This has hampered the electrical engineers in the development of the furnace, but since the induction furnaces as offered to the steel maker are not troubled by the phenomenon, it need not be considered here. Mr. Hering, indeed, has recently invented a most ingenious furnace whose prime feature is a means of utilizing this "pinch effect" to heat a large bath, by applying the current to one or more wells, as it were, in the bath's bottom. Several advantages are claimed for this design.

The low frequency of the current required by many of the induction furnaces is also a disadvantage in some cases, as it necessitates the installation of special generators.

The metallurgical disadvantages of the induction furnaces are, first, that as the heat is generated in the metal, and contributed to the slag only by conduction, it is impossible to maintain a very basic slag fluid; and for that reason, as we shall see a little later, desulphurizing of impure steel is not readily carried to the point that can be attained with arc furnaces.

The second is, that owing to the shape of the space containing the bath, it is not feasible to scrape off all of the oxidizing slag used for dephosphorizing, but a considerable amount of this slag has to be left in the furnace. The reducing conditions used to desulphurize the bath, at once reduce phosphorus from the slag left from the dephosphorizing period, so that a considerable rephosphorizing of the metal takes place. Thus it has been found that the degree of purification that can be attained in these furnaces is not as high as can quite readily be secured with arc furnaces.

The third disadvantage is the circulation of the bath in the narrow annular passages, which results in a mechanical erosion of the lining, in addition to the usual cutting action of the slag. In order to reduce the effect of this motion to a minimum, the annular passages are made of as great cross-section as possible; but there is a very definite and precise limit to the enlargement of the cross-section of the channels, inasmuch as the current density must be kept high in order to produce the requisite heat in the metal.

The advantage referred to is that the consumption of current in melting cold scrap is steady, so that no trouble on the rest of the line, such as has been described above, need occur in melting with an induction furnace. The power consumption figures that are available indicate also (though trustworthy figures are difficult to obtain) that the induction furnace will melt cold stock with less power than arc furnaces; so that for melting pure materials that need little refining, the induction furnace may have a certain advantage over arc furnaces. In this way it competes with the crucible process for the production of pure steel from pure raw materials.

Setting the Bottom.—Ordinarily, the bottom of an arc electric furnace is made up of magnesite, or occasionally dolomite, and is all placed at once by mixing the magnesite with enough hot tar to make it plastic, and ramming the mixture into position. The bottom is then dried out with a wood fire or oil burner, and set by melting down a small charge of scrap or pig, or by putting in a layer of coke, lowering the electrodes until they touch the coke and turning on the current.

A bottom so made cannot be properly set and baked in place and will last but a few heats. It is very prone to "come up" in chunks, and to cut through, resulting in break outs. In order to make a proper bottom that will "stay put" and last for a long time, the same method should be followed that has long been used in open-hearth practice; that is, placing but 1 or 2 in. of bottom at a time, and sintering each layer before the next is added. The method of heating used to set each layer is immaterial, so long as a high enough temperature is attained to partially fuse the refractory magnesite. By means of oil burners, or by covering each layer of bottom as shoveled in with coke and turning on the current, the furnace should be run up to a high heat and each layer well sintered. When the proper thickness of bottom has been attained, a wash heat of slag, or of pig and scrap, may be melted, the slag well splashed up on the banks and the bottom soaked as full of slag as possible. The bottoms containing large areas of iron conductors of course cannot be so set in.

If an acid lining is used it is set in just as an acid open-hearth lining is, and is made of the same materials.

Induction furnace linings cannot be put in by this method, and have in many cases given a great deal of trouble. Specially prepared refractory brick are commonly used for the purpose, and are said to last several months. Compared to that of an open-hearth bottom, or of some types of arc-furnace bottoms, this life is very poor.

Melting and Refining.—In the production of very pure steel from stock high in phosphorus and sulphur, the operation is divided into two distinct periods—the dephosphorizing and the desulphurizing stages. If cold scrap is melted, the dephosphorizing period overlaps the melting, as a proper slag is produced as soon as a part of the charge is melted, and melting and dephosphorizing go on together.

There will be a certain amount of FeO produced in melting, due to oxidation of iron, and some will come from the scale and rust on the stock. The oxidation of silicon in the scrap produces some SiO_2, which unites with the FeO and the added lime, to produce a fluid silicate of lime and iron. Steel foundry scrap will frequently have so much sand sticking to it, that a great deal of lime will be required to produce a basic slag. The bulk of the adhering sand should, therefore, be knocked off. By charging iron ore, or scale, and lime with the metal, a basic oxidizing slag is secured from the start. As melting proceeds, more lime and iron ore are added as needed. If molten metal is charged, the slag has to be made up by shoveling in iron ore, lime and a little silica. The slag desired is a silicate of lime and iron, very high in lime, in order that it may be able to hold the phosphorus in solution as phosphate of lime. Fluorspar is used to assist in liquefying the highly basic slag; and the metal is exposed to the action of this slag until the fracture of a test piece or a quick analysis shows that the phosphorus has been eliminated to the desired degree. In treating stock containing a very high percentage of phosphorus, the first slag frequently cannot be made to carry the elimination to the desired point, without increasing its bulk so much that it will be unmanageable. In this event the first slag is scraped off the steel with hooks and rabbles, and a second similar one made.

When the phosphorus is as low as desired (or a little lower, to allow for the inevitable rephosphorizing due to the slag that cannot be got out of the furnace), the slag is removed, and the metal is ready for the desulphurizing stage.

As the conditions to which the steel is now to be subjected are reducing, and as the steel is conveniently bare at this stage, the additions necessary to provide the carbon, manganese, etc., desired are often made after the dephosporizing slag is removed. Ferromanganese, ferrosilicon, pig iron, etc., are thrown in and melted; and the desulphurizing and deoxidizing slag is then formed.

Desulphurizing and deoxidizing are carried out by the addition of ferrosilicon and ferromanganese to the steel, the silicon reacting with the oxide of iron to form SiO_2 and metallic iron; and by forming of lime, sand and fluorspar, a slag composed largely of silicate of lime, which promotes the formation of sulphide of lime, and the elimination of the sulphur. In arc furnaces, coke dust is sprinkled over the surface of the slag, and acts partly as a deoxidizer, reducing FeO and MnO in the slag and sending iron and manganese into the steel; and partly as a desulphurizer, by the formation of calcium carbide. The latter is supposed to attack the sulphur in the steel, forming calcium sulphide, which is dissolved by the slag. Sometimes the coke dust is sprinkled upon the bare metal before the addition of lime and fluorspar, instead of on the slag. The additions of lime, coke and ferrosilicon are kept up until the slag is practically white, and falls to powder when allowed to cool.

Tests are taken every little while, which, when the steel is ready to pour, should set quietly in the mould and of course should pour cleanly from the spoon. These tests may be analyzed for sulphur, if very pure steel is desired. Sometimes a small steam hammer is used to pound the tests out flat; low carbon steel when sufficiently deoxidized should flatten out without cracks. The fracture of a test piece can be taken as an indication of the condition of the steel; when thoroughly deoxidized and fit to pour, the test should be perfectly sound, and of course should not rise and sparkle in the mould. Final additions are then made to bring the carbon, manganese, and especially the silicon, of the steel to the desired composition.

The Acid-lined Electric Furnace.—As there is no elimination of phosphorus or sulphur in melting scrap or treating hot metal in an acid-lined electric furnace, the metal supplied to the furnace must be low in those impurities. Indeed, owing to a slight loss of iron in melting, there may be an increase in phosphorus and sulphur, which, if the foundry scrap is remelted, can be figured about as in the case of crucible melting.

It is, of course, impossible to maintain a basic slag on an acid lining. Hence the elimination of phosphorus and sulphur is impossible in an acid furnace, and the only effects of treating the metal are to increase its temperature, to give the gases a chance to separate, and to deoxidize it by the absorption of silicon, which is reduced from the silica of the lining and slag by the carbon of the bath; the relative affinities of carbon and silicon for oxygen being reversed at the high temperature of the electric furnace.

So strong is this tendency to reduce not only the oxides of iron and manganese, but also the silica, that additions of iron ore have to be made at frequent intervals to flux the silica of the slag, and thereby diminish its reduction, by providing oxides which are attacked by carbon in preference to silica. In fact, the proportion of oxides in the slag is kept high throughout the operation. Were it not, the amount of silicon absorbed by the steel would be excessive.

The carbon of the bath is generally brought to the desired point early in the operation. If fluid metal is charged, it is recarburized by proper additions at once; if cold stock is melted, it is either so proportioned as to have the desired carbon content when melted, or recarburized after melting. The carbon content of the metal is steadily diminished throughout the process by the reaction of the carbon with the oxides of the slag; hence additions of pig iron are made every little while to keep it to the desired figure.

It will be clear from this that the reduction of the oxides of the metal is quite complete in the acid-lined furnace. The difficulty of keeping down the absorption of silicon, however, and the high cost of the low phosphorus (and sulphur) raw materials needed for the process, make the use of the acid-lined furnace of doubtful value, when the basic can be used for the production of steel of probably equal quality at a lower cost.

Aside from its use in treating hot metal from a basic open-hearth furnace, the acid-lined electric furnace is utilized chiefly to melt down very pure materials, following the precedent established by crucible practice. Whether there is any advantage in this procedure over the use of a basic-lined furnace melting impure stock, is open to question. The time-honored adage, "you can't make a silk purse out of a sow's ear," and the commanding position so long held by crucible steel made from very pure raw materials, together with the tremendous conservatism of mankind in the mass, will probably for some time to come keep alive the ancient methods. Actually, however, the use of very pure raw materials for the manufacture of fine crucible steels was not a matter of choice; it was forced upon us by the fact that we had no method of steel making that would refine our metal to the necessary degree. Now, however, when we have at our disposal a furnace in which we can first eliminate phosphorus from our steel, then by creating reducing conditions remove sulphur, and at the same time reduce oxides practically completely; and as these conditions undoubtedly produce from strongly oxidized and impure metal a steel as free from injurious impurities as any the world has ever seen, there seems to be but one reason for the melting of pure materials in a furnace that can be made so refining, and that reason is the caution of mankind.

Yet there is precedent on the side of the conservatives. The advent of the Bessemer converter was hailed as the doom of the puddling furnace and of wrought iron, yet we have wrought iron with us to-day, very much alive, and we have crucible steel made from wrought iron. The users of wrought iron and crucible steel would not abandon them until they were convinced that the new material was "just as good," and for some purposes it proved inferior. So we shall have to wait a few years to know whether the melters of pure pig and scrap in an electric furnace are or are not wrong in supposing that they make a better steel than those who refine cheap metal, melted in the furnace, or supplied hot by open-hearth or Bessemer furnaces.

The steel foundry, at any rate, is more than safe in using refining methods rather than the melting of pure and costly materials, since it has been thoroughly demonstrated that steel castings can be made from impure stock refined in an electric furnace, that are at least as good as any now made by other processes, and for many purposes considerably too good for the market.

Greene's Process.—Mr. Albert E. Greene proposes to supplement the usual reactions of the electric furnace by creating in the melting chamber an atmosphere of producer gas containing CO_2 and CO in proportions fixed within rather narrow limits, and has taken out patents on the process. Such an atmosphere at the temperature of the electric furnace can be used for the slow oxidation of carbon, phosphorus and sulphur with little or no loss of silicon, manganese, and some other alloys. For commercial purposes it is not quite clear that in order to avoid the loss and readdition of these comparatively inexpensive alloys it is worth while to install the gas producers and incur the necessary expense for coal and labor. There is, however, one application of this process which might be valuable, which is, to use it for the treatment of alloy steel scrap containing alloys not lost in the process during the elimination of carbon. In such a process it would in some cases be possible to remelt the scrap in a cupola, thereby obtaining it in a molten condition at the lowest possible cost, and then remove to the desired extent the excess carbon absorbed from the coke. In most cases, however, this would involve the elimination of a great deal of carbon, and would require a good deal of time. Even in this process it is not by any means sure that the saving in melting cost as compared to melting in an electric furnace would balance the expense involved in eliminating carbon.

Moreover, up to the present time, as far as the author is aware, this procedure has not been brought to such a stage of development that it can be called a process which can be relied upon in practice. The greatest difficulty with it probably lies in the fact that to turn out producer gas consistently, with its composition as accurately controlled as is necessary for the success of this process, is an extremely difficult matter and one which is likely to give constant trouble in regular operation.

THE RAW MATERIALS

As the electric furnace is almost always run with basic lining, as a basic, and hence refining, process, the raw materials that can be used are not subject to the rigid specifications as to phosphorus and sulphur that must be adhered to in crucible, Bessemer and acid open-hearth practice. Phosphorus and sulphur are eliminated as completely as desired at each heat, hence we can remelt our own scrap up to any proportion without increase in impurities

The amount of sulphur and phosphorus that we can allow in our raw materials, therefore, depends chiefly upon the degree of purity necessary in our finished castings, and upon the time that we desire to spend in treating the steel. If a basic open-hearth furnace is used to supply the electric furnace, raw material averaging .3 to .5 per cent. phosphorus can be delivered to the electric furnace at say .05 to .1 per cent. very readily, and the refining completed in the electric furnace without too great expenditure of time. As far as possible, the dephosphorizing should be done in the open hearth. To effect the removal of a high percentage of phosphorus in the electric furnace is feasible, but may require the making and removal of several slags. Hence if we are operating an electric furnace alone, or one supplied with hot metal by an acid open-hearth furnace or a Bessemer converter, the extra expense in power and labor involved in the purification of very high phosphorus metal may be so great as to more than offset the saving made in the cost of raw materials. A safe middle course should be steered; one would not be justified in melting low phosphorus pig and scrap in a plant making only electric steel by the basic process, since Bessemer (.1 per cent. phosphorus), or basic (1.0 per cent. phosphorus), grades at a lower price can generally be refined at a cost less than the difference between the two grades of stock. But to use foundry iron and very high phosphorus scrap (averaging perhaps 1.5 per cent. phosphorus) would involve an expense in refining that would much more than offset the saving in cost of raw material. The possible ways of using the electric furnace in a steel foundry are shown in the following table.

THE POSSIBLE USES OF THE ELECTRIC FURNACE IN A STEEL FOUNDRY

Melt scrap	Impure—eliminate P and S. Pure—get hot and cast. Alloy steels—save alloys.
Melt pig and more or less scrap —eliminate C, Si and Mn	Impure—eliminate P and S. Pure—get hot and cast.
Treat hot metal	From cupola—eliminate C, Si, Mn, P and S. From acid Bessemer or open hearth—eliminate P and S. From basic open hearth—eliminate P and S.
Melt pig and scrap or treat cupola metal.	Eliminate C, P, and S, without loss of Mn and Si. (Greene's producer gas process.)

Two of these methods, the melting of pure scrap, and of pure scrap and pig, have already been discused.

In considering the refining of impure raw materials, too much emphasis can hardly be placed upon the fact that the true function of the electric furnace is the final refining of steel, and that melting and the elimination of carbon, silicon, manganese, and the bulk of the phosphorus and sulphur should whenever possible be carried out in furnaces of other types.

To melt and refine impure scrap in an electric furnace alone is a rather costly way to make steel; yet in many cases it will be the most advantageous practice to follow, especially if scrap and power be cheap, and coke or other mineral fuel costly. In a very small plant it may well be necessary to follow this practice, especially if the possible output and the money available to build the shop do not justify the installation of an open-hearth furnace, or small converter, to supply hot metal.

To melt pig iron and scrap, the pig forming a large proportion of the charge, and eliminate carbon, silicon and manganese (and phosphorus and sulphur if impure materials are used), in the same way as in an open-hearth furnace, should not be attempted, unless conditions demand it, on account of the necessarily high cost of the metal produced. It is difficult to imagine the existence of the conditions that would make such practice necessary, as they would be—cheap pig and power, scrap at a higher price than pig, and, if the output is of fair size, mineral fuel suitable for open-hearth or Bessemer work not available.

One exception to these statements is the use of the furnace to melt down alloy steel scrap without loss of the contained alloys. The problem in this case is one purely of costs; if the scrap can be melted at a profit over the cost of the steel as made by other methods that remelt the scrap but lose the alloys, the method should be used. In many cases, however, it will not be found economical to do so.

Under ordinary conditions, if it is not deemed advisable to install an open-hearth furnace or a converter to supply the electric furnace with hot metal, it may in some cases pay to melt the scrap in a cupola and eliminate the carbon absorbed from the coke, and the phosphorus and sulphur, in the electric furnace. As far as the author is informed, this method has never been put in practice. In an electric furnace of the usual type the elimination of the carbon will be a slow and rather costly procedure; but by using a furnace without doors in the back, with the bottom carried well up the back wall, the hot metal practice used in tilting open-hearth furnaces could be followed. By melting down and heating up a little plate scrap in the furnace, and forming with iron ore a slag very rich in iron oxide, and then pouring in melted scrap (and possibly some pig iron) from the cupola, a lively reaction could be maintained, which would boil out the carbon very rapidly. By tilting the furnace back the slag could be kept from boiling out the doors, and during the violent part of the boil it is probable that current would not be needed. It is probable that the elimination of the carbon from the bath would take less time and consume less power than the operation of melting the cold scrap in the electric furnace itself, so that a saving could be made over that method.

For large tonnages an open-hearth furnace should be used to supply the hot metal for refining. Preferably it should be a basic furnace, in order to eliminate the bulk of the phosphorus and sulphur in the open-hearth rather than in the electric furnace; but acid metal of course can be treated, and need not be of very low phosphorus and sulphur.

Smaller shops may well find it advantageous to install small

Bessemer vessels to supply hot metal for the electric furnace. In this case all the phosphorus and sulphur would have to be eliminated in the electric furnace, yet by using basic raw materials the cost of production can be brought low enough to compare very favorably with that of Bessemer steel made from low phosphorus pig.

Open-hearth Electric.—In discussing the arrangement of a shop using open-hearth and electric furnaces, the combined open-hearth and electric furnace, recently patented by Mr. Walker, must be considered. As one of its applications is the melting of alloy steel scrap, the following paragraphs compare the usefulness of this combined furnace and of simple electric furnaces for this purpose; and of the combined furnace and of ordinary open-hearth furnaces in conjunction with electric furnaces, for refining hot metal.

This design consists of a tilting open-hearth furnace with the gas and air uptakes and ports mounted on wheels in such a way that they can be pushed back from the hearth of the furnace, allowing brick-lined sliding doors to be lowered into position to cover the open ends of the furnace. Through water-cooled openings in the roof of the furnace, graphite electrodes are introduced in the usual manner.

The disadvantage of this furnace is that it is difficult to make it both a good open-hearth and a good electric furnace. One of the disadvantages of the furnace as an open-hearth is that while the gas is shut off and the ends slid back, the gas and air uptakes, end blocks and checkers cool off very greatly, so that much fuel has to be burned to get them hot again. The disadvantage as an electric furnace is said to be that the exigencies of open hearth design make it difficult to build the furnace in such a manner that it shall give good electrical efficiency.

One application of this furnace would be to melt and partially refine pig iron and scrap, eliminating carbon, silicon and manganese and part of the phosphorus and sulphur, using gas (of course other fuel could be used); and then, shutting off the fuel and closing the ends, to lower the electrodes into position and complete the refining of the steel. The saving would consist in carrying out the two operations in one furnace, avoiding the chilling of the metal in transferring from one furnace to another and the extra installation cost of two furnaces. Unless the efficiency of the installation both as an open-hearth and as an electric furnace can be brought nearly to the efficiency of the separate furnaces, the advantage gained in cost of installation will be more than offset by the increased consumption of fuel and electric power, compared to separate furnaces.

The second application of the furnace is in melting scrap containing costly alloys that are oxidized and lost in melting by other methods. The procedure in this case would be to bring the charge to incipient fusion with mineral fuel, and then finish the melting and superheating with electricity. In this way a great part of the necessary heat will be obtained from cheap fuel, and the smallest possible amount obtained from electric power. Since it would obviously be impossible to carry out the same process in two furnaces, owing to the impracticability of transferring the semi-solid charge, this application is unique.

