LIQUID FUEL

FOR

MECHANICAL AND INDUSTRIAL PURPOSES.

COMPILED BY

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PREFACE.

THE present treatise on liquid fuel is, I believe, the first work of its kind in the English language. Hitherto no book has been published, to my knowledge at least, devoted solely to the mechanical and industrial applications of liquid fuel, and the problems involved thereby. No apology is therefore needed for introducing it to the public, except in so far as its imperfections may demand one. These I feel certain are many, and I can only crave the reader's indulgence, and ask him to make allowances for such shortcomings as he may detect, and to bear in mind the difficulties which are inseparable from a compilation of a work of this nature. I have entitled it a compilation, for it cannot pretend to anything more; indeed, had I called it a translation, I would perhaps have been more accurate, as it is principally based on the excellent series of articles recently published in the 'Zeitschrift des Vereines deutscher Ingenieure,' under the title of "Die Verwendung flüssiger Heizstoffe für Schiffskessel" (The Employment of Liquid Fuels for Marine Boilers), itself compiled by Herr Marine-Ingenieur Busley, of the German Navy, from every imaginable source. Of these articles I had the honour of preparing a condensed abstract for the columns of *The Engineer* newspaper, and it is by the kind permission of the proprietors of that periodical that I have been enabled to found the present work on this abstract. I have made additions to it from the Annual

Report of the United States Navy Department; from that admirable treatise on Petroleum, the posthumous work of Mr. B. J. Carew; from Mr. Marvin's popular 'Region of Eternal Fire,' Mr. Thwaites' pamphlet on liquid fuel, M. F. Hue's '*Aux pays de Pétrole*,' Mr. Urquhart's paper before the Institution of Mechanical Engineers, Mr. Craft's paper read at the Memphis meeting of the American National Association of Brickmakers, Messrs. Funck & Co's lists, &c. Nothwithstanding the pains I have taken, no one can feel more deeply than myself the hopeless inadequacy of the present volume. Perhaps it will serve the purpose, however, of stopping a gap until the time may have become ripe for the publication of a thoroughly comprehensive work. After all it is not from books, but actual practice alone, that really satisfactory knowledge on any given subject can be derived. As a guide, therefore, to the practical man, the book may, perhaps, be not unacceptable.

I must not omit to acknowledge publicly my great indebtedness to Mr. James Forrest, the Secretary of the Institution of Civil Engineers, through whose courtesy I was permitted to make use of the valuable library of that institution.

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LIQUID FUEL.

CHAPTER I.

INTRODUCTION.

"LIQUID FUEL" is a term used to designate the residuals of mineral oil, and is thus described by Mr. B. J. Carew in his 'Practical Treatise on Petroleum':—"Under the name of 'liquid fuel' the heavy residual oil left in the still after the burning oil has been taken off, and constituting about 60 per cent. of the original charge, is very extensively employed under the furnaces and locomotives all through the Caspian region." This residual oil the Russians call *astatki*, and have used very successfully for years past. In England, France and Germany, its introduction has hitherto been very much hampered by its very high price; but in Russia, while, as Mr. Carew says, Western Europe and the United States have been experimenting on, and devising all manner of, petroleum furnaces, the problem has been satisfactorily solved. This local success is not due to any great superiority of the inventions themselves, but simply to the fact that in the Caspian region the abundance of petroleum and the comparative scarcity of coal have jointly contributed to stimulate inventions having in view the consumption of petroleum as fuel, hence great attention has been given to the subject. Engineers of the highest skill and reputation have devoted much time to improving and devising apparatus for the convenient consumption of the heavy oil as a fuel. Their efforts have been eminently successful, and now this "liquid fuel" is the only fuel used in this district. It has certainly replaced wood and coal in all the steamers plying on the Caspian Sea, and in the locomotives on the Trans-Caucasian Railway, as well as in the furnaces and factories of that district. Its use has extended as far north as Moscow, to Teheran to the south, to Merv and Khiva to the east, and to Batoum to the west. Mr. Carew goes on to say that Baku is the Newcastle of the Caspian, and predicts that ere long the Black Sea steamers will find this fuel far more economical to use than English coal.

The use of petroleum as fuel, either as crude petroleum or in the shape of residual after the more valuable illuminating oil has been extracted, is not by any means an invention of the nineteenth century. To quote again from Mr. Carew's work :—"The use of petroleum in one or other of its varied forms as fuel is traceable to the remotest antiquity. Its combustible nature, with its heat-producing and light-bearing properties, very early attracted the notice of even the most barbarous and uncivilised nations. Its scientific adaptation to numerous practical uses, in accordance with its chemical composition, belongs to modern times. It did not require a very prolonged course of experiments to demonstrate its entire practicability and its immense advantages in some respects over any form of solid fuel."

Indeed, since the year 1860, about which time the scientific application of liquid fuel to industrial purposes may be said to have commenced, it has made most rapid strides, and in 1870 it was used during the siege of Paris, when coal had given out; and M. Fernand Hue, in his work entitled 'Aux Pays de Pétrole,' tells us that M. Sainte-Claire Deville's furnace for burning petroleum in a liquid state was the means of enabling Paris to keep several of its large factories going during that terrible year, as well as to grind its flour by steam.

The history of the introduction of liquid fuel to the notice of science may be thus briefly summarised :—In countries where it was plentiful, like Pennsylvania and Baku, it was used in preference to coal simply on account of its greater cheapness in cost. Finding it in use, scientists have experimented with it, and discovered that theoretically the calorific value of petroleum was twice as great as that of coal, and that in actual practice this efficiency could be increased, by the adoption of economical furnaces, by half, that is to say, liquid fuel is found to do three times the duty of coal. This highly satisfactory result was so startling, that theorists have ever since warmly advocated the adoption of this fuel for nearly all kinds of steam generation. But, unfortunately, the moment a stimulus was given to the production of oil residuals, notably in England, by Admiral Selwyn, it was discovered that the price was altogether forbidding. Indeed, it has been argued that the demand would be very much in excess of the supply, and that liquid fuel would soon reach famine prices. Three Government commissions, in England, France, and America, have inquired into the question, and have arrived at very nearly the same result; but Mr. Carew, whose work on petroleum is perhaps the most complete in existence, is nevertheless of opinion that all these experiments have established :—1st, that the calorific power of petroleum for the purposes of generating steam and evaporating water is several times greater than that of ordinary coal; 2nd, that when the price of petroleum does not greatly exceed that of coal, the former will be certainly selected for all ordinary purposes of fuel, both for the generation of steam and for furnace operations, especially where a high degree of heat is essential; and 3rd, that illuminating gas of a quality far superior to that of coal can be made from petroleum. He goes on to say that "We must look for the best results from petroleum, both economically and technically, in those uses where the improved product of the manufactured article more than counterbalances the difference in the price of the two kinds of fuel." Theoretically a generator fed with petroleum should consume a ton of liquid against two of solid coal fuel, but in reality, in well-built furnaces, the economy is greater still; it amounts to one in three. This is a magnificent result.

In summing up the case for liquid fuel, Mr. Marvin, in his 'Region of Eternal Fire,' makes the following statements :—"The Russian Government has recently been conducting experiments with liquid fuel at Sebastopol, with a view to using it instead of English coal for the men-of-war of the Black Sea fleet. It is contemplated to reduce the Caspian fleet to the proportions of a police flotilla, and place it under the control of the naval authorities of the Black Sea. This will render Baku dockyard a branch of the Black Sea naval establishment, and the Caspian will certainly prove a nearer source of fuel supply than either Newcastle or Cardiff. When petroleum fuel has spread to the Black Sea its extension to the Mediterranean is but a mere matter of time. The expensive English coal will be hardly able to compete with it here. But it is through the Suez Canal, along the Eastern trade routes, that the greatest triumph of liquid fuel may be expected. Every mile adds to the cost of English fuel in that direction and renders competition with *astatki* shipped from Batoum more difficult. From Malta to Singapore, Baku will be able before long to keep every coaling station abundantly supplied with inexpensive oil refuse. From Singapore to China, the task of maintaining the cheap oil supply could be undertaken by British Burmah, which possesses enormous deposits of petroleum, gradually being opened up. Baku and Rangoon could readily furnish enough petroleum fuel for all the trade-routes of the East, and may, in fact, be expected some day to do so, when its advantages are generally recognised.

"Those advantages are more important than is commonly supposed. The fuel is perfectly smokeless, which is a very great merit on board cruisers and men-of-war. Burned in locomotives on the Metropolitan Railway, it would put an end at once to the greatest difficulty experienced in working the line—the annoyance to the passengers occasioned by the smoke. If petroleum-burning engines ran on the Underground Line, as they run on the Trans-Caucasian Railway, there would be no need for hideous smoke-holes; and if employed in the projected Channel Tunnel, the necessity for using an elaborate and problematical system of ventilation would be done away with at once.

"Another great advantage is the absence of any stoking, and the ease with which the fire can be lighted or suppressed at a moment's notice. Few people realise the miserable life led by stokers afloat, particularly during the passage through the Suez Canal and Red Sea. The sufferings of thousands of unfortunates would be suspended at a stroke by using liquid fuel, which, being burned in the form of a huge gas jet, requires no stoking or personal attendance of any kind, and maintains what it is impossible to secure with coal, a steady temperature. The fire can be manipulated to any degree of intensity by simply touching the cock of the feeding pipes ; and the sole bit of trouble—burning a few handfuls of cotton waste or wood in the first instance to get up a little steam to start pulverising the oil (the work of ten minutes or a quarter of an hour)—is abolished in the recently perfected Walker furnace, in which some hydrocarbon gas is kept stored for this purpose. Instead of there being a stoker or two to each furnace, a single man can look after a dozen or twenty furnaces, and, as a matter of fact, does so in the Caspian oil-refineries. This is a very important economy. So simple is the fuel to use, and so reliable is the action of the pulveriser, that the English and the Russian engineers running the steamers from Baku to the mouth of the Volga told me that, having turned on and adjusted the flame at starting, they concern themselves no more about their fires until they reach their destination in a couple of days' time. The fuel is clean to use, and there is none of the dust arising from coal or wood, which is a great nuisance on board passenger steamers.

" Equally important is the economy gained in storage room. A ton of liquid fuel can do the work of two or three tons of coal ; thus a steamer can either take two or three times less fuel, and utilise the bunker space for cargo purposes, or it can go two or three times as far without stopping to coal. But there is an additional economy beyond even this. A ton of oil refuse, I believe, takes up very little more than half the space of a ton of coal. In this manner, in the more economical liquid fuel furnaces, 1000 tons of oil refuse not only goes as far as 3000 tons of coal, but takes up only the bunker space of 500 or 600 tons of coal, and allows the balance of 2500 tons to be applied to passenger or cargo purposes."

Farther on Marvin says :—"The *Constantine Kaufman* burns only five and one-third pounds per horse-power per hour; the *Alexander Jandre* burns six and a half pounds; and the *Peter the Great*, a large passenger steamer of 200 horse-power, has the reputation of burning least of all. Its consumption is only four and three-quarter pounds of liquid fuel per horse-power per hour. Theoretically a ton of liquid fuel ought to go as far as two tons of coal; as a matter of fact in the more economical furnaces a proportion of one to three is often attained. . . . Practice has demonstrated that petroleum refuse is a perfectly safe fuel; being indeed safer even than coal. One or two scientific men, among them Professor Lisenko, of St. Petersburg, have declared the crude oil to be dangerous, but Gulishambarov proves this to be a fallacy. Petroleum dregs constitute, owing to the difficulty of setting fire to them, a material perfectly safe for river steamers. This, however, cannot be said of crude petroleum, which ignites more readily; and hence, owing to its dangerous qualities and the irrationality of making use of it when dregs will do as well, its use ought to be prohibited on rivers." Gulishambarov, arguing from practice, combats both these opinions. He asserts it is quite safe after standing a little while in the air, and he rightly opines that if there is a strong demand for the article as fuel, and the crude oil is forthcoming in large quantities, the question of 'irrationality' ought not to be made a cause of official prohibition.

"'Crude petroleum,'" he says, "'only needs to stand in the open air for a few days, and then a firebrand may be safely thrust into it; men may be often seen doing this in the oil lakes of Balakhani. In summer it clears itself of its inflammable qualities very rapidly, which is proved by the fact that oil thrown up by the Baku fountains and forming lakes, loses in a few days ten or fifteen per cent. of its gravity. This operation may be accomplished in winter by heating the oil in open receptacles. The flashing point of crude petroleum fresh from the well, and having a gravity of 0·870, is 40 degrees Celsius; the flashing point of petroleum refuse ranges between 80 and 170 degrees Celsius.' But the same crude oil that flashed at

40 degrees on issuing from the well, will not flash under 60 degrees if allowed to remain in the open air a week; while after a fortnight the temperature must be 70 degrees for it to ignite. Abundant proof might also be cited from the experience of the last ten years at Baku. Thousands of tons of crude petroleum, thrown up by the fountains and allowed to spoil in the surface lakes, have been used as fuel without any mishaps. For years also the locomotives of the Petroleum Branch of the Trans-Caucasian Railway have been running daily from Balakhani to Baku with train-loads of crude petroleum freshly drawn from the wells, without a single case of explosion.' "

Briefly then there can be no doubt that the only grave objection to the general application of liquid fuel has been its price. This, however, depends upon the law of supply and demand, and there can be no doubt that, as fresh oil regions are discovered, this main objection will disappear. Already this necessary condition is being rapidly fulfilled. Besides the well-known oil regions of the United States and the Caspian, new ones have been recently discovered in Galicia, Canada, Burmah, Venezuela, and even China. That liquid fuel is the cheapest theoretically is now firmly established, and its use is already steadily increasing. We find it employed in manufactures as well as for locomotives and steamers. In America, it is used on a large scale for the manufacture of bricks and iron; we hear of its conversion into illuminating gas, and of whole districts being fueled (if we may be allowed such an expression) by the natural gas which arises from it. For steel it is said to be the only perfect fuel, and in a variety of industries its use is continually spreading.

The present magnitude and development of the trade in petroleum have been but little appreciated by the general public. Every year the world consumes in round numbers a thousand million gallons of petroleum lamp oil alone; and as liquid fuel on steamers, on railways, and in manufactories, petroleum is largely used in the United States, Russia, and France. In Pennsylvania, and especially at Pittsburg, natural gas, generated by the petroleum wells, is used almost exclusively for lighting and steam generating purposes, and on the waters of the Caspian, flotillas of steamers derive their motive power from heavy oil residuals that remain after the raw petroleum has gone through the refining process. In England alone the imports of petroleum from America and Russia amount annually to nearly 2,000,000 barrels a year, and the demand is steadily increasing at the rate of 200,000 barrels per annum, as the subjoined statistics published by Messrs. Henry Funck and Co., will show :—

Year.	American.	Russian.	Total.
	barrels.	barrels.	barrels
1888	1,286,148	549,126	1,835,274
1887	1,444,350	188,461	1,626,511
1886	1,363,801	46,814	1,410,615
1885	1,367,720	70,149	1,437,869
1884	927,919	17,078	944,997
1883	1,329,004	502	1,329,506

For heating, lighting, cooking, and even fuel, petroleum is coming steadily into greater use. For steam generating purposes, it is more economical than coal from a mechanical point of view, 95 per cent. of duty can be obtained from it, as against 33 to 45 per cent. of duty that can be got from coal. This in itself is a great advantage ; but when the other economies it entails are borne in mind, such as the abolition of stokers, the facilities of fueling ships with it, the ease with which it can be tried, and the great cheapness with which it can be transported from one point to another by means of pipes—so that it can be laid on to towns like a water supply—instead of being surprised at the enormous consumption of petroleum, one is astonished that this is not greater still, and does not compare better with that of coal.

Still, however, the price must remain for some time to come the great obstacle to its more general introduction. That this price might be reduced very appreciably even now without the aid of fresh oil-fields, Mr. Thwaite, in his able pamphlet* on this subject, abundantly proves. He says :—

"The average price, after a lengthened period of considerable fluctuation, has gradually receded from 89 cents per gallon in 1866, down to 2·4 cents per gallon in 1886. Taking the specific gravity of the oil to be 0·91, and the cost of delivery by one of the five projected pipe lines, free on board, at 5 cents per barrel, the cost would thus be about 25*s.* per ton.

"The production of crude petroleum in the Aspsheron Peninsula (Baku) in 1866 equalled 2,748,304 gallons. In 1885 the production had increased to 396,000,000 gallons, and the price had receded from 2½*d.* in 1866, down to 0·118 of a penny in 1885, or equivalent to 2*s.* 5*d.* a ton. The export of oil from Batoum has increased, from July 1886 to July of this year,† by 50,000 tons over that of the previous year.

"On the completion of the proposed great new pipe line from the Baku oil wells to the Black Sea coast, and assuming a very fair price of 7 copecks to be charged, per pood, for transport, the cost of the Baku Russian oil would thus be 10*s.* 11*d.* per ton.

"By chartering a tank steamer the oil could be delivered free on board at the ports of the United Kingdom for 1*l.* 10*s.* a ton.

"At present the railway tank wagons and storage tanks at Batoum are fully utilised for refined petroleum, and there are no conveniences for the transport or storage of the crude oil."

In view of these hopeful signs the time seems to have arrived for the publication of a treatise on the most economical methods in use for the employment of oil residuals as fuel for mechanical purposes, and in the following pages we propose to give as complete a review of these methods as it is in our power in the present early stage of this branch of

* 'Liquid Fuel: its Advantages for Firing Steam Generators,' by B. H. Thwaite, London, 1887, E. & F. N. Spon.

† 1887.

mechanical engineering to do. We shall first give a summary of the various furnaces in use for marine boilers, and from thence we shall proceed to give a short account of what has been done in locomotive furnaces, and finally we shall conclude by enumerating briefly a few of the applications of liquid fuel to industrial purposes.

CHAPTER II.

HEARTH-FURNACES.

THE methods employed for using liquid fuel may be roughly divided into three classes. According as the oil is used in a liquid, steaming, or vaporous condition, these can be described as :—(A) Hearth-furnaces ; (B) gas-furnaces ; (C) spray-furnaces. As a very large number of various applications of these methods of heating have been patented during the last thirty years, only those are illustrated which are best known, or which mark a fresh departure,

(A) *Hearth-furnaces.*—Under hearth-fires are included all those methods by which the liquid fuel is more or less equally distributed. These again are classified in their order of progress as :—(*a*) Pan-furnaces ; (*b*) step-furnaces ; (*c*) drop-furnaces ; (*d*) oozing-furnaces.

(*a*) *Pan-furnaces.*—The stationary pan-furnaces are the simplest and most primitive method of utilising liquid fuel. Engler * mentions them as to be found in some of the smaller mineral oil works of Baku. The liquid fuel residuum from oil distileries is pushed into the fire-box in flat bowls, or else it is allowed to drop on bowls, stones, and sometimes on the fire-bars themselves, where it is burnt up. This method, owing to the small amount of air admitted as compared to the quantity of fuel, is a very imperfect one, entailing much soot. The chimneys of furnaces fitted on this principle invariably give off a continuous and impenetrable black vapour. When the oil is extended over a larger surface, and is consequently brought in contact with a larger volume of air, a certain amount of progress is reached.

* Engler, 'Das Erdöl von Baku' (The Mineral Oil of Baku), p. 32, Stuttgart, 1886.

(2) *The Pan-furnaces of Bidle,** Figs. 1–3, were introduced in North America in 1862, and designed especially for marine boilers. They consist of a cast-iron fire-box made in one

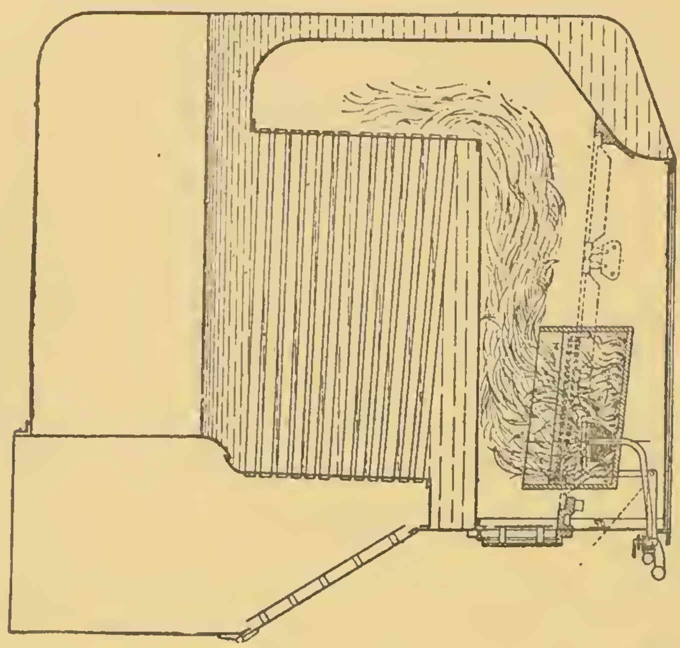


FIG. 2.

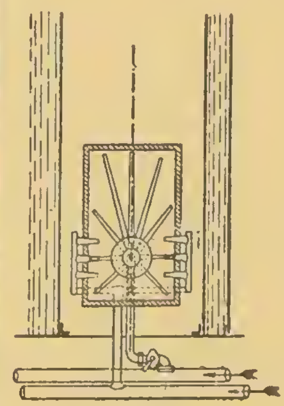


FIG. 3.

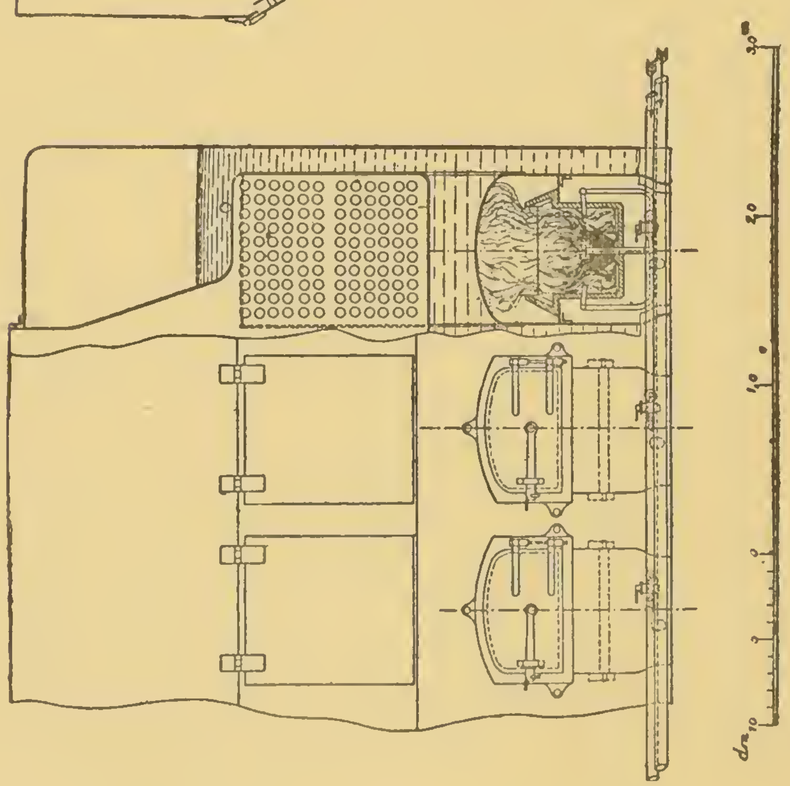


FIG. 1.

piece and closed at the bottom, Fig. 3. This bottom, which slants backwards, is fitted with grooves radiating from the centre, which ensure an equal distribution of the oil. The oil

* A. Ledieu, 'Les Nouvelles Machines Marines,' vol. iii. p. 166, Paris, 1882.

is pumped out of the storage tanks into a box over the boiler. From hence it is conveyed in a pipe along the outside walls of the boiler, and it then flows through branch pipes into the separate furnaces. These branch pipes, which enter in the centre of the fire-box, are surrounded at the mouth by an iron basket containing red-hot coal or coke, which set the oil on fire. The oil that escapes ignition flows along the grooves and is consumed there. Small orifices at the top of the fire-box, near the entrance of the pipe, Fig. 3, were provided, with a view to the admission of air to ensure perfect combustion. It was found, however, that these orifices were insufficient, and large volumes of smoke were the result. Bidle, therefore, introduced fans, and increased the number of orifices. The combustion was improved, but the fans had to be driven by steam, and the whole arrangement was found too complicated. All systems of pan-furnaces have the very great drawback that an adequate supply of air cannot be obtained without great difficulty, and consequently perfect combustion is not ensured.

(*b*) *Step-furnaces.*—This system of firing, used by Nobel and Wittenstrom, is an old one, and would not have been noticed here but for the fact that Ostberg * is employing it for his Mitis castings, and speaks very highly of it. The system consists of a series of iron troughs arranged in the shape of steps. The oil enters the topmost trough, and then overflows into the others, until it is all burned. Messrs. Noble and Wittenstrom introduced an air current to ensure perfect combustion, but Ostberg asserts that this object is attained by a special chimney construction, and that he has succeeded in getting so high a temperature that he can melt iron at a distance of 11·8 inches from the heating surface. Ostberg's system has reached so high a degree of perfection that he can produce eleven outputs in twelve hours. He has so reduced the melting point of his iron by adding from 0·05 to 0·10 per cent of aluminium that he can make it fluid enough to be cast in moulds without the loss of any of its properties.

Value of Step-furnaces.—For marine engines step-furnaces are impracticable, as the rolling of the vessel makes a regu-

* 'Engineering,' 1886, p. 360.

lation of the quantity of oil that should overflow from one step to the other an impossibility. Step-furnaces are, however, preferable to pan-furnaces, as they admit air from both

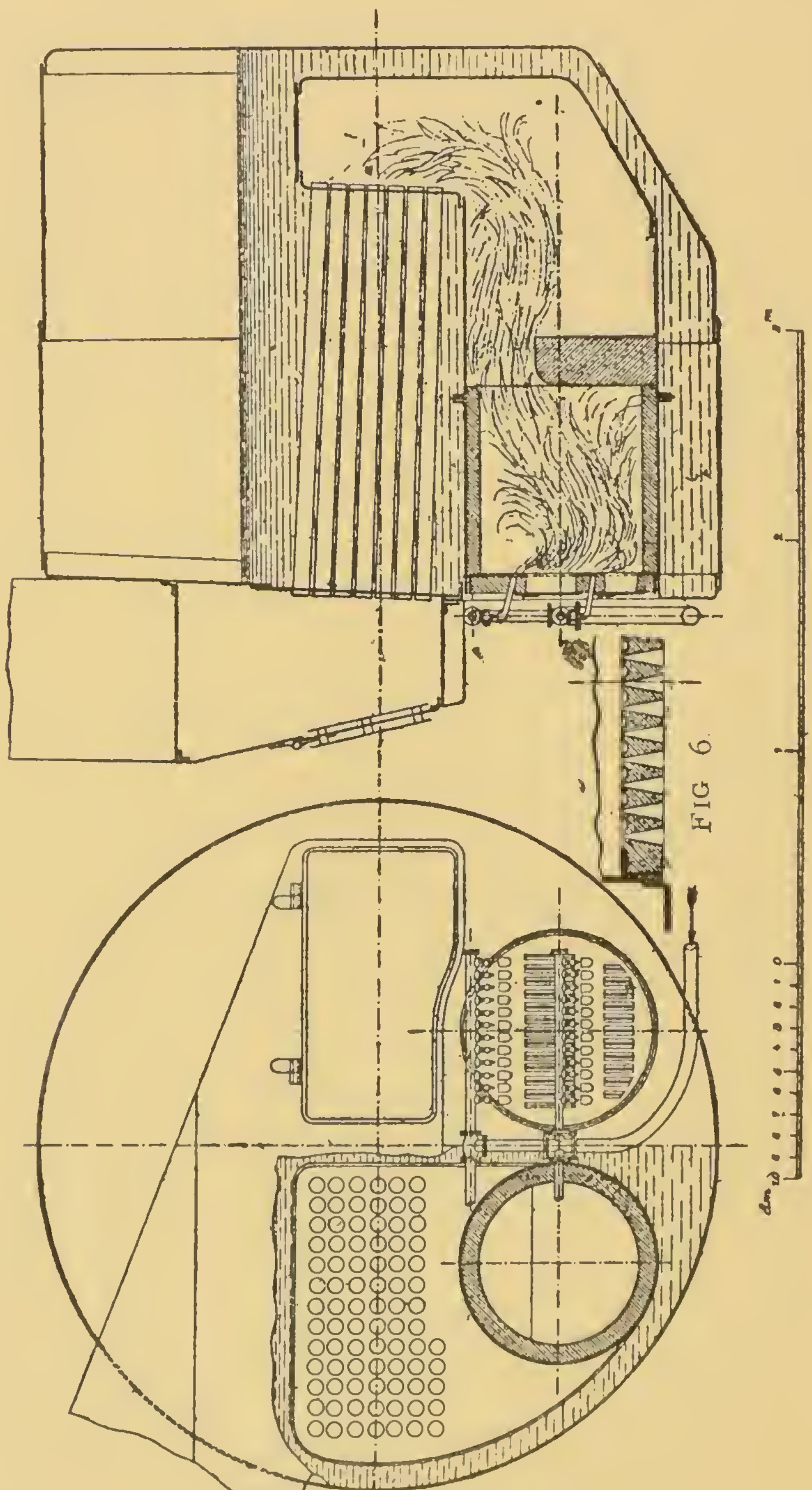


Fig. 5.

Fig. 6.

Fig. 4.

sides; and, moreover, as the mass of liquid fuel flowing over is much thinner than in the case of pan-furnaces, perfect combustion is much more easily attained.

(*c*) *Drop-furnaces.*—The system of drop-furnaces used by Audouin,* Figs. 4–6, was first tried in 1865, and exhibited at the Paris Exhibition of 1867. Audouin, as a gas engineer, attached particular importance to the use of the heavy tar oils, and placed a tube of pottery ware, about 29·5 or 39·4 inches long, in the grate, with a view to keep up a sufficiently high temperature to disperse and consume the oil. In place of a door to the fire-box, a plate was attached, to which were affixed, at the top and in the centre, rows of small iron pipes. Each pipe had a tap, and could be cut off from the supply pipe leading from the oil tank. To the mouths of the pipes a vertical groove was fitted, down which the ignited oil was conducted. In the case of stationary boilers, Audouin allowed the oil to flow from the supply pipe in a channel along the plate, from which it overflowed into the vertical grooves. This, of course, necessitates only one supply pipe and one regulating tap. The plate that takes the place of the door has openings 5 mm. wide between the grooves for the admission of air. Fig. 6 shows such an opening. The air supply is regulated by a valve movable in sections, and fitted in front of the openings. The chimney draught is equal to an air pressure that would raise a column of water 4 inches, and Audouin claims to have evaporated about 23·6 to 33 lbs. of water with 22 lbs. of heavy tar oil in a longitudinal boiler walled in, with internal firing and a wheel draught, which did a duty of about 20-horse power. But to judge from experiments made with this system the lower figure would appear to be nearer the truth than the higher one.

The Drop-furnaces of St. Claire-Deville and Dupuy de Lôme, Figs.† 7–9, are based on the system of Audouin, and were applied in 1868 to the boilers of the imperial yacht *Puebla*, the fire-door and fire-bars of which were taken away. A plate of cast iron was fixed on the top, and vertical fire-bricks surrounded by a frame were fitted underneath instead. The upper frame of the plate received the mouths of thirteen small pipes,

* 'Annales de Chimie et de Physique,' xv. 1868, p. 30.

† A. Ledieu, 'Les Nouvelles Machines Marines,' Paris, 1882, iii., p. 166.

each supplied with a funnel, and into these the oil fell in drops from a supply pipe. This supply pipe had a separate cut-off tap for each small pipe. The oil flowed into the supply pipe from a pipe, also provided with a tap, which was conducted from a tank placed high enough to ensure a constant flow of oil. The taps regulated the supply of oil into the different pipes, and consequently its evaporation and distribution. The burning oil flowed out on to the floor of the grate, which inclined slightly backwards and was made of fireproof stone, and was roofed over by the same material. The fire-bridge also had a vaulting of the same height. The space between the vaults

FIG. 7.

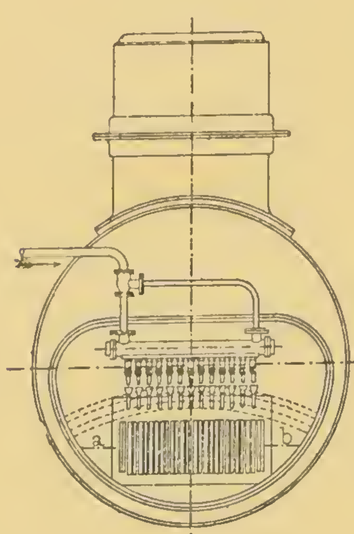


FIG. 8.

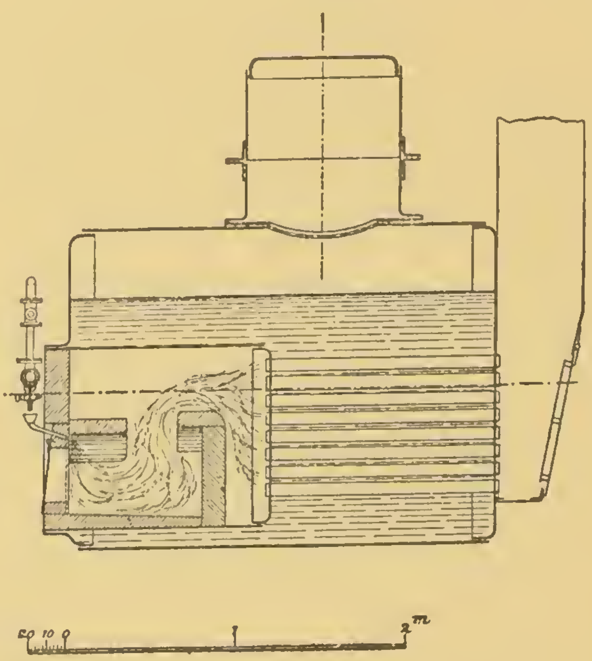
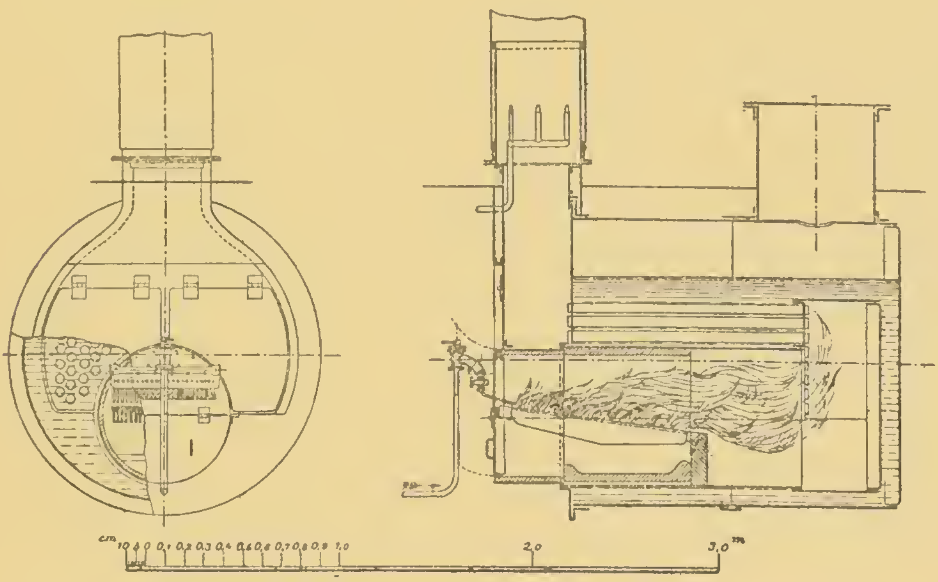


FIG. 9.

allowed of the escape of the gases into the tubes. Heavy coal-tar oil, with a specific gravity of 1·044, was the fuel used. At the trial the flame was easily regulated by the taps. Air was admitted by means of valves, as in Audouin's system. A hand fan had to be used to start the fires with, as the low funnel of the yacht did not give sufficient draught; but when the engine was set in motion the exhaust puffed through the funnel, and caused sufficient draught. During the trial trips on the Seine in March and April, 1868, the engines indicated 65 horse-power, and consumed $3\frac{1}{4}$ lbs. of oil per horse-power per hour; whereas they had only indicated 63 horse-power when coal was used, and had consumed $5\frac{3}{4}$ lbs. of coal per horse-power per hour. Experiments have since been made with this system on the locomotives of the French Chemin de Fer de l'Est, in which 22 lbs. of oil evaporated 24 lbs. of water, as against 22 lbs. of briquette evaporating only 17·6 lbs. According to St. Claire-Deville, still better results would have been obtained if specially constructed boilers had been used.

The drop-furnaces of Wagenknecht, Figs. 10 and 11, which were made in 1870 and 1871 for Durient, at Dantzig, for their torpedo-boats, were chiefly based on Audouin's system.

FIG. 10. FIG. 11.



Their principal feature is really the arrangement of the hearth. The oil flowed out of the pipes into the grooves in the fire-bars of which there were as many as there were pipes; the oil was consumed in these grooves, and air was blown through the spaces from the unused ashpit, as it was found that the natural draught was not sufficient. The petroleum was contained in four tanks fitted behind the engine, which were connected by pipes, and a simple pump worked by the engine. At each revolution of the engine a certain quantity of petroleum was driven into the collecting pipe in front of the fire-box. But notwithstanding the fans, the combustion was so imperfect that a constant column of thick black smoke came out of the funnel.

A particular amenity was the trickling of the oil out of the fire-bars into the engine room at each roll of the boats. Sometimes the fire went out altogether, owing to stoppage of the supply-pipe or other accidents. These torpedo-boats made about 7·46 knots, with petroleum. As the system proved to be inefficient, the boilers were altered and adapted for coal-stoking.

The drop-furnaces of Kamenski * were based on the principle of Wagenknecht, and were used with a stationary boiler at Baku in 1869, and fitted to the steamer *Nasr-Eddin-Shah* in 1872; these, however, proved so unsatisfactory that they were abandoned.

Value of Drop-furnaces.—The distribution of the burning oil in separate grooves is a great advance on the pan and step systems, as by this method the admission of air is more easy. Nevertheless, the distribution and sub-division of the oil were not carried far enough on this system to insure perfect combustion. The comparatively successful results obtained by Audouin cannot be allowed to carry much weight, as walled-in boilers have such great advantages over marine boilers that the two cannot be compared. Audouin's practice of inserting a pipe of pottery ware in the furnace was so successful that it has been largely adopted by modern constructors especially as by this means coal-using boilers can be easily converted into oil-users by removing the fire-bars which can always be replaced. But the drop-furnaces, although superior to pan and step furnaces, cannot be regarded as satisfactory. The number of pipes they necessitate renders them too complicated and makes them liable to get stopped up. They are also a source of much annoyance and even danger in rough weather at sea, as the oil is liable to overflow, and they cannot therefore be seriously regarded as practicable.

(*d*) *Oozing Furnaces.*—The oozing furnaces of Richardson † were patented in England in 1864, and experimented on at Chelsea and Woolwich by the inventor, largely assisted by

* 'Morskoi Sbornik,' viii., 1876, p. 5.

† 'Journal of the Royal United Service Institution,' 1866, p. 70.

the Admiralty. After three years a certain measure of success was attained, and illustrations of this method, tried in February 1867, are given at Figs. 12–15. The bottom of the furnace is lined with ordinary burned slack lime, which is even at the top but has vaultings underneath—see Fig. 14. The oil is conducted into these vaultings from two tanks situated near the boiler; the supply-pipe of each furnace has a separate tap at the front wall of the boiler, side by side with the oil pipe; there is a steam pipe in the furnace which, as is shown in Fig. 15, passes twice along the upper portion of the stratum of lime

FIG. 12.

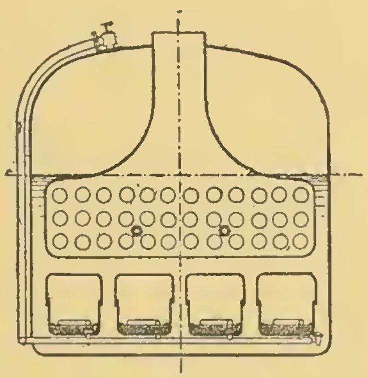
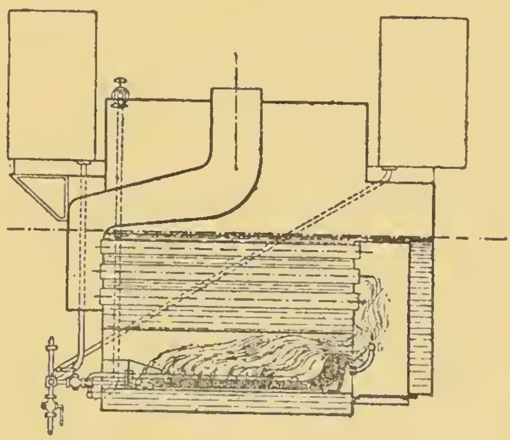


FIG. 13.



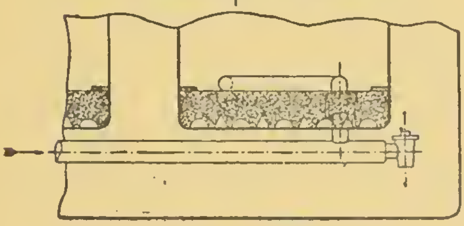


FIG. 14.

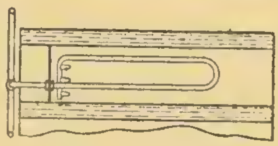


FIG. 15.

for the purpose of superheating the steam it contains, and then delivers into the entrance place of the oil by means of three conical mouthpieces underneath the stratum of lime. The oil oozes up through the covering of lime, which serves as a sort of wick and is ignited at once and consumed. The steam is used chiefly for the purpose of obtaining the requisite draught, but helps also to distribute the oil. Mr. Richardson's last experiments made in 1867 with a boiler fitted with two furnaces and with a grate surface of 3·72 square metres, and a heating surface of 14·78 square metres, and a steam pressure of 0·7 kilogs. per square centimetre, gave the following results :—

Date 1867.	Duration of experiment, hours.	Oil consumed per hour, lbs.	Water $100\frac{1}{2}$ F. evaporised by 1 lb. of oil.	Time required for getting up steam, minutes.	Oil required for heating, lbs.	Kind of oil used.	Smoke.
5 Feb.	8·0	115·7	11·24	55	39·91	$\frac{2}{3}$ tar oil, $\frac{1}{3}$ shale oil.	Very thick and black.
6 ,,	8·0	102·5	12·92	30	27·94	$\frac{1}{2}$,, $\frac{1}{2}$,,	Very moderate & light brown.
7 ,,	6·5	110·7	12·63	30	23·94	$\frac{4}{9}$,, $\frac{5}{9}$,,	Ditto.
8 ,,	7·0	103·8	14·71	45	20·02	$\frac{8}{21}$,, $\frac{5}{21}$,, and $\frac{8}{21}$ Am. raw petroleum.	Moderate and dark brown.
9 ,,	6·5	127·0	16·76	40	17·95	Shale oil.	Ditto.
11 ,,	6·1	112·5	19·66	60	20·02	Tar oil.	Very thick and black.

These experiments are interesting, inasmuch as they show that the unmixed oils had greater power of evaporisation than when they were mixed. It is doubtful whether in the last experiment the vaporisation attained was really twentyfold, for to judge by the thick black smoke that issued from the chimney the combustion could not have been perfect. The penultimate experiment, in which a seventeenfold vaporisation was reached, is nevertheless exceedingly remarkable. A Commission appointed by the Admiralty, to test this system reported very favourably ; but the system was not adopted, as the price of oils used by Richardson was then about 70*s*. per ton, whereas 15*s*. per ton of good coal was then a high price. Other considerations, to be discussed further on, also had weight.

The oozing furnaces of MacKine were patented in the United States in 1865,* but proved too complicated for practical use, and will therefore receive but brief mention. The floor of the furnace is covered with a layer of sand ; the door

* Specification of Patents of the U.S.A., 1865, No. 48,967.

of the furnace is constructed to admit the air. The sand lies in a closed cast-iron box filled with water. The oil is under this, and traverses this box in a pipe, and enters the layer of sand through which it percolates. The water-box is intended to cool the oil. By means of a tank and pipes this water is removed and replaced by other water when it gets heated. This tank is near the boiler, and its bottom lies rather lower than the sand layer. A pipe leads from this tank into the oil space, and the water can, by turning a tap, be let into the latter, and thus the oil is forced up the pipe that leads it into the sand. It is claimed for this system that the American mineral oil used was consumed by a fairly short flame with a natural draught.

The oozing furnace of Verstraët was patented in England in 1868,* and based on the same principle as those of Richardson and MacKine. Verstraët's grate is in the shape of a cup, which is filled with pumice-stone, which acts as the percolating medium for the oil. It has been mentioned by *Iron*—1885, vol. ii., p. 473—that Verstraët first made liquid fuel for steam generation known to the French, and that he was thus the teacher, so to speak, of St. Claire-Deville; but this is scarcely correct, seeing that the French were working with drip-grates and not oozing furnaces at that time. The system of the American, Hayes, resembles that of Verstraët very strongly. He uses mineral oil, and introduces it into a layer of coke dust and small stones, &c.

The oozing furnace of Paterson † was tried in 1878 in New Jersey, in a small vertical boiler of 16 in. in diameter, and 48 in. high, and was said to generate steam in a few minutes of 97 lbs. per square inch. It consisted of an iron tank 7·9 and 5·7 and 4·5 inches, which was filled with asbestos. There were openings at the side of the tank, and the oil was introduced from below through a pipe, which was regulated by a tap. As soon as the asbestos had become saturated with oil it was lighted up, and the flames rose up out of the asbestos and the sides of the tank. Combustion could

* English Specification of Patents, 1868, No. 1262.

† Dingler's 'Polytechnic Journal,' ccxxviii. p. 90.

scarcely have been very perfect, as much black smoke was given off; but later a very high temperature was developed. Any further success of this system has not been heard of.

Value of Oozing Furnaces.—Oozing fires must be regarded as the most successful of furnaces for liquid fuel, as by means of the layer of porous material employed distribution of the fuel is secured. Nevertheless, perfect combustion cannot be insured for long. The oil is not able to burn off equally, but its lighter components are given off first, whereas the heavier constituents remain in the porous layer. As the heavy constituents of the oil accumulate in the porous layer, the lighter oils, continually supplied, find increasing difficulty in oozing through; and a period must arise when this porous layer becomes completely choked up. This period will arrive earlier in the case of the Richardson furnace, which is, after all, the best, as he employs heavier oils. Oozing furnaces have, owing to this disadvantage, fallen into disuse, notwithstanding the fact that they succeeded in attaining with ease a fourteenfold vaporisation, whereas the drip-grates did not reach a higher figure than tenfold.

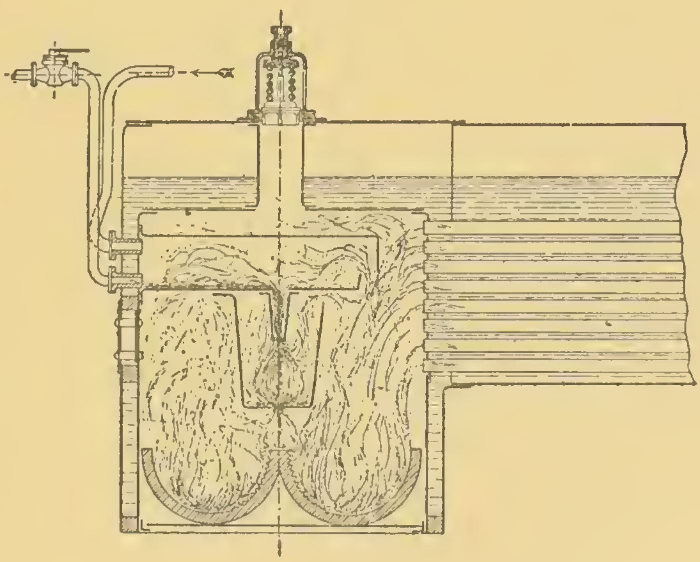
CHAPTER III.

GAS-FURNACES.

(B) *Gas-furnaces.*—Gas-furnaces are those in which the fuel is conducted to the furnace in a gaseous state. In comparison with the other systems there are not many of these furnaces, but the most remarkable will be briefly described.

The furnace of Shaw and Linton,* patented in America

Fig. 16.



in 1862, and intended for locomotives and marine engines, represents the transition from hearth furnaces to gas furnaces. As shown at Fig. 16, the oil enters a reservoir in a tank in the furnace, and flows on to the fire-plate, which has been previously heated by a coal or wood fire. The lighter oils

* 'Journal of the Royal United Service Institution,' 1886, p. 72.

evaporate and enter the fire-box, where they are consumed. The unconsumed oil flows into a receptacle below, which is heated to a greater temperature, and here the heavier oils are evaporated. The residuals that have survived so far are now conducted to the floor of the furnace, from which the fire-bars have been taken, and which is furnished with a cast-iron plate with indentations in it. Here the residuals are burnt in the fire. Next to the oil supply pipe there is a pipe for the introduction of air. This system had this disadvantage, that the mass of oil-vapour was not always in consonance with the amount that could be consumed, and consequently, to avoid explosions, a safety-valve had to be provided for the escape of the gases that were in excess. During the trials of Shaw and Linton with a marine engine, the reservoir over the boiler was kept supplied from the tanks by means of a pump, and a steam jet into the furnaces increased the draught. To obtain this steam jet a subsidiary boiler was heated with anthracite before the generation of steam commenced in the main boiler. The latter took about twenty-eight minutes with oil or the residuals of oil fuel, sixty minutes with coal, and 2·2 lbs. of oil evaporated 228 lbs. of water; whereas the anthracite did not evaporate more than 11¼ lbs. of water. The temperature was so high that the funnel got red-hot about 30 cm. from its base—a sign that the heat was not used up because the heating surface was not sufficiently large. This system was wrecked owing to the large working expenses it entailed.

The gas-furnace of Mallet* was patented in France, in 1864, but was intended for laboratories, and not much for boilers. Mallet heated the heavy oils and burnt the steam by means of strong currents of air, which created a very high temperature.

Foote's † gas-furnace, Figs. 17–19, was tried by the U.S. Navy Department, in 1867, on board the gunboat *Palso*, near New York, during her trial trips at sea. The whole appliance consists of a cast-iron retort A, Fig. 17, with a wrought-iron bottom riveted on, which can be fixed to any

* 'Brevets d'Inventions,' 1864, No. 62,498.

† 'Engineering,' i., 1868, p. 60; Dingler, vol. clxxxviii. p. 211.

boiler grate after removal of the fire-bars. The petroleum is introduced into this retort by a pipe B, about 12 inches in diameter; the vapour of the petroleum then streams out of

FIG. 17.

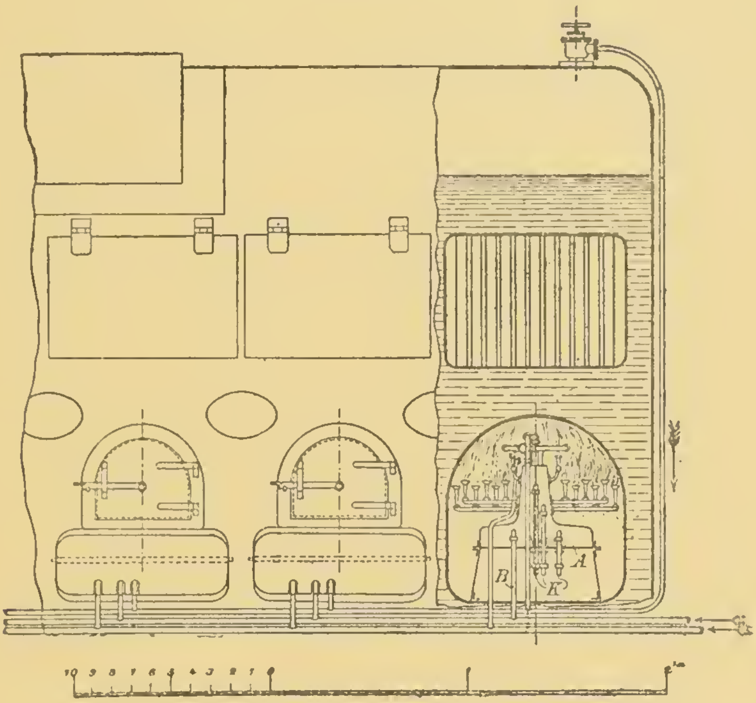
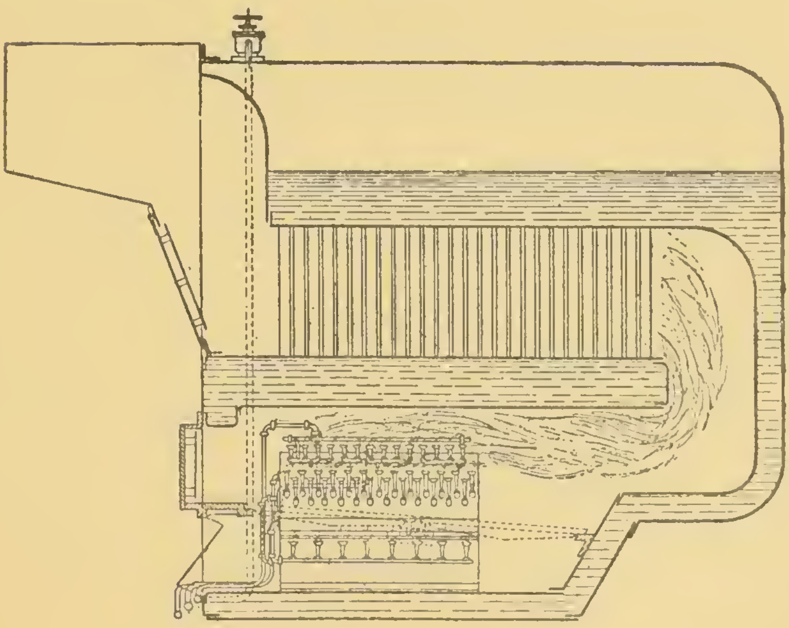
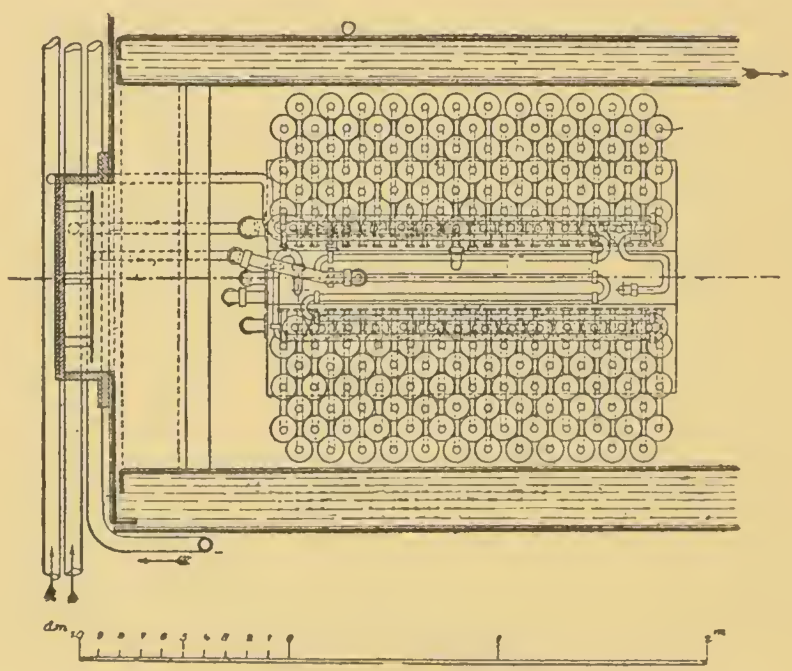


FIG. 18.



burners through another set of pipes. Fig. 19 gives the grouping of these burners on the floor of a furnace. At the top of the retort a pipe containing steam, and another pipe leading from an air pump, debouch. The pipes marked K convey the petroleum vapour to the burners under the retort. A wood fire is kindled on the floor of the retort, and kept up till the heat volatilises the petroleum the moment it enters. The petroleum is then allowed to flow out of a reservoir in the retort situated on a higher level, and the gases streaming out of the burners are ignited. The wood fire is now extinguished, because the burners now heat the retort, and the evaporation of the petroleum continues without interruption. The burners show at first a dull smoky flame; but the moment steam has been generated some of this can be

FIG. 19.



admitted into the steam pipe, which has by this time become red-hot; the steam gets superheated, and the combustion of the burners improves, but it is not yet perfect. This is not attained until the air pipe forces air at a pressure of about 4 lbs. per square inch into the retort. A clear blue intensely hot flame is said to be the result. Particles of oil that are not consumed are deposited on the circular covering of the burners, which are red-hot, and are instantly ignited; thus perfect combustion is ensured. The introduction of oil, steam, and air into the retort is regulated by taps in the pipes. During the trial trips steam was generated twenty-five minutes after lighting the fires, and the boat is said to have attained a speed of 13·04 knots; whereas before, when coals were used, it had never made more than 8 knots. These statements are decidedly exaggerated, as the *Palos* is said to have a displacement of 350 tons; whereas she appears in the Navy List as having 420 tons displacement, and to make on the average 11 knots, and not 8. Foote's statements of evaporations attained are also exaggerated. He avers that he evaporated in nine hours 6000 lbs. of water with 279 lbs. of petroleum—that is, obtained a 21·5-fold evaporation. He also states that the United States Navy Department was so pleased with the results that it ordered the adoption of this system for several large transport ships. But nothing has been heard of these vessels, and the technical press gave somewhat different accounts.* From these it appears that the retort, as well as the pipes and burners, have no durability in them; the temperature they are exposed to being so excessive as to necessitate constant repairs. Besides, it would seem that the residuals stop up the various pipes, and that some of these had to be taken out and cleaned after forty-eight hours' use. We have consequently not heard any more of Foote's system.

The gas-furnace of Dorsett and Blythe,† Figs. 20 and 21, was tried in England in 1868 on the steamship *Retriever*, 500 tons, 90 indicated horse-power. Dorsett and Blythe did not combine the retort and the burners as did Foote, but separated them. On board the *Retriever* they had erected, besides the usual tubular boiler with three furnaces, two small vertical boilers which served as retorts. When steam was generated these two boilers were filled with heavy tar-oil of 1·050 specific gravity, and this was evaporated by means of an ordinary coal fire. When the oil vapour had reached a pressure of about 20 lbs. per square inch it was conveyed to the retorts of the furnaces, where it entered into a couple of burners, which continued the evaporation of the oils. When the oil vapour had attained a pressure of 50 lbs. per square

* 'American Artisan,' 8th May, 1868.

† 'Engineering,' ii., 1868, pp. 324 and 340.

inch, or a temperature of 932° F., it was let into the furnaces of the steam boiler. Each of these was closed with an ash-plate.

FIG. 20.