The cost of power in this method of working, however (and also in working the furnace to refine metal melted and partially refined with fuel), will be greatly affected by the following considerations. If the furnace is supplied by a line that is taking care of other installations and therefore furnishes a great quantity of power at a correspondingly low unit cost, current will be paid for only as used, and the full saving from the use of fuel will be realized. On the other hand, should the furnace be supplied with power by its own generator, which would consequently lie idle during the period when the furnace was burning fuel, the cost of the generating plant would run on at almost its full figure during this idle time, because the operating force would have to continue on duty, and in a steam plant, fuel would be burned to keep up the steam in the boilers. As the overhead and other expenses would run on all the time, the cost of power in this intermittent operation of the generators would be greatly increased. In many cases this extra cost of power would offset, or more than offset, the saving from the use of fuel in one of these furnaces, as compared with melting in an ordinary electric furnace.

There is only one way to avoid this dilemma, which is to install two or three furnaces to operate on one power line. If the amount of time on fuel and on electric current were about equal, two furnaces on one line would keep the power plant constantly busy. If two-thirds of the time per furnace were on fuel and one-third on power, three furnaces would be necessary, and so on. On the other hand, should the time per furnace on power be greater than the time on fuel, the furnace would have to be allowed to lie idle part of the time, or a power plant be installed capable of supplying more than one furnace simultaneously. Thus, to take an extreme case, if the time on fuel were two hours and on current six hours, one power plant capable of running one furnace would operate as follows:

Furnace A	Furnace B
On fuel 12 m. to 2 p. m.	On fuel 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	On power 8 p. m. to 2 a. m.
On fuel 12 m. to 2 a. m.	On fuel 6 a. m. to. 8 a. m.
On power 2 a. m. to 8 a. m.	On power 8 a. m. to 2 p. m.
On fuel 12 m. to 2 p. m.	On fuel 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	On power 8 p. m. to 2 a. m.

Thus each furnace would make but two heats in 24 hours, and though the power plant would be kept constantly busy, each furnace would lie idle (burning some fuel to keep it hot), eight hours per day, in two periods of four hours each. This would run up the fuel bill, though obtaining current at a minimum cost.

Another way of distributing power over several furnaces, under the same conditions as above, two hours fuel, six hours current, would be to use three furnaces and a power plant capable of taking care of two of them at once. The schedule would be as follows:

Furnace A	Furnace B	Furnace C
On fuel 12 m. to 2 p. m.	f. 3 p. m. to 5 p. m.	f. 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	p. 5 p. m. to 11 p. m.	p. 8 p. m. to 2 a. m.
On fuel 9 p. m. to 11 p. m.	f. 12 m. to 2 a. m.	f. 3 a. m. to 5 a. m.
On power 11 p. m. to 5 a. m.	p. 2 a. m. to 8 a. m.	p. 5 a. m. to 11 a. m.
On fuel 6 a. m. to 8 a. m.	f. 9 a. m. to 11 a. m.	f. 12 m. to 2 p. m.
On power 8 a. m. to 2 p. m.	p. 11 a. m. to 5 p. m.	p. 2 p. m. to 8 p. m.

Each furnace would thus make three heats every 26 hours, with an idle hour between heats, keeping the power constantly busy, and allowing the furnaces to lie idle only one hour at a time.

In order to use one set of transformers to serve two or three furnaces, it would be necessary to put switches in the heavy busbars that carry the low-voltage current to the furnaces. In order to switch such high amperage currents successfully, very expensive oil switches would be needed.

In case expensive alloy steel scrap is to be melted, and power to be supplied by a separate plant, it might in some cases pay to install two or three small fuel electric furnaces operating in the manner just described, rather than one plain electric furnace, but in this connection allowance will always have to be made not only for the inferior electrical efficiency of the very small units (the efficiency is very low in sizes below 2 or 3 tons), but also for the very poor efficiency of the furnaces while burning fuel. Even when power is available that can be paid for only as used, so that the multiplication of furnaces is not necessary, it is doubtful if the fuel electric furnace holds out any hope of making a saving over the plain electric furnace.

For the melting and refining of impure pig and scrap it is open to question whether the combined furnace can compete with a tilting open-hearth operated continuously and supplying an electric furnace with partially refined metal. To take a hypothetical case, let us assume that a 10-ton tilting open-hearth furnace, run continuously, will supply 2 tons of metal every three hours (equivalent to a heat of 10 tons in 15 hours) to a 2-ton electric furnace, which will thus turn out eight heats per day, or 16 tons. If we can get 2 tons in two hours, our capacity will be 24 tons. Our plant will consist of

1 ten-ton tilting open-hearth furnace.
1 two-ton electric furnace.
1 generator for same.
1 set transformers.

To produce the same tonnage in open-hearth electric furnace, we will assume that the furnace will produce a heat in ten hours (including making bottom), or eight hours on fuel and two hours on power. To secure even current distribution from a separate generating plant, we shall need five furnaces, scheduled as follows:

A	B	C	D	E
Fuel 12 m. to 8 p. m.	2 to 10 p. m.	4 p. m. to 12 m.	6 p. m. to 2 a.m.	8 p. m. to 4 a.m.
Power 8 p. m. to 10 p. m.	10 p. m. to 12m.	12 m. to 2 a. m.	2 a. m. to 4 a. m.	4 a. m. to 6 a. m.
Fuel 10 p. m. to 6 a. m.	12 m. to 8 a. m.	2 a.m. to 10 a.m.	4 a. m. to 12 m.	6 a. m. to 2 p. m.
Power 6 a. m. to 8 a. m.	8 a.m. to 10 a.m.	10 a. m. to 12m.	12 m. to 2 p. m.	2 p. m. to 4 p.m.
Fuel 8 a. m. to 4 p. m.				
Power 4 p. m. to 6 p. m.	etc.			

This is the equivalent of $2\frac{2}{5}$ heats per furnace per day, or twelve heats per day for the battery. For a tonnage of 16 to 24 tons, each furnace would be of $1\frac{1}{3}$ to 2 tons capacity.

Our plant will consist of

5 one and one-third to two-ton open-hearth electric furnaces.
1 generator for same.
1 set transformers for same.
5 sets oil switches.

We see that we have to balance the cost of five open-hearth electric furnaces and five sets of switches against that of one tilting open-hearth furnace and one plain electric furnace. The advantage would probably be with the tilting open-hearth installation. Moreover, the labor costs on such an installation, and the repairs and upkeep per ton of metal, would undoubtedly be in favor of the more compact installation—to say nothing of the question of space, and of the difficulty of running several furnaces on a time schedule that must be adhered to quite closely.

Should power be available that could be paid for as used, the multiplication of furnaces would not be necessary. Assuming in that case the same rate of operation, eight hours on fuel and two on power, producing therefore $2\frac{2}{5}$ heats per day, our single open-hearth electric furnace would be of 16 to 24 (call it 20), divided by $2\frac{2}{5}=8\frac{1}{3}$ tons. This furnace could no doubt be built for considerably less than the 10-ton tilting open-hearth, and 2-ton electric furnace with transformers. Our plants in each case would consist of

Open-hearth electric	Tilting open-hearth and electric
1 eight to ten-ton open-hearth electric furnace.	1 ten-ton tilting open-hearth furnace.
	1 two-ton electric furnace.
1 set transformers 1200 to 1500 kw.	1 set transformers 300 kw.

The advantage in installation costs should be slightly in favor of the open-hearth electric installation. The power costs (though not the total fuel cost), would be less for the open-hearth electric furnace, figuring as follows:

Assuming that 150 kw. per ton will be required in each furnace, the fact that an 8-ton electric furnace should have a higher electrical efficiency than a 2-ton, being offset by the probably inferior efficiency of the open-hearth electric furnace, the latter will use 1200 kw., for $2\frac{2}{5}\times 2=4\frac{4}{5}$ hours per day ($2\frac{2}{5}$ heats at two hours each), or 5760 kw.-hr. for 20 tons = 288 kw.-hr. per ton. The 2-ton electric furnace would use 150 kw. per ton for 24 hours, or 7200 kw.-hr. for 20 tons = 360 kw.-hr. per ton. Should the efficiency of the open-hearth electric furnace be better, this advantage would be more marked. This will, however, be offset by the higher fuel cost per ton in the fuel electric than in the open-hearth furnace, so that probably the total fuel plus current expense will be greater in the former than in the open-hearth and electric furnace combination.

THE BESSEMER CONVERTER SUPPLYING ELECTRIC FURNACES

The Bessemer converter can be used to supply the electric furnace with hot metal for refining. A possible arrangement for a plant of limited output is outlined and discussed in the following paragraphs. The equipment would consist of:

Two or three 1000-lb. side-blown vessels. One to be run at a time, turning out two heats per hour.

Three 1-ton electric furnaces, each capable of turning out a heat every three hours.

The vessel would blow enough metal in one hour to fill the first electric furnace, would fill the second furnace in the second hour, and the third furnace in the third hour. Thus each furnace would have two hours to refine its charge, before it would be needed again to take metal from the vessel. Working in this manner, we could produce some eight heats per 24 hours in each furnace, or 24 tons per day, 144 tons per week.

The costs of metal produced by this method, if basic raw materials be used, should be sufficiently low to be attractive to shops of small output.

They can be roughly estimated as follows:

Raw material per ton of steel, calculating 16 per cent. loss, and using 50 per cent. pig, 30 per cent. shop scrap, and 20 per cent. purchased scrap,

1 ton ÷ .84 = 1.19 tons, of which
.595 tons will be pig
.357 tons will be shop scrap
.238 tons will be purchased scrap

.595 tons basic pig at $15.00	$ 8.93
.357 tons shop scrap at $14.00	5.00
.238 tons high phosphorus scrap at $10.00	2.38
	$16.31

	Per ton of steel
Raw material	$16.31
Bessemer plant labor, $42 per day, or for 24 tons	1.75
Bessemer plant, other expense (see estimates in introductory chapter)	2.53
	$20.59

Electric Furnace Labor	Per week
2 melters at $150 per month	$ 69.23
4 helpers at $4.00 per day (2 on Sunday)	104.00
4 helpers at $2.50 per day	60.00
	$143.23 or for 144 tons, about $1.00 per ton

Summary	Per ton of steel
Material delivered to electric furnace	$20.59
Electric furnace labor	$1.00
Other electric furnace expenses, (estimating 500 kw. -hr. per ton)	8.83
	$30.42

If the plant were run only single turn, blowing some 14 heats, or enough for seven electric furnace heats, the cost would be considerably higher. In this case two of the furnaces would be busy for six hours, producing two heats each, and the third for nine hours, producing three heats, giving us a total of 7 tons of steel. A rough estimate of costs is as follows:

	Per ton of steel
Raw material	$16.31
Bessemer plant labor $21 per day, or for 7 tons	3.00
Bessemer plant, other expenses	2.53
Electric plant labor, $71.62 per week, or for 42 tons	1.71
Electric plant, other expenses	8.83
	$32.38

Bessemer-electric.—The combined Bessemer converter and electric furnace has been patented. Its application would be to combine in one furnace the elimination of carbon, silicon and manganese by blowing, and dephosphorizing and desulphurizing by means of electric heating. The advantages of the process would be, first, avoiding loss of heat in transferring the metal from one furnace to another, and second, economy of installation.

Aside from the probability that the electrical efficiency of such an installation would be low, on account of the limitations imposed by the exigencies of Bessemer design, there would be several disadvantages of this furnace that must be considered.

In the first place, if dephosphorizing and desulphurizing is to be attempted, a basic lining will be needed in order to maintain a basic slag. In America, where only siliceous pigs are available for Bessemer blowing, such a lining will be too severely cut to permit its use. In this country, therefore, the furnace would have to be acid lined, and used as an acid electric furnace. In Europe where basic Bessemer pig is available, this difficulty would not appear.

In the second place, the production of this type of vessel would be low, probably a heat only every two and one-half or three hours, say four heats on a 12-hour turn, or 8 tons for a 2-ton vessel. Compared to the output of an ordinary 2-ton vessel, making some 20 tons on a turn, this is very low, and as we have shown, a half-ton vessel and three one-ton electric furnaces will make some 7 tons in one shift.

CHAPTER VII

SUMMARY—SPECIAL DEOXIDIZERS—LADLES

As a convenient reference, the changes that take place in the content of metalloids in the several steel-making processes are summarized as follows:

Process		Element									
		C	Si	Mn	S	P	Ni	Cr	W	Mo	Va
Crucible	graphite	gain	(gain)	loss	(gain)	(gain)	......	(loss)	(loss)	(loss)	loss
	clay	loss	(gain)	loss	(gain)	(gain)	......	(loss)	(loss)	(loss)	loss
Bessemer (acid)..		*loss*	*loss*	*loss*	gain	gain	(loss)	loss ¾	loss	loss	loss
Open hearth	acid	*loss*	*loss*	*loss*	gain	gain	(loss)	loss	loss	loss	loss
	basic	*loss*	*loss*	*loss*	loss	loss	(loss)	loss	loss	loss	loss
Electric (Basic bottom)	Melt	(loss)	(loss)	(loss)	(loss)	(loss)	......	......	......	......	....
	Melt and refine	*loss*	*loss*	*loss*	loss	loss	......	loss	loss	loss	loss
Electric (acid bottom)		(loss)	gain	(gain)	(gain)	(gain)	......	......	......	......	....

(gain) or (loss) indicates slight gain or loss.
gain or *loss* indicates practically complete gain or loss.
...... indicates neither gain nor loss.

Special Deoxidizers.—In addition to the regular recarburizers, it is frequently necessary, especially in making very low carbon steel by the Bessemer process, to use other materials to more thoroughly deoxidize the steel and make it fluid and clean running. Aluminum has been used for a number of years for this purpose and has greatly aided the steel foundryman in pouring sound castings. It is a more efficient deoxidizer than silicon or manganese, and the proportion of the oxides reduced is much increased by its use. There are, however, several objections to it, the most important of which is that the product of the reaction,

$$3FeO+2Al=Al_2O_3+3Fe$$

is alumina (corundum), an almost absolutely infusible mineral, which does not coalesce and float out of the steel but remains in finely divided form in the metal, and renders it somewhat weak. In rolled steel, especially plates, the effect of this alumina is well known to be a considerable reduction of the strength of the steel when tested in a direction transverse to the direction of rolling.

The first of the special alloys to be used as final deoxidizer or "wash" was "S-A-M metal," which contains generally about 10 per cent. of silicon, 5 per cent. of aluminum and 10 per cent. of manganese. The products of the reaction of this alloy with FeO are SiO_2, Al_2O_3 and MnO, which unite to form a double silicate of manganese and aluminum, of comparatively low melting point. Such a silicate will coalesce into globules of sufficient size to float out of the steel to a considerable extent. Moreover, as Mr. Hibbard[1] has shown in his suggestive article on this subject, globules of slag of considerable size are less harmful to the steel than very minute solid particles scattered broadcast throughout the metal.

Most of the other "washes" now on the market are designed to give reaction products of great fluidity. For instance, the alloy of calcium and silicon produces CaO and SiO_2, which are counted on to unite with the MnO resulting from the reduction of FeO by manganese, to form a fusible silicate of CaO and MnO.

A somewhat different object is aimed at in the use of ferrotitanium as a final addition to steel. Titanium has the property of burning in an atmosphere of nitrogen, that is, it readily forms a compound of titanium and nitrogen. The valuable property is claimed for the alloy of removing the last traces of FeO from steel, and also of removing a large part of the absorbed nitrogen. Many tests have been made that seem to demonstrate the ability of ferrotitanium to reduce the FeO and remove the nitrogen of steel very thoroughly, and the result of its use appears to be a clean, strong metal. In the manufacture of steel for rolled shapes, the segregation of carbon, sulphur and phosphorus in the ingots is considerably reduced by titanium, resulting in superior toughness in the steel from the upper parts of the ingots. Segregation, however, is seldom an evil in foundry practice, as it takes place chiefly in the sink heads.

Whatever "wash" be used to reinforce the action of ferromanganese, it should be added after the latter has had an opportunity to perform as much deoxidation as possible. The "wash" being a more active deoxidizer than manganese, if added before the latter, or at the same time with it, will be wasted in performing the work that manganese can do, and none will be left over for the desired final deoxidation. If the recarburizers are added in the ladle, the

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[1] *Transactions A. I. M. E.*, 1910, p. 803.

"wash" should be added last, when the ladle is partly filled, and of course the same applies to recarburizing in the vessel or furnace.

The Ladles.—The ladles and large "shanks" used in pouring steel are made of steel plate appropriately bolted together and braced; small shanks are often cast in one piece, in the shop. Shanks may be carried by hand, or suspended by means of a "bail" from an overhead trolley or crane. They are poured over the lip by tipping. Small ladles are generally hung from a bail and provided with a hand wheel, rack and pinion, so that they can be revolved on their trunnions for pouring over the lip, or in order to turn them upside down and dump them. They may also be provided with a nozzle. Large ladles, holding over 5 tons or so, are generally poured through one or more nozzles and are not arranged to turn over. They may be picked up by heavy crane-hooks under the trunnions, or provided with a bail like the smaller ones. In any case, they should not be so hung as to be top-heavy when full, lest failure of the catch to engage allow them to dump themselves suddenly and disastrously.

The ladles are lined with refractory material to a thickness sufficient to protect the metal of the ladle from the heat of the steel. The thickness of the lining, therefore, varies with the capacity of the ladle. Small shanks, and ladles of a capacity up to some three tons, are commonly lined out by daubing a coating of ganister over the plating. The coating is made quite thick at the bottom and thinner toward the top. For a 3-ton ladle, the lining in the bottom should be about 6 in. thick, and may be reduced to 2 or 3 in. at the lip. Large ladles are lined with one or more courses of clay brick; those on the side are generally laid with the medium dimension of the brick in the line of the radius of the ladle. Over the bricks in the bottom is spread a layer of ganister, which is brought a little way up the sides. Smaller ladles also may be so lined, but the difficulty of removing a heavy "skull" from a small, brick-lined ladle is so great that the ganister lining is to be recommended. Small skulls in lip-poured ladles, especially in Bessemer work, are often left in the ladle to be cut out by subsequent heats; but a skull should not be left in a cold ladle.

The lining should be thoroughly dried out, either with an oil or gas burner, or with a wood fire. When dry, the lining is heated up before use, either with the burner, or by inverting the ladle over a coal fire provided with forced draught. Large ladles, of course, cannot very well be turned upside down for heating, and must be dried with a burner. Small ladles and shanks are generally made at least red hot before use; large ladles need not be made so hot, though it does no harm, especially in case of a rather "cold" heat of steel.

The only feasible method of pouring large ladles into comparatively small castings, is by means of a nozzle and stopper. To ensure satisfactory pouring, two nozzles are generally provided, so that if one gets plugged up the other can be used. Small ladles, of 1 to 3 tons capacity, generally have but one nozzle and are poured over the lip in case of trouble with the nozzle.

Nozzles may be of graphite and clay, or of clay alone. They should be put in place with care, and the lining rammed in around them thoroughly. The nose of the nozzle should project well beyond the plate used to hold it in position, so that the steel from a dribbling nozzle shall not freeze on the plate.

The stopper head is generally made of graphite and clay. Sometimes it is threaded to screw on the end of the stopper rod; but this design is a poor one, because the expansion of the rod in heating up is very apt to crack the stopper head. A far better design is the head with a hole clean through it for the reception of a bolt, which enters a hole in the lower end of the rod and is keyed in place. The hole in the stopper over the head of this bolt is filled with ganister after the stopper has been fastened to the rod.

Nozzles with a deep seat for the stopper head, and in particular a steep-sided seat, should be avoided like the plague. Especially in large ladles, the stopper often gets slightly out of line with the nozzle, and with this steep-sided seat, the stopper then cannot "find" the opening. The best design is the round-nosed stopper and the nozzle with a seat sloping quite gently from the central opening to the outside surface. This type seldom gives trouble by refusal to seat properly.

Sleeves of clay brick, each with a tenon to fit inside a mortise in the one below, are slipped over the rod. All joints in the sleeves are smeared with clay before putting the sleeves in place. To hold them tightly in position, washers are put over the uppermost, and a key driven through a slot in the rod. A thread and nut should never be used for this purpose, because the thread is sure to jam from heat and abuse.

Before placing a nozzle and making up a stopper rod for it, nozzle and stopper should be matched to see that they fit closely. This can be determined by pressing the stopper into its seat in the nozzle and turning it around. It should touch the surface of the nozzle at all points.