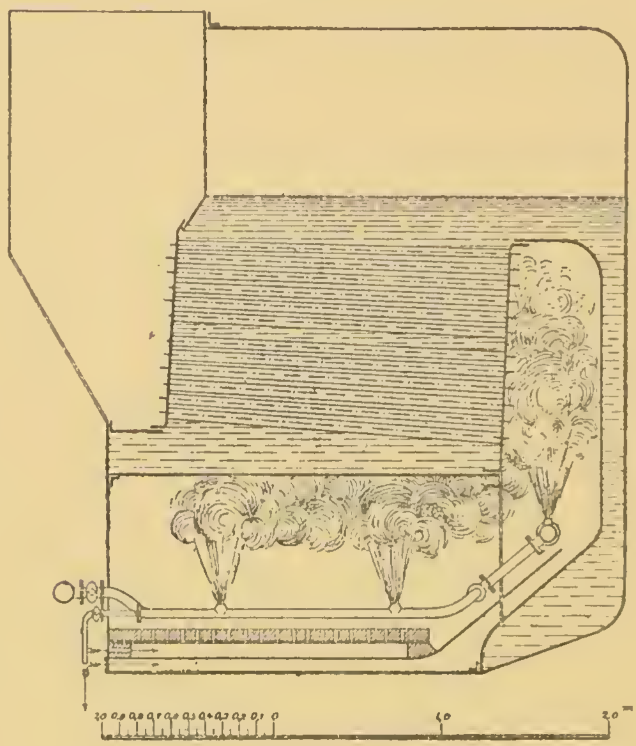
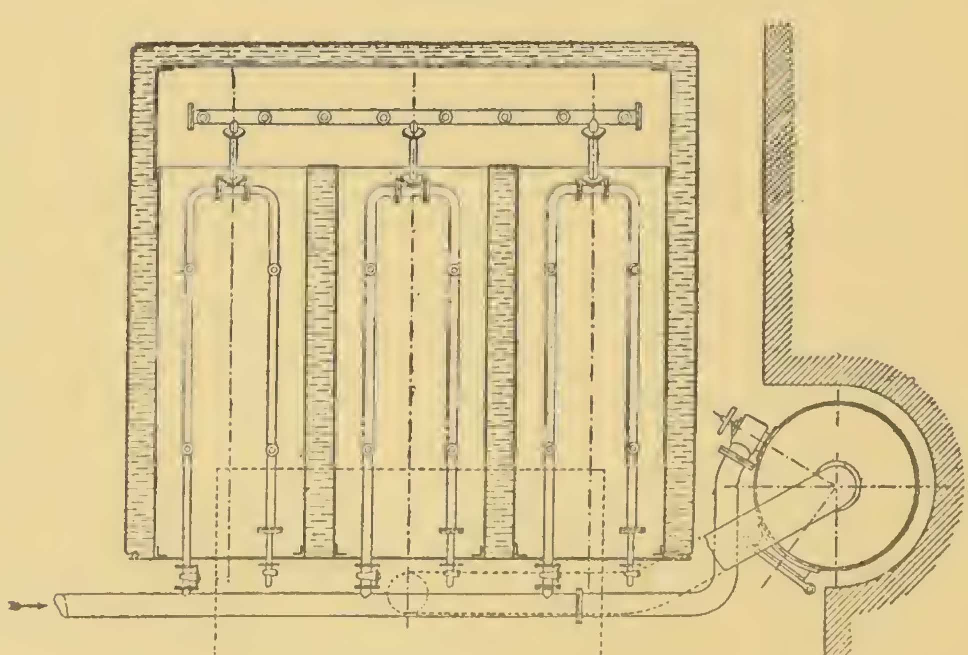


FIG. 21.



About 75 mm. above this a sheet of iron was attached which extended backwards as far as the combustion chamber. About

75 mm. above this sheet again, there was another iron sheet, shorter and perforated, which was covered with fire-bricks. The back opening between the two sheets was completely filled with such bricks, the forward part only partially so, so that a certain volume of air could enter and find its way through the holes in the sheet and the bricks into the furnace. Another volume of air which could be regulated by means of a sliding valve could enter into the combustion chamber between the lower iron sheet and the ash-plate. The gas-supply pipe that entered each furnace went along the fire-bricks as far as the combustion chamber and then turned back again. The combustion chamber at the back, which was common to all three furnaces, also contained a gas pipe which lay across and communicated with those in the furnaces. The gas pipes in the furnaces had four holes of 0·08 inch in diameter, and the pipe in the combustion chamber had eight such holes, so that the boiler was heated by twenty flames. Each pipe had an entrance and a vent tap. The first was for regulating the supply, the last for carrying off any condensed oil which might form during the heating. Owing to the very high temperature of the oil vapour the retort boilers as well as the gas pipes had to be covered with a coating of sheet iron and the spaces between were filled up with sand and pottery. About 150 horse-power was given out by the engine, which means, at an hourly consumption of 529 lbs. of oil, about 3·52 lbs. of oil per indicated horse-power an hour. The evaporation, which was 12·35-fold according to Paul, agrees with these data. The combustion seems to have been good also; between Gravesend and Deptford very little smoke was given out by the steamer, and that had a temperature of 752° F. Dorsett and Blythe conducted experiments later at Chatham,* for heating furnaces for armour plates, and they succeeded in bringing to a high temperature a 6-inch armour plate in an hour by means of their gas furnaces, whereas five hours are required when coal is used. The oil consumed in a day of twelve working hours per

* 'Engineering,' i., 1869, p. 324.

furnace was a little more than 1 ton, whereas in the same furnace and during the same period a consumption of from $2\frac{1}{4}$ to $2\frac{1}{2}$ tons of coal would have been requisite. But owing to the costliness of the oil furnaces coal carried the day, notwithstanding the superiority of the former.

Value of Gas-furnaces.—Gas-furnaces undoubtedly give better results than hearth-furnaces. The distribution of the fuel by using it in a gaseous form, and subdividing it in burners, has been well carried out by Foote, as well as by Dorsett. Sufficient air supply is easily procured, and thus good combustion is insured. The efficiency of gas-fires, from the point of view of performance, is therefore beyond doubt. The disadvantages which have prevented them from being generally adopted are to be found in their being too complicated, and consequently entailing a great capital outlay. Another disadvantage is the danger arising from gas furnaces, for the temperature of oil vapour is about three times as high as that of steam at the same pressure; so that the walls of the retorts have to be strong to an enormous degree, and are not safe. But the chief fault of the gas furnaces is the rapid stopping up of the supply pipes, owing to the residuals not vaporising.

In the case of the arrangements of Dorsett and of Foote, this was found to be the main disadvantage. Mr. Thwaite,* however, recommends this method and has applied it as follows:—The liquid hydrocarbon is injected by steam into the centre of the steam generator furnace; the steam and oil pass backwards and forwards through the retort and become, on contact with its sides, converted into gas. The gas issues in an annular ring from the front of the retort, and, striking against a divert-plate of the air-receiver, returns around the outside of the edge of the retort, where the gas is met by an annular blast of air, producing a hollow cylinder of flame in the inside of which is the retort, encircled with flame from end to end. The outside periphery of the flame is in close contact with the perforated refractory linings of

* 'Liquid Fuel: its Advantages for Firing Steam Generators,' by B. H. Thwaite, London, 1887, E. & F. N. Spon.

the flue, which not only become incandescent, and prevent the oxidising action of the flame on the plates, but prevent also a too serious reduction in the temperature of the flame. After extensive trials conducted by Mr. Thwaite, the tubes were examined and found free from deposited carbon.

CHAPTER IV.

SPRAY-FURNACES—SLIT-SPRINKLERS.

(C) *Spray-furnaces.*—On this principle the oil is divided into small sprays by a steam and air jet, and is then nearly completely burnt up in a vaporous condition by means of the introduction of air. This air is generally introduced by the draught caused by the jet, and the oil is supplied from a tank above; in the case of ships, however, it is pumped up from the hold below. The combustion is so perfect that scarcely any smoke is generated. Indeed, Engler * says of these fires that there is a special charm about their chimneys, which produce no smoke, and only give forth trembling gases. But he says that the oil residual in locomotive boilers is not so smokeless or free from smell. During the railway journey between Tiflis and Baku he noticed smoke and smell, though these were not so strong as in the case of German locomotives. It is, of course, possible that these locomotives are not provided with the latest system of spray-firing. The temperature attained by these fires is so high that it is found necessary to protect the sides of the fireboxes with fireproof stone, or else deflect the flames from them. The oils are divided into minute sprays by means of sprinklers, the arrangement of which differentiates the various systems into the following classes:—(*e*) slit-sprinklers, (*f*) pipe-sprinklers, and (*g*) nozzle-sprinklers.

(*e*) *The Slit-sprinklers.*—Lenz's old slit-sprinkler (see Figs. 22–29) was first used in 1870, and is probably the best known on the steamers of the Caspian and the lower Volga. Two pipes lead to the sprinkler in the fire-door. The upper

* C. Engler, 'Das Erdöl von Baku' (Mineral Oil of Baku), p. 38.

pipe introduces the oil, the lower one the steam. The sprinkler is of cast brass, and divided in two halves by a partition A, Fig. 25, so as to prevent the intermixture of the oil and

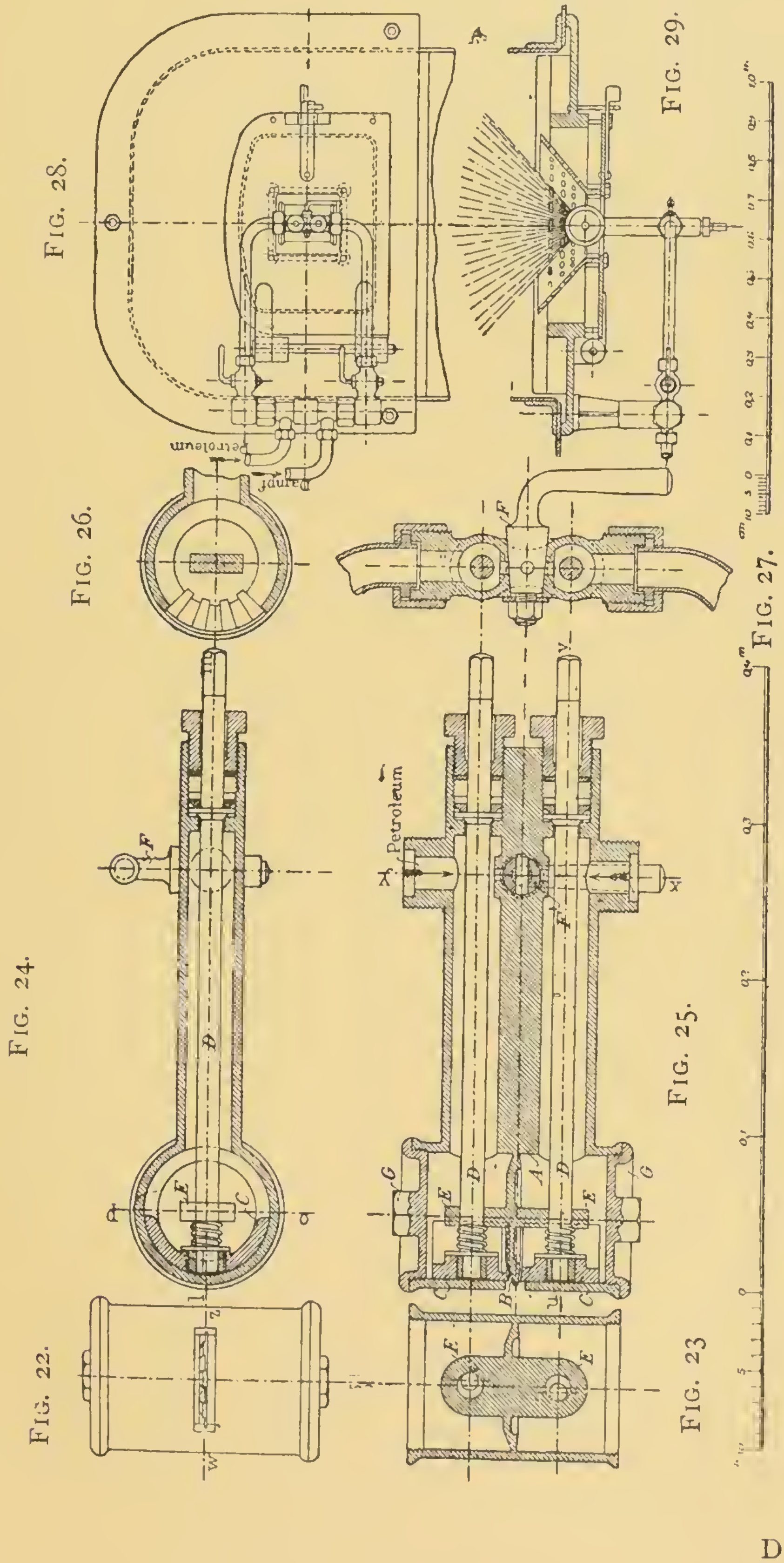


Fig. 22. Fig. 23. Fig. 24. Fig. 25. Fig. 26. Fig. 27. Fig. 28. Fig. 29.

steam. The partition terminates in front in a tapering tongue B, in the filed grooves of which, see Fig. 26, the oil flows out to be blown away in separate thin sprays by the steam that streams out from underneath this tongue. The intervals between the sprays of oil serve to facilitate the access of air. The flow of oil and steam is regulated by the circular slides C C, Figs. 24 and 25, which are pressed by spiral springs against the inner walls of the cylindrical sprinkler. A spigot fastened eccentrically in the axle of the spindle D grasps each slide. The spindles D are firmly packed at E against the partition and terminate outside the sprinkler with a square section, so that they can be turned by keys, and can thus effect the displacement of the slides. Should the flow of the oil residual be stopped up, the oil pipe is shut off, and the tap F is opened and the tongue-openings are then blown through. When a thorough cleaning is necessary, the cover G is unscrewed. Figs. 28 and 29 represent a Lenz sprinkler fitted into the fire-door of a marine boiler. It revolves round its own supply pipes, so that the door can be opened and shut without being interfered with by the sprinkler. On lighting the fires the sprinkler has to be turned out of the fire-box and lighted separately so as to avoid explosion inside the fire-box, of which mention will be made later. The old Lenz sprinklers did not give satisfactory results, as the flame, which was kept well together, destroyed the walls and ends of the pipes. As the fire-box was not uniformly heated all over by the flame combustion was imperfect. Considerable soot formed, which had to be cleaned out frequently, and this caused a very poor duty to be yielded per indicated horse-power per hour, requiring as much as 6·6 to 7·7 lbs. of mineral oils. The slit sprinkler of Körting, Figs. 30 and 31, was made in 1872 and worked with air, which was compressed in a specially constructed steam jet apparatus. The compressed air was conducted into the sprinkler by means of tubing, and was divided by a partition into two flat currents, above and below which the slits for the oil were placed. Fig. 31 shows the mouth of the sprinkler, full size ; it will be seen that the slits are very narrow, they get frequently stopped up. The sprinkler could not be cleaned without being taken completely to pieces, which entailed considerable delay, for which reason Körting introduced the pipe and nozzle sprinklers, to be described further on. The new slit sprinkler of Lenz,* Figs. 32 and 33, is furnished with a circular opening round the cylindrical chamber, instead of a straight slit. This insures a circular flow of the oil spray. The slides C C are also made cylindrical

FIG. 30.

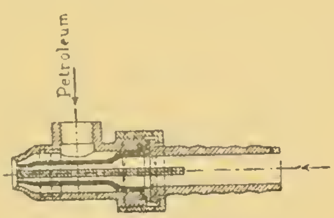


FIG. 31.

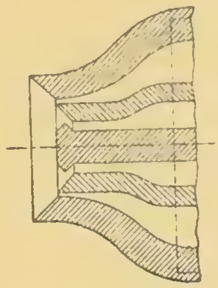


FIG. 32.

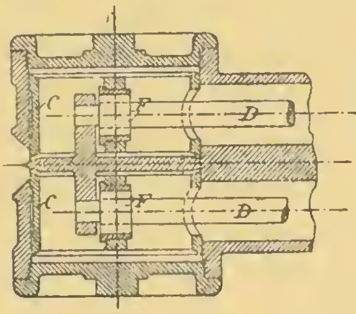
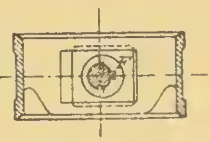


FIG. 33.



and are movable backwards and forwards in the chamber. For this purpose grooved eccentric rings F are placed round the spindles D D, and are run along a groove shown in Fig. 33, in the centre of the slides C C. The tongue is also altered with a view to obtain a broader flame, as will be seen from Fig. 32, but the rest of the arrangement of the sprinkler remains the same. This improvement was introduced some fifteen or twenty years ago, and was specially adapted for marine boilers and locomotives. Through its introduction the usefulness of Lenz's sprinkler was enormously increased, although it made it rather dearer and more complicated.

* Engler, 'Das Erdöl von Baku' (Mineral Oil of Baku), p. 37.

The slit-sprinkler of Artemiev,* Figs 34–39, became generally known towards the end of 1878. It is simpler than Lenz's new sprinkler and consequently much cheaper. The difference consists chiefly in the regulation of the supply of

FIG. 38.

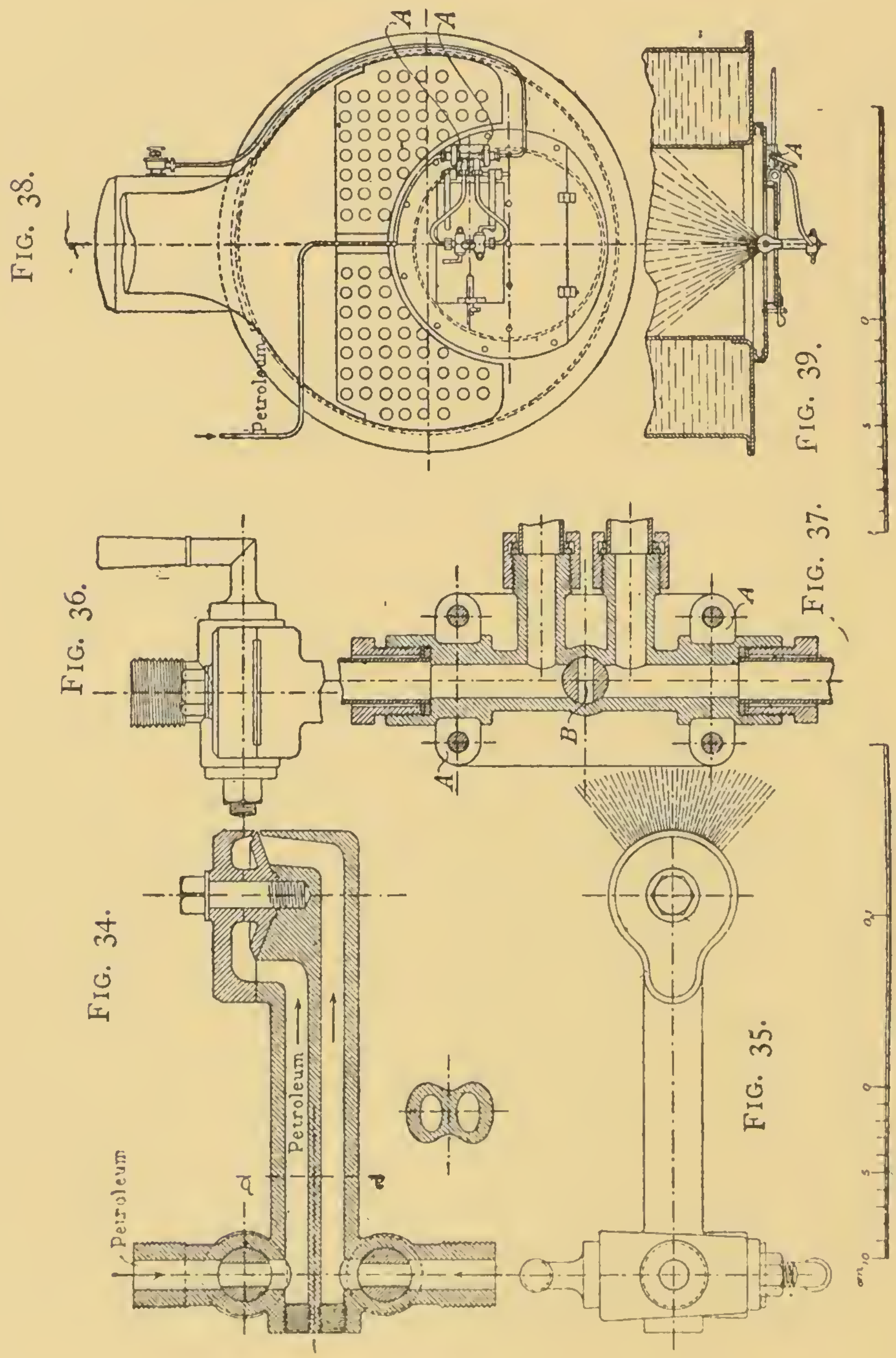


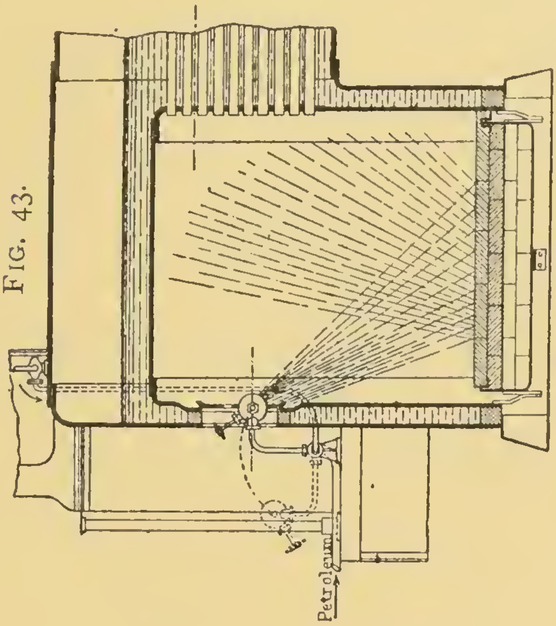
FIG. 39. FIG. 36. FIG. 37. FIG. 34. FIG. 35.

oil and steam, which is done by taps instead of cylinders. The steam and oil are conducted in separate pipes to the semi-circular slit, the tongue of which is formed by a disc sharpened

* 'Engineering,' i., 1883, p. 577.

at its edge. This disc, with its cover, is held in the sprinkler by a single screw. The apparatus is attached to the boiler by

FIG. 43.



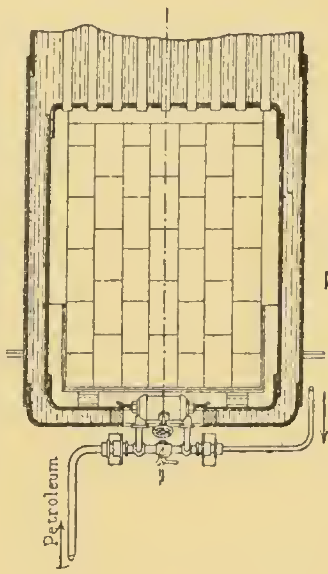
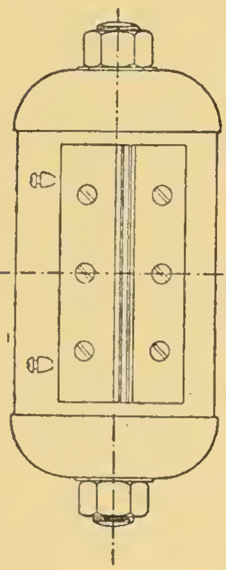


FIG. 44.

FIG. 40.



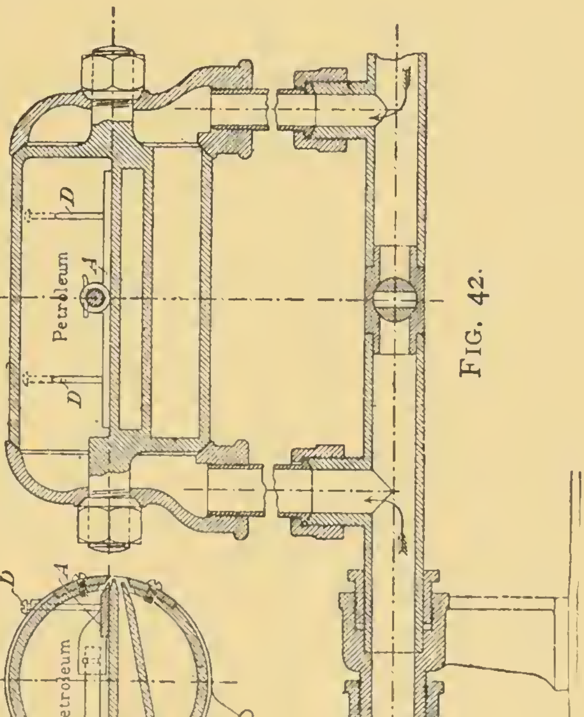
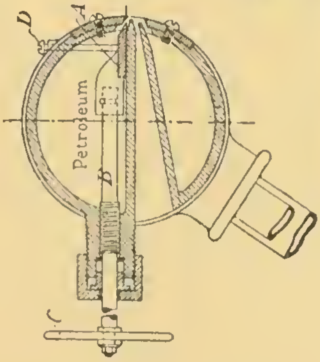


FIG. 42.

FIG. 41.



means of the two castings A A, Fig. 37, in which it can revolve. Should the slit get stopped up the blow-cock B is opened and the cock regulating the oil supply is closed; should the entire apparatus get dirty it can be taken to pieces and cleaned in a few minutes, being previously turned out of the fire-box and the screw of the cover being taken off. This can be done so quickly that the steam need not be stopped for a moment. Next to its cheapness this is the chief advantage of Artemiev's apparatus.

The slit-sprinkler of Karapetov,* Figs. 40–44, has been regarded as one of the best, and was used more especially for locomotives. It resembles those described above that are fixed to the boiler with movable pipes, but it has the advantage of directing the flame on to a fire-proof brick hearth, Fig. 43, which attains a very high temperature, and ignites any drops of oil that may have been unconsumed. The apparatus is composed of a central body and three channels; the upper channel conducts oil, the central air, and the lower steam. The ends of the sprinkler, which have oil and steam supply pipes, are secured to the central body, Fig. 42. The steam jet, leaving the slit, draws the air through the central channel and brings it to bear on the particles of oil to be consumed and favours their complete combustion. The supply of oil is regulated by a slide A, with a spindle B and a hand-wheel C, whereas the steam is regulated by a cock or valve. Two screws D D prevent the slide A from slipping back. For purposes of inspection and cleaning the sprinkler is brought into the position indicated by dotted lines in Fig. 43. Even this apparatus uses so much oil per horse-power per hour that it can only be adopted when the fuel is procurable for next to nothing.

The slit-sprinkler of Brandt,† Figs. 45–48, which was introduced in 1880 for locomotives but can be applied to torpedo boats, is the most complete apparatus of its kind, inasmuch as it insures a circular outflow of the oil, and produces a flame which fills equably the whole fire-box. The oil flows through the central pipe into the sprinkler, Fig. 45, and passes into the larger upper part A of the exit

* 'Engineering,' i., 1883, p. 577.

† 'Engineering,' 1883, i., p. 600.

chamber, which is divided into two compartments by a tongue disc, the steam being introduced into the lower and smaller section of the same chamber. The upper end of the oil-pipe has a socket furnished with the slots B B, which can be moved to the channels C C on unscrewing the cap D, by which means the distribution of oil can be regulated. The oil flowing through the channels C C enters

FIG. 45.

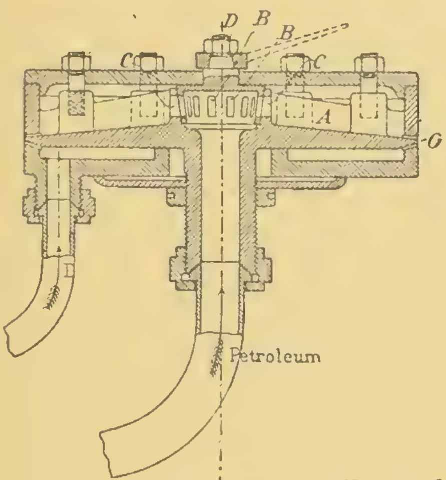


FIG. 46.

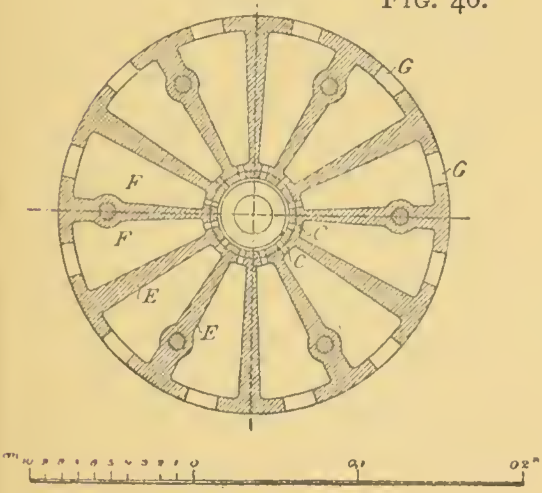


FIG. 47.

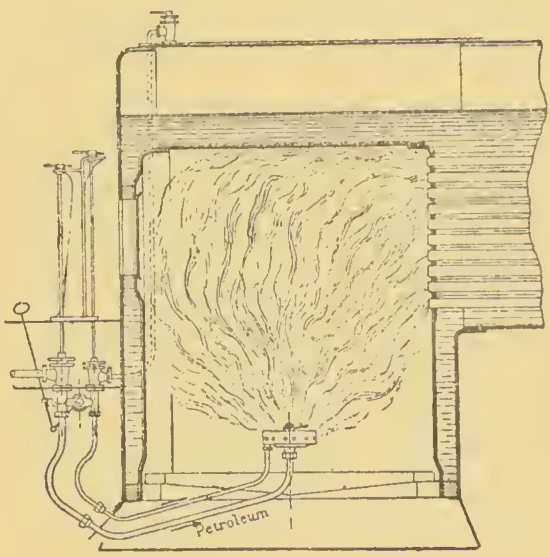
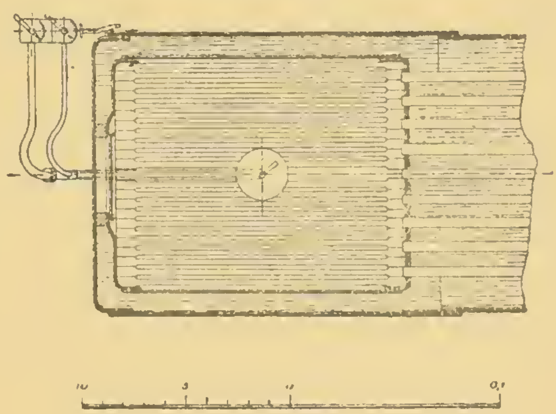


FIG. 48.



the compartments F F, Fig. 46, formed by the ribs E E of the tongue discs, and leaves the exit chamber in separate thin rays through the orifices G G. On its exit the oil is seized by the steam jet leaving the lower exit chamber and vaporised. The supply of oil and steam is regulated by cocks. The sprinkler is fastened to the ordinary fire-bars, which need not be removed—a great advantage. The circular flame is blown upwards by the air entering under the fire-bars, which is drawn up by the chimney draught, and circulates round the walls of the fire-box in fairly equal proportions. A disadvantage of this sprinkler is its difficulty of access. This may necessitate cutting off steam entirely should cleaning be wanted. The slit-sprinkler of Jensen* was experimented with in 1883 by the "Forges et Chantiers de la Méditerranée" in Marseilles, with the result that it was fully demonstrated that liquid fuel could be successfully employed for the Russian torpedo boats of the Black Sea.

The sprinkler represented in Figs. 49–52, requires no further explanation, except that the original mouthpiece A, which allowed the parallel exit of the oil and steam jets, had to be altered, as no regular combustion was possible with it. The alteration consisted in making the steam and oil jets meet at an angle of 45°, and in removing the partition at the mouth; this was most successful. The cock B was in connection with a manometer for the purpose of observing the steam pressure necessary for the vaporisation of the oil. This cock, which regulated the supply of oil, had the gearing E, the air and steam supply cock the gearing D.

Value of Slit-sprinklers.—All slit-sprinklers have great disadvantages, amongst which, however, the waste of oil and steam which they entail are foremost. An average oil consumption of 6·4 lbs. per horse-power per hour and the fivefold or sevenfold evaporation—which is the highest attainable according to experiments by Nobel and Gulishambarov—render the use of this system out of the question in any but oil regions. The consumption of steam is on the same scale, and reaches about 6 or 8 per cent. of the steam generated by the boiler. A compound engine of 100 indicated horse-power, which consumes hourly 22 lbs. of steam per indicated horse-power, would entail for the working of the sprinkler a consumption of steam in twenty-four hours of $10 \times 100 \times 24 \times 0{\cdot}08 = 4232$ lbs., or nearly two tons a day Moreover, as salt water can only be used when, as in the case of the Caspian Sea, the salt is present in

* 'Morskoi Sbornik,' 1884, No. 1.

very small proportions—1·4 per cent.—and as it is impossible to carry fresh water for the sprinklers' use, these sprinklers are only applicable in cases where steamers are always in fresh

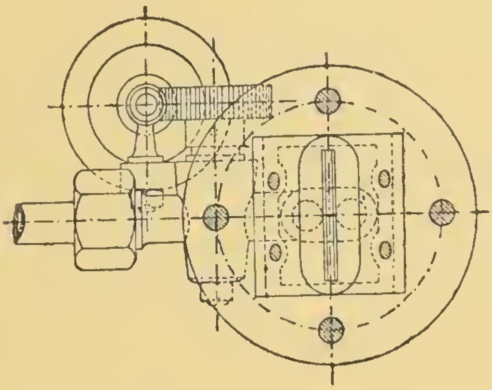


FIG. 52.

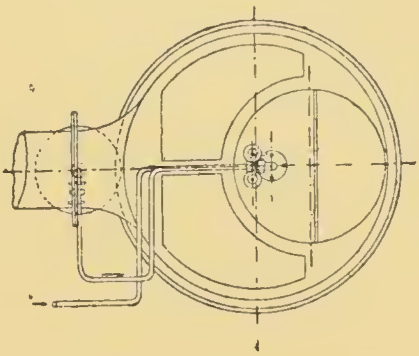


FIG. 49.

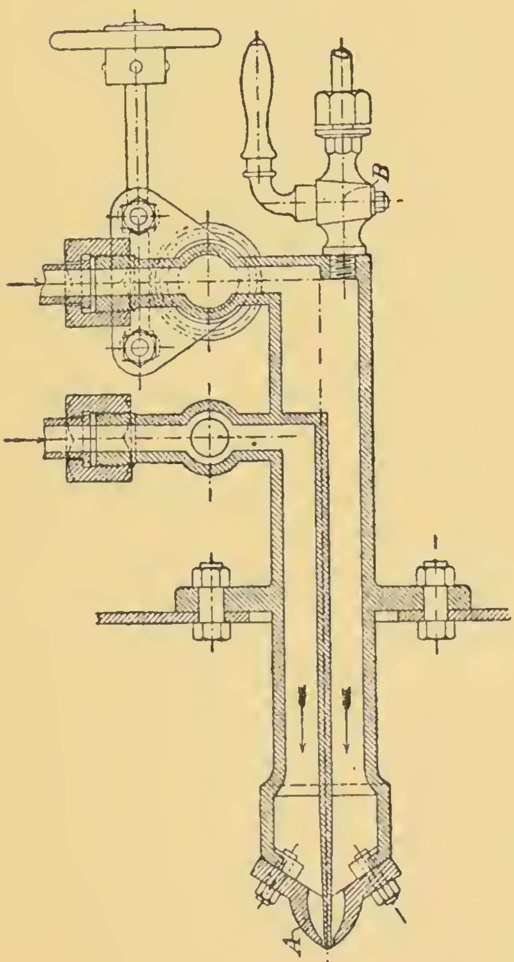


FIG. 50.

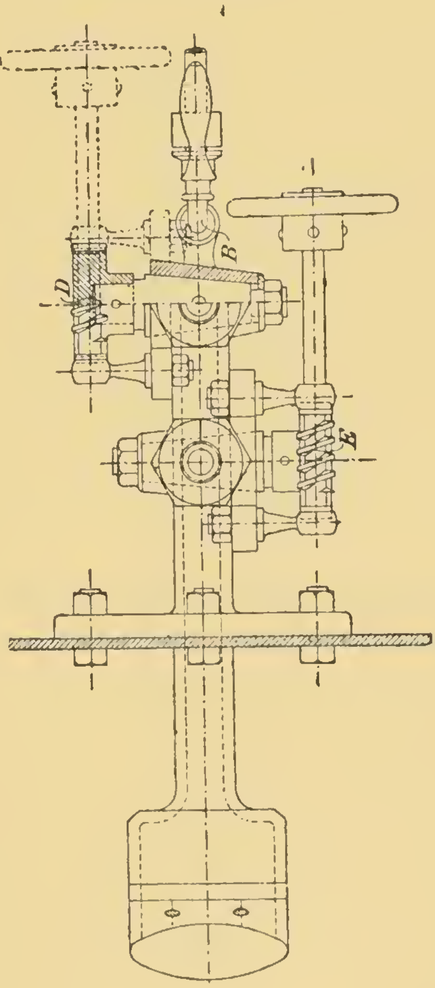


FIG. 51.

water, like the Volga steamers for instance, or in waters like that of the Caspian. In the Mediterranean, however, where the proportion of salt is 4 per cent., a steamer fitted with liquid fuel slit-sprinklers would have to be continually blowing off four-fifths of the water in the boiler; this would mean 6·4 per cent. of the entire fuel consumption. But on the Caspian no more than 1·5 per cent. would be thus blown off. Another great disadvantage arises from the continued stopping up of the slits. This is caused by sand and other impurities in the oil, and produces intermittent combustion. It has been found necessary in these cases to have two sets of sprinklers in the same furnace, so as to prevent a stoppage when cleaning becomes suddenly necessary, or to work them alternately. Further, it is of frequent occurrence that, owing to strong draughts or sudden gusts of wind, these sprinklers are blown out. This causes an accumulation of carbonised oil residual in the slots, and the entire apparatus has to be taken to pieces and thoroughly cleaned before it can again be worked. A worse feature, however, is the sudden cooling of fire-walls, caused by the extinction of the flame: the temperature being very high, the walls are expanded; a sudden extinction causes their contraction; and thus leaks are of constant occurrence, especially in the pipes. But a good many of these very serious drawbacks are overcome by the spray fires to be considered in the next chapter.

CHAPTER V.

SPRAY-FURNACES—PIPE-SPRINKLERS.

(*f*) *Pipe-sprinklers.*—Pipe-sprinklers were first used by Mr. Brydges Adams,* who adopted them in 1863 in America for locomotives. They are, however, just as applicable to marine engines. Near the boiler is an air-tight oil-tank, through the cover of which the pressure pipe of an air-pump is conducted. Two concentric pipes, one within the other, lead from this tank to the fire. The inner pipe reaches down to the bottom of the tank, the outer pipe, only as far as the compressed air over the oil. The pressure from the air-pump forces a continuous stream of oil into the pipe, and this is surrounded by a circular air current from the outer pipe, which vaporises it, and thus perfect combustion is insured. The oil and air supplies can be regulated at pleasure by means of independent cut-offs. The floor of the hearth is closed, and is covered, on making the fire, with a layer of glowing coke which serves to ignite the oil. The Brydges Adams sprinkler worked satisfactorily, but was found too complicated for locomotives owing to the air-pump, which had to be worked by the same engine.

Bullard,† the manager of the Aerated Fuel Company, Springfield, Mass., U.S.A., has lately reintroduced this sprinkler as something entirely novel. He has certainly made it more practicable, but his improvements have also increased the complication and expense of the system. The distinction of Bullard's system from that of Brydges Adams consists

* A. Ledieu, 'Les Nouvelles Machines Marines,' Paris, 1882, iii. p. 165.

† 'The Iron Age,' New York, 27th October, 1887.

chiefly in the introduction of an oil and air tank on each side of the fire-box, into which any desired number of burners in the fire-box communicate. The fire-box can be used for coals when preferred. The air is compressed by a Westinghouse pump to a pressure of 8·33 to 9·72 lbs. per square inch, which corresponds with the pressure of 11·1 lbs. per square inch, used in the Jensen sprinkler.

A noteworthy improvement of Bullard's is the simple and practical pressure regulator for the air. The air as it enters presses against a valve, which is kept down by a spiral spring. If the air pressure be too great the valve is lifted, at the top of the piston rod of the valve a toothed rod is fastened which turns a toothed sector on the axle of the steam regulator tap, so that the supply of steam to the steam cylinder of the pump is reduced. The pump now works more slowly until normal speed is again reached, when the spring presses the valve down into its old place. The supply of oil is regulated by a ball valve. The flame of each burner can be reduced or enlarged by means of a hand-wheel, which brings the oil pipe nearer or takes it further away as desired. In the former case the supply of oil is increased and that of air decreased: in the latter the converse is the case. A great advantage claimed by this system is that the sprinklers are said not to get heated, and it is further stated that they do not get stopped up with oil residuals. This latter assertion must be received with reserve, however.

Bullard's sprinklers are in use at paper works in Mechanicsville, New York, and supply the town heating of Springfield.

The pipe-sprinkler of Brandt,* Figs. 53–55, was constructed in 1880, principally for marine engines. The steam and oil pipes are united in a brass casing; their supplies are regulated by cocks. The oil escapes through a circular orifice which is regulated by a hand-wheel and spindle and a needle. The steam escapes through another orifice surrounding the former. The oil and steam mix in the space between the needle and the cap, which is regulated by a screw

* H. Engler, 'Das Erdöl von Baku,' p. 34; and 'Engineering,' 1883, i. p. 600.

in the brass casing. and enters the fire-box in a conical bundle of streams, which are then burnt up. The cocks in the orifice

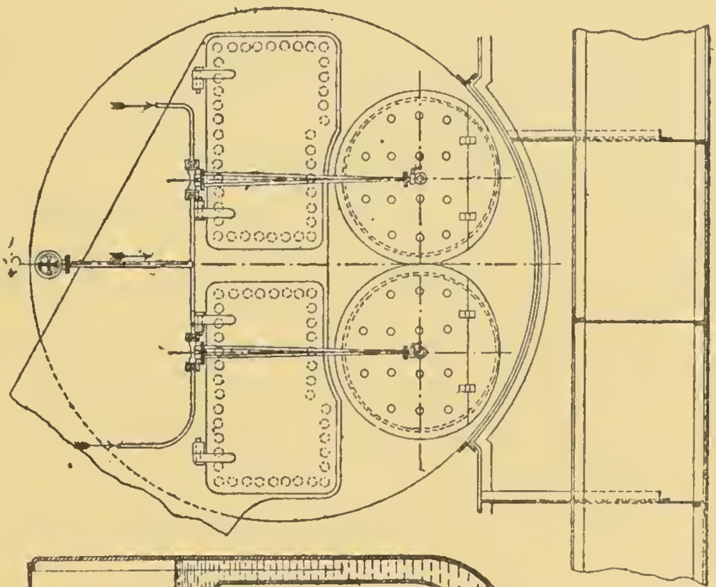


Fig. 55.

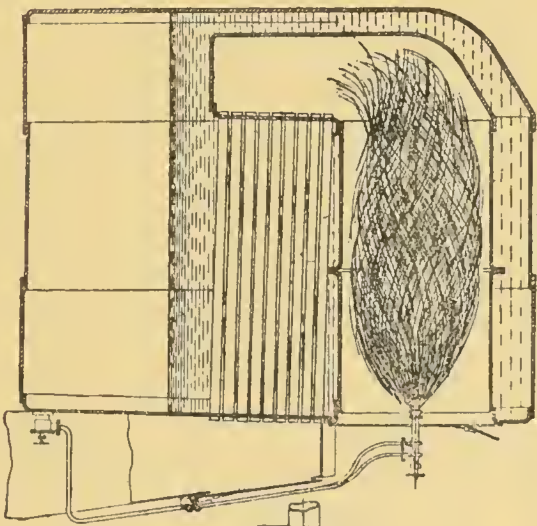


Fig. 54.

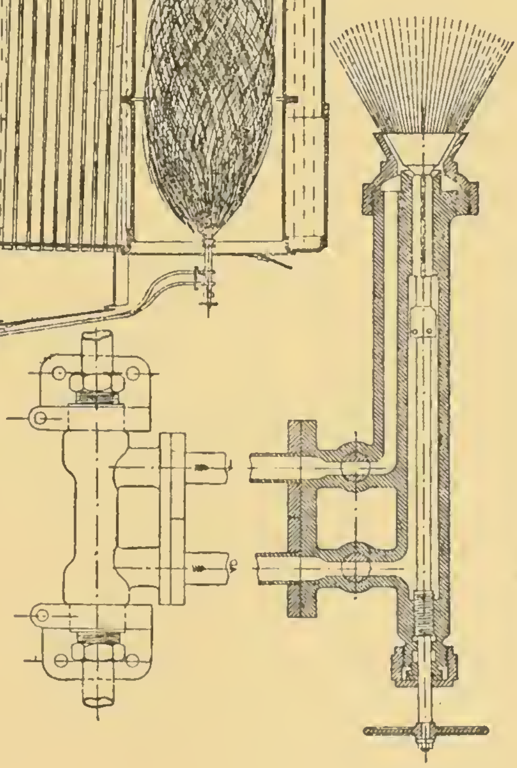


Fig. 53.

and steam pipes are left open during work, and the supply is regulated entirely by the needle.

The sprinkler is so constructed—as will appear from Fig. 55—that it can be turned out of the fire-box, the cap can be removed, and the entire apparatus thoroughly cleaned. The requisite air enters through holes in the door and the ash valve in the fire-box. This sprinkler is preferable to slit-sprinklers, inasmuch as it heats the fire-box more equably and entails a smaller, though still extremely high, comsumption of oil.

The pipe sprinkler of Nobel is an improvement on that of Brandt, as, by means of a spirally grooved cylinder in the sprinkler, a spiral movement is given to the oil and steam spray, and thus the fire-box is more equably and thoroughly heated, the radiation is improved, as well as the combustion.

A steam boiler on this system at the Moscow Industrial Exhibition of 1883 is said by Gulishambarov* to have generated as much steam with from 50 lbs. to 60 lbs. of oil residual as could have been generated under the same circumstances by 100 lbs. of coal. This statement, however, agrees doubtless with the reputed fact that from 4·4 to 6·2 lbs. of oil residual was required for each indicated horse-power per hour, and leads to the conclusion that the boiler and engine must have been exceptionally inefficient. For if 1 lb. of coal had vaporised only 5 lb. of water, 1 lb. of oil must have evaporated at least 8·3 lbs. of water. Besides, the effect of Nobel's improvement may be secured by cutting spiral grooves into Mault's escape pipe.

Smith's † pipe-sprinkler, Figs. 56–58, which has been lately patented in England, consists of two concentric pipes, of which the inner one can be displaced against the outer one, and of a central screw spindle with a cone-shaped outlet. The outer pipe receives the oil from a supply pipe, which has a branch pipe for the admission of air. The oil and air enter the inner pipe through openings in its circumference, and reach the cone outlet. The space between the outer and inner pipes is filled by steam, which streams out of the cone-shaped outlet in a circular form. The inner pipe has a valve

* Gulishambarov, 'Die Naphthaheizung der Dampfer und Lokomotiven' St. Petersburg, 1883, p. 124.

† 'Transactions N. E. Coast Institution of Engineers and Shipbuilders,' November, 1886, p. 31.

at its outlet leading to the cone, and leaves circular slits for the escape of the oil and air as the central spindle keeps turning. In a similar manner the expansion of the inner pipe and the contraction of the outer pipe act like a cone valve when the inner pipe is displaced by means of a hand-

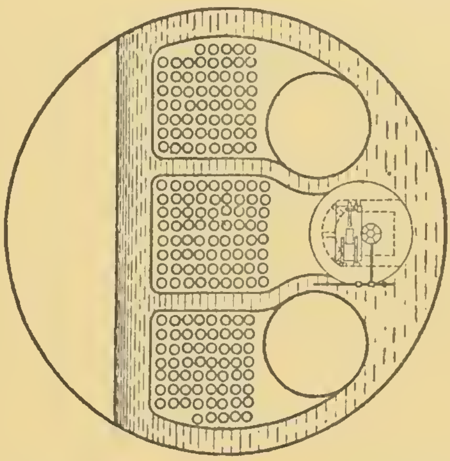


FIG. 58.

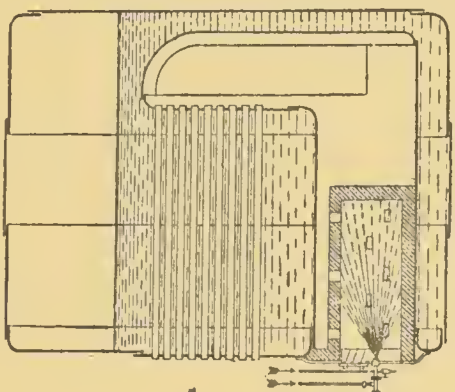


FIG. 57.

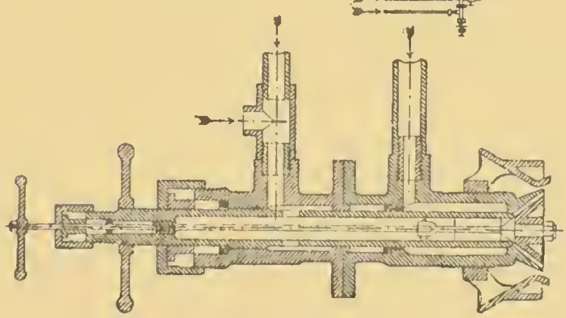


FIG. 56.

wheel, whereby the escape of steam is regulated. A hollow cone is screwed over the outlet, which enables the air to be sucked up while the spindle is at work, and which can be displaced according to requirements. The advantage of this sprinkler is supposed to lie in the convenient regulation of the oil, steam, and air supplies; but on the other hand it is much more complicated than others, and would take some time to clean, although it can be taken to pieces quickly.

Körting's pipe-sprinkler, Figs. 59–62, is distinguished from all the above by the circumstance that it is not the oil but the steam which is sent through the inner pipe and that the oil is supplied to the outer pipe, by which arrangement it is found much easier to clean out the sprinkler in the event of its getting stopped up. The steam reaches the outlet through

Fig. 59. Fig. 60.

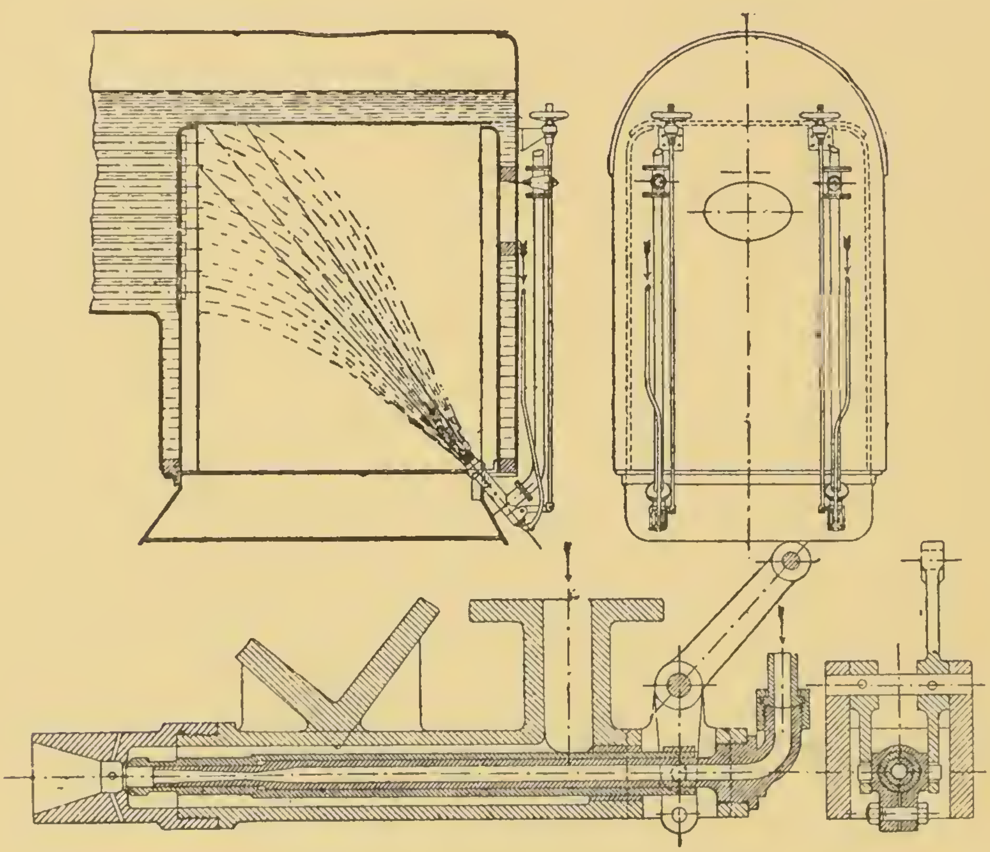


Fig. 61. Fig. 62.

a pipe that is narrowed considerably at its mouth. This pipe is secured by a socket, to the back of which an elastic chuck, with two pivots worked by two small levers, is fastened. On the axis of these levers there is another lever, which is movable from without by means of a drawing rod and a hand-wheel. When this lever is moved the socket at the mouth of the pipe moves also, and thus the flow of oil is regulated. The steam, can be turned off by a tap or valve. The oil and steam spray as it leaves the pipe sucks in air through the holes in the side of the outflow cone, by which means combustion on the surface of the oil is increased. Air is also admitted from the ash flap. The flame is, in the case of locomotives, projected against the opposite upper corner of the fire-box; in the case of marine engines, however, it is thrown back on the fire-bricks behind. These sprinklers have the advantage of great simplicity of construction, and can be easily cleaned when the mouthpiece is unscrewed. A disadvantage of the slanting sprinklers for locomotives is that the flame is directed straight against the roof of the fire-box and of the tube plate wall, which subjects them and the ends of the tubes to an excessive strain. Further, should the supply of oil be inadequate, the lower half of the circular outlet would be filled with oil, and the steam, instead of vaporising it, would only break it into small sprays.

Value of Pipe-sprinklers.—Pipe-sprinklers work more economically than slit-sprinklers. The first require as much as 6·6 lbs. of oil per 1 indicated horse-power per hour while the latter do not require more than from 4·4 to 5·5 lbs. The consumption of steam is also very much less, and does not amount to more than from 4 to 6 per cent. of the entire steam consumption, whereas slit sprinklers use as much as 6 and even 8 lbs. per cent. What has been said of the frequent stopping up of the outlets of the slit sprinklers applies to the pipe sprinklers, although in a less degree. They are, however, all furnished with removable mouthpieces, and are even in some cases, as shown at Fig. 60, provided in duplicate. The principal advantage of the pipe sprinkler consists in the spherical flame, which fills up the cylindrical fire-boxes of marine boilers better and heats them more equably than does the stream of the slit sprinkler. The pipe-sprinklers therefore save the walls of the boiler, and render, when properly fitted, fire-bricks at the back of the fire-box unnecessary.

CHAPTER VI.

NOZZLE-SPRINKLERS.

(*g*) *Nozzle-sprinklers.*—The nozzle-sprinkler of Aydon, Wise, and Field,* Figs. 63–65, is one of the oldest methods of burning liquid fuels. This sprinkler was first used at South

FIG. 63.

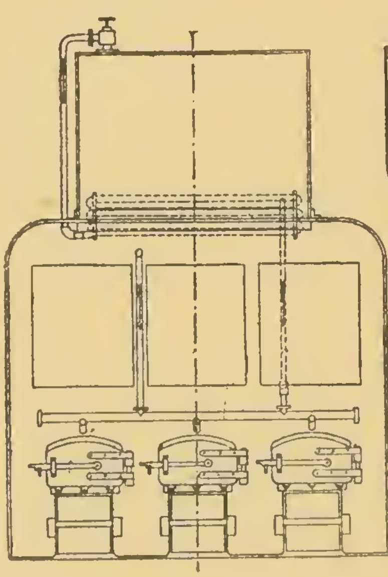
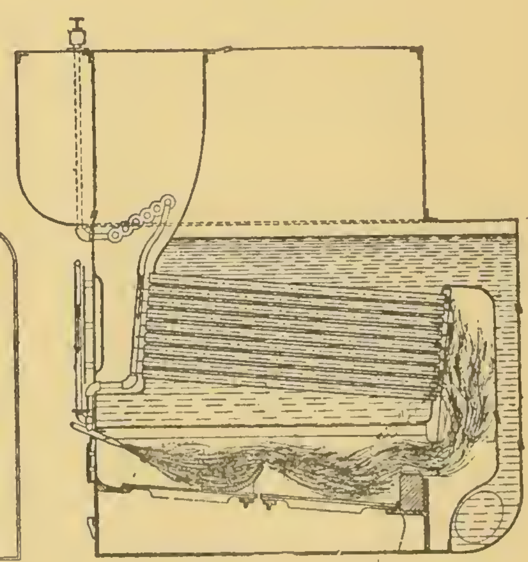


FIG. 64.



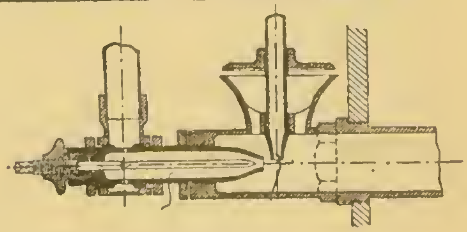


FIG. 65.

Lambeth in 1866 fitted to a Cornish boiler. The oil—petroleum or tar oil—entered the sprinkler from a vertical pipe through an opening which was about 12 inches in diameter: through this opening it flowed continuously from a

* 'Mechanics' Magazine,' 1867, p. 79.

tank above it at the rate of about 3·3 gallons per hour. During its fall the oil was forced into the discharge pipe by the stream of superheated steam escaping from the horizontal pipe, which sucked in air through the funnel. The oil, steam, and air amalgamated in this pipe and arrived through a cone-shaped mouth over the fire-door into the fire-box. About 39 inches from the fire-door there was a fire-bridge of tiles against which the stream of oil and steam impinged in the form of a cloud of thin vapour; this superheated steam having partially distributed the oil and vaporised the rest. The unconsumed particles of this vapour either got ignited at a coal fire or against the fire-bridge, which was intensely hot; this was facilitated by the previous mixture with air. The supply of oil was regulated by a tap in the supply pipe, that of the steam by a spindle, and that of the air by a cap. The fire was lighted by placing some red hot coals on a sheet of iron on the grate, and these ignited the oil.

At the trials made by Admiral Selwyn, Figs 63 and 64, these coals had to be renewed every twenty-four hours; not so much because they went out, but because they were gradually blown away. During the trials at Lambeth this sprinkler heated the factory boiler alone for nine hours; and the boiler evaporated at a pressure of 34·6 lbs. per square inch. It was stated that 2·2 lbs. of oil evaporated 43 lbs. of water; but this result was reduced to half by subsequent official experiments.

The nozzle-sprinkler of Aydon and Selwyn, Figs. 66–69, was used in the trials that were conducted by the Admiralty at Greenwich in 1868 with a Field's marine boiler. As a heavier oil tar-oil was used. Aydon, to insure a more powerful vaporisation, altered his apparatus so that the oil and steam should not meet at a right angle but at an acute angle. The steam spray was regulated by a tapering spindle, which was kept in position by a small pressure screw. The pipe in which the amalgamation of oil and steam and air took place remained the same, with the difference that an opening was provided underneath for the admission of air. During the first experiments of Selwyn two fire-bridges were placed in the fire-box and the floor was covered with fire-bricks, see Fig. 67. Subsequently all this brickwork was taken away and the fire-bridge necessary for the coal fire alone remained ; but a serpentine pipe was hung between the Field tubes, and through this the steam, being previously superheated, had to pass before it arrived at the sprinkler. The serpentine pipe was protected from the flames by a plate of tiles and a covering of the same materials. The fire-door was removed and replaced by a

FIG. 66. FIG. 67.