The stopper rod is fastened to the "goose-neck," which in turn is inserted in its socket on the ladle slide. Small ladles may be heated up with stopper rod and goose neck removed, and the rod dried out separately. For large ladles, it is necessary to leave the stopper rod in place, and merely raise the stopper off its seat while heating the ladle.

In any case, the stopper should be carefully adjusted before the ladle is heated, so that it closes the hole in the nozzle exactly. To ascertain if the stopper leaks, it is seated firmly and a little fine sand thrown around it. This testing with sand should be repeated when the stopper is put in place or lowered into position, after heating the ladle, and a ladle should not be filled until the ladle man is sure that it does not leak.

Some ladle men prefer, especially for large ladles, to arrange the stopper so that it strikes the outside of its seat in the nozzle, and slides into position as it is pressed home. It is generally best, however, to have the stopper come vertically down upon its seat.

In pouring through a nozzle, the rod should be raised slowly the first time the nozzle is opened, and the pourer will do well, soon after he has got his stream going, to close off once or twice. By so doing he clears away from the nozzle any half-melted sand that may be sticking to it, and ensures a clean shut-off. The first few times the nozzle is seated after the first opening, it often will not shut off clean.

Should the stopper get stuck hard to the nozzle, it should be poked off with a pricker from below, rather than trying to pull it off with the ladle handle. Too much enthusiasm at the handle sometimes pulls a stopper head off the rod. A frozen nozzle in large ladles is pricked open in the same way. Wooden prickers are better for this purpose than steel ones, as they do not freeze to the metal in the nozzle. But a steel pricker often has to be used for a badly frozen nozzle. In pouring a small ladle, if the nozzle freezes up, the steel had better be poured over the lip.

CHAPTER VIII

MOULDING, POURING AND DIGGING OUT

The effect of the moulding and pouring methods used upon the soundness of the castings is so great that in order to be useful to a steel foundry, the metallurgist is obliged to be thoroughly familiar with the subject. Not that he need necessarily be a foundry expert, versed in the economies of moulding practice, the use of machines, etc., but as concerns the effects of different methods upon his steel he must be an expert. Many a foundry makes a practice of holding the steel maker responsible for blow holes, hot checks, shrinkage cavities, etc., in the castings, when the trouble is really the result of ignorant or careless foundry practice, and the melting shop men too often take the attitude that nothing is wrong about their metal, which would pour into the most beautiful castings ever seen, if only the foundry were in charge of men who knew their business. To prevent this cat and dog attitude of foundry and melting shop, often calls for a degree of tact on the part of the superintendent that too few men possess. Frequently an attempt is made to cut the Gordian knot by giving the foundry superintendent charge of both moulding and steel making, and indeed when a man can be found who is well versed in the practice of both departments, no better arrangement can be made. Too often, however, the man who is an expert in handling the moulding, possesses but a smattering of the principles of steel making, and under his rule the lives of the melting shop men are made a burden to them.

Mixing the Sand.—The moulding sands that are used in a steel foundry must be selected with care, and generally chemical analysis is needed at intervals to determine the suitability of a given sand for the work. The sand must be sufficiently high in silica to be quite refractory, in order that it may not be melted or softened by the heat of the steel. The average size and shape of the particles is also of importance, since they affect the porosity and bonding power of the sand. The practice in past years has been largely rule of thumb, and even to-day there is no way of making sure that a sand is suitable, without trying it. The mixture of several brands of sand with more or less fire clay to secure the desired results, is giving way to an increasing extent to the use of a single sand of high silica content, mixed with just enough fire clay to give the necessary plasticity and holding power.

A formula used successfully in some shops is as follows:

Green Sand Facing	Dry Sand Facing
8 shovels new sand.	12 shovels new sand.
4 shovels old sand.	1½ shovels clay.
1 shovel clay.	

The amount of moisture in both "facing" and floor sand, depends somewhat upon whether the moulds are to be poured "dry" or "green." As a general rule, however, no more water should be used than is absolutely necessary to keep the sand in place. Green sand facings should be mixed as dry as it is possible to make them, without having the sand too dry to hold together. A handful of the facing given a single good squeeze in the hand should just hold together and no more. Too much moisture in green sand moulds gives rise to an excess of steam, which cannot escape through the close rammed mould and causes blow holes in the steel. The floor sand, therefore, should not be made too wet.

Dry sand facing is frequently mixed with molasses water to make it hold together, and somewhat more clay can be used in it than in green-sand facings. The sand should not be too moist, however, as it is then prone to flake and spall in drying, rendering necessary a good deal of patching in setting up the mould. If the patches are not dried out, and especially if the silica wash be applied to them too freely, the resulting wet spot may cause blow holes in the casting.

The sand should not be too wet, even in a dry sand mould, as very damp sand packs so hard as to be impervious to the escape of gases, even when thoroughly vented; and a wet sand results in greatly increased drying time, or in a mould brought from the oven and poured with damp spots in it. A mould impervious to the escape of gases, especially if it is wet in spots, is sure to cause blow holes in the steel.

Venting.—Another prolific cause of blow holes is the insufficient "venting" of the mould. This is especially dangerous if the sand used is very wet and hence hard packed. It is impossible to overemphasize the importance of thorough "venting," or in other words loosening up the sand of the cope over the casting by driving a long needle or bodkin, used for the purpose, through the sand in numerous places. Especially in green sand pouring, where a great deal of steam is evolved which must be carried away quickly, thorough "venting" is a necessity.

Skin Drying.—Again, the skin drying of green sand moulds just before closing, by spraying them with gasoline and setting it afire, or better, by the use of oil or gas torches, is of great assistance in reducing the amount of steam and gas to be taken care of in pouring. This has become universal practice, and enables castings to be poured in green sand that would otherwise have to be poured in dry sand.

Frequently it will be found impossible to pour a shape in green sand without the loss of many castings from blow holes. With ordinary steel of .20 to .30 per cent. carbon, green sand pouring is possible on only a limited number of castings of medium section; the heavy work, and frequently the very light castings, have to be poured in dry moulds.

Cores.—"Blowing" cores are often responsible for abundant blow holes. To avoid this, long cores should be vented by making a hole in them, from end to end, which will carry off the gas from the core into the sand of the mould. Cores with one end exposed to metal, of course, cannot have a hole entirely through them, but if long, should have a vent going nearly to the exposed end. Insufficient drying, and the gases generated by the flour, oil, or other binder used in mixing the core sand are the sources of the gases evolved from cores.

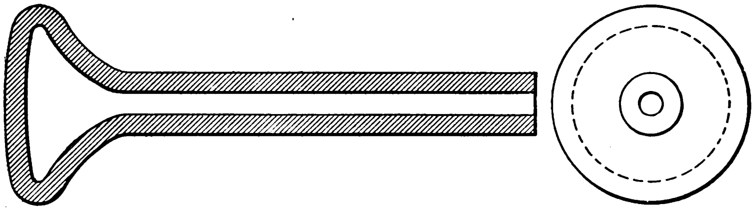

FIG. 15.—Gas engine valve. A casting that is apt to give trouble from blowing of the core.

The author recalls a gas engine valve, shown in Fig. 15, which gave great trouble in a foundry; the "blowing" of the core, even with the most thorough venting, produced harmful blow holes in the large section. Even well-vented dry-sand moulds, with the most carefully vented cores and careful pouring, could not be counted on to give a sound casting. With the welding methods now so common in steel foundries, it would very probably be possible to cast this shape with the core going through both ends, and weld up the hole in the big end afterward.

Hot Cracks.—Hot cracks in castings may be due to the high sulphur content of the steel, resulting in red-shortness, that is, brittleness when hot; to sharp corners, especially where a thin section joins a thick one, that are not protected by fillets (rounding off of the corner), or by brackets (extra metal in the shape of tie pieces across the corner); or to slow work in digging out the cores after the steel has frozen, in order to allow the casting to shrink unopposed. Many cracks that are blamed upon the steel, as the easiest explanation, can be traced to other causes. The test should be, did only one or two castings of a heat crack, or a great many? If the former, it is plainly not the fault of the steel—if the latter, it may not be, but the steel will bear investigating.

Sink Heads.—The location and shape of the "sink heads" or "risers" used has an important bearing on the soundness of a casting, not only on the porosity of the steel, but also, and more especially, on the formation of shrinkage cavities or "pipes." As steel contracts about $\frac{1}{4}$ in. to the foot in solidifying and cooling, the liquid metal occupies more space than the same metal solidified and cold. The metal around the outside of the casting, of course, solidifies first, and contraction of the interior metal produces cavities in the top of the casting, unless liquid metal be fed down to fill up the voids as they form. For this purpose sink heads are moulded in such places that the liquid metal from them will feed down into the heavy sections of the castings, and make them sound. The heavy sections, naturally, are the places where the opportunity for interior shrinkage occurs, since only in heavy sections does the interior lag much behind the outside in cooling. In the shaping and placing of sink heads several governing principles should be kept in mind. The first is, to make the sink head heavy enough to remain molten in its interior longer than the section of casting to be fed; hence it has to be of greater section than the casting at that point. The second is, that the thickness of the "neck" of the head must be such that this neck shall not freeze before the section of casting to be fed, or the sink head that is to do the feeding. If it does, the metal, of course, cannot feed. The third is the law of pressure in fluids, which teaches us that in a column of liquid, whether water or fluid steel, the *pressure* in any direction at any given depth below the surface of the fluid, is dependent only upon depth of metal. Interpreted literally, this law shows us that if the maximum area of cross-section of the neck of a sink head (imposed upon us by the size of the casting) is 2 by 2 in. as great pressure of fluid metal will be exerted upon that neck by a head 2 in. square as by one 2 ft. square, if both are of equal height. The neck being generally short, however (and the shorter the better), is kept hot by the mass of metal in the casting below and in the head above, so that a head considerably larger than the neck can be used. In fact, in order that the head may remain fluid and contain enough metal to feed properly, it generally has to be a good deal thicker than the neck. There is a limit, however, to the size of head that it is worth while to use when the diameter of the neck is fixed. Frequently heads 6 to 8 in. in diameter are seen on castings, with necks no more than 1 in. thick, where a 4 in. head would serve as well. Another error frequently committed is to increase the diameter rather than the height of a head, in order to secure better feeding, without increasing the size of the neck.

To consider this matter more in detail, let us assume that a casting has been poured with sink head and neck of a given size, and has proved unsound; that is, it contains a shrinkage cavity that has not been "fed" by the head. More effective feeding is desired, and the best means of securing it is being considered.

If the cavity is deep down in the casting and separated from the sink head and neck by a layer of sound metal, the trouble obviously is that the upper section of the casting did not remain fluid long enough to feed the lower section—the error is in the location of the head, or the position of the casting in the mould. The casting must be poured so that the last freezing portion is above, not below, the first freezing portion. In most cases such a cavity will not be detected unless the casting is cut open for inspection, or breaks in service.

If, however, the cavity is immediately under the neck, the head and neck were obviously to blame—they did not thoroughly feed the casting, but froze, or were drained completely, before the latter was solidified. The question now is, was the head too small to do the feeding? If the neck and head remained fluid long enough to allow the head to feed the casting as fully as possible, it is clear that the head will be hollow almost if not quite to its bottom—it did not contain enough metal to feed the casting. This occasionally happens with some alloy steels of low melting point and great fluidity. The remedy is more metal in the head, and therefore a larger head. A higher head will produce the most pressure at the neck, hence it is desirable to increase the height. But if we go too far in this direction it will take so long for the high head to empty itself that it will freeze to the center before feeding is complete. We may, therefore, be obliged to increase the diameter (generally of both head and neck), also. By so doing, we do not increase the pressure of metal on the neck, but we guard against the freezing of the head and neck before feeding is complete. We can judge of the necessity of increasing the diameter as well as height of the head, by the thickness of the walls of the head that has already proved too small. If they are very thick, it is plain that an increase of height only will be ineffective, since the head froze nearly to the center as it was. The diameter, therefore, must be increased as well.

Should the head be largely solid, and not drained of its interior metal, obviously either head or neck froze to the center before the part of the casting that was to be fed. We now ask ourselves, did the neck, or the head, freeze too soon? It is conceivable, but not probable, that the head was to blame. If it was, the neck obviously remained fluid and continued to feed after the head froze. We shall, therefore, find the neck hollow, with a hole running up into the head. In this case, the diameter of the head must be increased.

More probably, however, we shall find the neck, or at least its upper part, quite solid. This indicates that the neck closed up by freezing before the head had completed its work and was either too narrow, or too long, or both. The neck should if possible be widened and shortened—but the head may well be found to be amply large.

In case a narrow neck is unavoidable, it should be kept in mind that the narrowness of the opening decreases the flow of metal from the head, especially as the opening grows smaller, by the friction of the stream of metal on its walls. It may well be, therefore, that the opening in the casting grows too rapidly to be filled by the metal from the head during the last part of the time that the latter is still actually feeding. More pressure on the metal in the neck will increase the flow, and this pressure is obtained by increased height, not increased diameter, of head.

It is, of course, impossible to give hard and fast rules for such reasoning, especially in view of the fact that the shrinkage of the metal in the plastic state that succeeds solidification changes the shape and size of the interior cavities. Their location and shape may be such that exact deductions from them are impossible. It will, however, be advisable in a great many cases to consider the remedies to be applied, along the lines suggested above, rather than to jump blindly from the obvious fact that a shrinkage cavity has occurred, to the conclusion that a wider head is the remedy.

In placing sink heads the rule to be remembered is that a head will feed far more effectively downward from its base than sideways from its base. Efforts to cast a shape "on the flat" by the use of heavy heads, attached to the broad side of the section, frequently prove utterly futile—and then some fellow comes along and casts the thing "on end," and secures a solid casting with a sink head of half the size and weight used before. As sink heads are so much metal on which money is spent in melting, without return as salable casting, it is needless to say that the lighter the sink head the more money the shop will make.

The principle just stated, that a sink head acts best downward, is of course, simply another way of expressing the obvious fact that when a casting is poured "on end," each section of the casting, from below upward, feeds the section immediately under it and the head feeds the upper sections. A further precaution suggested by this line of thought, and one that has been mentioned already in discussing the size of sink heads, is so to locate the casting in the mould that as far as possible the upper portions will freeze last, and thus feed the lower portions and be fed in turn by the heads.

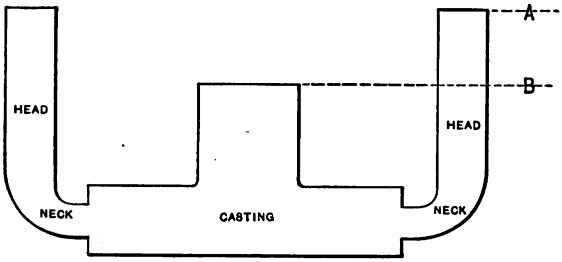

FIG. 16.—Ineffective manner of attaching sink-heads.

One of the least effective ways of placing sink heads, and yet one that is frequently attempted, is to attach them to the bottom of the casting by means of thick necks, in the manner shown in Fig. 16.

A few moments reflection should show the moulder who uses this method of attachment that the casting has as much tendency to feed the head, up to the level *B*, as the head has to feed the casting, and that only the portion *A–B* of the head is effective in producing pressure on the metal in the neck. A head equal in height to *A–B* placed on top of the casting will be as effective in feeding, as far as pressure exerted goes, and will be far more effective in fact, as it will feed the whole casting. The side attached head cannot by any stretch of the imagination be expected to lift the semi-solid metal within the casting and fill the cavity forming in the top. This is an extreme example, yet men have tried for a week to get a sound casting in a case almost as simple as this.

When a casting has to be poured in a horizontal position, so that a great horizontal area is presented that must be provided with heads to feed shrinkage, the rule that a sink head feeds most effectively downward, not sidewise, shows us that we shall secure the most effective feeding, by the use not of a few large heads, but of a number of small ones, placed closer together. The extent to which even a large head will feed sidewise from its base is so slight that the only way to secure a thoroughly sound casting under these circumstances is to see to it that the heads are close enough together to allow their effects to overlap.

Chills.—"Chills," so-called, are commonly used on steel castings to promote soundness. Their function is not, as in iron castings, to produce a change in the structure of the metal next to them by which it is made harder, but simply to cause the metal that comes in contact with them to cool rapidly. The usefulness of this is not at once apparent. It consists, first, in evening up the cooling of a casting with light and heavy sections, and thereby lessening the tendency to pull apart when the light section solidifies and contracts, and tears away from the soft and weak heavier section; and second, in assisting the sink heads to feed heavy sections. This is the more important of the two functions, and frequently makes it possible to reduce the size of the heads, or in extreme cases to dispense with them almost altogether. That a chill should have the same function as a sink head is not at once evident. On reflection, however, it is plain that the formation of shrinkage cavities in the steel is due to the fact that commonly a mould is poured full and the supply of metal through the gate cut off by freezing, before the setting of a heavy section has had time to proceed far. The contraction that then begins can be fed only from a head. Could the freezing of the steel be instantaneous from outside to center, no shrinkage cavity would form, since contraction would then take place throughout. As Prof. Howe has shown in his classic article on "Piping and Segregation in Steel Ingots,"[1] it is the lagging of the

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[1] Transactions American Institute of Mining Engineers, 1907, page. 3. See also Howe and Stoughton, same volume, page 109.

cooling of the interior after the outside has frozen that accounts for shrinkage cavities.

Now, if the metal, as fast as it runs into a mould, can be instantaneously chilled and frozen in successive concentric layers, each inside its predecessor, obviously each layer will assume its proper dimensions as fast as it freezes, and when the mould is filled the metal will all be solid. The same will be true if the metal freezes in successive layers from below upward. Though this condition cannot be attained, yet by the judicious use of chills the steel can be made to solidify so rapidly that much of the shrinkage occurs while the metal is still being poured into the mould, and hence much of the feeding of the shrinkage cavity is done by the stream of metal running in through the gate, and the action of the sink heads is made to occur earlier, and therefore more efficiently and thoroughly.

This is the same principle as that utilized to pour solid ingots—freezing the bottom of the ingot rapidly by casting in a heavy-walled iron mould, with the small end down, and causing the top to cool slowly by making it heavier than the bottom, by the use of a mould whose walls are thin at this point, or by means of sand sink heads. The casting corresponds to the bottom of the ingot, the chills to the heavy mould walls, and the sink head to the top of the ingot whose freezing we retard.

Obviously, to retard the freezing of the sink heads by scattering charcoal or sand on them, or even by the use of artificial means of heating, will assist us in the steel foundry. There is a distinct limit, however, to the extent to which it will pay to go in this direction. Charcoal and sand are often put on top of the heads of important castings to keep them hot, but artificial heating of sink heads generally does not pay.

Gates.—The manner of gating a casting and the size, number and location of gates and runners, have a very considerable effect upon its soundness and general appearance. Theoretically, to take the reasoning that has been so well worked out for the pouring of ingots, the best way to pour would be straight down into the casting, so that the bottom would be filled first, and chill first, and each succeeding layer would be poured of hot steel, the sink head last. The shrinkage of the lower parts of the casting would then take place first, the upper parts would "feed" the lower, and the sink head would feed the top thoroughly. It is from the nature of the case inexpedient to pour castings in this manner because the falling stream of metal would destroy the mould, and as a rule separate runners or vertical pouring channels are used, with horizontal passages or gates leading to the mould near the bottom. The bottom of the runner is "dished out" slightly to form a pool from which the steel shall flow quietly into the casting; and this cavity is protected from the cutting action of the falling stream of metal by a paving of nails. In this manner the metal is taken into the mould with the least possible commotion and bubbling, which is essential to prevent the surface imperfections which result from having the steel come swirling and splashing into contact with the walls of the mould and freezing while still in commotion.

In consequence of this necessity for filling the mould quietly, the gate or gates are commonly put at or near the bottom of the casting, and, in consequence, the metal fills the mould from below upward. In pouring castings of considerable height, this results in the worst possible condition of the metal for filling shrinkage cavities, since the cooling proceeds from above downward. To overcome this difficulty it is most useful to place a second and often a third gate part way up the casting. By this arrangement, the mould is filled in successive layers, the metal flowing through gate 2 as soon as the metal reaches its level, and running in on top of that introduced through gate 1 and so on. As each layer feeds the one below it, the heads will act more efficiently. To carry this procedure to its logical conclusion, obviously the sink heads should be poured from above, and poured slowly, in order to keep them molten as long as possible and add fresh hot metal to feed shrinkage. In pouring very small work it is not always possible to take these precautionary measures, but it is very common when large and important work is being cast to take the ladle over the heads when the metal reaches them, and pour them from above. Sometimes the sink heads are fed again with hot metal from the ladle, a few minutes after they are first filled. Since these extra gates and this method of pouring sink heads from above tend to reduce the size of heads necessary, a little forethought in this direction is often of great value.