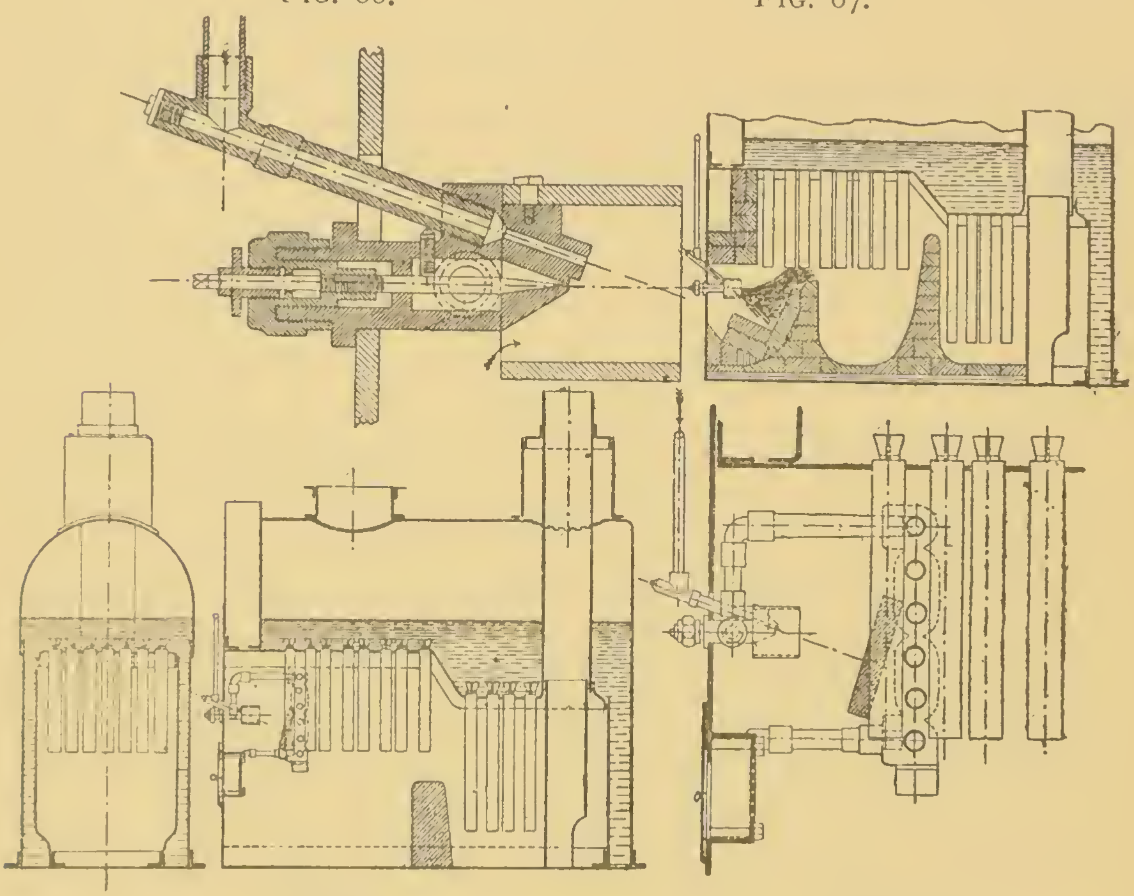


FIG. 68. FIG. 69.

cross-barred slide, by means of which the admission of air was regulated. The trials with this sprinkler are of great interest, inasmuch as the boiler was alternately heated with oil and coal. The results of these trials showed a 7·5–fold evaporation with coal against a 10·5–fold evaporation with tar residual.* The Admiralty was so well pleased with this, that the boiler of H.M.S. *Oberon* was placed at Admiral Selwyn's disposal for further experiments. It had a heating surface of 1707 feet, whereas the Field boiler had a heating surface of only

* See Appendix I.

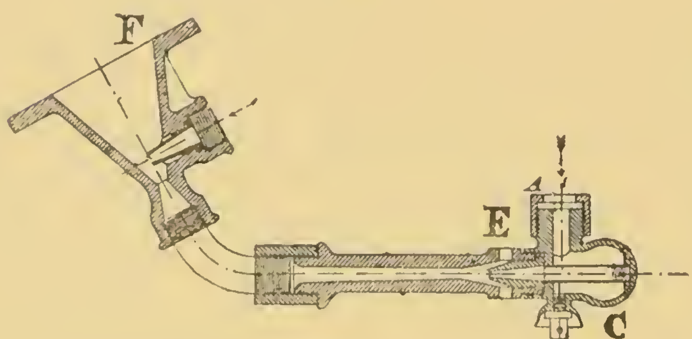
1063 square feet. For these experiments * Admiral Selwyn used a nozzle-sprinkler which he has indeed described but of which no drawings are published. Much as in the case of the pipe-sprinklers the oil was delivered through a central pipe, and the steam through a concentric pipe, in which the former was placed. With a view to making the boiler immediately available for coal firing, the grate was not removed, but was merely covered with fire-proof stones, which attained a white heat, and were found to be excellent non-conductors. For the same reason the superheating pipe for the steam from the fire, see Fig. 69, had to be placed in the forward smoke-box, see Fig. 64. During a trial lasting three hours—on November 13th, 1868—2·2 lbs. of tar oil evaporated 33·9 lbs. of water at a temperature of 100½° Fah. with a steam pressure of 40¼ lbs. The other trials did not show results quite so satisfactory. In cases of water of a temperature of 212° Fah. the best result attained was an evaporation of 37¼ lbs. of water with 2·2 lbs. of tar oil, the theoretical evaporating power of which is put down at 38·6 lbs. A perfect combustion of the oil was therefore practically obtained. Notwithstanding this highly satisfactory result, and notwithstanding Admiral Selwyn's endeavours, the movement in favour of liquid fuel did not make any way, owing to an immediate rise in prices.

The sprinklers of Aydon and Admiral Selwyn therefore did not come into practical use. Latterly Selwyn has again agitated the question of liquid fuel, especially at the Royal United Service Institution, but he has not published descriptions of his latest appliances. However, he claims to be able to evaporate 48¼ lbs. of water with 2·2 lbs. of tar oil of 1·060 specific gravity in a marine boiler of 40 indicated horse-power and 53½ lbs. per square inch pressure. This oil is said to possess a practicable evaporating power of 32·8 lbs. It has been attempted to minimise the importance of Admiral Selwyn's work in the face of the results obtained in Russia, but to him belongs the merit of having used in 1867 nozzle sprinklers, to which we are now returning after having in vain endeavoured to employ other methods.

* 'Transactions' of Institution of Naval Architects, 1869, p. 32.

The nozzle-sprinkler of Körting, Figs. 70–72, was introduced in 1876. It has been used in boilers arranged for coal-fires without requiring any alterations in the fire-box. It has only to be fastened to the side of the fire-door, previously making an opening through this. The non-superheated steam is admitted into the sprinkler by the valve A, and enters first into a well-shaped compartment, from which it escapes into the nozzle through the small orifices in the copper tube. This arrangement insures the liberation of the steam from the

FIG. 70.



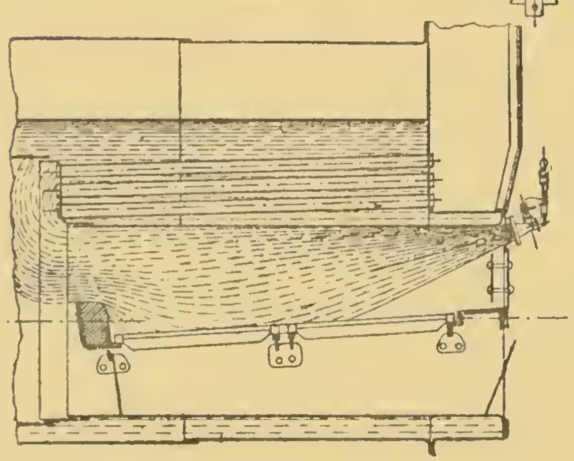


FIG. 71.

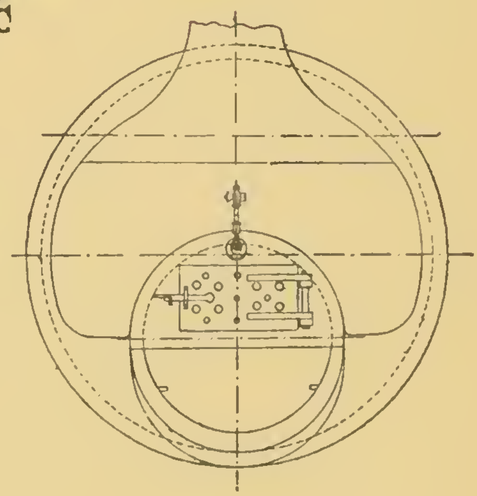
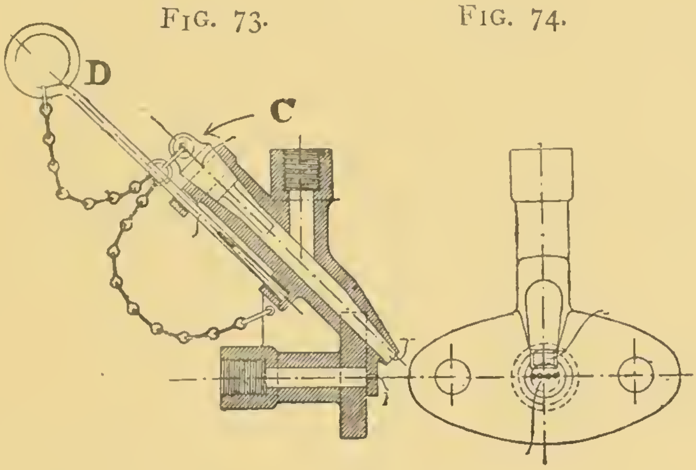


FIG. 72.

deposited water, the volume of which might become very considerable in a small steam pipe only 15 mm. in diameter. The condensed water does not pass out of the orifices with the steam, but remains behind in the bell-shaped compartment, and is drawn off from time to time by means of the screw valve C, and does not, therefore, interfere with the sprinkler. The steam streaming through the nozzle sucks in air through the orifices E, mixes with it, and this mixture vaporises in the mouthpiece F an oil spray 6 mm. diameter, which flows out of the nozzle and is regulated by a tap. The vapour spray and the oil spray meet at an angle of 90 deg., and the flame is blown slanting into the fire, much as in the case of the first Aydon sprinkler. The air sucked up by the steam jet is said to produce a better combustion by mixing with oil. Gulishambarov, who saw this sprinkler at work in Körting's factory, is of opinion that the steam jet loses power in consequence of this admission of air, and that the oil is therefore inefficiently vaporised, which means that the perfect combustion aimed at is not attained. An advantage of the apparatus is that its outlets are so arranged as to prevent stopping up.

FIG. 73. FIG. 74.



Since 1886 Körting has used the sprinkler shown in Figs. 73 and 74, at first for tar,* and subsequently for oil. This sprinkler resembles very strongly the sprinkler of Aydon and Selwyn, Fig. 66, which was constructed in 1868. The tar flows out of slit-like openings A, and is vaporised by steam jets B B, which meet it at an acute angle. The steam jets, which issue from orifices of from ·04 to ·08 inches in diameter, are together somewhat broader than the stream of tar. Should the tar nozzle get stopped up, the plug C is taken out, the tar is turned off, and the nozzle is cleaned out with the needle D. Both the needle and plug are fastened to the sprinkler by means of a chain. The steam and tar supplies are regulated by taps. This tar-sprinkler has been

* 'Journal für Gasbeleuchtung,' 1886, p. 548.

found preferable to pipe sprinklers for gasworks, and within the last few months Körting has endeavoured to apply it to oil fires. Figs. 75 and 76 show the application of such an oil-sprinkler to a marine boiler. The cleaning needle has been omitted, probably because the less solid oil causes less stoppages than the tar.

FIG. 75.

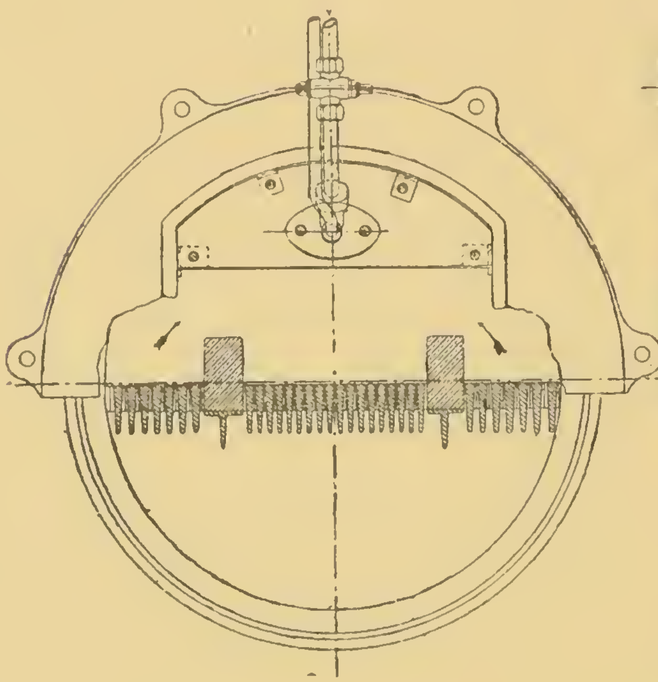
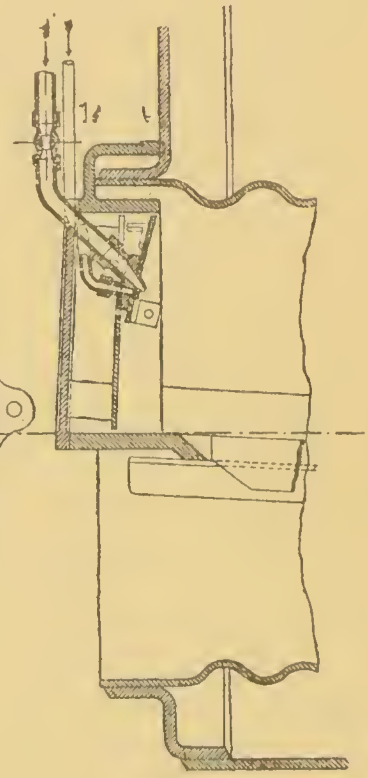


FIG. 76.



The nozzle-sprinkler of Dickey,* Figs. 77 and 78, was patented in the United States in 1878, and introduced on a passenger locomotive on the Long Island line, on a trial trip, with very satisfactory results. Dickey employed raw petroleum, which he kept in a tank in the tender. From this tank two pipes led to the fire-box, each of which conducted to a sprinkler, from the nozzle of which the oil issued at a very low pressure. At right angles with the oil nozzle is a nozzle for the superheated steam. This steam is superheated in a suspension pipe that is carried along the top of the fire-box, which it has to pass on its way from the boiler to the nozzle.

* 'Transactions,' N.E. Coast Inst., &c., November, 1886, p. 51.

The openings of the oil and steam nozzles can be enlarged or reduced by means of a sprinkler. The steam-jet sucks up air from a pipe projecting underneath the fire-box, and carries it to the oil nozzle. The oil, steam, and air-vapour is blown against a number of cast iron plates, arranged like venetian blinds, and through the interstices—which can be enlarged

FIG. 77.

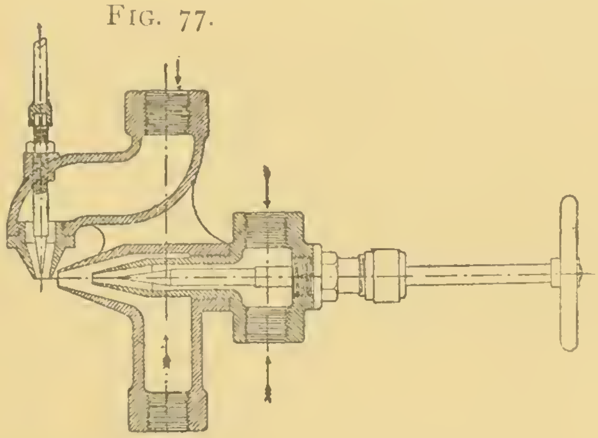
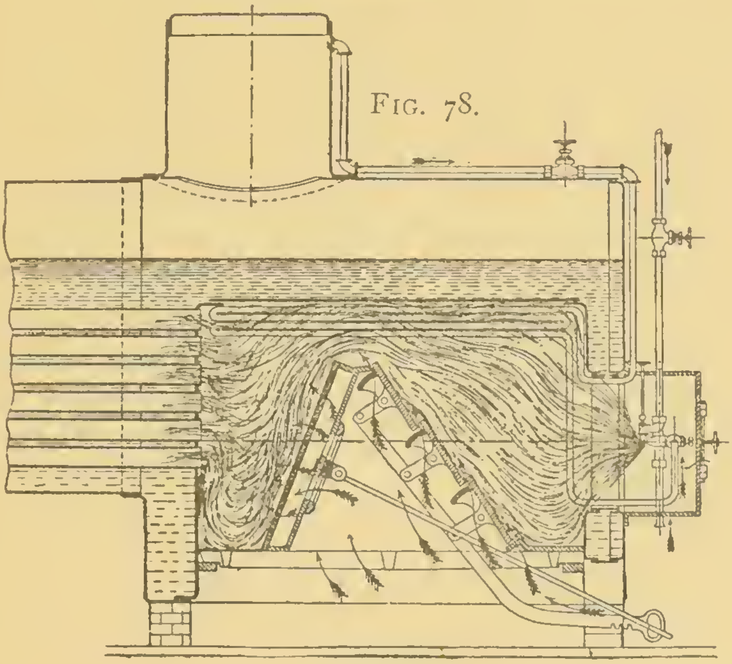


FIG. 78.



or reduced at pleasure—additional air is admitted. This suction is shut off from behind by a double-walled cast iron box, through the front wall of which still more air can be admitted through a circular wire slide. Besides being very successful in the introduction of air, this arrangement, which is placed on a coal-grate, keeps the fire-box full, and heats it equably.

At the trials the combustion was perfect, for no smoke escaped through the funnel. The velocity of the train is said to have been very regular, and much greater than in the case of coal. No particulars of evaporation are recorded; but it is stated that the proportionate price of oil and coal was as 1·2 : 2·0, and therefore very favourable to the oil. Notwithstanding all this, however, and the fact that the

FIG. 79. FIG. 80.

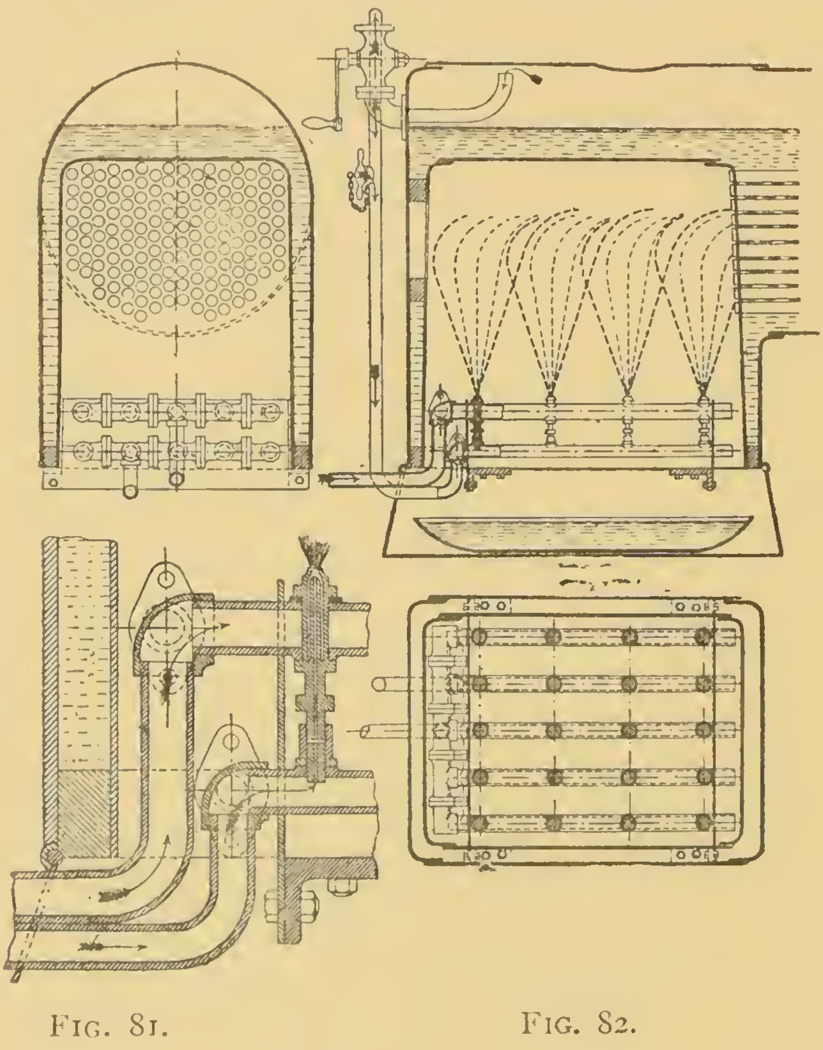


FIG. 81. FIG. 82.

Great Western Hydro-fuel Company, which worked Dickey's patent, had large means at its disposal, the system was not generally adopted.

The oldest nozzle-sprinkler of Urquhart * (Figs. 79–82) was also specially adapted for locomotive boilers. These resemble in some measure the marine boilers of torpedo boats, and are interesting in tracing the development of nozzle-sprinklers.

* 'Engineering,' i., 1877, p. 9.

Urquhart's system was tried in 1874 on the Griasi-Tsaritzin Railway, in south-eastern Russia. The residuals are stored in trucks in the tender, and are conducted through a tube into a horizontal pipe that runs along the wall of the firebox, and into which five other horizontal parallel pipes are driven. Under each of these pipes is a steam-pipe, fitted with four nozzles, which taps the steam at as high an elevation as possible, so as to keep it dry; it is not superheated. An arrangement in this steam-pipe enables the steam to get mixed with air and to force this into the steam through the nozzles. These are so constructed that the steam and air pass through the centre and blow the petroleum, which flows round it, in a circular spray of vapour into the fire. Any oil dropping over is caught in the water in the ash-pan, and is thus extinguished. Mr. Urquhart maintains that the residuals were burnt without smoke, there being a good development of steam and abundant air supply. During stoppages, however, a good deal of smoke was frequently given out. The great expenditure of oil which this system involves caused it to be speedily dropped.

The latest nozzle-sprinklers of Urquhart * (Figs. 83–86) came out between 1882 and 1885. In these the oil passes from tanks in the tender by means of a tube and a pipe into the sprinkler. The non-superheated steam leaves the dome of the boiler and enters the sprinkler; it passes through orifices into the interior of a bronze spindle and escapes through the front of the nozzle. A spiral wheel which moves on a spring in a groove regulates the outlets for the oil residuals. To obtain the requisite air the sprinkler is fixed so as to protrude into a pipe-rest, and a space of about 1 inch is allowed between the flange of the sprinkler and the plate of the boiler. The oil and steam are separated inside the sprinkler by means of a box filled with asbestos packing, which latter has to be renewed about once a month. The admission of steam is regulated by a special valve in the pipe. Urquhart made very thorough experiments with these sprinklers in 1884, and found that by using oil for

* 'Engineering,' i., 1886, pp. 563 and 609.

his locomotives instead of anthracite, though there was no difference in the price of the fuel, a saving of 53 per cent. was effected. In locomotives burning anthracite and with a steam pressure of eight atmospheres, from 7 lbs. to $7\frac{1}{2}$ lbs. of water was evaporated by 1 lb. of anthracite; whereas 1 lb. of oil

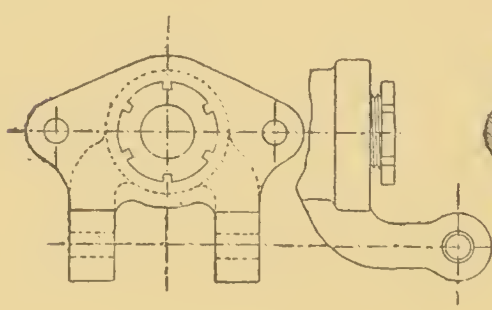


Fig. 85.

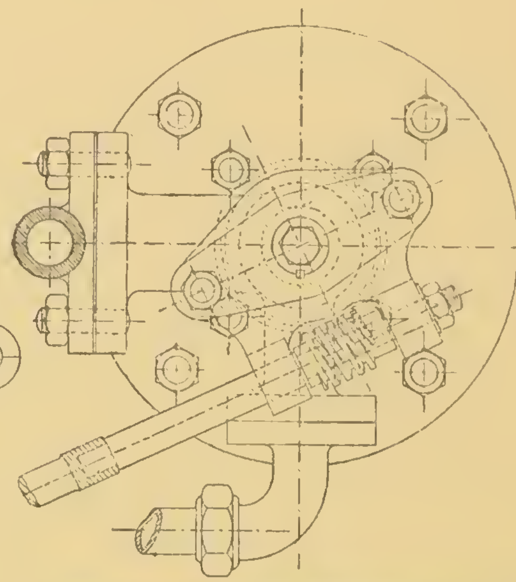


Fig. 86.

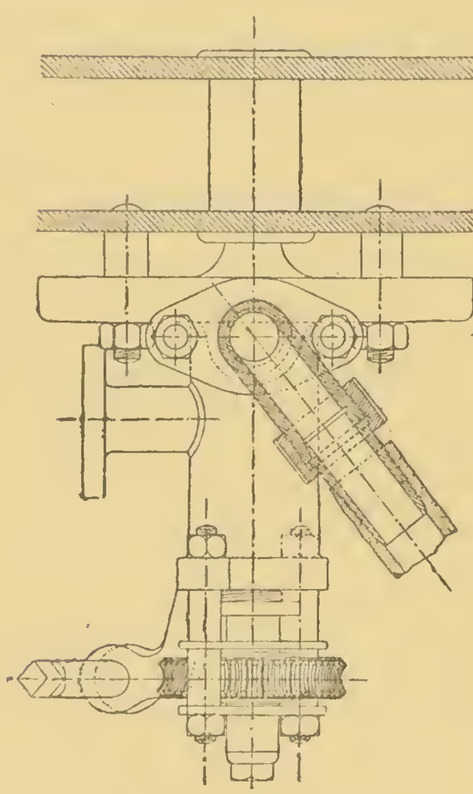


Fig. 83.

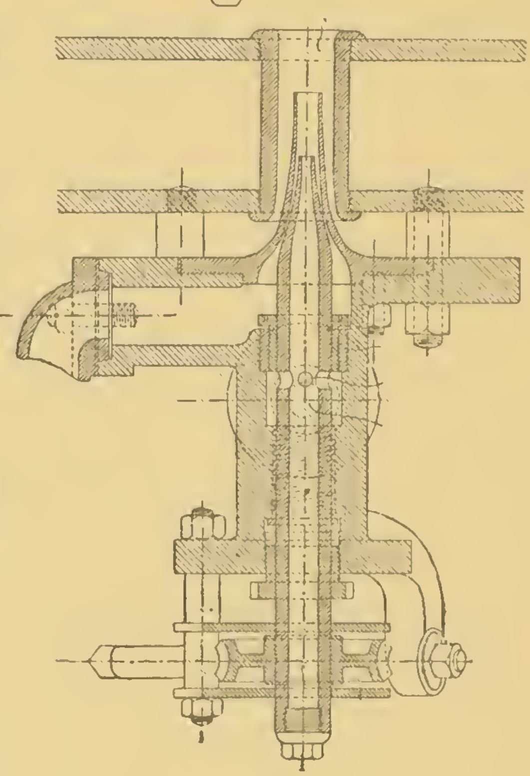


Fig. 84.

residuals evaporated from 11·35 lbs. to 12·25 lbs. of water. Owing to these results 143 locomotives were fitted with this system on the Griasi-Tsaritzin Railway as early as 1885.

Urquhart claims as a special advantage the fact that his apparatus is fitted outside the fire-box, but the sprinklers of

Körting possess this advantage as well. Sprinklers that enter the fire-box are exposed to the heat of the flames, which partially carbonises the oil, and thus stops up the orifices in the sprinkler. Should the Urquhart sprinkler get stopped up through any reason the spindle has only to be screwed back and the oil will force the carbonised particles into the fire-box. Urquhart has also protected the walls of the pipe against the flames, and prevented all the deteriorating effect on the boiler

FIG. 87.

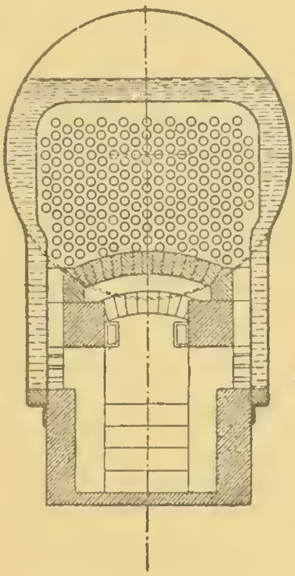
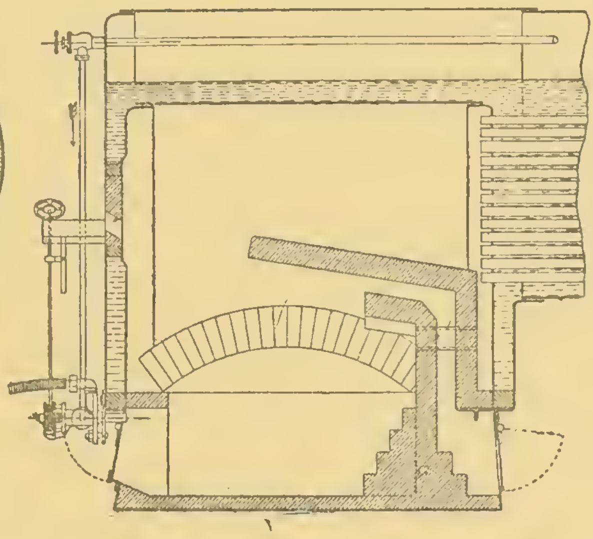


FIG. 88.



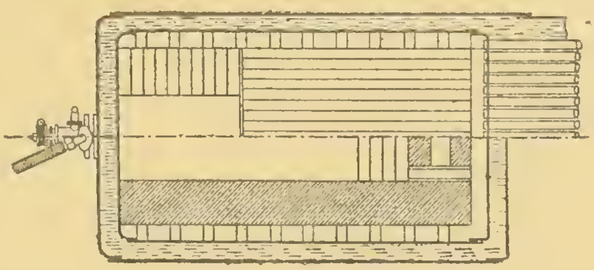


FIG. 89

which their direct action entails, by lining the inside of the fire-box with brick, Figs. 87–89. The sprinkler is placed low down, and blows into a furnace chamber built into the fire-box and covered with a vaulted roof which slants off in the direction of the tube plate. The brickwork does not lean against the wall of the fire-box, but is about 2 inches from it (Fig. 89), so that these walls may not be lost to the heating surface. The flame beats from the furnace chamber against what used to be the fire-door, now bricked up, leaving only a peep-hole, and reaches the tubes through an opening in the roof of the chamber at this point. Two channels are built into the walls of the furnace chamber, and lead a portion of the heating gases to the lower surface of the tube plate, as well as into the spaces between the brickwork and the other walls of the fire-box, so as to give these an efficient heating surface. The requisite air is forced into the furnace by the sprinkler, and more air is admitted by the ash-pan dampers, which are regulated by chains and chain wheels. The air entering at the front ash-pan damper passes through a channel, and is warmed before being admitted to the gases. Complete combustion of the oil is insured by fitting the fire-box with tiles, which, being non-conductors of heat, keep the walls of the fire-box at an equal temperature, and even re-light the oil-stream should a short interruption of work occur. This also greatly simplifies management.

The nozzle-sprinkler of Spakovski,* Figs. 90–93, was first used for marine boilers in 1870, but was much improved, and was subsequently adopted in its present exceedingly simple form, among others, by the Rostock Steamship and Engineering Company, and in 1879 and 1880 on board four steamers on the Caspian Sea. The liquid fuel, in this case oil residuals, flows out of the inner nozzle, which protrudes into the mixing pipe about ·04 inch, Fig. 90; the steam escapes through the circular opening surrounding this nozzle. Air is admitted through holes in the circumference of the mixing pipe; the mixing pipe prevents excessive air expansion of the steam-jet and thus slightly aids the vaporisation of the oil; but this is not done so efficiently in the case of the Spakovski apparatus as in that of Urquhart's latest improvement. The steam jet surrounding the oil only acts strongly from underneath; the upper part expands without materially aiding the vaporisation, so that, by looking through a piece of blackened glass, drops of fluid oil can be observed falling into the furnace, where they are burnt up in their liquid state. The flame has a broom-like shape, and is very long, so that it acts

* 'Gulishambarov,' p. 36.

most forcibly on the fire-bridge, and heats the other parts of the fire-box only by radiation, and even that rather unequally. In cases where the furnaces are very large one sprinkler is

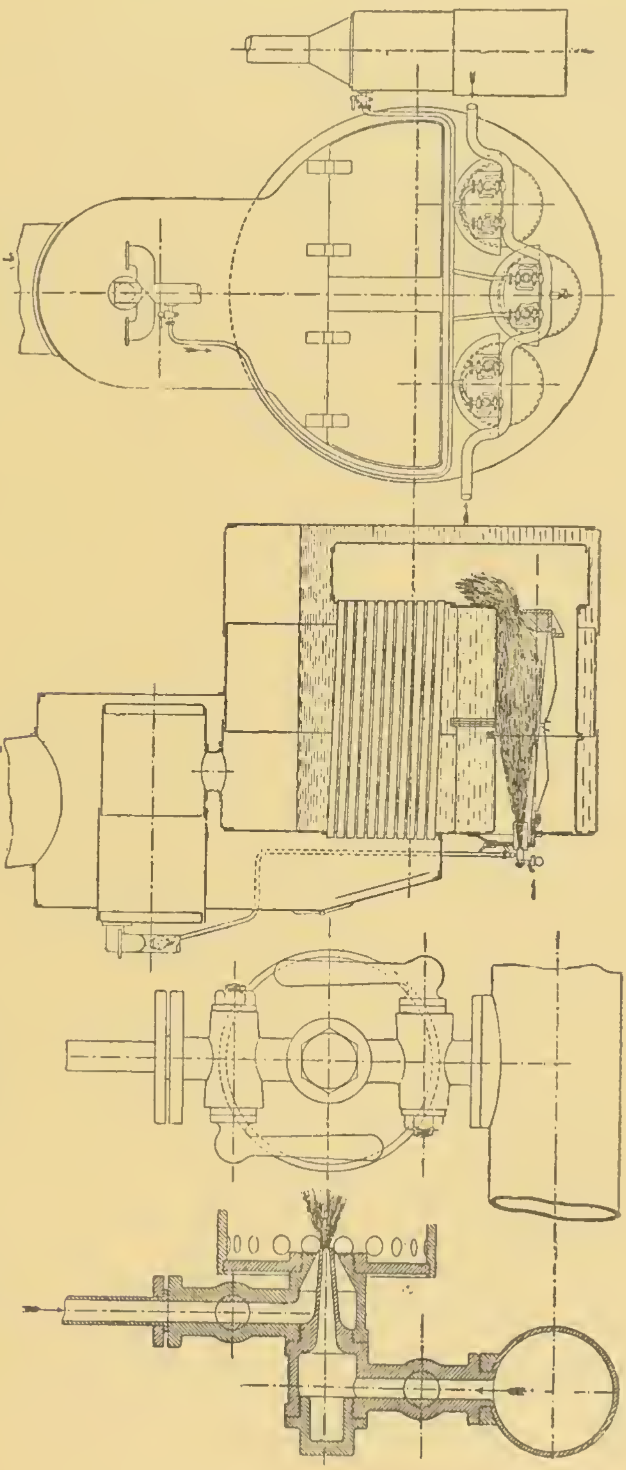


FIG. 93. FIG. 92. FIG. 91. FIG. 90.

inadequate, and two or three have to be fitted, which causes complication. The supply of oil and steam is regulated by means of separate taps for each sprinkler.

Spakovski's first sprinkler was worked in 1870 on board the steamship *Ivan*, on the Caspian. This steamer has a Penn low-pressure engine. The boiler had two furnaces, and worked with a steam pressure of $17\frac{1}{3}$ lbs. per square inch, and had previously used coal for as much as fourteen years. Each furnace was fitted with three sprinklers, which used 9·36 lbs. of oil per horse-power per hour, with ninety-two revolutions of the engine per minute and 45 indicated horse-power. In 1873 the steamship *Helma*, also with a low-pressure engine, was fitted with Spakovski's sprinklers. The boiler worked with a steam pressure of 20·8 lbs. per square inch, and had two furnaces, each of which had a sprinkler. With eighty-five revolutions per minute and 21 indicated horse-power, 6·85 lbs. of oil residuals was requisite for 1 indicated horse-power per hour. The oil did not flow down into the sprinkler from tanks above, but was sucked up from tanks in the hold by an injector, which caused a great waste of steam; besides, the engines had only injection condensers. This will practically explain the enormous consumption of oil. In 1879 the steamships *Pyr Bazaar* and *Atreck*, which had been built at Rostock, were fitted with Spakovski sprinklers and tried on the Caspian. Each of these steamers, which had compound engines and surface condensers, was fitted with a boiler with three furnaces that had a steam pressure of $55\frac{1}{2}$ lbs. per square inch. Each furnace had two sprinklers, see Fig. 93, of which four were for continual use and two did relief duty. During the voyage the engines made 125 revolutions per minute on the average, indicated 80-horse power, and used about 4·4 lbs. of oil residuals per indicated horse-power per hour.

In 1880 the Rostock Works supplied two more twin screw steamers, *Dagestan* and *Tschikischlar* for the Caspian, each of which had two double-cylinder compound engines, with surface condensers and boilers, with a pressure of 62·4 lbs. per square inch. Each of these engines indicated on the trial trip from 140 to 150 horse-power and made 135 revolutions per minute, and used, according to report of the builders, 2·2 lbs. of coal when that was employed, and only 1·9 lb. of oil residual, when oil was the fuel, per indicated horse-power per hour. When it is remembered that these last engines were nearly twice as large as the two previous ones, and that their oil consumption is based on the trial trips, whereas that of the others is calculated on the average performance during an entire voyage, the difference of 4·4 lbs. and 1·9 lbs. of oil per indicated horse-power per hour will be understood, and consequently this last performance of the Rostock Works must be regarded as exceedingly satisfactory.

The nozzle-sprinkler of Sadler,* Figs. 94, 96, is one of the simplest. It consists of two small bronze nozzles, which are screwed on to the opposite ends of a T-shaped malleable iron pipe. Another T-shaped pipe is screwed into the third orifice

FIG. 94.

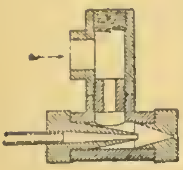


FIG. 95.

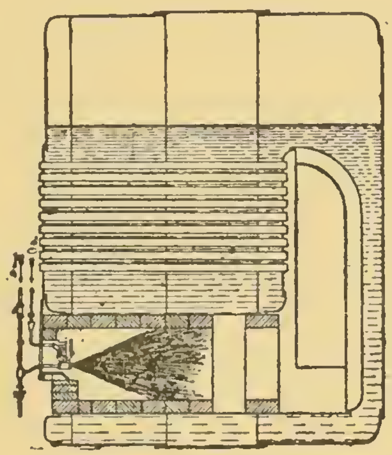
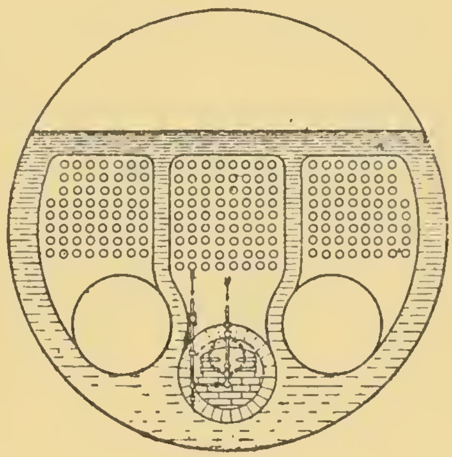


FIG. 96.



of the first, and the horizontal pipe of this admits the oil, while the perpendicular end admits the air. The steam pipe, before reaching the sprinkler, is conducted into the furnace, and forms a winding pipe here, through which the steam is passed to get superheated. The oil and air enter the sprinkler through the same orifice, and in the space between the nozzles. The furnace is lined with fire-proof brick. The oil and steam supplies are regulated by separate taps or valves. The sprinkler was tried with tar and heavy tar oils, with which a large tank was filled. Steam pipes passed through this tank, so as to melt the tar. The tar then flowed into a smaller vessel covered

* 'Transactions,' North-East Coast Inst., &c., 1886, November, p. 32.

with brass gauze, so that all coarse impurities that might stop up the sprinklers were arrested. The tar entered a pipe with a clear width of 2 inches, which had a steam pipe $\frac{1}{2}$ inch in diameter inside it, and flowed from thence into the sprinkler. On entering this the tar had the appearance of a dark and rather thick mineral oil. According to chemical analysis, these heavy tar oils possessed a theoretical steam power of 43 lbs., but in actual practice 2·2 lbs. of heavy tar oil is said to have evaporated $38\frac{1}{2}$ lbs. of water at a temperature of 212° Fah., which shows a superiority of about 85 per cent. over the duty of ordinary coal.

CHAPTER VII.

THE EXPERIMENTS OF D'ALLEST.

THE nozzle-sprinkler of d'Allest * was tried in the August and September of 1885 on board the s.s. *Aude*, the firing arrangements of which are shown at Figs. 97 and 98. Both the furnaces of the boiler were lined with fire-proof brick, which rests on the old coal-grate. Two sprinklers blew Baku oil into each of the furnaces. The experiments of d'Allest are in so far very instructive that they were first conducted with French coal and then with Baku oil. During trial trips in the open sea, which lasted several hours, the double-cylinder compound engines made from 87 to 88 revolutions per minute, and indicated about 170 horse-power. The coal consumption amounted to 3·6 lbs. per indicated horse-power per hour, and the oil consumption was only 1·62 lbs. for the same duty. According to calculations made, 2·2 lbs. of coal evaporated 15¼ lbs. of water and 2·2 lbs. of oil, as much as 27¼ lbs. The sprinkler consumed an abnormally large quantity of steam; as much as from 8 to 10 per cent. of the entire steam consumption, which proves that this first sprinkler was very imperfect. D'Allest then tried to vaporise the oil by means of compressed air instead of steam, to avoid the enormous loss of the latter. But the first experiments of this kind, in which the compressed air was generated by means of a Root blower, were unsuccessful, because the attainable density of the air was inadequate.

In the spring of 1886 experiments with compressed air were made at the works of the Compagnie Fraissinet, in Marseilles.

* 'Le Génie Civil,' Nov. 1885, Nos. 1, 2.

The air was pressed by an air-pump, Figs. 99 and 100, into a cylindrical tank, and was conducted from thence to the

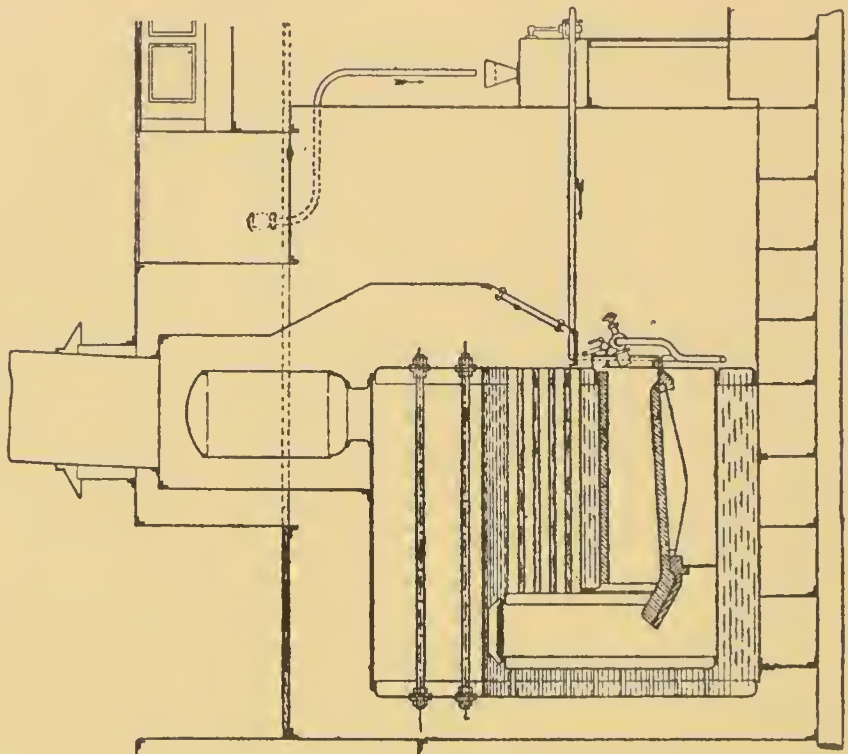


FIG. 98.

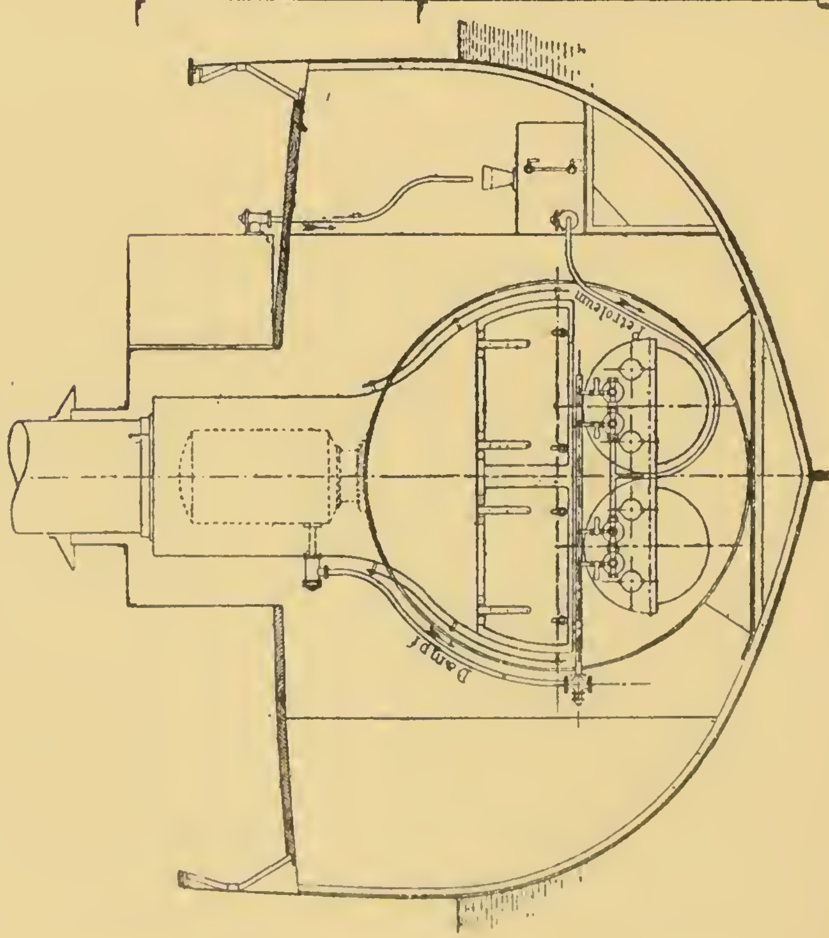
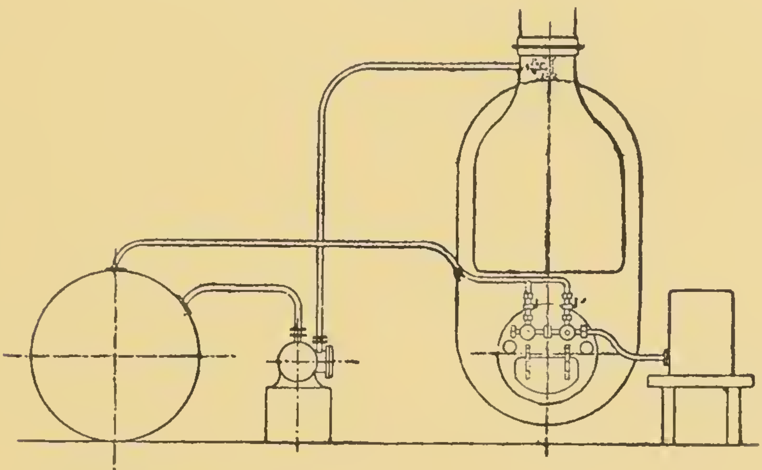


FIG. 97.

sprinklers, where it must have retained a pressure of at least 18 to 20·8 lbs. per square inch. The oil flowed from a tank into the sprinklers of the boiler. The results of these experiments showed that the combustion of oil is much more perfect when it is vaporised by compressed air than when vaporised by steam, as indeed is proved by the increased whiteness of the flame. When the compressed air is previously warmed, 1·1 lb. of water for 2·2 lbs. of oil can be evaporated more than when this has not been done. In vaporising with cold

FIG. 99.



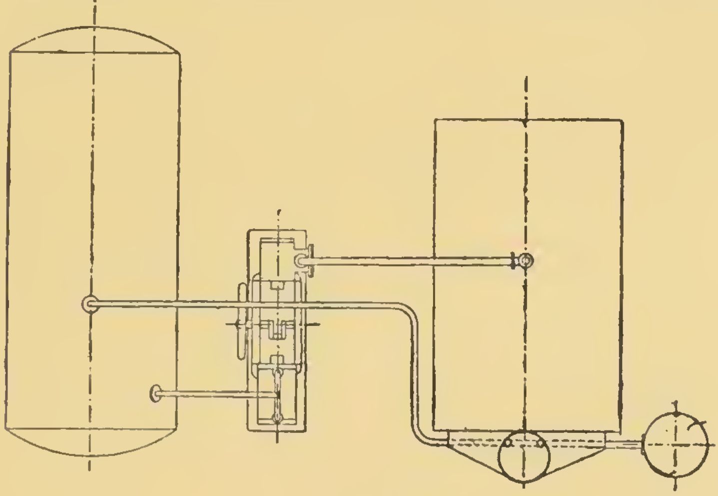


FIG. 100.

air the walls of the furnace must be lined with fire-proof brick, otherwise the flame is nearly extinguished. The weight of air necessary to work the sprinkler amounted to about 5 per cent. of the steam generated.

D'Allest has also conducted experiments to discover whether oil fuel could be used in cases where an artificial draught was raised, and when it is especially necessary, as with the boilers of torpedo boats, to generate as great a weight of steam as possible per square foot of heating surface in the hour. For this purpose the arrangements shown in Figs. 101 and 102 were made. A clay receiver was placed in the furnace and two sprinklers were fitted in front of it. The vaporisation could be effected either by steam or compressed air of 20·8 lbs. per square inch pressure. The artificial draught was

FIG. 101.

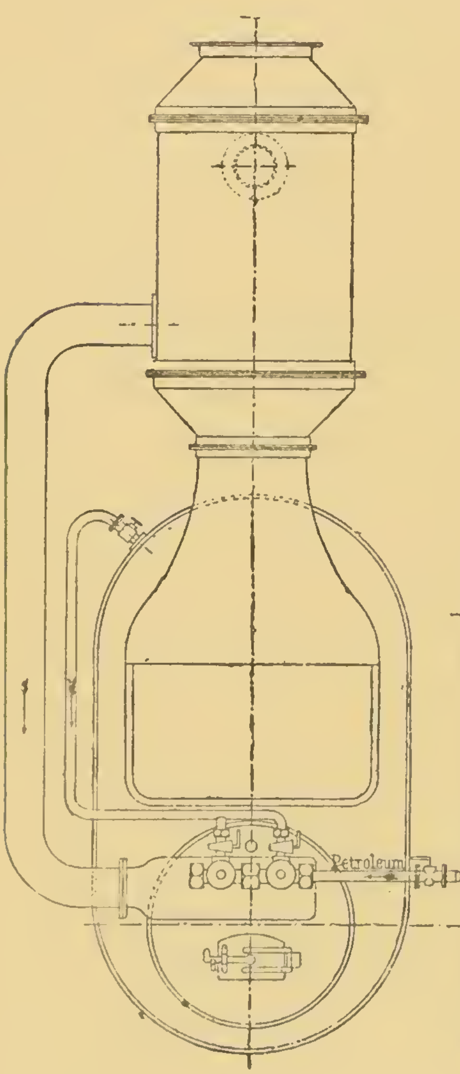
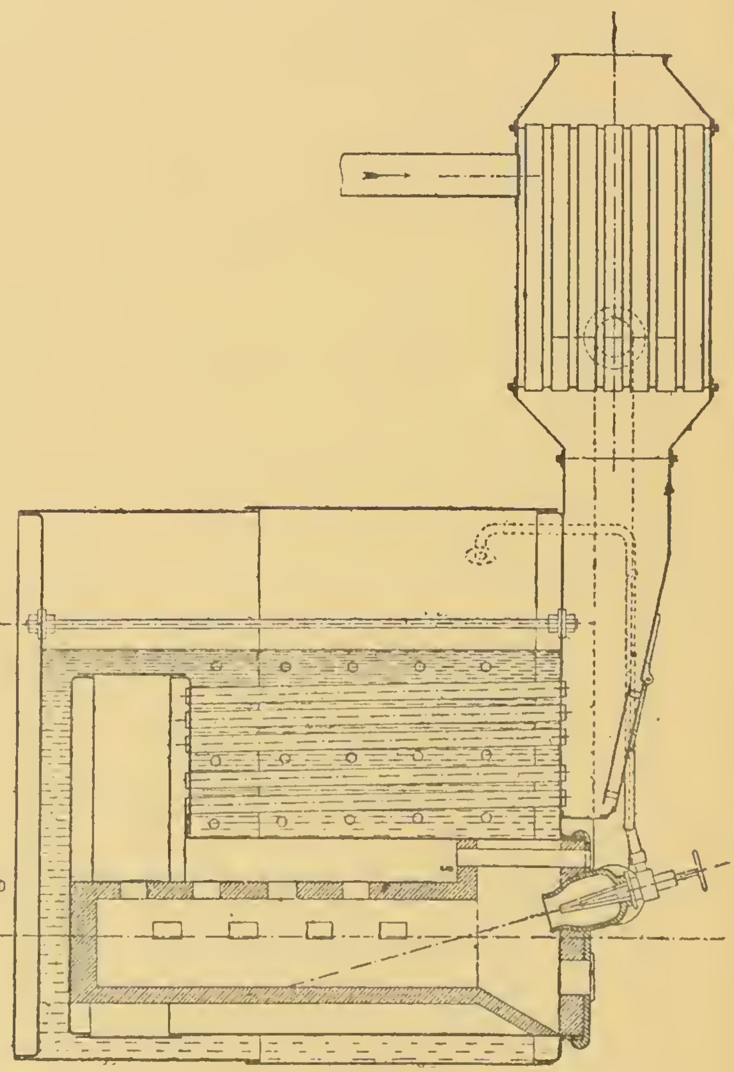


FIG. 102.



produced by a bellows in a heater in the throttle in the chimney, and was then conducted into a box which encased the two sprinklers. D'Allest affirms that these experiments were satisfactory, and that he has used the above arrangement for actual work with success. He maintains that they prove that liquid fuel can be burnt up with artificial mixed draught, and that the waste of water caused by steam sprinklers can be avoided by substituting air. This last fact was indeed clearly proved in 1883 by the experiments of the "Forges et Chantiers" in Marseilles with Jensen's sprinkler.

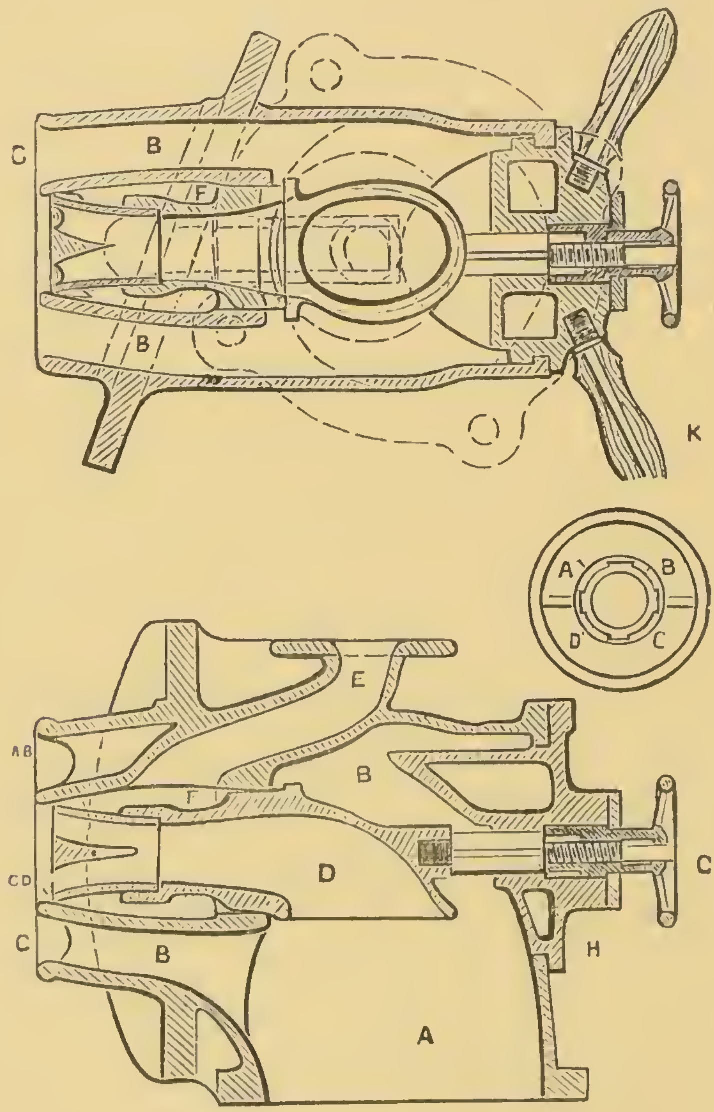
D'Allest subsequently published the results of his experiments,* and the deductions he draws, especially with reference to the application of liquid fuel to torpedo boats, are of the greatest interest. These experiments were conducted by order of the French Admiralty with Baku oil on board the torpedo boat *La Chevrette.* The best system of furnace for torpedo boats is the one that will produce the maximum of steam and require the minimum weight of boilers so long as a fairly adequate speed is attained. As these conditions are complied with most completely in cases where the boiler works with forced draught, it was necessary to find out whether the same method could be used with oil fuel, and whether the same increase in duty would result, as in the case of coal.

It has been shown that Wagenknecht endeavoured to im prove the combustion of his drop-fires by introducing compressed air. D'Allest tried to improve on this by using the compressed air for purposes of vaporisation as well as draught. But all attempts in this direction failed. The sprinkler used for this purpose is shown at Fig. 103. The air for vaporisation enters at A, and passes partly through the inner tube D and partly through the outer tube B to the mouth of the burner, which receives the oil through E F. The oil leaves the sprinkler at the small orifices *a b c d*, where it gets mixed with the air, the very low pressure of which only produces incomplete vaporisation and combustion. During subsequent experiments no compressed air was applied, and the sprinkler represented at Fig. 104 was used. The oil, which enters at B, passes into the bronze nozzle A, the orifice of which may be closed by the conical pointed spindle C. By means of the hand wheel K, C can be so controlled that it can either entirely close the nozzle A or leave a circular space for the escape of the oil, which can be made, according to the force of

* 'Le Génie Civil,' Nos. 21–24; 24th September to 15th October, 1887.