When horizontal moulds are tipped up at the pouring end to assist the metal in flowing freely into the casting, as is often done with long thin pieces, top pouring is to a certain extent substituted for bottom pouring. Care has to be taken, under these circumstances, that the metal does not flow so fast as to scour the mould, and in general any part of the mould where metal flows rapidly or falls a few inches has to be protected with nails.

In the case of a long casting having one end much heavier than the other, two methods of pouring can be followed, depending upon the relative cross-sections of the ends and the kind of steel of which the casting is made. With some alloy steels of low melting point and great fluidity, heavy chills placed upon the large end will serve to make that end freeze before the metal has filled the casting, so that by gating at the light end and tipping that end up, the casting can be made solid by the use of chills alone. In that case the bottom (large end), freezes first and is fed by the metal flowing from the small end, which in turn is fed and made sound by the metal in the gate and runner.

When, however, the large end is so much heavier than the light end that chills will not cause the heavy part to freeze in time to be fed by the metal running from the gate, sink heads on the heavy part are needed to take care of the shrinkage that occurs after pouring ceases. In that case, if the casting is gated and tipped up at the small end, the sink heads are not well placed to feed the whole casting. For instance, in the casting shown in figure 17, if chills will not cause the heavy end to freeze early enough to be fed by the metal from the gate, there will be fluid metal in the upper portion of the casting practically from end to end, when pouring ceases. Let us assume that the runner will suffice to feed the casting as far along as the point where the horizontal line XY intersects the casting at D. The rest of the fluid metal from D to C will tend to run downward to feed the shrinkage of the big end, and will exert a fluid pressure equal to the vertical height of D over C, or DE. This will be balanced by the portion of the sink head from C to B, equal in height to DE, and only the portion of the head AB will exert effective pressure downward. The cavity will by definition tend to form somewhere between C and D, because the fluid metal will run down to feed the shrinkage near C, and leave a void above, and it is not at all probable that the portion of the head AB will exert suffi-

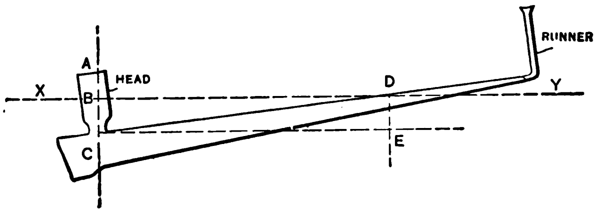

FIG. 17.—Illustrating action of sink-heads and chills.

cient pressure to force the solidifying metal back along the length of the casting and close this distant opening effectively. Though a second head between *C* and *D* will help matters to a certain extent, yet the same reasoning applies to a second and a third head as to the first. True, a second head located exactly where the cavity tends to form would no doubt prevent its formation. But it will be a difficult matter to determine in advance just where this head should be located, because many factors, such as temperature of metal, speed of pouring, etc., will affect the rate of cooling of the castings to such an extent that the cavity will not be located in the same position in every case.

Moreover, the metal that rises into the lower head will have run over the chills and become cold, reducing the effectiveness of the head, if the pouring is confined to the gate. In case cores that would be cut out by the running stream, or other considerations, render gating at the large end impossible, the head should be filled by a second ladle as soon as the metal from the gate reaches it, in order that it may be poured with hot metal and so tend to remain molten longer than the casting.

Should there be no objection to gating at the large end, this casting should be so gated, and tipped up at that end. Then the freezing of the upper end will occur after that of the lower, both because it is heavier, and because it is poured last. It will effectively feed the lower portions, and the head, especially if filled separately from above, will be in a position to feed the upper portion most thoroughly. The chills in this case should be omitted, since it is not desired to hasten the cooling of the upper portions, in fact quite the contrary; and moreover, they would possibly so cool the entering metal that it would not "run" the light end. If any chills are used, they should be placed at or near the lower portion of the casting, *i.e.*, the light end.

Though a fairly large head would be needed in this method of pouring, since it would have to take care of the entire shrinkage of the casting, while the head in the other method of pouring would take care of only the shrinkage occurring after the casting was filled (and therefore the excess over what the chills were able to accomplish); yet as the conditions would favor complete soundness, better work would be done, with perhaps no more metal in heads, than in the method of pouring with big end down, using chills and a head.

To use big end down pouring, with chills at the lower end and the head at the small end, is assumed to be impossible in this discussion, owing to the light end being too small to stay liquid long enough to carry metal from a head to the lower end.

The size and number of the gates and the size of the runners must be such that the metal flows freely into the mould. Steel, especially low carbon steel, has so high a melting point that it is comparatively sluggish at temperatures that make cast iron as fluid as milk. The gates for steel castings are therefore made much larger than those used in pouring iron.

In pouring a casting that is filled up from a gate in the bottom, the metal, of course, is always at a higher level in the runner than in the casting. Were it not, the flow would cease, as the pressure on the metal in the gate is due to this difference in level, and proportional to it. To make the runner large and heavy does not increase this pressure, nor, as long as the steel is fluid, does it tend to send any more metal through a given size of gate.

If the gate is as large as the runner it will, of course, carry the metal into the mould with the minimum loss of flow by the friction between the metal and the sides of the gate. With a gate much smaller than the runner, which cannot carry the metal into the mould as fast as it is poured down the runner, the latter will fill up and produce great pressure on the gate, so that the steel will enter the mould at high velocity. But though at first this high pressure will maintain the flow, yet as the casting fills, the pressure will fall, and the amount of metal running in will be less than if the runner and gate were of the same size. The result will be, first, that when pouring begins, the steel will flow too rapidly over the mould, resulting in great scouring and cutting of the sand; and second, that the mould will fill slowly, especially toward the last, and the gate may even freeze before the casting is filled. The gate area, therefore, should be equal to that of the runners.

In filling a high mould, the cross-section of runner and gate needed will be greater than for a low mould of the same approximate section, for the reason that as the metal rises in the mould it becomes chilled (and even semi-solid at the surface), and hence flows less freely. The runner will fill up to levels increasingly higher and higher than that of the metal in the mould, and partially overcome the increased resistance to the flow. But there is a limit to this, which is reached when the runner is full, and any further slowing down of the flow may well result in the freezing of both gate and runner. Hence to fill a tall mould with one gate, heavy runners and gates are needed, that the pouring may be done rapidly.

If, however, use is made of gates at several levels, in the manner already described, this difficulty is overcome, since as soon as the metal in mould and runner has reached the level of the second gate, the metal flows in on top of the sluggish steel already in the mould, and no longer has to lift it. Should the runner or gate freeze at the bottom before this level is reached, moreover, the runner will at once fill up to the second gate and fill the mould through it, whereas if but one gate is used, pouring would have to be finished down the sink head.

The use of several gates at different levels, therefore, decreases the size of runners and gates needed, since the runner between the bottom and the second gate need stay open only until the latter begins to work. After that, the runner down below can freeze without hurting anything. We can, therefore, fill for instance a 10-ft. mould, using two gates, with a runner of the same size that we would use for a 5-ft. mould. The saving in metal scrapped in runners and gates by this method is considerable.

In a high casting, it is plain that the use of gates of smaller cross-section than that of the runners will by decreasing the amount of metal entering the mould, increase the tendency to slow filling of the mould and consequent freezing of the gate or runner.

Pouring.—To secure the best results in running castings, the rate of flow of the steel should be under control. That this is true will be at once apparent if we consider the extreme, and of course impossible, case of a mould filled instantaneously. The metal being then at an even temperature throughout, cooling will begin at all parts of the surface at once, thin sections will cool much before thick ones, setting up heavy stresses; and the entire work of feeding the shrinkage will fall upon the sink heads. In some cases very rapid pouring, approximating these conditions, does not reduce the effectiveness of the sink heads—but frequently, the result of rapid pouring is that the top of the casting cools as rapidly as the bottom, so that the feeding is very incomplete. Generally it is most desirable to get the first metal into the mould as rapidly as possible without cutting into the sand, and gradually decrease the rapidity of flow as the mould fills. Such pouring, especially when the gating has been so arranged that the metal enters the mould at successively higher levels, or from above, allows the maximum proportion of the shrinkage of the solidifying bottom portions of the casting to be taken care of by the hot metal being run in, and leaves the sink heads less to do when the pouring is stopped. The heads when possible should be filled from above with hot metal.

The desirability of being able to control so nicely the rate at which the mould is filled is the chief argument against the use of ladles that pour through the bottom with stopper and nozzle in the usual manner. The bottom pour ladle gives a stream that runs with great velocity; and the velocity is dependent upon the depth of metal in the ladle. To check the flow of steel, we can only lower the stopper head, which results in a fan-shaped stream that strikes the pouring cup instead of running cleanly down the runner, and the wear on stopper heads prevents us from indulging in this practice too freely, lest we cut the head off.

Large ladles, of course, cannot be poured with nicety over the lip, but can be handled only with a nozzle. Used for castings of such size that the full flow of the nozzle is required for some minutes (and in very large work it is often hard to get the steel in fast enough), the nozzle does excellent work. But for small castings it is generally best to use a ladle of not over 3 tons capacity and pour over the lip. It is even probable that many of the moulds that are commonly poured from a 10-ton ladle with nozzle, could be far better handled by the use of two or three light ladles filled from the large one—the big ladle meanwhile handling the heavy work. To follow this practice makes necessary some means of tipping the big ladle to pour into the small ones, which is not commonly provided.

Again, when we have to pour very light castings, the 2- or 3-ton ladle is too big, and its stream is too heavy and falls too far. It would take too long also to pour a great many small flasks from the big ladle. "Bull ladles" or "shanks" are needed for this work, and are used in sizes of from as light as 50 lb. capacity up to 1000 lb. or so, depending upon the size of the castings to be poured. For a given weight of castings, say an average of 5 lb. each, it is questionable whether the very small shanks sometimes used are desirable. Some foundries making 2-ton heats use 100-lb. shanks, pouring 20 castings from each, working five shanks at once; and thus are obliged to refill each shank eight times. The metal to be sure is held in the shanks a very short time, and hence has little time to cool off; but in such small masses it cools rapidly, and the time lost in running back to the big ladle to refill increases the time spent in pouring the heat, and hence the cooling off of the steel in the big ladle. To save the time spent in refilling ladles it is desirable to use the largest shanks that can be poured without allowing the steel to grow "cold" in them.

When heats of some 2 to 3 tons are made, as in the majority of the small Bessemer shops, many heats are poured partly from the large ladle, partly from the shank. In this case, the first of the heat is, of course, used for the light work, poured from shanks, and the pouring generally kept up until the metal becomes too "dull" to run the light castings, when what remains in the ladle is used for heavier work. The advantage of providing both light and heavy work for each day's pour is too plain to require extended exposition, as the heavier work uses the dull metal from the last of many a heat, which would have to be poured as scrap, if only light castings were made up for pouring.

In small Bessemer foundries (and to some extent in small electric furnace work), the relative advantages of "shanking from the vessel" and "shanking from a ladle," are in debate.

The advocates of the former method base their arguments upon the fact that the hot vessel keeps the steel up to temperature better than the ladle. On the other hand, the advocates of pouring the whole heat into a ladle point out that filling shanks from the vessel is slow and rather dangerous, so that the heat is poured more rapidly by shanking from a ladle—and further that by taking the steel at once from the vessel and starting another heat, the vessel is kept very hot, with the result that the steel of each heat is hotter when blown. The advantage probably lies with shanking from the vessel when rather large shanks are used, and access to the vessel for filling is made easy, and with shanking from the ladle when very light shanks are employed, and access to the vessel is difficult.

In the case of the small electric furnace the question of initial heat of the steel does not come up, since the furnace can be kept up to full temperature while the steel is being poured by means of shanks—hence shanking from the furnace undoubtedly will result in the steel being brought to the moulds hotter than if shanked from a ladle. Should the shanks used be very light, the time spent in filling them would seriously affect economy, by cutting down the day's output of the furnace. Shanking from the ladle should be practised when possible, in order to increase production, and decrease the consumption of current per heat. Should a great deal of very light work have to be poured, necessitating extremely hot steel, the metal can be shanked from the furnace—or the heat can be poured into several ladles, each serving four or five shanks.

The foundry lay-out governs to a very great extent the pouring methods that can be used. This will vary so widely from shop to shop that only general consideration of the subject is possible. The lay-out for the day's pouring should be so arranged that a definite routine can be followed with each heat. Care should be taken that the moulds are not so distributed as to necessitate carrying the ladle long distances in moving from casting to casting. Should several ladles be necessary, especially if each ladle is serving several shanks, the floor space must be ample, to avoid interference between crews. A little attention given to this subject in planning the shop when first built will save countless vexatious delays when the productive capacity of the shop is reached.

Digging Out and Cleaning.—Frequently, especially with steels whose shrinkage is high, a casting cannot be kept from cracking, unless cores or portions of the mould are broken up as soon as the steel has solidified. Large cores and portions of moulds are frequently made partly collapsible, for instance by making their interior portions of cinders or of some inflammable substance like sawdust, so that they will yield to the pressure put upon them when the casting begins to contract; but it is generally necessary also to break up the cores thoroughly. By making their interior of loose ashes, and the arbors of very brittle cast iron, the destruction of the cores with bars and sledges is greatly facilitated. Many castings, especially of some of the alloy steels, must be dug out of the mould and the cores thoroughly broken up, the moment the steel is strong enough to bear handling.

Castings of very uneven section, especially of steel of high shrinkage, even if thoroughly dug out when red hot, will crack if allowed to cool in the air. The author has seen a 6-ton casting of ordinary carbon steel break clean in two through perfectly sound metal, some 36 hours after it was cast and some hours after it was cold enough to lay the hand on, from the strains set up by the unequal cooling of the thick and thin sections. To avoid this difficulty, the castings may be deeply buried in sand and allowed to cool; or cleaned very roughly, charged into a furnace or heated pit, which is brought to about the temperature of the castings, and there allowed to grow cold. These precautions, in the majority of cases, will be sufficient to insure against cracking and breakage.

Many castings of steel that has a high shrinkage, however, must not be allowed to grow actually cold before charging into the heat treatment furnaces; unless kept quite hot, they will break in cleaning, or in the first stages of heating up in the furnaces. It is not pleasant work to clean the sand and nails from a casting hot enough to show a temper color on the fresh fractures when the heads are knocked off, but it has to be done. Castings of this class almost always have to be taken from the sand and cooled in a preheated furnace or pit, mere burying in sand not being a sufficient safeguard against cracking, and are removed from the cooling furnace while still hot enough to show temper colors on a fresh fracture, when the heads and runners are knocked off, the sand and nails cleaned off as rapidly as possible, and the cored holes cleaned out, and are got into the furnaces while still hot enough to boil water that falls upon them. Heads that cannot be knocked off without danger of cracking the casting are burned off with the blowpipe.

Fortunately, these steels often have a low melting point and are very fluid, hence a neck very small in proportion to the sink head can be counted upon to feed the casting so thoroughly as in many cases to completely empty the head, leaving it a mere shell. The small necks, especially if the steel is brittle, make it possible in the majority of cases to knock off the heads, either by hand or with a dolly or drop, without fear of cracking the casting. Very good judgment, however, is needed in proportioning the necks and heads, in placing the heads, and in knowing how far to go in hammering on a head that refuses to come off. Many a casting is destroyed by an overenthusiastic man who persists in pounding away at an obstinate head or runner.

Steel castings that can be allowed to grow completely cold before cleaning and annealing, either by merely shaking them out and leaving them to cool in the air, or by cooling them in a furnace, can be cleaned at leisure. In removing runners and heads, good judgment is necessary. They may be broken from the castings, when the necks and gates are small enough. It is a pretty safe rule, however, that if a head cannot be broken off by hand, or by a very light "dolly" or drop, it had better be burned or sawed. By cutting away the neck with an air hammer and chisel or the torch, many heads can be broken by hand; but to make the necks small enough to break, at the cost of bad feeding of the casting and holes under the head that require a lot of plugging, is poor economy.

The large heads, if accessible, can be cut off with a cold saw; and it is part of the business of the moulders so to place the heads that they shall be accessible, unless it is manifestly impossible to do so. In that case the oxyacetylene or other burning torch comes into play and either cuts the head entirely off, or so cuts into the neck that it can be broken without jar.

The practice occasionally followed of setting a casting up and beating off the sink heads by means of a heavy falling weight, is especially to be avoided. The casting is commonly full of strains; if of very brittle steel, so much the more danger is there of the casting giving way under the interal strain plus the gratuitous strain imposed by the heavy blow; if of soft steel, and consequently less brittle, so much the heavier the blow needed to break off the head, and so much the greater the added strain produced by the blow. There is really no need for haste in removing the heads, as in the case of steel that has to be cleaned hot; and the money saved by the quick and cheap method of getting off heads will be lost in the castings that break and are scrapped, or that crack but do not fail until they are in service—a far worse matter than the loss of a casting in the shop.

CHAPTER IX

HEAT TREATMENT AND ANNEALING

Frequently, steel castings are sold without annealing, especially when the sections are not so unequal as to cause shrinkage stresses. The impression prevails very generally that the relief of these stresses is the chief function of annealing. Though this is far from the truth, yet it is an important function.

The magnitude of the stresses set up in the shrinkage of steel can be roughly measured by means of a test bar of the shape shown in Fig. 18. By measuring the distance between two punch marks, located as shown, on the thin portion of this casting, before and after cutting through this section with a hack saw, it will be found that this distance after sawing in two will be about .013 in. less than before.

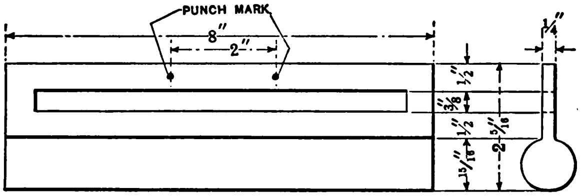

Fig. 18.—Stress-test casting.

This amount, however, is the sum of the shortening of the large section, and the lengthening of that portion of the small section lying outside the punch marks. In this case the punch marks were 2 in. apart, and the length of the casting 8 in. Therefore this sum of .013 in. equals the extension of three-fourths of the small section, plus the contraction of the large section. If we call the total extension of the small section X, then the contraction of the large section equals $.013-\frac{3X}{4}$.

Now the stresses in each section in pounds are equal. The cross-sectional areas of the sections are .6902 sq. in. and .125 sq. in.

If the modulus of elasticity in compression is equal to that in tension, and amounts to 29,000,000 lb. per square inch, then:

$A = \frac{29{,}000{,}000}{8} =$ the force in pounds per square inch needed to stretch or compress the bar 1 in.

A times $.6902 =$ the force in pounds needed to stretch the large section 1 in.

A times $.6902$ times $\left(.013 - \frac{3X}{4}\right) =$ the force in pounds needed to stretch the large section $\left(.013 - \frac{3X}{4}\right)$ parts of an inch.

Similarly,

A times $.125$ times $X =$ the force in pounds needed to compress the small section X parts of an inch.

Then,

$$A\ (.6902)\ \left(.013 - \frac{3X}{4}\right) = A(.125)(X)$$

Whence $X = 0.014$ in.

Then,

$\frac{29{,}000{,}000}{8} \times (.014) = 50{,}750$, the stress in pounds per square inch that was set up in the small section of this casting. This figure is of course only an approximation, as the accuracy of measurement is not great, and the bars are somewhat deflected by the stresses set up in cooling. Indeed, this figure is above the elastic limit in compression, and hence an impossible one. The great severity of this stress, however, will be easily believed when it is stated that only by cutting such a casting from its sprue can it be kept from breaking; if it is pounded with a hammer, a few blows will cause the light parts connecting the two legs to snap in two like pipe stems, and many of the castings will break apart even in cooling in the air.