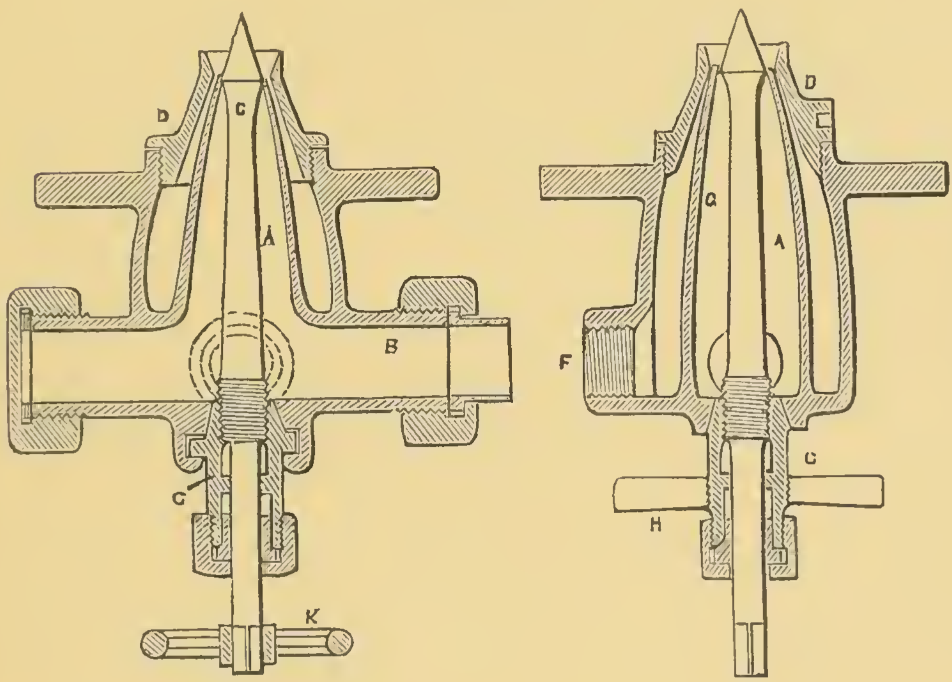
the fire, as wide as 2 mm. The steam for vaporising passes through the tube F, and circulates round the nozzle A, warms its contents and then escapes between A and the capping D. Any possible stopping up is avoided by screwing back C as far as possible. The force of the escaping stream of oil carries, as in the case of Urquhart's sprinkler, any impurities or un-

Fig. 103.



consumed particles with it. Should the sprinkler require a thorough cleaning, the hand-screw H is turned half a turn, and the stuffing-box G, with the spindle C, can then be removed from the nozzle A. To prevent any cessation of work, two sprinklers are fitted to each furnace, as is indeed the case in most recent applications of liquid fuel. With each of these sprinklers an hourly combustion of from 10 to 20 kilogs. of oil could be obtained, and as each kilog. of oil evaporated 13 kilogs. of water, a maximum evaporation of $2 \times 80 \times 13 =$ 2680 kilogs. of water per hour could be attained. With a heating surface of 69 square metres as was the case with the boiler used at the trials, which was an oval boiler, such as was shown in Figs. 101 and 102, for the consumption of Caucasus oil residuals—this gives an hourly vaporisation of 30 kilogs. of water per square metre of heating surface, such as is usually required for good marine boilers. As in marine boilers a heating surface of 59 square mm. on the average has to be

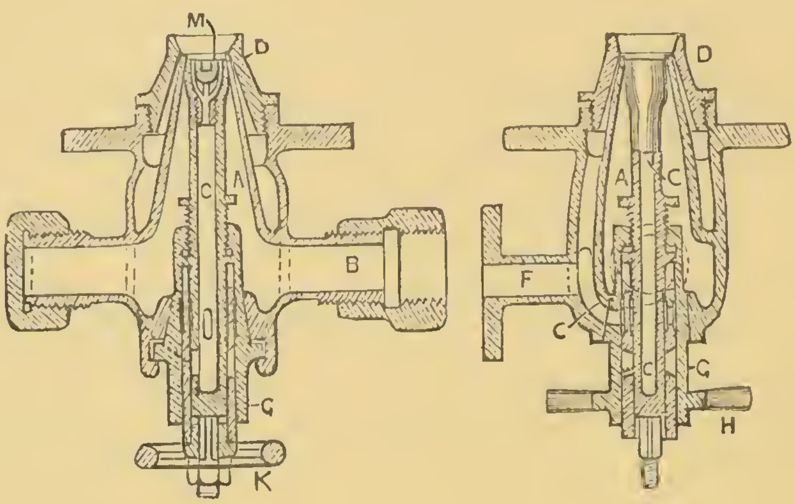
FIG. 104.



sacrificed to each fire, it follows that two sprinklers of the above size would suffice under ordinary circumstances to keep up a furnace.

The case is different with torpedo-boat boilers when at least 50 kilogs. of water have to be evaporated hourly per square metre of heating surface. The sprinklers were not equal to this task; for when the diameter of the nozzle A was increased the steam jet was inadequate to the vaporisation of the oil, and incomplete combustion was the result. D'Allest was therefore obliged to alter his sprinklers, and introduced an air current produced by steam into the centre of his oil-spray, with a view to attaining a more powerful vaporisation. This improved sprinkler is shown at Fig. 105. The oil coming from B passes as before into the nozzle A, and the steam required for vaporisation, or compressed air used for this purpose, passes through F, not only into the capping D, but through the

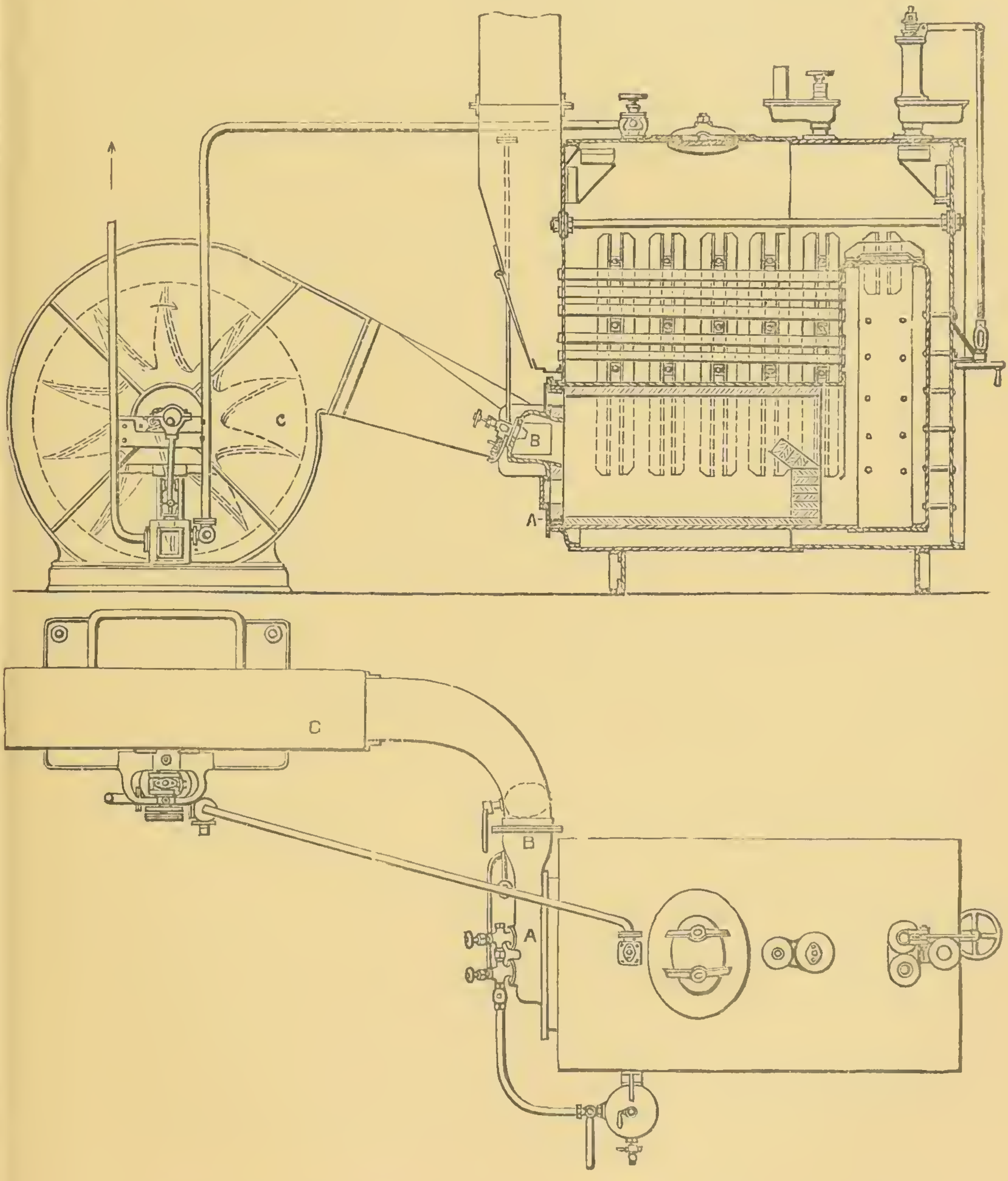
FIG. 105.



orifices O and the hollow spindle C into the circular opening M. In other respects the sprinklers remained unaltered, as the results attained with them were stated to have been highly satisfactory, and as much as 882 lbs. of oil were said to have been burnt per hour without any smoke being given off.

At the trials with these sprinklers the boiler shown at Figs. 101 and 102 was arranged as represented in Fig. 106. During the first trials with natural draught the furnace, which was fitted with a lining of tiles and a fire-bridge, was closed by a cast iron plate which received the sprinklers at the top and was furnished with the door A at bottom for the supply of air. At the subsequent trials the sprinklers were fitted to a cast iron receptacle B, in which the pressure pipe of the fan C terminated, from whence the compressed air requisite for the increased combustion was brought. The expansion of the compressed air was indicated by two manometers, one of which was fitted at the air supply, while the other was in communication with the inside of the fire-tubes. During the trials with natural draught as well as during those with induced currents, the oil supply was kept up to the point at which smokeless combustion would be maintained. The vaporisation was effected by steam in each case.

FIG. 106.



To show the superiority of oil fuel over coal d'Allest has compared the results of his trials with the results of those conducted by Guillaume for the French Admiralty * and of similar trials conducted by the English Admiralty with a Thorneycroft torpedo-boat,† in both of which cases coal was used and forced draught employed. The following are the results obtained :—At his first trials with natural draught d'Allest succeeded in evaporating 26 lbs. of storage water, or 39 lbs. of water at 212° Fah. with 2·2 lbs. of oil. In his subsequent trials with forced draught he evaporated 25 lbs. of storage water, or 29·1 lbs. of water at 212° Fah. with 2·2 lbs. of oil. In contrast to this Guillaume could not evaporate more than 17¾ lbs. of storage water or 21·3 lbs. of water at 100° with 2·2 lbs. of briquettes ; and Thorneycroft evaporated only 13·9 lbs. of storage water, or 16·4 lbs. of water at 212° Fah., with 2·2 lbs. of coal. With coal fires and forced draught Guillaume evaporated at most 138 lbs. of water per square yard, and Thorneycroft 224½ lbs., whereas d'Allest, under similar circumstances, could evaporate with oil fuel as much as 209¼ lbs. of water. This result might have been exceeded if the boiler, which was working at a pressure of three atmospheres, had not commenced to prime to such an extent that the fires had to be kept low.

In summing up the advantages in favour of oil fuel, d'Allest points out that 1 kilog. of mineral oil residuals of the normal chemical constituents requires 10·8 cubic metres of air in order to a theoretically complete combustion ; whereas 1 kilog. of average coal requires theoretically only 8 cubic metres of air. This theoretical quantity of air he increases, in accordance with Péclet's calculation by 33 per cent. In the case of spray fires it is probable that the theoretical quantity of air would suffice, owing to the internal mixing of the oil particles with the air. Should this not be the case, the same proportion would have to be added there as well. Thus 1 kilog. of coal requires $8 \times 1 \cdot 33 = 10 \cdot 64$ cubic metres of air, and 1 kilog. of oil requires $10 \cdot 8 \times 1 \cdot 33 = 14 \cdot 36$ cubic metres of air. The boiler using coal evaporated 8 kilogs. of water with 1 kilog. of coal, and

* Bienaymé, 'Les Machines Marines.' Paris, 1887 ; p. 470.

† 'Engineering,' 1880, vol. ii., p. 244.

1 kilog. of water with $\frac{10 \cdot 64}{8} = 1 \cdot 33$ cubic metres of air. The boiler fired with oil showed a thirteenfold evaporation with an air supply of $\frac{14 \cdot 36}{13} = 1 \cdot 104$ cubic metres. Consequently every cubic metre of air that passed through the boiler evaporated, in the case of coal fires, $\frac{1}{1 \cdot 33} = 0 \cdot 75$ kilogs., and in the case of oil fires $\frac{1 \cdot 104}{1} = 0 \cdot 190$ kilogs., which gives oil an advantage of 20 per cent. From this it follows that a boiler fitted for oil fuel may be 20 per cent. smaller than one fitted up for coal fuel, and yet evaporate the same quantity of water in the same period of time and with the same force of air current. As a matter of fact, however, this proportionate advantage on the part of boilers burning oil could be greatly increased, as the comparisons with the trials of Thorneycroft and Guillaume show an advantage of duty on the side of oil-consuming boilers under similar conditions, which surpasses coal-burning boilers by more than 30 per cent.

Finally d'Allest shows that the wear and tear is much greater in the case of coal, than in that of oil fuel, and that the fire-tubes in cases of forced draught are completely stopped up when coal is the fuel after a few hours' work. In the case of sprinklers this is avoided.

CHAPTER VIII.

METHODS OF WORKING SPRINKLERS.

THE various methods of working sprinklers prescribed by their respective inventors offer but few points of difference, so that they can be comprehensively described under the following headings :—(*a*) Raising steam ; (*b*) overcoming obstacles ; (*c*) letting down steam ; (*d*) prevention of corrosion of boilers.

(*a*) *Raising steam* is best accomplished by means of an auxiliary boiler, which may be used in harbour for heating, cooking, and ventilating purposes. The steam supply pipe of the sprinkler is put into communication with the auxiliary boiler by means of a branch pipe, as shown at Fig. 93 in a previous chapter, and the steam of the latter is used for heating, until the steam of the main boiler has attained the pressure necessary for vaporisation, viz. 20·8 lbs. per square inch pressure. When the sprinkler is worked by compressed air instead of steam an air reservoir is fitted next the air-pump when space and other considerations permit. The contents of this air chamber are brought up to the highest possible pressure before working is commenced ; it is then used for vaporisation as soon as the firing begins, as in the case of Bullard's and d'Allest's sprinklers. In cases where neither an auxiliary boiler nor an air chamber can be used, stoking had best be commenced with a wood fire ; but in this case care must be taken that the fire-bars—or grates—remain in the boiler. Most of the sprinklers begin to do duty at an expansion of $2\frac{1}{2}$ to 4 lbs. per square inch pressure, so that the sprinklers can be put into action the moment this is reached. Of course vaporisation is at first rather incomplete, and considerable smoke is given off, but this gets reduced gradually as the steam pressure increases. In cases where there is only an air-pump, wood fires must be used until the engine has been set going, but this can be arranged to take place at a steam pressure of 7 lbs. per square inch. To reduce the wood fire to its smallest possible limit in cases where no auxiliary boilers are extant, Tarbutt,* who uses either steam or hot compressed air, has devised the following contrivance. The nozzle-sprinkler allows the oil to leave the inner nozzle. Around the oil stream steam or compressed air, as the case may be, is blown; in the latter case the sprinkler is connected with an air-pump. The steam or air pipe is conducted along the tiled floor of the furnace, which it covers in a sort of zig-zag, and runs from thence to the sprinkler. To set the latter into action a special hand pump with a carefully closed chamber is fitted up; this communicates with the zig-zag pipe on the floor of the furnace by means of a regulating valve. In lighting the fires a few handfuls of wood dipped in oil are placed on this pipe; this then lights up. The chamber is filled with water. When the zig-zag pipe has been sufficiently warmed by the wood fire the regulating valve is turned on slightly, and a little of the water drops into the pipe, and is at once evaporated. As the steam cannot return to the chamber, which is kept under pressure, it has to escape through the sprinkler. The oil is now also admitted to the sprinkler, and is here vaporised by the steam and ignited by the wood fire. This burning oil now warms the zig-zag pipe, and if the chamber is kept under uniform pressure by the pump, the steam generated in the pipe can be used for vaporisation until the steam in the boiler, or in the air-pump which is worked by it, can be used. Getting up steam with this contrivance takes about three-quarters of an hour to an hour and a half according to the size of the boiler. When the steam is up, the zig-zag pipe is covered with thin fire-proof plates to protect it against fire, and the hand pump and chamber are disconnected. Generally when wood has to be used, it takes quite as long to get up steam with liquid fuel as with coal, which is indeed no disadvantage, for the boilers are spared by being slowly heated. But in cases where auxiliary

* 'The Marine Engineer,' January, 1887, p. 325.

boilers or air chambers can be applied, steam can be generated much more quickly; but this is only of importance to men-of-war, and to them only under particular circumstances. In lighting sprinklers it is of importance to remember that the steam jet should be sent through first before the oil is turned on. The same rule should be observed in turning off steam —the oil should be shut off first, and then the steam jet. If this rule be not rigidly observed, explosions in the furnaces might easily occur, which, although they might not seriously injure the boiler, might nevertheless do considerable damage. If the oil drips against the side plates of the furnace, and if these should be less hot than the oil, this evaporates and the hydro-carbon gas that results, from contact with the air which forces its way into the furnace, forms an explosive mixture, which ignites the moment it comes in contact with the flame of the sprinklers. If a handful of engine waste is dipped in oil and placed in the furnace and lighted, and if the sprinklers are put in action according to the rule given above, the lighting of oil fires will be found to be attended with as little danger as that of coal fires. The moment the requisite steam pressure has been reached, the further management of the engine is as simple as possible. Should much steam be wanted, the oil, steam, and air valves of the sprinkler are opened full way, and should only a small quantity of steam be required, these valves can be nearly turned off. The service of marine engines is thus rendered very much easier.

(*b*) *Overcoming Obstacles.*—Besides suffering from fitfulness in their flame, as is the case with slit-sprinklers, and which is generally traceable to the impurities in the oil, all spray fires are liable to have their sprinklers stopped, and to be extinguished by the steam. In the case of slit and pipe sprinklers, this stopping up, which is caused by impurities in the oil, or carbonisation owing to imperfect combustion, is remedied by means of blowing or cleaning. As has already been stated, it is usual to fit two sprinklers to each furnace, so as to prevent interruption of work, and the second is then set going before the first is cleaned. Nozzle-sprinklers get much less frequently stopped up, and can be more easily cleaned, as, for instance, in the case of the more recent Urquhart sprinklers—Fig. 84. In cases where only one sprinkler is fitted to the furnace, tiles have been found very useful. These tiles retain heat for a long period and keep almost incandescent whilst the sprinkler is being rapidly cleaned out. Consequently there is no perceptible diminution of steam, and, when the sprinkler is returned to the furnace, no burning foreign body need be introduced, for the oil is relit by the heat radiated from the tiles. The flame is sometimes extinguished by steam when the vaporisation is carried out with steam that is too damp, which reduces the combustion. The water from the steam pipe should therefore be frequently withdrawn. It is also desirable to superheat the steam, for this will insure the oil being warmed in the sprinkler without causing condensation of steam. Besides, superheated steam expands to such an extent that much less weight of steam is required for vaporisation. Of course superheating steam means using up heat, but if the steam pipes are laid along the floor of the furnace, as Tarbutt places them, instead of along the roof, as is done by Dickey and Selwyn, the extra expenditure of heat will be found to be inappreciable, for the heat generated here is practically but little utilised in ordinary circumstances. Some, however, maintain that highly superheated steam decomposes in the very high temperature of spray fires, as in the case of water-gas furnaces, into oxygen and hydrogen, and that while the liberated oxygen increases the efficient combustion of the oil the high temperature of combustion of the hydrogen is said to increase the difference of the temperature between the gas fuel and the boiler plates, and consequently increases the efficiency of the gas fuel. Selwyn,* who takes a similar view, believes that by such combustion 101·4 lbs. of water could be evaporated with 22 lbs. of oil; and Henwood † asserts that he has by these means succeeded in obtaining an evaporation of 41·2 times with his spray fire in an ordinary marine boiler working at a pressure of 62·4 lbs. per square inch. According to

* 'Journal' of the Royal United Service Institution, 1885–86, p. 692.
† 'The Marine Engineer,' April, 1886, p. 24.

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previous practical experiments, it would appear, however, that such a decomposition of the steam in spray fires cannot be attained, even when it is very highly superheated, and Tarbutt * states that he has found in his experiments that the results were better in proportion as the sprinklers used little steam. Indeed an extinction or even dulling of the flame can be entirely avoided by using only compressed air instead of steam for vaporising, and the combustion is most perfect when the compressed air is previously warmed. Besides, the experiments with Jensen's sprinklers go to show that compressed air has the additional disadvantage of working the sprinklers with very much noise. This noise was so great in the case of the Spakovski sprinklers, for instance, that the sound of the marine engine was completely drowned by them, which of course is a great defect. A correspondent from Baku states that all the sprinklers he has seen there work with considerable noise. But d'Allest † on the contrary, tries to prove that in his last experiments vaporisation by steam with induced current was carried on with less noise than in the case of compressed air. This noise is said to resemble that made by a large ventilating fan, and may probably be caused by a continual succession of extinction and re-ignition of the flame, much as in the case of Higgins's chemical or gas harmonium.‡ d'Allest believes that this noise can be avoided by using for vaporisation fuel gases given off instead of compressed air. For this purpose the gases would be first cooled before they were sent into the air-pump, so that such an application would present no difficulties. Sudden breaking off or extinction of the flame through too strong a current or steam jet only occurs in the case of slit-sprinklers, and more rarely in that of pipe-sprinklers. In the case of nozzle-sprinklers, according to the experiments of d'Allest, it can only occur, when cold air has been used for vaporisation and the fire-plates have not been sufficiently warmed. Consequently the latest improvements

* 'The Marine Engineer,' January, 1887, p. 326.

† 'Le Genie Civil,' 1887, vol. xi. p. 421.

‡ L. Pfaundler Müller Pouillet's 'Lerbuch der Physik' ('Text-book of Physics'), 8th edition, 1887, vol. i., p. 439.

in sprinklers enable us to overcome almost entirely the old tiresome obstacles to working with spray fires,

(*c*) *Letting steam down* is effected by closing the oil-tap and the steam-cock of the sprinkler. As in the case of coal fires, it then becomes important to close all apertures leading to the fire-box, so as to prevent the entrance of cold air, and to assure the gradual cooling of the boiler. When compressed air is employed the compressor must also be stopped. The steam of the marine boiler is sufficient to set working the sprinkler of the auxiliary boiler on arrival in harbour. In lying under steam the sprinklers of the different fires are set going alternately with a short weak flame, so that in each boiler only one low flame is burning, which distributes very little heat, and the position even of this is continually changed to avoid too partial a heating of the boiler. The very small quantity of fuel requisite when lying under steam is considered a special advantage of oil furnaces.

(*d*) *The Prevention of Deposit.*—The enemies of liquid fuel are continually urging the danger of burning boilers arising from the rapid consumption of fresh water from steam jets, and the consequent introduction of salt sea water into the boiler. But the following example will show how far this is to be feared in the case of an ordinary freight steamer with a compound engine of 5 atmospheres boiler pressure, and doing an average duty of 500 indicated horse-power. The engine uses for 1 horse-power per hour 20 lbs. of water; this means $500 \times 20 = 10{,}000$ lbs. of water per hour. The boilers are fitted with the latest and best sprinklers which require 3 per cent. of the entire steam consumption to work them; in other words, per hour $10{,}000 \times 0{\cdot}03 = 300$ lbs., of steam, which must be replenished by sea water containing $3{\cdot}5$ per cent. of salt. Therefore there is hourly added to the boiler $300 \times 0{\cdot}035 = 10{\cdot}5$ lbs. of salt, which give the boiler water, of which there are $10{,}000 + 300 = 10{,}300$ lbs., an addition of salt that is equal to about $0{\cdot}1$ per cent. As, however, the fresh water in the surface condenser has, owing to unavoidable losses, to be replenished by about 5 per cent. of sea water, the boiler water generally has about $0{\cdot}2$ per cent. of salt on the high seas, and this will sometimes increase to as much as 0·5 per cent.; consequently the addition of 0·1 per cent., owing to the consumption of the sprinkler, does not really make any appreciable difference. If the boiler has 9 per cent. of salt, 269 gallons of water are needed hourly, or, speaking roughly, only about 30 lbs. of water need be blown out of the boiler to make the salt quite harmless. It has been calculated that this blown-off water would not involve a waste of more than about 0·4 lbs. of oil per hour, which means less than one hundredweight of uselessly burnt oil in ten days. This goes to prove that the waste caused by the substitution of sea water for the fresh water used in steam for the sprinkler is of no importance, and this is confirmed by the fact that the 200 steamers on the Caspian which use liquid fuel do not complain on this score. Nevertheless, in the case of steam pressure of from 10 to 12 atmospheres, and above that, vaporisation by steam cannot be allowed, as the admission of salt water into the boiler should then be rigidly avoided.

Experience with boilers fitted with the latest triple expansion engines shows that in cases of a steam temperature of 356° Fah., and beyond that even, small precipitation may cause blisters in the crowns of the fire-boxes and smoke chambers. In such cases, therefore, the vaporisation must be carried out by compressed air, and the question arises whether the fitting of compressors and the other appliances requisite for liquid fuel would not seriously add to the weight of the vessel. If we retain the example given above of the 500 indicated horse-power engine, and suppose her to use, as a triple expansion engine, only 1·5 lbs. of coal per 1 indicated horse-power per hour, about 90 tons of coal would be requisite for a voyage of ten days. This would take up a bunker space of 4000 cubic feet. The same engine, when served with the residuals of mineral oil, would require for the same period 52 tons of oil, while the combustible value of oil in comparison with coal is 7 : 4. The 52 tons of oil having a specific gravity of 0·9, would take up a space of about 2000 cubic feet.

A saving in weight of 38 tons, and a saving in space of 2000 cubic feet, is therefore effected by using oil. An engine requiring 1·5 lb. of coal per 1 indicated horse-power per hour needs, according to the formula, $1·5 : x = 7 : 4$, roundly only 1 lb. of oil for the same duty. To vaporise 2 lbs. of oil, 35 cubic feet of air is all that is wanted at the outside, or 3 lbs. with an atmospheric pressure of 1·3 to 1·5, for d'Allest did not want more than 17·6 cubic feet at 0·75 atmospheric pressure; in any case for one hour $1 \times 500 \times 1·3 = 650$ lbs., of compressed air is wanted. To generate this volume of compressed air a compressor, with a steam engine of about 20 indicated horse-power, which would not weigh more than 2000 lbs. at most, is needed. The boiler must also be increased to correspond with this increase in the engine power. A boiler filled with water, and of the usual cylindrical form, with return flues, should weigh from 175 to 250 lbs. per 1 indicated horse-power. In the case of torpedo boats, however, the weight is reduced to from 33 to 44 lbs. Consequently, there is an increase of weight in the boiler of about 5000 lbs. To this must be added the weight of the sprinklers, with their service of pipes and tanks, about 1500 lbs. Further, the weight of the steam pump which has to pump the oil out of the bunkers into these tanks, with its pipes, is about 1000 lbs. The weight of the tiled lining of the furnaces will scarcely amount to as much as that of the fire-bars which it supersedes. The same may be said of the arrangements in the bunkers for the storage of the oil, such as manhole covers, ventilating pipes, pumps and supply pipes, which supersede the slides for the removal of coals, coal-hole covers, gratings, &c. Next comes, the weight of the filling trucks of the bunkers and of the partition plates in the heating space: this can be put down at 7500 lbs. For lighting, one of Tarbutt's apparatus must be added; this consists of a hand pump, pressure tank, and of a service of pipes, weighing altogether, in round figures, 1000 lbs. The wood necessary for lighting would be less in quantity than that required for coal fires, but this is not worthy of consideration. There is, therefore, an addition in weight of the following :—

	lbs.
Air compressor, with engine of 20 indicated horse-power	2000
Increase of weight of boiler	5000
Sprinkler, with pipe-sinker and tank	1500
Oil pump	1000
Alteration of bunkers	7500
Stand pump and pressure tank	1000
Total	18.000

If we estimate the space that would be taken up by the air, oil, and hand pumps, as well as by the double partition plates, at 25 cubic feet, which is very high, we should find that we should have 30 tons of weight to spare, or gained about 170 cubic feet of cargo space. Of course, we have not taken into account the reduction of weight in the boiler which liquid fuel, owing to increase of efficiency, admits. If we assume that the boiler can only show a duty of 10 indicated horse-power on 1 ton of weight, it would have to weigh 50 tons if coal were used. By the use of oil its efficiency is raised 20 per cent., and consequently it need not weigh more than 40 tons, by which indeed the extra weight shown above is completely compensated for. That oil vaporisation by compressed air can be introduced on board torpedo boats without increasing their displacement or lowering their efficiency was proved in 1883 at Marseilles with the Jensen sprinkler.* But that the same displacement may attain a greater velocity owing to the increased efficiency of the boiler was not at first admitted until d'Allest made his latest experiments.

* 'Morskoi Sbornik,' l. 884, No.1.

CHAPTER IX.

STORAGE ON BOARD SHIP.

THE best directions for the storage of liquid fuel on board ship will be found in the regulations issued by the Russian Government* for heating the steamers of the Caspian Sea with mineral oil residuals. Suggestions may also be gathered from published descriptions of arrangements that are now made on board ship for this purpose, petroleum being no longer stored in casks, but carried across the ocean in specially built vessels.

In treating this subject we must take into consideration (*a*) the factors that must be kept in view in the construction of oil bunkers; (*b*) the construction and arrangement of the bunkers; (*c*) precautions against explosions.

(*a*) *The Factors to be kept in view in the Construction of Oil Bunkers.*—Whereas oil has hitherto been stored on board ship in separate receptacles, the weight of which was very considerable, it has been proved that in the case of modern tank ships petroleum can be stored in bunkers as easily as coal if the following factors be kept in view:—(1) The expansion of the oil with every rise of temperature; (2) leakage through the seams; (3) the separation of the water which is always present in the oil; (4) the effect on the stability of the vessel produced by the gradual emptying of the bunkers; (5) the carrying off of the gases given off by the oil; (6) keeping the oil away from heating surfaces; and (7) warming the oil in times of severe frost.

* 'Gulishambarov,' p. 135.

(1) The expansion of the oil by every rise of temperature which may be occasioned by the radiant heat of boiler fires as well as by the tropical heat of the bunkers themselves, is very considerable. The coefficient of expansion of the different oils varies, according to experiments made by St. Claire-Deville, from 0·0007 to 0·0009, so that a rise of temperature of 71·6 Fah. or 73·4 C. suffices to create an increase in the volume of oil of from 1·5 to 2 per cent. If the bunkers then should be fully charged at the commencement of the voyage, they must be fitted with such appliances as will enable them to be enlarged or reduced according to the rise or fall of the temperature.