These residual stresses can be relieved almost entirely by allowing the castings to cool slowly and evenly from the initial heat in a furnace—the castings either being put in at a high temperature, or got in at such temperature as can be managed, and heated up. Were the relief of stress the only, or even the chief function of annealing, therefore, it would be quite sufficient to cool the castings in pits, such for instance as are used for chilled iron car wheels, or in annealing furnaces.

We know, however, that in order to secure the greatest toughness and strength, we must heat our castings for a certain length of time to proper temperatures, and cool them from those temperatures at an appropriate rate. This annealing could be carried out without allowing the castings to grow cold after solidifying; commonly, however, they are allowed to cool and are cleaned of adhering sand, and the sink heads and sprues removed, before annealing. The difficulty and expense of properly heating them up when heavily coated with sand, and the extra expense involved in heating sink heads, make this practice essential for proper annealing.

It is very commonly assumed that the fracture of a bar of cast steel, as viewed by the eye, is sufficient examination of the "structure" to indicate whether a given piece of steel has been annealed or not, and if the annealing has been properly carried out. It may be stated without hesitation, however, that the fracture is a most insufficient indication of the thoroughness of the annealing, since in any piece of cast steel that has been reheated above a certain temperature, the characteristic coarse crystallization of the raw steel will be found to have been replaced by a practically uniform fine grained fracture, quite regardless of the rate of cooling from the annealing temperature. The eye, therefore, is unable to distinguish in the fracture of the steel any considerable differences in internal structure, due to variations in their rate of cooling. When we come to study the internal structure of the steel, as revealed by examining under the microscope the polished surface of a test piece etched with suitable acids, we find that in two steels whose fractures as judged by the eye are identical, there may be enormous differences in structure; and tests will soon show us that these differences in *microstructure* are accompanied by, and can be used as indications of, great differences in physical properties.

The science of metallography is a study in itself, has its own most extensive literature, and can be covered here only in the barest outline, as applied to cast steels. First and foremost, it must be understood that by this term is meant not the mere examination of the steel under the microscope; the science of metallography in its broadest sense includes the physical, and all other testing of steel, and the study of the effect of chemical analysis, methods of manufacture, methods of heat treatment, even methods of moulding and pouring, upon it. The microscope is but one tool, although an important one, in the hands of the metallographist.

In preparing steel for microscopic examination, one face of the specimen is first brought to a mirror surface by polishing on emery papers or cloths of increasing fineness, and on buffing wheels coated with tripoli powder or jeweler's rouge. The polished surface is next etched with acids, iodine, or other corrosive agents, that attack the microscopic constituents unequally, then washed and dried. The microscopic constituents of ordinary steel thus revealed are as follows:

Ferrite.—Pure iron, free from carbon; slightly colored by acids; the junctions of the ferrite crystals are brought out by etching agents, which eat into the junctions and reveal them as black lines. Carbonless steel or wrought iron is composed almost entirely of ferrite, but in wrought iron the slag fibers make up a considerable part of the section.

Cementite.—The chemical compound, Fe_3C, of iron and carbon. Very hard and brittle; not colored by acids, appears clear white; but colored yellow by sodium picrate.

Pearlite.—The eutectoid mixture of cementite and ferrite found in steel containing carbon, when cooled slowly from above the recalescence point. It is built up of thin parallel plates of ferrite and cementite alternately. Colored black by acids, when viewed under low power. Under high power, the banded appearance is seen—cementite white and ferrite black, because the ferrite is eaten away below the level of the cementite plates and does not reflect the light.

At from .80 to .90 per cent. (generally given at .89 per cent.), carbon, the entire mass of ordinary steel in the slowly cooled state consists of pearlite.

Steels between 0 per cent. carbon and .89 per cent. carbon are composed of ferrite and pearlite in proportion varying with the carbon. Low carbon steels are composed of ferrite with small areas of pearlite. In steel of .25 per cent. carbon the pearlite occupies about one-third of the cross-sectional area. As carbon increases, pearlite increases, the ferrite occupying less and less of the area; at about .60 per cent. carbon the ferrite appears chiefly as a net-work surrounding meshes of pearlite; as .89 per cent. carbon is approached the net-work of ferrite becomes discontinuous and the nets thin, finally disappearing.

Above .89 per cent. carbon, free cementite appears as a net-work surrounding pearlite meshes, the net-work growing more continuous and the nets thicker, as carbon increases. Many needle-shaped cementite areas intersect the pearlite meshes at various angles.

In general, the strength of the steel rises, and the brittleness increases, in direct proportion to the carbon content.

Steels below .89 per cent. carbon are called hypo-eutectoid steels.

Steels of .89 per cent. carbon are called eutectoid steels.

Steels above .89 per cent. carbon are called hyper-eutectoid steels.

Sorbite.—Pearlite that cannot be resolved under the microscope. The alternate plates of ferrite and cementite are too thin and discontinuous to be visible. Sometimes called "emulsified pearlite"—the pearlite having visible plates being called "lamellar pearlite." Typical of carbon steel that has been cooled in air from above the recalescence point, so that the austenite has been transformed too rapidly to produce lamellar pearlite.

Austenite.—The solid solution of Fe_3C, in iron; above the critical range, the entire mass of a steel exists as austenite. Cooled with great rapidity from above the critical range, as for instance, by quenching a thin piece of steel in iced brine (particularly if much carbon, nickel or manganese is present), steel consists wholly or partly of austenite.

Colored yellowish by acids; appears as uniform grains of a single substance, resembling ferrite; the crystal junctions outlined as black lines.

Martensite.—Austenite partly transformed; a transition product between austenite and sorbite. Very hard and brittle. Etched with iodine exhibits markings in acicular or arrow-head arrangement, sometimes heavily outlined in black. Characteristic of carbon steel that possesses marked hardening power, and that has been quenched from above the recalescence point.

By measuring the rate of heating or cooling of a sample of steel, it will be found that at certain well-defined temperatures, marked changes occur in this rate. These are called the "Critical Points," and correspond to changes of state of one or more constituents of the steel. That which occurs at the lowest temperature is known as the "Recalescence Point," because at that temperature, steel containing enough carbon to form a fair proportion of pearlite, evolves sufficient heat in cooling to cause its temperature to remain stationary for some moments, or even to rise slightly. This phenomenon is known as recalescence.

Two of the critical points, A_1 and A_3, occur at somewhat higher temperatures in heating than in cooling. This phenomenon, which is really the raising or lowering of the critical point from the temperature at which it should occur, is due to lag, or molecular inertia—the fact that the transformations require time to complete themselves. Hence the raising or lowering of the temperature is the greater, the more rapid the rate of heating or cooling. Could that rate be made infinitely slow, the critical points in heating and in cooling would be at the same temperature. As it is, the temperature interval is considerable, so that we have to distinguish between the two points by the symbol *Ac* for heating and *Ar* for cooling. Normally Ar_1, for instance, occurs at 680 or 690° C., and Ac_1 at 720 to 740°.

It is this dragging down of the transformation points by rapid cooling, assisted by the influence of carbon, manganese, nickel and some other alloys, that gives steel its hardening power. Very rapid cooling so far depresses the temperatures at which the transformations take place that they are wholly or partially suppressed, giving us austenite in the former case, and martensite or sorbite, in the latter. This discussion omits troostite and some other transition constituents that are not of great importance in the heat treatment of steel castings; and omits also some other means by which the transition constituents can be obtained, as for instance, quenching steel heated above the recalescence point, but below the other critical points.

The Carbon-iron Diagram.—The carbon-iron diagram (Fig. 19) shows the temperatures at which steels of varying carbon content solidify, and the temperatures at which their critical points occur, plotting temperatures against carbon per cent. With all that portion of the diagram lying to the right of the point, carbon equal 1.75 per cent. we shall not concern ourselves in this discussion, as the very high carbon steels and cast irons are of little interest to the steel foundryman.

Referring to the diagram, the line *PSK* is the recalescence point A_1 at which pearlite is formed on cooling, and changes to austenite on heating (called Ac_1, heating, Ar_1, cooling).

MO is the point A_2 (Ac_2 heating, Ar_2 cooling), at which alpha ferrite becomes beta ferrite on heating, and *vice versa.*

GOS is the point A_3, (Ac_3 heating, Ar_3 cooling), at which beta ferrite is liberated from austenite on cooling, or changes to gamma ferrite and dissolves in austenite on heating.

It will be seen that above about .35 per cent. carbon, A_3 falls until A_2 and A_3 unite, becoming a single point A_{2-3}.

A_{2-3} continues to fall as .89 per cent. carbon is approached, until at .89 per cent. carbon, the transformations all take place at the recalescence temperature A_1, giving us a single point A_{1-2-3}.

SE represents the temperature at which free cementite in steel above .89 per cent. carbon is dissolved in austenite on heating, and is set free on cooling.

In crossing the line *MOSK* in heating, iron loses the bulk of its magnetism; and, of course, recovers it on recrossing the line as it cools.

At the line *AB*, solidification of liquid steel takes place. The line *Aa* represents the temperature and composition of the solidfying metal, the line *AB*, that of the molten mother metal. The first freezing particles are of lower carbon content than the mass of the steel. Thus, a steel of .5 per cent. carbon begins to freeze at the point (*q*), and the composition of the first freezing layers is (*p*). As freezing proceeds, the molten mother-metal becomes progressively richer in carbon, its temperature and composition sliding along the line *AB*, and the successive particles of freezing metal also become richer in carbon, their temperature and composition sliding along the line *ps*. Meanwhile diffusion of carbon begins in the frozen portions of the mass, tending to equalize the composition of the successive layers. If this diffusion is complete, the temperature and composition of the frozen portion slide along the line *pr*.

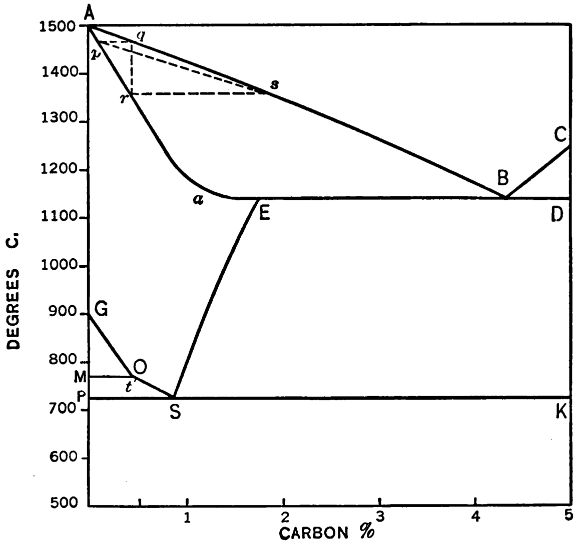

FIG. 19.—The carbon-iron diagram. From Proceedings of Sixth Congress, International Association for Testing Materials.

When the temperature of the steel has fallen to *Aa*, the final particles freeze. Thus a .50 per cent. carbon steel is completely frozen at a temperature represented by (*r*); the temperature and composition of the last freezing particles will be (*s*); that of the last particles of the molten mother-metal to freeze, also (*s*), and if diffusion has been complete in the frozen portions, the composition and temperature of these portions (*r*).

At any temperature between (*q*) and (*r*), on the line (*qr*), the amount of solid is proportional to the horizontal distance between this point and the line *AB*, the amount of liquid by the horizontal distance from this point to the line *Aa*. Thus when we reach the temperature (*r*), no liquid remains, and the composition and temperature of the last freezing particles have reached (*s*). If diffusion were complete, these last freezing particles would then assume the composition (*r*), of the frozen portion.

Actually, diffusion is not complete, so that the first frozen particles contain less carbon than those last frozen. The austenite of the just frozen steel is thus heterogeneous, the first freezing particles forming a net-work of low carbon austenite, the axes of the nets being lowest in carbon.

During the cooling of the steel through the region *AaESOG*, further diffusion occurs; and if time enough were allowed for diffusion to complete itself, the initial heterogeneity of the steel would be effaced. With ordinary rates of cooling, however, the net-work of low carbon austenite (primary austenite), remains to form primary ferrite when the line *GOS* is crossed.

On reaching temperature (*t*) on the line *GOS*, free ferrite begins to be liberated from the (solid), austenite, the composition of the remaining mother austenite as the temperature falls sliding along the line *OS* until it reaches the composition *S*, when the remaining austenite transforms to pearlite, with the accompanying evolution of heat. In the liberation of free ferrite as the steel cools from *GOS* to *PS*, those parts of the steel lowest in carbon liberate their ferrite first, because their transformation point is highest; and thus the primary austenite net-work is perpetuated as a net-work of (primary) ferrite, which is made visible by etching. The (secondary) ferrite set free within the meshes of austenite forms finer net-works and veins.

Referring to Fig. 21, a cast steel showing typical net-work ferrite, it will be noticed that the heavy white lines are not arranged in a true net-work, but rather are roughly parallel. The inclusions of slag or sulphide of manganese are located at the axes of these ferrite lines. This suggests that in the original solidification of this steel, the austenite that froze first assumed the pine-tree or dendritic shape generally characteristic of the first-freezing crystals. In such a method of crystallization, the austenite shoots out into the molten metal in long sheets, with parallel side branches. If there is anything in the theory of nucleus action, it is reasonable to assume that these dendrites may be formed upon slag or sulphide droplets as nuclei. According to this reasoning, the just frozen steel would be heterogeneous in the manner shown diagrammatically in Fig. 20. The lines *Aa* represent the low carbon axes of the first-freezing austenite dendrites, the lines *B*, the corresponding axial lines of the highest carbon austenite rejected, during the process of freezing, into the spaces between the dendrites. It must be understood that the carbon content increases progressively from *A* to *B*; and that diffusion will partly eliminate the smaller side branches *aa*, and also, of course, lessen the difference in carbon content between *A* and *B*.

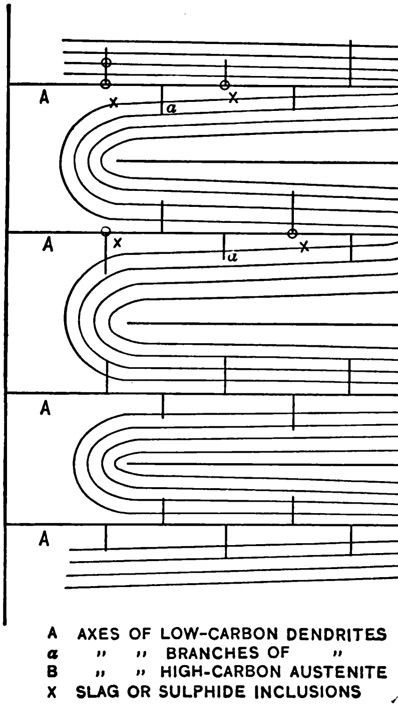

FIG. 20.—Dendritic freezing upon nuclei of slag or sulphide of manganese.

When the transformation range A_3 is reached, the low carbon axes *A* will liberate their ferrite first, because the liberation of ferrite takes place at a higher temperature, and therefore sooner, in the lower carbon portions of the steel. If this ferrite tends to precipitate upon the slag or sulphide inclusions, as it is reasonable to assume it will, the ferrite will largely remain in the position of the axes of the original dendrites of primary austenite; and perhaps will concentrate strongly around the inclusions. The ferrite rejected from the space between *A* and *B* will to some extent follow the first precipitating ferrite, and no doubt will concentrate upon the inclusions.

The greater the time consumed in crossing the transformation range A_3 to A_1, the more thoroughly will the ferrite be concentrated from this intervening space. Thus, in the comparatively small casting shown in Fig. 21, there is a great deal of ferrite precipitated in this intervening space; while in much heavier castings, especially in the interior where the cooling is slowest, the concentration goes further, producing large lakes of ferrite about the slag inclusions, and leaving the intervening space much freer from ferrite. The coarseness of the original heterogeneity of such a large steel casting reinforced by this transformational segregation, makes these ferrite masses very large.

The researches of Professor Howe[1] show that in the formation of ferrite at $A3$, the net-works are first formed, then a great deal of ferrite is liberated within the meshes of austenite, much of it being located in the octahedral cleavages of the austenite crystals; then, if the cooling is slow enough, this ferrite migrates to the net-works, thickening them, and decreasing the amount of ferrite within the grains. In certain cases, the ferrite in the octahedral cleavages is so abundant as to mask the net-works, and occasionally the latter appear to be lacking. The evidence at hand appears to show that in rolled or forged steels, a long, high heating (above $A3$) so increases the tendency of this cleavage ferrite to persist that it is not absorbed into the net-works. Belaiew[2] obtained this structure, associated with a net-work, in a steel cooled very slowly from the solidification point. It is characteristic of meteorites; and has been found in masses of steel that are known to have been heated for a long time to an elevated temperature.

It is possible that the absence of slag or sulphide nuclei, upon which primary austenite can precipitate, may in some cases so retard the

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[1] American Society for Testing Materials, 1911, p. 263. *International Journal of Metallography*, Vol. III, p. 4, and elsewhere.

[2] *Revue de Metallurgie*, 1910, p. 510; 1912, p. 321.

precipitation of that austenite in freezing that the initial heterogeneity of the steel is not as great as in the majority of cases. Should this tendency to restrain initial heterogeneity be reinforced by a cooling slow enough to allow diffusion to make the austenite quite homogeneous, the ferrite might be so largely precipitated at A_3 in the cleavages of the austenite grains, by a suitable rate of cooling through the transformation range, as to give rise to this structure to a very great extent. At any rate, the presence in cast steel of this Widmanstättian structure, as it is called, is often accompanied by a marked lack of slag or sulphide inclusions. Fig. 22 shows a typical example of this structure.

It may be that the amount of slag or sulphide inclusions may have a determining influence in fixing the size of the ferrite net-works in steels that show a net-work structure. Thus the presence of but few inclusions, especially if they are large, may concentrate the primary austenite at a few points, and so give rise to a coarse net-work; and that of a great many small inclusions, to a fine net-work. If the location of the net-work ferrite is governed in part by the position of the primary austenite net-works, and if the ferrite set free at A_3 has a tendency to precipitate upon the inclusions, they may well have this effect upon the size of the structure.

The size of the casting, however, is the chief factor in determining the net-work size. This is partly, no doubt, because the austenite net-works formed in the slow freezing of the large casting are coarse; and partly because the migration of the cleavage ferrite into the net-works, and that of the smaller net-works into the larger ones, during the cooling from A_3 to A_1, has time to proceed very far, on account of the slow cooling of such large castings. The interior of heavy castings, moreover, exhibits to a marked extent the "balling up" of the net-work ferrite, and its concentration into great lakes (often surrounding slag or sulphide inclusions), which, as Professor Howe has shown in the articles referred to above, takes place to a marked extent during slow cooling.

The prime object of annealing or heat treatment is to break up by heating the coarse crystallization of ferrite and pearlite (ingotism, or ingot structure), and replace it by a uniformly fine crystallization of the constituents, with resulting strong inter-crystalline bonding; and the abolition of the long planes of inter-crystalline weakness due to the large sheets of ferrite in the slowly cooled steel. Heating the steel above AC_3, that is, above the line *GOS*, causes the pearlite to transform to austenite (in crossing AC_1), and the ferrite to dissolve in the austenite (in crossing $AC3$). The absorption of the ferrite, however (especially the primary ferrite), requires time, since it necessarily consists in the diffusion of carbon from the high carbon into the low carbon portions of the steel (a microscopic cementation, as it were, of the ferrite by the pearlite portions), and cementation we know is a gradual process.

The coarseness of the microstructure of the steel, as we have seen, depends chiefly upon the size of the casting, which determines the rate at which it has frozen and cooled. The time necessary for a fairly complete diffusion of the carbon at a given temperature, therefore, depends upon the size of the castings, since the larger the ferrite areas the longer it takes to cement them. This necessary time should be counted, not from the moment that the annealing furnace reaches the desired temperature, but from the time when the casting itself is hot through. It has been found, however, that the time necessary to cement the small ferrite areas in a piece of a casting $\frac{1}{2}$ in. thick, is not a great deal shorter than the time needed to cement the large areas in a piece cut from the center of a casting 6 in. thick; so that evidently the time actually needed to eliminate the larger masses of free ferrite is not as much greater than that necessary to eliminate the small masses, as their difference in size would lead us to expect.

The carbon-iron diagram shows that .60 per cent. carbon steel can be annealed at a lower temperature than .20 per cent. carbon steel. But the rate of diffusion is so much lower at the lower temperatures, that for practical purposes it will in many cases be found convenient, for steel normally containing free ferrite, to use a uniform annealing temperature of from 850 to 900° C.

The castings should be heated to this temperature for at least two hours and preferably four hours, *after they have become hot through*—very large castings may be heated longer if it is found necessary. The total annealing time of the large castings will in any case be considerably longer than that of the small ones, as it requires so much longer to bring them up to heat throughout their mass.

By heating cast steel containing free ferrite to about 1200° C. for a few minutes, the diffusion of the carbon is made much more rapid—but a coarse structure will generally be produced by heating to this temperature, to remove which a second heating to about 900° is required. Hence, it is generally a saving of fuel to use a single heating to about 900°, for from two to four hours. The high heat (1200°) is expensive in fuel, in wear and tear on furnace brickwork, in scaling of the steel, and in excessive warping of the castings, and partakes more of the nature of a laboratory method than of a practical one.

Now, upon cooling from the annealing temperature, these initially coarse-grained cast steels have a strong tendency to reprecipitate their ferrite in heavy masses, apparently located to a great extent along the lines of the old primary ferrite net-work. Steels which possessed the Widmanstättian arrangement of the ferrite appear on slow cooling from the annealing temperature to show a ferrite-pearlite structure of fair uniformity, though not fine grained; but steel that was of the net-work class shows ferrite in very coarse masses. Reference to the accompanying microphotographs illustrates this very clearly.

Figs. 21 and 22 show the characteristic microstructures of medium carbon steel in the cast condition, Fig. 21 being of a typical net-work structure steel, Fig. 22 of a steel in which the Widmanstättian structure predominates.

ANALYSIS OF STEEL SHOWN IN FIGS. 31–36

No	C	Si	Mn	S	P
21	.43	.38	.47	....	....
22	.37	.32	.51	....	....
23	.42	.51	.60	....	....
24	.39	.48	.47	....	....
25	.41	.45	.51	....	....
26	.43	.49	.60	....	....
27	.41	.52	.68	....	....
28	.39	.41	.55	....	....
29	.35	.42	.65	....	....
30	.35	.42	.65	....	....
31	.59	.14	.72	0.23	.017
32	.21	....	1.17	....	....
33	.18	.41	.93	.065	.052
34 35 36	.20	.45	1.02	.057	.049

Fig. 23 shows a similar steel annealed for two hours at 900°, cooled slowly to 800° and quenched in water; and Fig. 24 a steel annealed for two hours at 900°, cooled slowly to 750° and quenched in water. Fig. 23 shows a very uniform sorbitic structure (the cooling being too slow, owing to the size of the test bar, and the carbon too low, to produce martensite), while in Fig. 24, as the steel has been allowed to cool slowly to a temperature below *Ar*3, the ferrite has reprecipitated, and shows a marked tendency to the net-work arrangement. This tendency of the ferrite to coarse crystallization

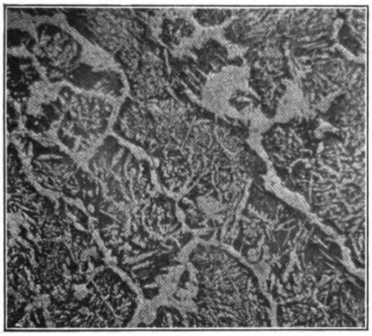

FIG. 21.

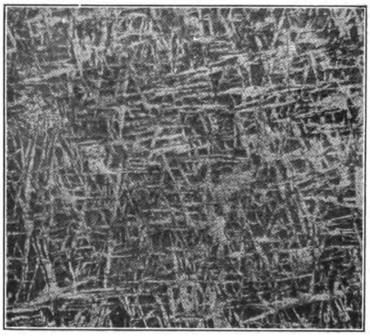

FIG. 22.

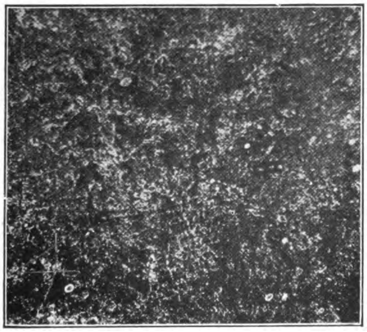

FIG. 23.

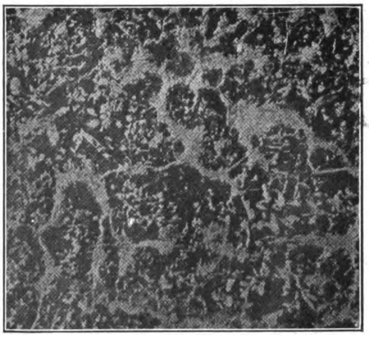

FIG. 24.

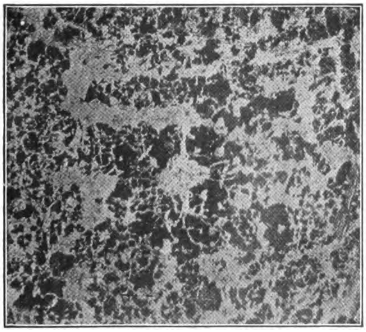

FIG. 25.

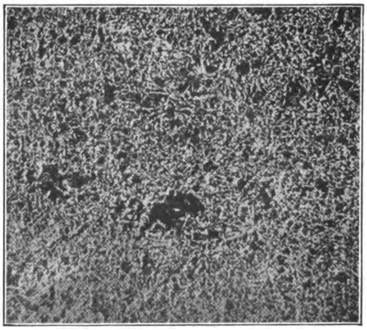

FIG. 26.

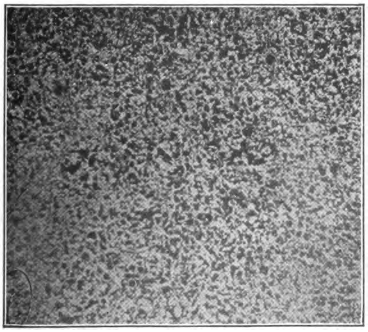

FIG. 27.

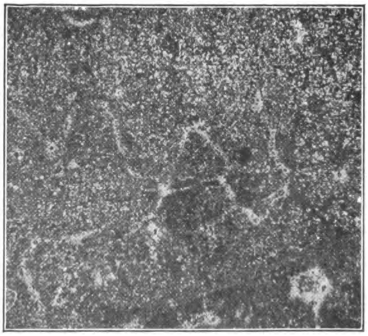

FIG. 28.

Reduced about $\frac{2}{3}$ from original magnification of 60 diameters.

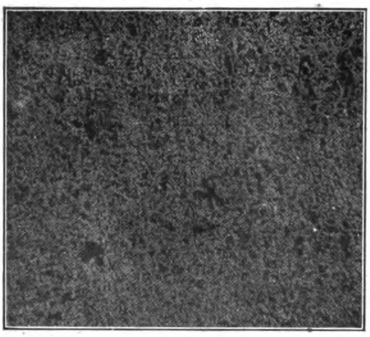

FIG. 29.

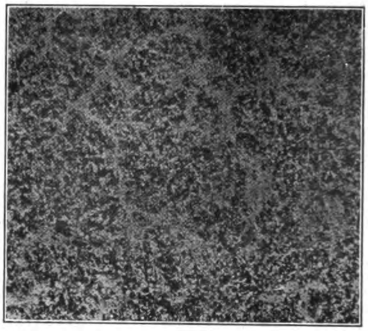

FIG. 30.

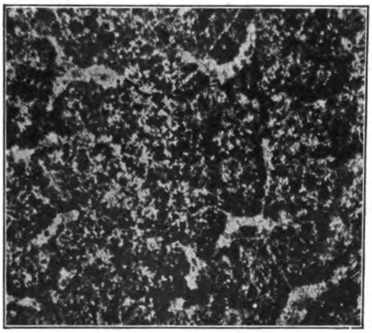

FIG. 31.

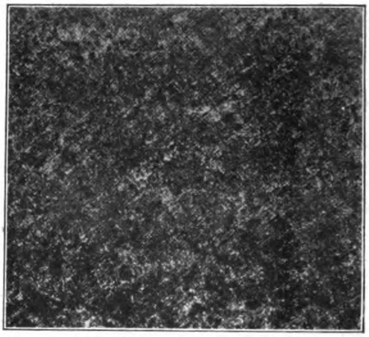

FIG. 32.

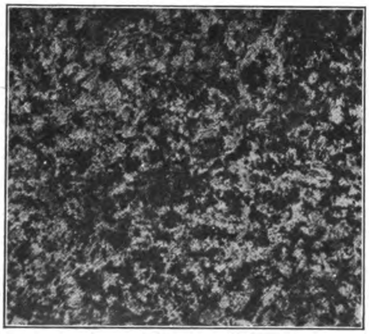

FIG. 33.

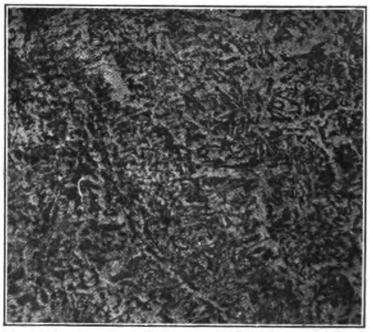

FIG. 34.

Reduced about $\frac{2}{3}$ from original magnification of 60 diameters.

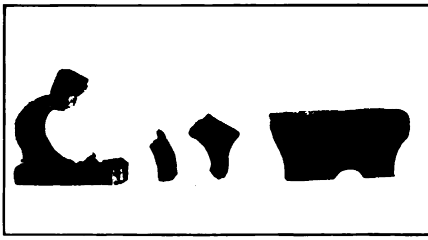

FIG. 35.—About $\frac{1}{6}$ full size.

FIG. 36.—About $\frac{1}{3}$ full size.

is also very strongly marked in Fig. 25, a similar steel annealed at 900° for three hours and cooled very slowly; six hours were spent in cooling this bar from 900 to 600°. There is more ferrite in Fig. 25 than in Fig. 24, because in the latter the separation of ferrite that normally takes place in cooling from 750 to 680° has been partially suppressed by quenching.

The black areas in Fig. 24 are sorbite, because the rapidity of the final cooling has prevented the formation of true (lamellar) pearlite; in Fig. 25, the black areas are pearlite. Higher magnification should show this clearly.

Fig. 26 shows the structure of a similar steel annealed at 900° for three hours, and cooled in the air in about 10 minutes. Here, evidently, we have quite a different structure from any that we have yet seen. The black sorbite remains, and in two places it shows a strong tendency to dominate and give a structure like that of Fig. 23, but the cooling, although not sufficiently rapid to repress altogether the liberation and agglomeration of ferrite, yet has not been slow enough to allow the ferrite to agglomerate to such an extent as to leave large ferrite areas. Hence, we have the comparatively fine ferrite net-work, resembling somewhat a rolled steel after annealing.

Fig. 27 shows a similar steel heated to 900° for one hour, and cooled to black in about 40 minutes; the cooling through the critical range has been too rapid again to permit the formation of large ferrite patches, though, as will be seen by comparing Fig. 26 and Fig. 27, the coagulation of the ferrite has partially taken place, since the ferrite in Fig. 27 is noticeably coarser than that in Fig. 26. The white areas in Fig. 27 are ferrite, the black, sorbite or pearlite.

The formation of lakes of ferrite which has been prevented by quenching as shown in Fig. 23, or by air cooling as shown in Fig. 26, will take place again if the steel is reheated to $Ar1$, or nearly to that point. Curiously enough, the reappearance of ferrite in a coarse net-work takes place at a lower temperature in the reheating of a quenched steel than in the reheating of an air-cooled steel.

Thus, Fig. 28 shows a steel of this class annealed at 900° for two and one-half hours, cooled slowly to 800° and quenched (resulting of course in structure like that of Fig. 23), then reheated to 700° for a few minutes and again quenched. The separation of very finely divided ferrite from the sorbite background is clearly shown, and also the agglomeration of ferrite into lakes in a partially defined coarse net-work.

Fig. 29 shows a similar steel annealed at 900° for one and one-half hours and cooled in air, then reheated to 700° for one hour and cooled slowly; and Fig. 30, a steel heated to 900° for two hours and cooled in air, then reheated to 750° for one hour and cooled slowly. Comparing Fig. 29 with Fig. 26, we see that the structure of the air-cooled steel has been little if at all altered by the reheating to 700°, a temperature which brought out coarse ferrite in the quenched steel. In Fig. 30, however, there is an agglomeration of ferrite over the whole background, and also a well-defined agglomeration of ferrite into a large net-work.

These microphotographs have been selected from some hundreds which were made in the course of an extended research into the behavior of cast steel in heat treatment, and are typical examples. No hypo-eutectoid carbon cast steel tested in this research, and none yet brought to the author's attention, has failed to behave in the characteristic manner shown by these photographs. To be sure, the tendency to the formation of coarse ferrite showing traces of the net-work arrangement is not equally marked in all cast steels, yet none are wholly free from it. The predominance of a Widmanstättian arrangement of primary ferrite in the raw steel appears to decrease or mask the formation of this coarse net-work after annealing; and the presence of many slag or sulphide inclusions (usually associated with a strongly marked net-work structure in the raw steel), to increase it.

All electric furnace steels, however low in sulphur and phosphorus, that have come under the author's attention, show this same tendency to the retention of coarse ferrite patches after annealing; some more than others. Fig. 31, an electric furnace steel containing but .023 per cent. of sulphur and .017 per cent. of phosphorus, shows that even a steel very low in sulphur exhibits this tendency very strongly. The rather numerous inclusions in this specimen must be largely slag, which suggests that slag resists the advance of carbon into the ferrite as strongly as does sulphide of manganese, which would naturally be the case if the inclusions act as mechanical barriers to the progress of the diffusing particles; that slag as well as sulphide of manganese particles tend to hold the ferrite because it adheres to them; or that, as already suggested, the action of the inclusions is indirect, that is, that they act as nuclei upon which net-work austenite is deposited in freezing, and so favor the formation of coarse ferrite net-works, which are eliminated slowly by diffusion in annealing. This steel was annealed at 900° for four hours and cooled in air, then reheated to 760° for two hours and slowly cooled.

The well-marked coarse net-work is clearly shown, though it is less noticeable than in the previously exhibited examples, because, owing to the higher carbon (.59 per cent.), there is much less available free ferrite in this steel to form the coarse patches.

The great majority of steel castings requiring annealing are heated to about 900° and after soaking are slowly cooled, resulting in a structure similar to that of Fig. 25; coarser in larger castings, finer in smaller ones. In some cases, by opening the furnaces more or less and hastening the cooling, structures like Fig. 26 and Fig. 27 are obtained. The annealed steel will have a higher tensile strength, elastic limit, extension, contraction of area, and bend than the steel in the raw state; and by accelerated cooling the strength and elastic limit can be raised without sacrifice of toughness, or with actual gain of toughness; accelerated cooling, in particular, increases the resistance to sudden shock. The annealed castings will be softer than the raw steel—and, of course, quite free from shrinkage stresses, unless the accelerated cooling is continued until the castings are cold.

If accelerated cooling is used, the furnace should be closed up after the castings have reached black heat, and the cooling finished slowly enough to allow of the relief of cooling stresses. If the accelerated cooling has been very rapid, or if an air or water cooling has been used, the stresses set up in the castings will be nearly as great as in the raw state, and they must be heated a second time to relieve the stresses.

For convenience, the rates of cooling from the annealing temperature may be classified as follows:

1. Slow—over 50 minutes from 900° to black.
2. Accelerated $\begin{cases}\text{over 10 minutes from 900° to black.}\\ \text{less than 50 minutes.}\end{cases}$
3. Rapid $\begin{cases}\text{less than 10 minutes from 900° to black, as for instance}\\ \quad\text{cooling in air or air blast.}\end{cases}$
4. Very rapid (quench in oil or water).

GENERAL RULES

General rules for the heat treatment of hypo-eutectoid carbon-steel castings may be given as follows:

Heat to 850 or 900° for from two to four hours after the castings are hot through.

The more rapid the cooling from the annealing temperature, the finer will be the microstructure, and the greater will be the hardness of the steel, and the stresses resulting from unequal cooling of sections of unequal size. Rapid coolings always, and accelerated coolings sometimes, must be followed by a second heating to a lower temperature to reduce hardness and relieve stresses. Accelerated coolings should be followed at least by a period of slow cooling, as, for instance, by closing the furnace again after the castings have cooled to black heat.

The temperature used for reheating after rapid cooling should not exceed 680°, if the castings have been quenched in oil or water, and should not exceed 720°, if the castings have been cooled in air or air blast. The castings should be held at these temperatures a sufficient length of time to produce the softening effects desired. Quenched castings, which may be reheated to from 640 to 680°, should be held at the reheating temperature from two to eight hours. Air-cooled castings, which may be reheated to from 660 to 720°, should be held at the reheating temperature from two to six hours. The lower the reheating temperature and the shorter the reheating time, the higher will be the strength and elastic limit of the steel, and the less the toughness, as measured by extension, contraction of area, bend and shock test. Reheating to temperatures that liberate coarse ferrite causes great loss of strength and toughness.

In general, the more rapid the cooling from the annealing temperature, if proper reheating temperature and time have been used, the greater will be both strength and toughness—these properties bearing a direct relation to microscopic fineness of structure. More especially, the shock toughness of soft and medium soft steel is greatly increased by rapid cooling and proper reheating.

The maximum softness, and the maximum magnetic permeability, however, are attained by very slow cooling from the annealing temperature, which results in the liberation of the maximum amount of free ferrite.

In selecting a method of heat treatment for a given casting, careful attention should be given to the size and intricacy of the piece, and especially to the possibility of cracking it if quenching is attempted. Frequently also, it will be impracticable to remove a casting from the furnace while hot, in order to quench it or cool it in the air, on account of the danger of bending it seriously. In such cases, accelerated cooling by opening all doors, etc., of furnaces, followed by proper reheating, will give good results.

In the majority of cases, accelerated or air cooling after reheating may be resorted to without setting up harmful stresses.

The maximum allowable reheating temperatures are those which effect the softening and relief of stresses in the least possible time, without resulting in the liberation of free ferrite in heavy masses. For the greatest toughness, the maximum time quoted must be used. That no harmful stresses are produced by air, or even water, cooling from the reheating temperature, has been proved by careful tests on stress test bars, and on full-sized castings of various shapes. That no hardening is thus produced has been carefully proved by experiment, and it is to be expected, since hardening results only on cooling steel after it has been heated above Ac1, and the reheating temperatures given do not exceed Ac1.

The author's experience of several years in the heat treatment of cast steel has shown conclusively the falsity of the widely held opinion that rapid cooling, and especially quenching, of steel castings, is almost sure to result in dangerous stresses and many cracked and broken pieces. Of course, very heavy sections, especially of hard steels, cannot be quenched without rupture. To quench successfully a solid spherical or cylindrical casting 8 or 10 in. in diameter, is well-nigh impossible. But if the steel is not too high in carbon, castings with quite widely varying sections, in all weights from a few pounds up to at least a ton, can be quenched in oil or even in cold water without the loss of a single piece, especially if they are not allowed to grow dead cold in the water. In the reheating, of course, the furnace men must take pains to heat these quenched castings up slowly until they reach a temperature of 300 or 400° C., but the work presents no difficulties not easily mastered by men familiar with the handling of high-grade steels. In a paper read before the American Foundrymen's Association, Mr. Stoughton[1] has called attention to the advantages of heat treatment of ordinary steel castings. In a recent article in the technical press,[2] the possibilities of these methods were disposed of in a few words. The writer of this article found that air cooling produced greater strength, etc., than slow cooling, but that to preheat the steel to a higher temperature, air cool it, reheat to the ordinary annealing temperature, and cool slowly, left the steel in the same condition as if it had been once annealed and slowly cooled. Very naturally, a slow cooling from the ordinary annealing temperature produced identical results in two castings, one of which was slowly cooled after one heating to this temperature, the other preheated, air cooled, then re-

[1] Proceedings American Foundrymen's Association, Vol. XX, p. 451.

[2] Edwin F. Cone, *The Iron Age*, May 1, 1913, p. 1049.

heated to the ordinary annealing temperature, and slowly cooled. How the double heating, so carried out, could be expected to give superior strength to the steel, is hard to understand. It is as though a blacksmith should say that it is useless to harden a chisel, because a second heating to the hardening heat, followed by slow cooling, leaves the steel dead soft. Just as the "tempering" of a hardened chisel has to be carefully controlled, in order to "draw the hardness" to just the right degree, so air-cooled or quenched cast steel must be carefully reheated to just the right temperature, to relieve the cooling stresses and draw to the required extent the hardness due to rapid cooling.

The Value of Heat Treatment of Hypo-eutectoid Cast Steel.—A test of some kind to reveal brittleness under shock is of great value in judging the effect of heat treatment. There are a number of impact testing machines now on the market, most of which use a notched test piece of small cross-section, which is broken by a heavy blow from a falling weight or pendulum provided with a knife edge to come in contact with the test piece. The force consumed in breaking the test piece is the measure of the brittleness of the steel, and the deflection of the test bar before rupture is a further indication of value. The force recorded is the sum of that necessary to effect the elastic deformation, and that necessary to effect the plastic deformation and rupture of the test piece. Because the plastic deformation of hard steels is slight (that is, they break without bending very far), while that of soft steels is very great, the total amount of force needed to break a soft steel and that required to break a hard steel in this test, are quite disproportionate. The test, therefore, should not be used to compare steels of varying carbon content. But to ascertain the toughness of a particular steel, as affected by heat treatment, it is of great value.

It has been suggested that by measuring the angle of bend in this test,[1] a basis may be found on which to subtract the work done in overcoming plastic deformation from that expended in overcoming elastic deformation and affecting rupture, and thus that a means may be found of using the test to compare different steels.

Fremont's machine tests a bar about $\frac{1}{4}$ in. by $\frac{3}{8}$ in. by 1 in., notched with a hack saw, and broken by the blow of a weight of 10 kgm. falling 4 meters. Charpy's testing machine is of the pendulum type. Several other designs are on the market.

In a paper[2] presented at the 1913 fall meeting of the American

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[1] Professor Henry M. Howe, Discussion of the author's paper, referred to below.

[2] Shock Tests of Cast Steels.

Institute of Mining Engineers, the author has pointed out what, at least in his opinion, is the weak point of this method of testing as applied to steel castings; that is, the wide variation in the value of the impact test from different parts of the same coupon of heat-treated cast steel. Two conclusions can be drawn from these variations: first, that the test is not reliable as an indication of the average toughness of heat-treated cast steel in any but very light sections; second, that the extreme toughness obtainable by quenching and reheating mild cast steel is confined to the outside half inch or so of thicker sections.

Experiments carried on for a period of years have shown conclusively that the presence of coarse ferrite, especially if it exists in a net-work structure, or in a partially developed net-work structure, whether formed on slow cooling from the annealing temperature, or on reheating after rapid cooling, to temperatures that allow the liberation of such ferrite, is always accompanied by more or less brittleness of the steel; and this brittleness is particularly marked when the steel is tested under sudden shock. This statement applies to all *coarse* ferrite microstructures, even if the structure is uniform.

This conclusion is in agreement with Mr. A. Le Chatelier's results on brittleness of steel.[1] That eminent authority has shown that in any hypo-eutectoid steel which has been cooled slowly after being heated above Ac_3, though under slow tensile testing very considerable toughness is exhibited, yet as the speed of testing is increased, the toughness decreases, and when the speed of testing is so great that the ultimate strength of the steel is reached almost instantaneously (shock test), the test bar breaks practically without elongation or contraction of area. On the other hand, quenched and reheated steels, provided the reheating temperature does not exceed 700° C., exhibit as great toughness when tested by shock tensile test as when tested by the usual slow tensile test.

In the table below are given the physical properties and heat treatments of test bars cut from a single casting of steel containing .10 per cent. carbon, .19 per cent. silicon, and .23 per cent. manganese.

Blow holes made it impossible to secure tensile tests on two of the bars, and one bending bar that undoubtedly should have bent 180 degrees was spoiled by a blow hole. It is particularly to be noted in these tests that the superiority of the heat-treated over the raw steel,

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[1] Congrès International des Méthodes d'Essai des Materiaux de Construction, Paris, 1900, Vol. II., part I, pp. 13–25—see especially p. 16, paragraph 4.

as judged by the tensile test alone, is not very great; as judged by the bend, is considerable, without revealing any variation in the toughness of the bars heat treated by the several methods; but as judged by the shock test, the toughness is improved some four-fold in the annealed and slowly cooled bar, seven-fold in the air-cooled and reheated bar, eight-fold in the bar cooled at an accelerated rate, and ten- to eleven-fold in the quenched bars, whether reheated or not. The shock test of 2.5 kgm., given by the raw steel, is extremely low; and the breaking of this specimen without measurable deflection, with a coarse crystalline fracture, confirmed the reading of the machine. The two tests that gave 25 and 27.5 kgm. did not break. It would be difficult to find a more striking example than this of the inadequacy of slow tensile testing alone, or even in combination with a bend test, to reveal even very considerable brittleness. That cast steel of .10 per cent. carbon requires annealing at all, is not admitted by many foundrymen. Yet, as the tests show, not only does it require annealing, if used for any purpose demanding toughness, but if the maximum resistance to suddenly applied stresses is to be secured, castings of even this very soft steel should be quenched, and of course, reheated to relieve stresses (the actual hardening of such a steel by quenching is too slight to affect the usefulness of the castings).

No.	Treatment Temperature and time	Tensile strength	Elastic limit	Ext. % in 2 in.	Cont, %	Fracture	Bend ½ in. ×1 in., on 1-in. mandrel	Fremont, kgm.
A	none	50,020	23,930	35.2	47.85	Coarse cryst.	50	2.5
B	900–3 cool in 40 minutes	55,390	28,750	38.5	67.0	Silky cup	180	20.0
C	900–3 cool slowly	....	....	......	......	....	45 (blow hole)	10.5
D	900–3 quench	....	....	......	......	....	180	27.5
E	900–3 air cool 710–6 air cool	56,450	32,950	39.25	65.2	Silky cup	180	17.5
F	900–3 quench 680–8 air cool	53,200	27,100	34.95	60.4	Silky cup	180	25.0

Medium carbon steels, especially those containing a large proportion of manganese, are made tremendously strong, and at the same time very highly resistant to shock, by rapid cooling and reheating. Examples could be given of the results of several years' experience with such steels, but only a few will be quoted. They are, however, typical.

Fig. 32 shows the microstructure of a steel containing .21 per cent. carbon and 1.17 per cent. manganese, heated to 900° for five hours and quenched in water, then reheated to 650 to 680° for six and one-half hours and cooled in air. This microphotograph was taken from a test coupon attached to a large casting; the physical properties of the bars cut from this coupon were:

TS	EL	Ext. % in 2 in.	Cont., %	Fracture	Bend	Fremont, kgm.
91,900	71,650	20.37	50.25	Silky	180	21.0

The very high shock test and bend, coupled with great strength, is particularly noticeable.

Figs. 33 and 34 show the microstructures of two small castings. They were too small to cut tensile or bending tests from them, but a bend of a projecting lug of one casting was made, the lug being bent flat on itself without fracture. The analyses and Fremont tests of these castings were:

Fig.	C	Si	Mn	S	P	Fremont, kgm.
33..................	.18	.41	.93	.065	.052	5.0
34..................	.20	.45	1.02	.057	.049	7.0

The very low shock test value, despite good slow bending toughness, is especially to be noted. The shock tests broke with almost no deflection, and showed a rather coarse crystalline fracture, practically identical in both. This coarse fracture of the shock tests of such steels is typical. The annealing of these castings had been by heating and slow cooling, and was very insufficient in No. 34, as the microstructure shows. Yet, the Fremont tests were about alike, even slightly better for No. 34 than for No. 33.

Casting No. 34 was sawed into two approximately equal parts, and one-half heat treated as follows: Heated to 900° for four hours and quenched in water, reheated to 680° for eight hours and cooled in air. The two halves, one in the annealed, the other in the heat-treated condition, were then subjected to the blows of a drop of about 500 lb. falling weight, with the result that the annealed half broke in three pieces at the first blow of the drop from a height of 4 ft. showing a coarse crystalline fracture; while the heat-treated half endured without fracture one blow from 4 ft., one blow from 5 ft., one blow from 6 ft., one blow from 7 ft. and two blows from 8 ft.; six blows in all. The two halves of the casting, after test, are shown in Fig. 35, annealed half (three pieces) to the left, heat-treated half (one piece) to the right. In Fig. 36 a back view of the heat-treated half, after test, is shown.

This drop test confirms the result of the Fremont test, which showed that the castings as annealed were brittle under suddenly applied heavy load, though they gave a good bending test. No section of these castings was over 1 in. thick, and the average thickness was about ½ in. The impact test is excellent for revealing brittleness in thin castings of this sort.

A rough test used by the author to demonstrate the toughness of heat-treated cast steel in heavier sections consisted in striking a 2½-in. square bar of the steel, resting on supports 24 in. apart, with a drop of about 500 lb. weight, falling some 10 or 12 ft. A 2-in. round bar was set in the middle of the test bar to localize the shock, and the test bar reversed after each blow. The result was a sort of accelerated endurance test under shock, the bars being deflected about ½ in. at each alternate blow, and straightened by each alternate blow. Of course, the greater toughness of the outside fibers, which are subjected to the maximum stress, increases the resistance of the bars to fracture in this test. Quenched and annealed bars of steel of about .25 per cent. carbon and 1.20 per cent. manganese, tested in this manner, have endured from 28 to 57 blows before rupture. What was particularly noteworthy in the performance of these bars was that frequently they exhibited cracks completely across each face, and extending some ¼ in. into the bar, three or four blows before final rupture took place, indicating very considerable toughness and resistance to the spreading of the cracks in the interior portions of the test bars.

Another rough test, used to exhibit the toughness of castings treated by quenching and reheating, was adopted for castings having an eye some 6 in. in internal diameter and 2 ft. long, with walls about 2 ½ in. thick, used to fasten these castings by means of a heavy pin, to another part of the machine. A hard steel wedge of suitable taper was seated in this eye, and then driven down by the blows of a heavy drop, weighing about 1500 lb. and falling about 12 ft. Quenched and annealed steel castings (.25 per cent. carbon, 1.20 per cent. manganese, of about 85,000 lb. tensile strength), so tested, endured from eight to fourteen blows before rupture; and in some cases the wedge could be driven no further with the drop employed. The rupture of the walls of the eye almost invariably followed an irregular line, the steel tearing slowly apart. No comparison with steel of the same carbon, annealed by heating and slow cooling, was made, but compared with higher carbon castings of approximately equal strength, the results of the tests were most illuminating, the harder steels never enduring over two blows. The second blow on the harder steel castings sent the fragments, or sometimes the whole eye, hurtling across the shop.

That these castings possessed great strength and toughness is demonstrated by the fact that in service they wore down on one side of this eye, which endured very heavy stresses applied somewhat suddenly, from the original thickness of some 2 ½ in. to a thickness of ¼ in., without rupture of the eyes.

The following figures are given to show the physical properties of a number of test bars, selected at random, cut from these castings. Each group represents a lot of tests made on the same day, though not in every case from the same annealing furnace.

Tensile strength	Elastic limit	Ext. per cent. in 2 in.	Cont., per cent.	Fracture	Fremont, kgm.	Bend ½ in. by 1 in., on 1-in. mandrel
88,850	63,500	26.60	52.9	Silky cup	19.0	180
88,300	61,240	28.11	54.75	Silky cup	14.0	180
89,600	60,400	26.19	47.3	Silky cup	15.0	180
85,950	60,400	28.36	59.05	Silky cup	22.0	180
89,200	61,020	26.19	51.0	Silky cup	11.0	180
100,000	70,820	23.8	49.65	Silky cup	23.5	180
92,850	62,300	24.66	55.6	Silky cup	15.0	180
90,100	60,200	26.95	58.75	Silky cup	13.0	180
98,800	66,680	22.80	48.75	Silky cup	24.0	145
88,550	60,600	26.60	54.4	Silky cup	11.0	180
96,150	65,070	25.57	57.15	Silky cup	15.0	180
90,000	55,100	31.05	56.3	Silky cup	15.0	180
85,100	55,970	29.14	58.8	Silky cup	30.0	180
80,800	51,510	29.14	62.5	Silky cup	28.5	180
90,700	62,780	27.2	56.6	Silky cup	25.5	180
85,950	51,040	25.26	58.6	Silky cup	30.0	180
83,450	51,700	29.69	60.45	Silky cup	27.5	180

Endurance Test.—Under ordinary conditions of service, of course, a casting will never be strained beyond the elastic limit, and therefore a casting of soft steel heat treated to give great shock toughness, will not be called upon to exhibit the plastic deformation which it is capable of enduring. A casting used, for instance, for the front axle of an automobile, will have a very long life under ordinary conditions of service, if it is capable of enduring a great number of stresses repeated constantly, none of which exceeds the elastic limit. We know that the higher the elastic limit of a steel, the higher in general will be its resistance to repeated stresses of a given intensity. As the elastic limit rises in proportion to increase in carbon content, it is in general better to use a medium high carbon steel for an axle than to use a soft steel, under ordinary conditions of service. Experience with locomotive axles has proved this to the satisfaction of engineers.

In certain classes of service, however, allowance must be made not only for ordinary, but for extraordinary, conditions. Thus, for instance, some manufacturers of taxicabs who use a cast steel front axle, make one portion of the casting sufficiently light to either bend or break, and thus save the rest of the car from injury, when it collides with some heavy object. In practice, they find that some of their axles have been so bent, straightened and returned to service, several times. Now, for such service as this, in which it is expected that the steel will occasionally be strained far beyond its elastic limit, a steel of great shock toughness and which will endure plastic deformation will be of value in two ways. First, in such an accident, it will be far less apt to break than a hard steel, and hence will in many cases prevent a serious smash-up. Second, such a steel can be bent and straightened more times than a more brittle steel, so that its use will result in a saving of money spent on replacement.

In order that such a steel should possess a good resistance to repeated stresses which do not exceed the elastic limit, it should be heat treated in such a way as to give it the maximum strength. It is true that, by so treating a hard steel, it will be given much greater resistance to repeated stresses than can be given to the soft steel. But the hard steel can never possess great shock toughness.

In the following tables, unfortunately based on but few examples, it is shown that a soft cast steel, quenched and annealed, will possess a tensile strength and elastic limit equal to those of a much harder steel annealed in the usual manner by heating and slow cooling, or heat treated by air cooling and reheating; and that the endurance of the soft steel so treated, to alternate stresses, at least of this type, is greater than that of the harder steel. Leaving out test *C*, five bars of the harder steel endured an average of 3,805,000 revolutions at a fiber stress of 28,270 lb. to the square inch; and five bars endured an average of 10,451,240 revolutions at 28,270 lb. to the square inch, and 590,560 revolutions additional at 38,870 lb. to the square inch. The four bars of the softer steel endured an average of 10,373,050 revolutions at 28,270 lb. to the square inch, and 823,950 revolutions additional at 38,870 lb. to the square inch. In every case but one, the soft steel gave a better test than the hard steel. These tests were made on the White-Souther endurance testing machine.

No.	Cut from	C	Si	Mn	S	P	Treatment		
							Heated to	For	Cooled
A	4 in. sq.	.42	.46	.73	....	....	900 degrees	5½ hours	air
							700 degrees	5½ hours	slowly
B	4 in. sq.	.44	.38	.59	....	....	900 degrees	5 hours	air
							690 degrees	3 hours	slowly
C	4 in. sq.	.48	.42	.71	....	....	960 degrees	? hours	slowly
D	4 in. sq.	.36	.54	.71	.049	.051	920 degrees	5 hours	air
							690 degrees	3 hours	slowly
E	4 in. sq.	.47	.56	.73	....	....	900 degrees	5½ hours	air
							700 degrees	11 hours	slowly
F	4 in. sq.	.43	.46	.65	....	....	900 degrees	4 hours	air
							700 degrees	5 hours	slowly
G	1¼×2½ in.	.23	.31	1.07	.037	.047	900 degrees	6 hours	water
							680 degrees	8 hours	air
H	4 in. sq.	.27	.46	.71	....	....	900 degrees	5 hours	water
							680 degrees	8¾ hours	air

No.	T S	E L	Ext. in 2 in., per cent.	Cont., per cent.	Fremont
A	82,100	45,990	8.41	9.79	7.5
B	76,170	42,990	14.64	15.11	5.0
C	76,730	42,750	12.05	15.81	5.0
D	73,200	40,630	14.08	19.79	10.0
E	79,590	44,020	10.94	11.49	8.5
F	73,200	40,200	12.5	16.4	7.5
G	67,200	44,400	14.19	31.3	32.0
H	78,710	46,400	22.8	24.21	17.0

ENDURANCE TEST

No.	Fiber stress	Deflection	Revolutions No. 1 end	Revolutions No. 2 end
A	28,270	.06	10,709,600	10,709,600
B	28,270	.06	4,685,000 (B)	6,708,000 (B)
C	28,270	.06	2,796,800 (B)	10,000,000+[1]
D	28,270	.06	3,474,300 (B)	2,368,700 (B)
E	28,270	.06	10,158,400	1,789,400 (B)
F	28,270	.06	10,339,300	10,339,300
G	28,270	.06	10,475,100	10,475,100
H	28,270	.06	10,271,000	10,271,000

No.	Fiber stress	Revolutions No. 1 end	Revolutions No. 2 end
A	38,870	280,800 (B)	302,000 (B)
B	....	....	....
C	38,870	....	288,700 (B)
D	....	....	....
E	38,870	1,828,600 (B)	....
F	38,870	366,000 (B)	175,400 (B)
G	38,870	393,900 (B)	845,500 (B)
H	38,870	834,100 (B)	1,222,300 (B)

B signifies bar broke.

[1] Exact number uncertain.

As already stated, it would no doubt have been possible by quenching and annealing the hard steel, to make it superior to the soft steel in this test, but the heat treatment would not have given the hard steel a much greater resistance in the impact test. Hence, although an automobile axle made of the hard steel quenched and reheated, would probably give longer life under ordinary conditions of service than the soft steel similarly heat treated; yet in case of a smash-up, there is little doubt that the hard steel would be broken short off by a blow which the softer steel would endure without rupture. In order, therefore, to have in our machinery parts a steel which will resist both repeated light stresses and occasional heavy stresses, we should use a comparatively soft steel which has been quenched and annealed. The automobile front axle is of course a very special case, and is seldom made of cast steel. It is referred to here, however, as a striking example of a type of service for which many machinery castings are made.

Experience with marine engine shafting and steam hammer piston rods has shown in many cases that a heat treatment which gives the steel great shock toughness will increase the life of the forging even as much as five- or six-fold.[1] What is true of forgings will be equally true of castings, except that because a casting almost inevitably contains small blow holes or flaws, it can never be made as reliable as a forging, so that the lengths of life of a number of similar castings will not be so nearly equal as would be true of forgings. But to maintain, as some quite competent engineers do, that because a casting is a casting, and almost sure to contain flaws or blow holes, it is not worth while to heat treat cast steel to give great toughness, is most illogical. It is certainly poor reasoning to say that because a casting is almost sure to contain a starting place for a crack, it is

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[1] Professor Henry M. Howe, discussion of the author's paper "Shock Tests of Cast Steels" referred to above.

not worth while to treat the steel to make it as resistant as possible to the starting and spreading of that crack.

High Carbon and Alloy Cast Steels.—Hyper-eutectoid cast steels, that is steels containing over .89 per cent. of carbon, and therefore consisting of pearlite and free cementite, are very little used. Their heat treatment has, therefore, not been worked out with the same thoroughness as that of mild steels. It follows from a consideration of the carbon-iron diagram that the heat treatment of these steels must be similar to that of hypo-eutectoid steels. Annealing must be at a temperature above the line *SE* in order to dissolve the cementite in the austenite, and the effect of varying the rate of cooling should be quite similar. The researches of Boynton[1] on hyper-eutectoid rolled steels have shown that by hastening the cooling from above the line *SE*, the separation of cementite can be largely suppressed. The temperatures for reheating should be the same as for hypo-eutectoid cast steels.

Chrome and nickel cast steels, containing about 1 per cent. of chrome, or 2½ to 3½ per cent. of nickel, and of carbon below the eutectoid ratio, which, like carbon steel, contain in the normal condition free ferrite, exhibit somewhat marked differences in the effect of annealing, from the behavior of the carbon steels. This is particularly noticeable in the case of slow cooling after heating above Ac_3. In these steels, though on slow cooling free ferrite appears, yet the distribution of this ferrite in heavy masses is much less marked than in carbon steels. Annealing and slow cooling of these steels, therefore, produces a much more uniform microstructure. The same rules as to increase of toughness and strength by special heat treatment methods, however, apply with almost equal force to these alloy steels.

The addition of nickel to steel lowers the critical points to a degree proportional to the amount of nickel added. The annealing and reheating temperatures, therefore, can be lowered to a corresponding degree, though it is by no means essential to do so. But as the sluggishness of the molecular changes in steel increases as temperature falls, the time of exposure to these temperatures should be increased in proportion as the temperatures themselves are lowered.

Manganese steel, containing, as usually made, from 10 to 15 per cent. of manganese, and from .80 to 1.5 per cent. of carbon, is heat treated by methods quite different from those followed for ordinary cast steel. By the combined effects of carbon, manganese and rapid

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[1] *Iron and Steel Magazine, May*, 1904.

cooling, manganese steel is rendered entirely austenitic and very tough, because the transformations are nearly or quite suppressed. In the cast condition, or when heated and slowly cooled, this steel is very brittle, owing to partial transformation of the austenite, and to the liberation of free carbide of iron and manganese (manganiferous cementite?), between the austenite grains.

As the steel is quenched from a high temperature, generally over 1000° C., the castings, if of unequal section, are left after treatment in a state of heavy stress. Relief of these quenching stresses is, moreover, extremely difficult, as to reheat the steel to a temperature high enough to relieve them, results in great brittleness of the steel.

The brittleness of the steel when cast; its high shrinkage, which results in heavy stresses in cooling in the mould and in treatment; and its low thermal conductivity; these properties make the design and heat treatment of manganese steel castings of complicated shape a difficult and fascinating task.

Annealing Furnaces.—Annealing furnaces are built in a great variety of designs, and almost any fuel may be burned in them. Coal, fuel oil, natural gas, or even occasionally producer gas, may be used, depending upon the price of the fuel. Producer gas, however, which requires regeneration for its combustion, is not commonly a good fuel for this purpose, since annealing furnaces generally have to be cooled off very considerably between heats, and often lie idle for many hours. Such conditions interfere seriously with the operation of a furnace that is at its best only when run continuously, and prevent the attainment of the economy that regenerative furnaces will give under suitable conditions.

In general, annealing furnaces should not be built large enough to take the entire day's output of a foundry at one charge, particularly if the size of the castings varies considerably. The practice of charging large and small castings in the same furnace is a very poor one, since if time enough is given the large castings to heat through properly, the small ones suffer from oxidation and consequent scaling; and a real loss is experienced in that the small castings are heated much longer than necessary, at a considerable expense in fuel.

Very large annealing furnaces, heated by one or more fire boxes so small that the temperature in the furnace will vary considerably from point to point, are most inefficient for two reasons, if not more. First, the castings at the "cold" points are seldom properly annealed; second, those at the "hot" points are annealed longer than need be, in an effort to bring the "cold" castings up to a proper heat.

Considered from this standpoint, the large "catch all" annealing furnace is most uneconomical, and it is extremely doubtful if the saving in labor attained by its use is sufficient to offset its great wastefulness in fuel and the poor quality of its work. One man can fire three small furnaces nearly as easily as one large one—quite as easily if oil or gas fuel is used—and if the three or more furnaces are designed with a view to making them suitable to the size of castings that are to be annealed in them, an economy of fuel will result from their use.

The deep furnace with a lift-off top gives great economy in charging labor, and when used for castings that are to be annealed by slow cooling, or accelerated cooling, does fairly good work. If heat treatment, properly so-called, is to be used, so that the castings have to be taken from the furnace for quenching or air cooling, it will frequently be necessary in such a furnace to set them on a heavy steel plate that can be lifted out. To remove castings one at a time from an open-topped furnace will not be very easy; and if they must not be allowed to cool before quenching, it will be hard to get them all out in time. Though the castings are generally piled in these furnaces more or less haphazard, it will in most cases be best to set them up more carefully so that they can be heated evenly and will not suffer from warpage.

The side-drawing furnace with a movable bottom is in most cases the best type to install, when heat treatment is to be used. They are more costly to build than open-top furnaces, but can be charged quite as cheaply, and make it easy to withdraw the castings one at a time for quenching, without cooling off the rest of the charge; or to take out a number of comparatively small castings set on plates and quench them in batches. A side-drawn furnace with fixed bottom can of course be used for the same work, by charging and drawing with piels, but the labor expense in such work is very great.

Continuous furnaces may be used for the heat treatment of very light work, if there is a great deal of it to be done. Such furnaces are often used to anneal small forged parts, and can of course be utilized to equal advantage for small castings.

Pyrometers.—Temperature control in steel casting annealing, has long been one of the weakest points in the practice of the shops, and lack of proper precautions to ensure correct annealing temperature has been almost universal. So common has been the practice of annealing steel castings without control of temperature, that in the majority of shops heat treatment has had no chance of success.

The great majority of castings require only annealing by heating and slow cooling; or at most, by accelerated cooling, followed by slow cooling to relieve strains. For such work, it may sometimes be possible to estimate the temperature closely enough by the eye, but when the eye is relied upon it will be found that no two heats will be annealed quite alike, because the man is not yet born who can recognize small temperature intervals by color. For the heat treatment of ordinary steel, the heating of alloy steels, and all work where the temperature must be closely controlled, pyrometers are absolutely indispensable; and their general use is advisable.

In practice, however, the use of pyrometers is not an absolute guide to the temperature of the castings, since it is neither economical nor sensible to install enough thermocouples in each furnace to give its temperature throughout. The eye must always be relied upon to a great extent to make sure that the steel throughout the furnace has reached the correct temperature. With one or two thermocouples in the furnace, the fireman can heat his steel quite uniformly to a prescribed temperature, because he can *match* colors very well indeed, and can bring all the castings to the color of the spots where the couples are. In this way he can do far more accurate work than is possible even by the use of a painted color scale; such a scale is not as useful as might appear, because the color sensation produced on the eye by a hot object is not capable of being matched closely against that produced by a painted board.

The men, however, should not be allowed to fall into the habit of simply heating up the furnace until the pyrometer indicates the correct temperature, holding the pyrometer at that temperature the proper length of time, and then cooling off the furnace or drawing the castings, as the case may be. Once taught to rely entirely upon the pyrometer, they consider that the burden of responsibility for the proper annealing of the steel has been shifted from their shoulders to those of the man who standardizes the pyrometers, and they no longer take pains that the steel shall all be at the temperature desired. Perhaps the best way to secure their attention to their work is by the use of test bars attached to various castings, or charged with the steel at several points in the furnace. A few test bars in every heat have a wonderful effect in making the men "sit up and take notice," and even if they are never tested at all (so long as the men do not find it out), are extremely useful. Used for tests, recorded in such a way as to be readily consulted and compared, they are invaluable.

At least one recording galvanometer should be installed, in addition to the direct-reading instruments, arranged so that it can be switched on to any furnace, or any two, three or more furnaces at once. Needless to say, the connections to this instrument should be entirely beyond the control of the men, and they should never know on what furnace the recording instrument is reading. Under these circumstances, especially when the pyrometer man comes around several times a day and makes sure that the instruments are all reading correctly, the men hesitate to try to cover up errors in the temperature of the furnace, lest the recording instrument "show them up." It is an excellent scheme to require the firemen on the furnaces to keep a record of their pyrometer readings at suitable intervals, on blanks provided for the purpose, because if they must read the instruments and record the readings, subject to check by the automatic galvanometer, they will be pretty sure to keep their furnaces at the right temperature.

No pyrometer system yet invented is "fool proof," nor a substitute for care and conscientious work on the part of the fireman, nor an absolute guide to correct annealing and heat treatment, but properly handled, such an installation is so useful and removes so much uncertainty that after a few months' use it appears well-nigh indispensable.

CHAPTER X

FINISHING, STRAIGHTENING AND WELDING

Castings frequently become warped to a certain extent, either from shrinkage in solidifying, or from bending when hot in the annealing furnaces, and then have to be straightened. As far as possible, this should be taken care of in the design of the pattern. For instance, if a projecting lug which should be at right angles with the casting is found to consistently take a position at an improper angle, it is far simpler to shift the lug on the pattern in the opposite direction, so that the lug on the finished casting shall be at the correct angle, rather than to bend the casting. Frequently, however, the bending of steel castings cannot be avoided, and the best way to do the work has to be considered. If the steel is sufficiently ductile, the part to be bent not too thick, and the degree of bend not too great, bending cold can be practised without harm to the casting. In too many shops this cold straightening is done with a drop of some kind, a practice that cannot be too heartily condemned. The effect of the suddenly applied blow is necessarily largely local, instead of being spread out along the casting, and frequently results in the cracking of the work. The crack may be visible, and spoil the piece; or even worse, it may be concealed and appear later in a broken casting whose failure results in loss of time, money, and even life. Even very tough alloy steels are frequently injured by this practice, and many failures of alloy steel castings have been traced to abuse in straightening. The hydraulic or power press, which enables the bending to be carried out slowly, is the proper instrument for bending castings and should be used to the absolute exclusion of bending by blows.

Bends in hard and comparatively brittle steels, or heavy bends, especially of thick sections, can be made only while the castings are hot. Experiments have shown that the lowest temperature that can be used for this purpose is about 600° C. Below this temperature ordinary cast steel is not sufficiently softened by heating to bend easily.

Should the casting have been heat treated by rapid cooling and reheating, or by accelerated cooling, it is desirable not to heat it again above 720° C., since temperatures higher than 720° destroy the heat treatment, producing coarse ferrite and reducing the ductility of the steel. Such work has to be straightened at temperatures between 600 and 720°, and several heatings may be necessary to complete the job. Steel annealed in the ordinary manner by slow cooling, may be heated for straightening to any temperature below the annealing heat, without damaging the heat treatment. In case these higher temperatures are used for straightening, however, it is necessary to allow the castings to cool slowly after straightening, or heavy shrinkage stresses will be set up in the metal, neutralizing to a certain extent the benefit of the annealing.

In particular, the practice of heating only one part of a casting in a bed of coals or a small furnace, straightening it, and allowing it to cool freely in the air, is to be avoided as far as possible, because the stresses set up in the piece by the local heating and rapid cooling may be as heavy as those existing in the casting before it was annealed, and may well result in trouble when the casting is put to work. If a coal fire or small furnace must be used for local heating of castings, the least that can be done is to allow the steel to cool slowly at one side of the fire, or in the furnace, after it has been straightened. In the majority of cases, however, heating the whole casting is the best practice, and as far as possible should be resorted to.

Welding.—Blow holes, shrink holes (as for instance under sink heads), cracks, etc., which not many years ago would have made it necessary to scrap a casting, are to-day welded up by means of the oxyacetylene or other gas torch, or the electric arc. If the work is properly carried out, a welded casting is nearly as strong as one that was sound in the first place. There are, however, many precautions to be observed in the welding of steel, some of which must be mentioned here.

In filling up holes, it is absolutely essential to heat up the entire surface of the hole before any metal is run in. To do this, it is frequently necessary to enlarge the top of the hole to a considerable degree, in order to get at the lower portions. Too frequently, the hole is merely run full of metal, which does not weld to the casting except at the surface of the work, resulting in a job little better than can be done by pounding cold metal into the hole—a mere device to cover up bad work and get it past the customer's inspectors.

In welding cracks, it is almost always necessary to preheat the metal for some distance on each side of the weld, to avoid the pulling apart of the weld when it cools and contracts. In some cases it is sufficient to preheat the casting near the crack with the welding torch; but frequently the entire casting has to be put in a furnace and heated up.

The steel of the weld itself, and the casting adjacent to the weld, are hardened to a remarkable degree in cooling in the air. This is due probably to the high temperature to which the metal is heated by the flame or the arc, which results in a very rapid cooling through the critical range, the heat being absorbed from the hot portions both by the air and by the cold parts of the casting. Under these circumstances, an air cooling becomes the equivalent of a water quenching, hardening the weld so much that it cannot be machined. For this reason all castings that have to be machined on the welded face, and all castings in which large and important welds have been made, should be reannealed after welding. At first sight, it would appear easier to weld the castings before annealing. But the brittleness of the metal in the raw condition makes it impossible to weld cracks until after the casting has been treated, more especially in view of the heavy shrinkage stresses existing in the unannealed casting.

Hammering the weld as it cools is often of great assistance in cases where the weld tends to pull apart from contraction of the casting. By spreading the cooling metal with hammers, the shrinkage is largely neutralized, so that the weld holds.

CHAPTER XI

LABORATORIES

To-day, the steel foundryman who should attempt to run his shop without chemical analysis of his raw materials and product, would be in danger of incarceration as a lunatic. Yet it is but a few years since steel makers scoffed at the idea of employing a chemist. The very small foundry, of course, may not have its own chemical laboratory, and may analyze only occasional heats; nevertheless, chemical analysis is an essential in handling the shop.

"An ounce of prevention is worth a pound of cure," is a maxim that the steel foundryman may well keep in mind. In the conduct of the shop, systematic use of the chemical laboratory to keep record of the analysis of raw material used and steel made, from day to day, is worth a hundred "investigations" started after trouble has developed in the foundry, or in the machine shops of the customer. Whatever analysis of the steel is deemed necessary, should be made and recorded every day, and the records kept in such a manner that if trouble occurs there will be some information to go on, in searching for the cause of the difficulty. The first result of maintaining such a system will be that trouble will be easier to account for; the second, that trouble will be less frequent.

As a general rule, the chief chemist should not be the man who does the calculating for the melting shop. In the large shops, of course, this is seldom the case. But small Bessemer or crucible steel foundries frequently have but one man on the premises who is capable of doing this work, and that man the chemist. The human being may some day be born who will be capable of figuring a heat of steel, and gazing undismayed upon analytical results for that heat that show a composition that was not desired. But, allowing for the little weaknesses of human nature, it is best to have one man calculate the steel, and another analyze it.

Just as our fathers doubted the value of chemical analysis in steel making, so this generation questions the usefulness of microscopic examination and physical testing of their product, as a part of the shop routine. Some decry these methods altogether, others say they are of value solely as "post mortems." The author's experience in this line has been, that just as systematic records of analysis are of value not only in locating the causes of trouble, but in preventing it, so daily checking up of the work of the shop, particularly the annealing furnaces, by means of test bars, will keep the product uniformly excellent and lead to many improvements. When a certain amount of information, as for instance tensile test, bending test, microstructure and perhaps shock test and hardness, is obtained each day from test bars in every annealing heat, or a certain number of heats, it will not be long before enough data are accumulated to show the probable cause of the poor quality of a broken casting. Moreover, once this information is at hand, a poorly annealed heat can be recognized and held up before it gets out of the shop; and by investigation of one's best and poorest product, as well as that of competitors, much improvement will almost certainly result. The metallographist is rapidly winning his place in the steel business, and when the dust clears away, it will be found that his work is parallel with that of the chemist who is now no longer called on simply to conduct autopsies, but has his recognized place in regulating things so that autopsies shall not be needed.

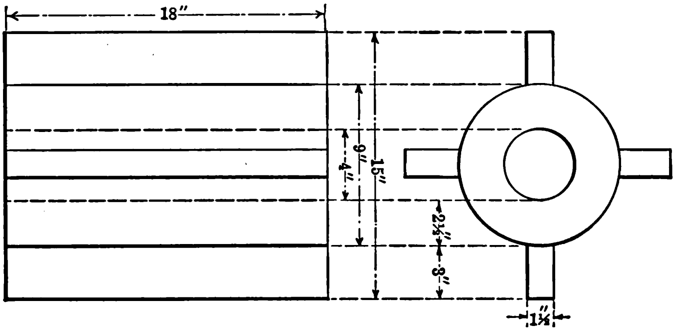

FIG. 37.—Test coupon casting.

It is the author's experience that test coupons upon ordinary steel castings should be attached to the casting along the full length of one of their long sides. A coupon attached to the casting by a narrow neck is not so reliable as a side attached one, even if cast on end and provided with a sink head of its own, unless its cross-section is made undesirably large. The same is true of coupons moulded and cast separately, with gate and sink head; to be truly reliable, they must be some 3 by 3 in., or better 4 by 4 in., in cross-section.

To obtain reliable coupons for experimental work the author has used with great satisfaction a casting in the shape of a hollow cylinder with a number of side attached, vertical coupons upon its outer face, like the spokes of a wheel. A sketch of this casting, which some one christened "the porcupine," is shown in Fig. 37. Each coupon gave two test bars 9 in. long. Four or eight coupons can be used.

CHAPTER XII

"BUILDING UP" IMPURITIES IN STEEL

In a number of places in this volume calculations are submitted showing the maximum increase in non-oxidizable impurities of the steel, that is to be expected after making a great number of heats, each of which contains a certain proportion of scrap from previous heats. These calculations are based upon the method worked out by Mr. A. H. Jameson, the gist of which is given here for reference. For the full text of this article see *Iron Age*, February 23, 1911, p. 480, and August 21, 1913, p. 406.

"It should be remembered that, through the melting and converting losses, we do condense in the steel any element which does not itself suffer loss in the melting or conversion. But this condensation takes the form of an increase in the percentage by gradually decreasing increments, and theoretically the increase goes on for an infinite number of operations. But it approaches a limit, even though it never reaches this limit, and if we plot a curve to show the increase in percentage by ordinates and the number of operations by abscissæ we find that at infinity the curve becomes a straight line."

"Practically we are interested in the limit only. We wish to know what will be the maximum content in the steel after a long run, and this we can determine readily."

"Let a = the percentage of steel scrap in the cupola charge.
$100 - a$ = the percentage of pig iron in the cupola charge.
b = percentage of loss in both melting and converting.
c = percentage of the element in question in the pig iron used.
x = the maximum percentage of the element in the steel after an infinite number of operations.

"When the limit is reached, and 'the curve becomes a straight line,' we shall find, of course, that after any operation our steel contains exactly the same percentage of the element in question that was in the steel scrap which was charged to the cupola furnace as stock for that blow, so that

$$x = \frac{(100-a)c + ax}{100-b}$$

and by resolving

$$x = \frac{(100-a)c}{100-(a+b)} \text{ or } \frac{100c - ac}{100-(a+b)}$$

"It will be noted that the foregoing formula and calculation are applicable to an element which, like copper, gains nothing from outside sources. Now, let us see what is the problem in the case of sulphur or phosphorus, which are increased by the amount absorbed from the fuel in the melting. Let d = the percentage of the element which is taken up by the metal in one melting operation; this can be determined readily by analysis of the stock before and after melting, and is a constant for a given fuel and burden. Then our original formula will become

$$x=\frac{(100-a)\,(c+d)+a(x+d)}{100-b}$$

and by resolving,

$$x=\frac{(100-a)\ c+100\,d}{100-\,(a+b)} \text{ or } \frac{100\,(c+d)-ac}{100-(a+b)},,$$

Mr. Jameson's method is manifestly applicable to any method of melting in which the percentage of a non-oxidizable impurity is increased by melting losses, with or without "pick up" from the fuel; or, for that matter, to a case where by gain of weight in melting (owing for instance to ore additions), the percentage of the element is decreased, with or without a countervailing gain from "pick up." In this volume, the particular method of using these formulæ has been varied from place to place, for greater convenience. Thus, for instance, it is permissible to substitute for percentages of pig iron, scrap, etc., and percentages of metal obtained, the actual weights of material charged and of the metal obtained. In certain cases where a "pick up" occurs, the figuring has been done by multiplying the weight of each portion of the charge by the percentage of the element in question in that postion, adding the products, adding to this the weight of the whole heat multiplied by the percentage of "pick up" of the element in question, and dividing the sum total by the weight of the heat. That these variations in the method of using the equations are permissible, is clear at once. Thus the reasoning has been applied to all methods of steel making by the acid process, and to special mixtures of raw materials. The influence of the recarburizers, which often contain high percentages of phosphorus, has also been shown in a number of cases; and the method has been used to work backward from a known permissible maximum of impurity, to ascertain the percentage of impurity in the raw material that cannot be exceeded without producing steel above the desired maximum.

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