(2) Leakages occur through the peculiar tendency of the oil to ooze through seams and joints that are perfectly water-tight. This peculiarity, however, is less marked in the case of thick or coarse oils, and is consequently not so great in residuals as in the oil itself. In the case of the latter, the loss in cargoes sent in barrels is estimated at 2 per cent. In bunkers, where, in proportion to the volume of oil, a much smaller length of seam is requisite, this loss, especially when the caulking has been carefully carried out, is very much less. We may, therefore, assume that the leakages of liquid fuel in bunkers do not attain greater proportions than about 1 per cent. of its entire weight.

(3) The separation of the water from the oil during its storage in the bunkers is absolutely indispensable, to ensure the avoidance of interruptions in working, such as the extinction of the gas flame, as well as to prevent any loss of heat. This water gets mixed with the oil either from atmospheric depressions during carriage on the railway, or else through its admission by accident on board lighters, &c.

(4) The effect on the stability of a vessel, especially in the case of well-fitted cross bunkers, may be very dangerous. If a certain depletion of the bunker be taken for granted, it will be seen that the rolling of the ship must cause the displacement of the oil.

(5) It is absolutely necessary to carry off the gases generated in the oil by heating and agitation, which spread

themselves along its surface, otherwise there is a considerable danger of fire or explosion.

(6) It is, for the same reason, of equal importance to prevent any oil that may have oozed through the sides of the bunkers from getting near the furnaces or the heating surfaces. But, apart from this, the smell of the constantly dribbling oil evaporating near the fire-boxes would very quickly become unbearable for engineers and stokers.

(7) In cases of severe frost or in voyages in high latitudes it is imperative to keep the oil warm, so as to maintain it at a sufficient state of thinness, otherwise its density would become too great for practical use, and for this reason the oil should always be kept at a temperature of 53° Fah. By this means water, as well as all other foreign substances, are easily separated from the oil.

(*b*) *The Construction and Arrangement of the Bunkers.*—The above considerations, as well as the regulations of the Russian Government already referred to, enable us to make the following rules for the construction of oil bunkers.

(1) Wood must not be used for the walls, floors, or covers of the bunkers, as it is too combustible a material.

(2) New vessels that have to be fitted at once with oil bunkers must have double partition walls fitted to all those parts bordering the engine and boiler space. It would be advisable to keep the spaces between these partitions filled with water, or, at any rate, to have a collecting tank at their deepest point, so that any oil which may ooze out of the bunkers and find its way there may thus be collected and pumped out at intervals. Any gases that might form in these spaces when they are not filled with water should be cleared out by a steam ejector. No sluice valves or other openings should be fitted to these partition walls. In fact, every precaution should be taken to prevent the oil from getting into the boiler and engine space.

(3) The shell and the double bottom can, in the case of new ships, be turned into the immediate boundaries of the oil bunkers when they are well riveted at these places like boilers, and after they have been subjected to a cold water

test of a pressure double what they will later be exposed to. This, according to Swann, is the method adopted by Messrs. Armstrong* for their ships. As an example of a riveting for an oil ship, by Messrs. Gray and Co.,† of West Hartlepool, the following data will be useful :—The inner double bottom, which forms the lower boundary of the oil bunker, had tin-plates that were ·6 inches thick, the rivets were ·63 inches in diameter, and stood $2\frac{1}{4}$ in. apart. The shell tin-plates were ·63 to ·69 inches thick, and the rivets were ·87 inches in diameter, and were in the longitudinal rivetings $2\frac{1}{2}$ to $2\frac{3}{4}$ inches, and in the cross-rivetings $2\frac{3}{4}$ to 3 inches apart. Where rivets of $\frac{3}{4}$-inches were used they were 2 to $2\frac{1}{2}$ inches apart. The rivets between the knees and skin were 6 to $6\frac{1}{2}$ inches apart. The overlappings in the cross partitions were riveted with rivets ·63 inches thick with a distance from each other of $2\frac{1}{4}$ inches. Such close riveting, combined with good fitting together of the rivet holes—which were probably punched on the spot—careful riveting, and stopping up of any interstices, are a guarantee of oil tightness.

(4) The decks, insomuch as they are the boundaries of the bunkers, must be of sheet iron, and must be riveted as securely as the skin and the bottom. We recommend, should the deck be planked, to place a layer of felt or cement on the iron, and to coat the planks underneath and along the sides with lime or varnish, so as to prevent, if possible, their being saturated with oil. It is, however, safer to omit planking the deck. In the place of the ordinary coalholes, manholes should be cut in the bunker-decks.

(5) The old coal bunkers, although they may be watertight, cannot be used without alterations for oil bunkers. They must be fitted all round with a carefully-riveted double wall ; in other words, carefully-constructed tanks have to be built into them for the reception of the oil.

(6) All bunkers must be fitted with self-acting filling appliances, so that they may be kept full until their contents are wanted for fuel. As we have already stated, a certain contraction of the oil takes place on lowering of temperature ;

* 'Engineering,' 1886, ii., p. 114.

† 'Engineering,' 1886, ii., p. 111.

besides this, a certain quantity of oil keeps oozing through the shell into the water, although the water cannot possibly get into the ship through the careful riveting. During bad weather the oil in one of these partially empty bunkers becomes much agitated and strains the ship to its utmost, until at last it succeeds in escaping in large quantities through the loosened communications. These disadvantages have to be overcome by keeping the bunkers continually full by means of an oil tank situated above them, which communicates with them either together or separately. This tank does not only replace the losses occasioned by leakage and diminution of volume, but receives the expanding oil in the case of a rise of temperature as well. The lower the liquid level in this tank the less is it likely to influence the stability of the vessel. Cylindrical erections in the bunkers reaching to the next deck and containing a proper quantity of oil are the best.

(7) Cross bunkers, should they be required, must be partitioned into two or three sections, so that when they are getting empty they may, by change of oil level, reduce the stability of the ship as little as possible.

(8) Every bunker must be in communication with a ventilating pipe at its highest point. This pipe must be either separately, or after its union with a main pipe composed of numerous such branch pipes, led on deck, and there carried to a considerable height as a ventilating pipe. To prevent an explosion of the gases as they stream out of this pipe, its mouth must be covered with wire gauze; the suction pipe of the steam pump must be laid to a deep point in the bunker; this pipe conducts the oil into the tanks above the furnaces, from whence it flows into the sprinkler. Each bunker must, besides, have a supply-pipe for filling itself with.

(9) Every bunker must have a collecting tank for the water which gets separated from the oil; this must be in communication with a Lenz pump or an ejector.

(10) A steam-pipe must be laid through the bunker for the purpose of keeping the oil warm and separating the water from it, if the vessel be intended for high latitudes.

(11) The carefully coated boilers must be at least 45 cm. from the wall of the bunkers, so as not to warm them too much.

(12) The bunkers must be provided in their lower parts, with oil-level gauges, so that their emptiness can be easily discovered.

(*c*) *Precautions against Explosions.*—The frequent explosions of the oil, especially on board the steamers of the Caspian were at first attributed to spontaneous combustion, when they really owed their origin to the inflammability of the oil, and particularly to carelessness. According to the investigations of Boutleroff and Sinin, spontaneous combustion of mineral oil is impossible, inasmuch as it does not condense any gases on its surface, and none of its components take up the oxygen of the air ; on the contrary, they are all opposed to oxidation. It is only when very inflammable bodies are present, such as sawdust, cotton, wool, &c., which are completely saturated with petroleum, that spontaneous combustion becomes at all possible. To avoid this danger, which the great inflammability of the oil entails, the Russian Government has prohibited the use of such mineral oil on board ship as shall have a point of ignition lower than 70° C., for the temperature of the oil in the bunkers frequently exceeds 149° Fah., owing to the heat radiated by the boiler in addition to the heat of the sun.

This prohibition only touches the undistilled mineral oil. The residuals after the first distillation, as well as the other heavy oils used for fuel, have an ignition point of 212° Fah. Gulishambarov, however, is of opinion that even undistilled oil can be used as fuel, so long as the evaporation of its volatile particles is not left out of sight; and this view is indeed justified by practice in the United States, where, in all trials of liquid fuel, the undistilled oil has always been used.

The precautions to be observed in using oil as fuel turn on this point, namely, that the oils themselves are not to be feared, but only the explosive gases formed by the admission of air ; and even these only when they are brought into contact with an open flame. If the bunkers, therefore, are provided with shafts to carry off these gases, and if, when they are empty, they are carefully aired, and not till then inspected with safety lamps, all elements of danger have been eliminated, especially if the fuel used is residuals, which have scarcely any gases left to evaporate. In this case it may be safely stated that there is actually less danger of explosion than in cases where coal is the fuel. When, however, as Russian enginemen, with remarkable carelessness, have actually done, half-empty bunkers are lighted up and examined with unprotected open hand-lamps, accidents are almost inevitable.

In the engine-room of all Russian oil-burning steamers a notice is put up which points out the danger of inspecting bunkers with open hand-lamps, and insists on having all bunkers emptied and aired before they are examined and entered. The Russian Government engineers are responsible for the carrying out of all the Government regulations with reference to the use of liquid fuel on board steamers.

CHAPTER X.

LIQUID FUEL FOR LOCOMOTIVES.

In Russia the great success in the use of petroleum residual fuel in the locomotives of the Griazi-Tsaritzin Railway has been followed by its adoption on several other lines, after adapting several locomotives to its use, so as to test it in comparison with other methods. The Griazi-Tsaritzin Railway uses for all its locomotives (143) stationary boilers (50), and in the shops, petroleum residuum. The following are the results from the use of petroleum residuum fuel in two types of locomotives used upon this railway in 1885, compared with results from the use of coal in 1882. The annual average result shows that by weight 1 lb. of petroleum was equal in effect to 1·78 lb. of coal :—

	6-Wheeled Engines.	8-Wheeled Engines.
Average consumption of coal per mile, 1882	57·25 lb.	81·43 lb.
,, ,, petroleum ,, 1885	32·23 lb.	46·63 lb.
Saved on petroleum against coal in weight, per cent.	43·70	43·68
Unproductive run of locomotives :		
With coal in 1882, per cent. of aggregate	35·25	15·85
With petroleum in 1885 ,, ,, ...	36·08	15·97
Average cost per mile :—With coal	7⅘*d.*	11½*d.*
,, ,, ,, ,, With petroleum	4½*d.*	6½*d.*
Saved on petroleum against cost on coal, per cent. ..	42·35	43·13
Average yearly cost per ton :—Of coal	£1 6*s.* 3*d.*	
,, ,, ,, ,, Of petroleum	£1 6*s.* 4*d.*	

With such a considerable run as is made by the locomotives upon the Griazi-Tsaritzin Railway, the gross annual saving to the company from the use of petroleum residuum fuel in locomotives and stationary boilers, and from indirect saving in repairs, will be about 41,666*l.* The comparative cost of running 1000 car axles per mile given below, from the official reports of the Griazi-Tsaritzin Railway, points to the great importance of petroleum fuel for railway purposes. The cost of running 1000 car axles per mile was in 1881, 18*s.* 5*d.*; in 1882, 17*s.* 2*d.*; in 1883, 16*s.* 9*d.*; in 1884, 11*s.* 6½*d.*; in 1885, 10*s.*; with coal, in 1882, 18*s.* 5*d.*, and with petroleum residuum in 1885, 10*s.*, or a saving of 46·7 per cent.

Mr. F. V. Urquhart, whose system for burning petroleum is almost universally adopted by the railways in Russia using that kind of fuel, and who is most probably the most competent authority on the subject, has recently published the results of working with coal and petroleum residuum on the Griazi-Tsaritzin Railway, where petroleum residuum has been the sole fuel used since 1st October, 1884. The comparison is accurate, complete, and comprehensive, and is the result of a year's use of each article.

In a paper read before the Institution of Mechanical Engineers * Mr. Urquhart states that since November 1884 the whole of the 143 locomotives under his superintendence have been fired with petroleum refuse, besides fifty stationary boilers, both horizontal and vertical, two scrap-welding furnaces, four tire-heating fires, two brass-melting furnaces, and three plate and spring heating furnaces. Petroleum refuse is in fact the fuel used for all steam-generating purposes to the complete exclusion of all solid fuel, except a very small quantity of wood for starting the fires in horizontal boilers of pumping engines. For all metallurgical operations also petroleum is used as fuel, except for the smiths' fires and the foundry cupolas, and strong hope is entertained of applying it even here. For passenger locomotives Mr. Urquhart finds it preferable to use a longer nozzle to his sprinkler than that used for goods locomotives. The divider or vertical grid at one

* Proc. Inst. Mech. Eng., 1889. "Supplementary paper on the use of petroleum refuse as fuel in locomotive engines," by F. Urquhart, M.Inst.C.E.

GRIAZI-TSARITZIN RAILWAY.

CONSUMPTION OF COAL IN 1882 AND PETROLEUM RESIDUUM IN 1885, INCLUSIVE OF KINDLING WOOD, ON TWO TYPES OF ENGINES.

EIGHT-WHEELED ENGINES.

With Coal in 1882.

Month.	Average number in train.	Aggregate distance run by locomotives.	Aggregate distance of unproductive run of locomotives.	Aggregate distance run by freight cars.	Average consumption of fuel and cost per mile.	
					Petroleum residuum.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January ..	33·82	41,296	7,003	1,294,696	98·83	14·76
February ..	34·21	37,444	5,770	1,082,924	86·91	12·66
March ..	33·41	20,881	1,956	632,410	87·44	12·99
April	38·14	24,293	3,329	850,147	73·01	10·60
May	41·24	31,145	4,757	1,170,956	70·62	10·36
June	40·53	37,520	4,907	1,321,835	73·04	10·73
July	43·64	29,749	5,802	1,045,201	71·74	10·55
August ..	39·99	38,751	6,028	1,308,734	71·28	10·01
September	39·54	56,586	9,298	1,866,171	76·26	10·75
October ..	35·13	71,041	11,891	2,081,474	77·06	11·04
November ..	36·56	70,466	12,648	2,114,172	92·54	13·49
December ..	34·00	52,763	7,166	1,416,010	99·82	14·42
Total and average for year	37·51	511,935	80,555	16,184,730	81·43	11·50

With Petroleum Residuum in 1885.

Month.	Average number in train.	Aggregate distance run by locomotives.	Aggregate distance of unproductive run of locomotives.	Aggregate distance run by freight cars.	Average consumption of fuel and cost per mile.	
					Coals.	Cost.
		miles	miles.	miles.	lbs.	*d.*
January ..	37·72	83,636	16,066	2,549,230	48·30	6·71
February ..	37·15	55,222	10,449	1,663,813	49·98	5·36
March ..	30·95	38,742	3,247	1,405,162	52·79	8·82
April	41·03	60,477	9,809	2,079,544	42·68	6·95
May	40·81	87,805	13,489	3,033,003	41·00	6·32
June	41·68	75,175	11,029	2,673,988	41·84	5·47
July	38·80	63,901	8,160	2,120,526	38·19	5·46
August ..	40·32	74,272	10,796	2,560,034	41·50	6·02
September	39·76	82,415	13,241	2,654,637	41·22	5·88
October ..	37·61	101,253	15,468	3,226,698	47·74	6·77
November ..	36·24	82,346	16,434	2,388,761	42·95	7·48
December ..	34·85	63,468	9,482	1,881,136	54·19	8·60
Total and average for year	38·08	868,712	137,670	28,565,555	45·83	6·50

SIX-WHEELED ENGINES.

With Coal in 1882.

Month.	Average number in train.	Aggregate distance run by locomotives.	Aggregate distance of unproductive run of locomotives.	Aggregate distance run by freight cars.	Average consumption of fuel and cost per mile.	
					Petroleum residuum.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January ..	21·32	78,244	36,032	897,826	62·60	9·35
February ..	27·47	43,160	23,008	560,152	55·15	9·90
March ..	26·52	27,742	15,337	329,249	52·73	7·66
April	28·59	57,514	22,497	1,004,129	53·84	7·78
May	31·90	111,181	40,974	2,241,273	56·58	8·08
June	30·74	147,720	48,638	3,043,384	57·46	8·46
July	28·39	145,232	51,826	2,652,482	48·69	7·13
August ..	27·04	152,659	52,697	2,703,475	49·88	6·92
September	28·93	143,000	50,112	2,693,239	55·49	7·71
October ..	23·30	163,442	53,837	3,101,778	62·29	8·26
November ..	21·60	159,669	43,640	2,508,388	63·88	9·15
December ..	20·04	112,118	36,081	1,517,773	68·37	9·72
Total and average for year	26·32	1,341,681	474,679	23,253,148	57·25	7·80

With Petroleum Residuum in 1885.

Month.	Average number in train.	Aggregate distance run by locomotives.	Aggregate distance of unproductive run of locomotives.	Aggregate distance run by freight cars.	Average consumption of fuel and cost per mile.	
					Coals.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January ..	22·14	114,192	46,052	1,509,005	34·43	4·77
February ..	22·01	89,648	37,513	1,148,056	34·09	4·84
March ..	22·58	88,950	33,721	1,097,442	28·98	4·82
April	25·33	141,584	46,654	2,354,348	31·73	5·16
May	28·49	179,872	65,985	3,246,003	29·88	4·59
June	28·35	144,669	55,347	2,533,104	29·93	4·28
July	24·77	131,341	48,001	2,064,742	27·57	3·71
August ..	28·27	128,559	46,677	2,315,544	28·75	4·17
September	31·89	130,846	46,088	2,703,087	32 07	4·55
October ..	28·04	125,523	38,266	2,448,912	35·55	5·09
November ..	21·41	119,788	36,258	2,451,573	35·74	5·21
December ..	22·15	92,361	34,171	1,287,893	38·13	5·74
Total and average for year	25·45	1,487,333	534,733	25,159,709	32·23	4·50

time used inside the fire-box, close in front of the orifice of the sprinkler, for the purpose of still more thoroughly breaking up the spray jet, is now discarded in favour of bringing the brickwork closer up to the orifice, so that the spray may break itself up against a rugged brick wall.

If the use of liquid fuel for locomotives has had such eminently successful results in Russia we must admit that the trials instituted in America by the United States Bureau of Steam Engineering have been at least equally satisfactory. We cannot do better than subjoin the report of Chief Engineer Greene, and C. W. Rae and R. S. Griffin, assistant engineers.

" *Report of a Board of United States Naval Engineers on the trials, with petroleum as a fuel, of the burner of the Petroleum Fuel and Motor Company, fitted to a locomotive, at Alexandria, Va., May* 3, *1888.*

WASHINGTON, D.C., May 31, 1888.

" SIR,—In obedience to the orders of the Department, dated April 4, 1888, and under the instructions of the Bureau of Steam Engineering (letter No. 499), we have made a test of the value of crude petroleum for fuel, as used in the patented device of the Petroleum Fuel and Motor Company of this city, and report as follows :—

" In the system employed by this company the oil is first atomised, or probably partially gasified, by highly superheated steam, after which it is supplied with a quantity of hot air within the pipe by which it is conducted to, but at some distance from, the burner. The apparatus as applied to a locomotive belonging to the company, which was placed at the disposal of the board for trial, consists of the atomiser located below and secured to the floor of the cab ; the oil pump, drawing its supply from a closed tank in the coal-box of the tender and forcing it through the atomiser and pipes to the burners ; the air-tank, and coil in the smoke-box for heating air, which is supplied by an ordinary Westinghouse air-pump, which pump also supplies the air-brake system ; the superheating coil for superheating steam for the atomiser, which is located inside the fire-box ; the burner, and the air-pipes for supplying air around and near the burners for the more perfect combustion of the atomised oil.

"The atomiser consists of a hollow globular casting 5 inches in diameter and divided into two parts by a curved diaphragm. Through a nozzle on one side passes a pipe $1\frac{1}{4}$ inches in diameter which extends through the diaphragm and then narrows to a one-eighth inch opening. In the interior of this pipe and having the same axis is a second pipe three-eighths inch in diameter and narrowing to a one-sixteenth inch opening directly opposite the opening of the larger pipe. The superheated steam enters the globular part from below and passes through a number of small holes in the larger pipe and jackets the smaller pipe for a distance of 10 inches. The oil is supplied through the inside smaller pipe, being heated by the jacket, and passes in a jet through the one-sixteenth inch opening, and then with the superheated steam passes through the one-eighth inch opening in the end of the larger pipe. From the globular part, the atomised oil and superheated steam are conducted a distance of 20 inches through a $1\frac{1}{4}$ inch pipe, and then upwards to the post of the furnace door, and thence to the burners.

"At the bend the hot-air pipe is attached, the heated air being delivered through a $\frac{1}{8}$ inch pipe extending upward to the hollow door-post. The door-post is so arranged with a packed joint that the door can be opened and closed readily without deranging the oil apparatus.

"The oil pump is conveniently located within the cab at one side, and arranged with a safety valve and branch in its delivery pipe, so that when the oil pressure exceeds the limit set, the valve opens and the excess of oil flows back to the tank from which it was drawn.

"The air tank is a simple cylindrical drum to serve as a reservoir, and the heating coil is of ordinary iron pipe, bent to form, and set directly opposite the tube ends in the smoke-box, so that the heat which it receives is only that which would otherwise be lost up the funnel.

The steam superheating coil is located within the fire-box and rests on an inclined shelf of fire-brick, which shelf protects it as well as the tube sheet and tube ends from the direct action of the flame. A space over the top of the shelf, 8 inches wide, and at the sides and bottom 2 inches wide, permits the passage of the products of combustion to the boiler tubes.

"The coil is of copper pipe $1\frac{1}{4}$ inch diameter with $\frac{3}{4}$ inch bore. The pipes supplying both the air reservoir and the superheating coil lead first to the cab, for the purpose of having regulating valves at hand, and then back to the coils, from which they lead directly to the atomiser.

"The burners are placed on the lining plate of the furnace door. The burners proper are 124 in number and are in the form of hollow frustums of cones $\frac{3}{4}$ inch at base and $\frac{1}{4}$ inch at the point with $\frac{1}{8}$ inch openings, and projecting $1\frac{1}{2}$ inches from the face of a flat casting. A second flat casting is faced and secured to the first one, and between the two is cut a spiral groove in which the pipe from the door post, supplying the atomised oil, is placed. Drilled into this pipe opposite each of the hollow conical projections are four 1·32-inch holes, and the pipe itself terminates near the middle of the casting with a screw plug which can be removed for blowing through.

"The air supply pipes have bell-mouth openings, pass under the grates on both sides, thence up into the fire-box, and entirely around and at a short distance in front of the burners. They are perforated on the side toward the flame. It is designed that these shall catch the air and force it up to the flame by the forward motion of the locomotive. A damper in the door performs the same office when the engine is backing.

"All the pipes through which the oil, either in the liquid or atomised form, passes, as well as that for superheated steam, are of copper or of a composition of 90 per cent. of copper, and it is the use of this material, it is claimed, which prevents the deposit of solid carbon and consequent choking.

"The boiler is of the usual locomotive type, and its principal proportions are as follows, viz. :—

Grate surface	square feet	11·33
Heating surface:		
Fire-box	do.	72·88
Tubes	do.	736·70
Front head	do.	6·24
TOTAL	do.	815·82

Ratio of grate to heating surface		1 to 72
Area of opening through tubes	square feet	2·92
Ratio of opening to grate surface		1 to 3·88

"The water used was taken from the city hydrant and was extremely muddy, so that the boiler water legs, which were clean at the start, were filled from 8 to 10 inches in depth with hard mud at the end of the trial.

THE TRIAL.

"For the purpose of the trial, the locomotive was taken to the yard of Messrs. J. P. Agnew & Co., in Alexandria, Va., and a box-car placed on a siding to serve as a platform for the measuring tanks and to furnish a convenient place within for making the calorimetric tests.

"Two large casks were used for measuring tanks and their capacities accurately determined by weighing. The casks were placed on the roof of the box-car, and pipes from each led to the engine water-tank.

"The steam was blown off at the safety-valve at the pressures shown in the table on page 69, and the steam for the calorimeter was taken from the boiler dome directly below and as near as possible to the safety-valve, the mouth of the pipe being directed against the current of the flow. This pipe led inside the box-car where the calorimetric tests were made.

"The water was fed to the boiler by the injector, but all the overflow was caught and returned to the tank. Care was taken that there were no leaks or loss from any cause.

"All preliminaries having been arranged, the trial was begun on the morning of the 3rd instant. As steam was required for the atomiser, it was necessary to start fires in the usual way with wood and coal.

"Fire was started at 8.20 a.m., 247 pounds of pine and 756 pounds of anthracite coal (egg size) being used for this purpose. Steam formed at 10·10 a.m., and at 10.52 a.m., there being 75 pounds pressure indicated by the gauge, the dampers were tightly closed, the surface of the coal in the fire box covered to the depth of 2 inches with refuse and earth, and the oil fire started. It was believed that the closing of the dampers and covering of the coal would wholly eliminate any effect the starting fire might otherwise have, but to be doubly sure the oil fire was continued at full force until 11.30 a.m., three hours and ten minutes from starting, before the trial proper was begun. At that time the water level in the boiler was as near as possible midway between two and three gauge cocks (there was no glass gauge), the level of water and oil in the tanks of the tender was marked, and the taking of data, which were recorded half hourly, commenced. The trial lasted for six hours, or until 5.30 p.m., at which time the level of the water in the boiler and in the tank was the same as at starting.

"Three barrels of oil, all that was at hand, had been weighed and supplied to the tank and four inches in depth additional used from the tank. The area of the tank was then carefully measured, and it was found that this additional amount was 45·6 gallons, which, at 6·85 lbs. per gallon, was 312 lbs.

"The three barrels weighed 1015 lbs. net, or there was used a total of 1327 lbs. of oil.

"The capacities of the water tanks were, No. 1, 786 lbs. of water; No. 2, 718 lbs. of water.

"The observed data with totals and averages are given in the following table (p. 103).

The apparent evaporation of water per lb. of oil from a temperature of 67·25°, and under an absolute pressure of 122·5 lbs. per square inch, then was:—

$$19{,}945 \div 1{,}327 = 15{\cdot}03 \text{ lbs.,}$$

Hour.	Pressures per gauge.			Temperatures.				Barometer.	Times at which tanks were emptied.		Pounds of oil used.
	Steam.	Oil in pipe.	Hot air in pipe.	Atmosphere.	Feed water.	Steam (thermometric).	Uptake.		No. 1.	No. 2.	
M. 12·00	118	150	65	69	61	340	540	30·56	12·00	12·07	
P.M. 12·30	108	145	63	67	64	337	550	30·56	12·35	12·42	
1·00	105	142	64	67	67	335	550	30·56	12·55	1·00	
1·30	102	140	62	68	67	335	550	30·56	{1·18 1·30}	1·23	339
2·00	101	136	55	68	68	332	552	30·57	1·55	1·35	
2·30	105	140	54	70	68	332	552	30·57	2·15	{2·04 2·20}	
3·00	106	125	53	70	68	333	552	30·57	2·40	2·47	330
3·30	107	120	53	71	68	333	565	30·57	3·20	3·28	
4·00	106	105	53	69	69	332	565	30·59	3·45	3·50	346
4·30	112	100	57	70	69	340	565	30·59	4·23	4·28	
5·00	112	93	58	70	69	335	565	30·59	4·58	5·06	
5·30	108	120	55	69	69	335	575	30·59	*5·28	5·28	†312
6 hours	1,290	1,516	692	828	807	4,019	6,681	366·88	‡13½	‡13	1,327
Averages	107·5	126·3	57·7	69	67·25	334·1	556·75	30·57	§10,611	§9,334	

* Half barrel. † 45·6 gallons measured. ‡ Tanks. § Total water, 19,945 pounds.

and for the equivalent evaporation from and at a temperature of 212° we have :—

Absolute pressure (p)	=	122·5
Total heat of steam at this pressure (H)	=	1,186·4361
Temperature of feed-water (t)	=	67·25°

Total heat of water at temperature t (h)	=	35·2616
Units of heat required to vaporise 1 pound of water from temperature t, and under an absolute pressure p ($H-h$) ..	=	1,151·1745
Units of heat required to vaporise 1 pound of water from and at a temperature of 212°	=	965·7

"Then $15·03 \times 1151·1745 \div 965·7 = 17·916$ lbs., which would be the true equivalent evaporation from and at 212° had the water been all vaporised, or had the product been dry saturated steam.

"During the trial five reliable calorimetric measurements of the quality of the steam were made, and the observed data and computed results, calculated by the formula

$$Q = \frac{1}{l}\left[\frac{W}{w}(h' - h) - (T - h')\right]$$

are given in the following table (p. 105).

The averages of these results give 92·7 per cent. of dry steam and 7·3 per cent. of moisture which passed off with the steam.

To determine the correct potential evaporation and the actual heat units realised from the combustion of the fuel, as measured by the steam produced, we have the following data and computations.

Units of heat required to vaporise 1 pound of water from temperature 67·25° and under absolute pressure 122·5 = ...	1151·1745
Units of heat required to raise the temperature of 1 pound of water from 67·25° to 342·61°, the temperature due to the absolute pressure 122·5, 314·4726—35·2616 = ...	279·2110
Total pounds of water fed to boiler	19,945
Pounds of water vaporised, 19945 × ·927	18,489
Pounds of water raised in temperature, 19,945 × ·073 = ...	1,456
Units of heat required to vaporise the water = 18,489 × 1151·1745 = ...	21284065·33
Units of heat required to raise the temperature of the water = 1456 × 279·211 = ...	406531·22
Total units of heat derived from the fuel, as measured by the steam discharged	21690596·55
Units of heat per pound of oil, 21690596·55 ÷ 1327 = ...	16345·59
Number of pounds of water of temperature, 67·25° that would have been vaporised under an absolute pressure of 122·5 pounds per pound of oil, or potential evaporation, 16345·59 ÷ 1151·1745 = ...	14·199
Equivalent potential evaporation from and at 212°, 16345·59 ÷ 965·7 = ...	16·926

No. of test.	Average steam pressure per gauge.	Weights.		Temperatures.						Proportion of dry steam.
		W.	*w.*	*t.*	*t'.*	*h.*	*h.*	T.	*l.*	Q.
1	109·3	304	11	74·7	110·2	42·7193	78·2972	315·6092	871·1623	0·8562
2	101·0	300	15	60·7	111·1	28·7067	79·2002	310·2483	874·9403	0·8901
3	107·5	300	13	63·4	110·7	31·4085	78·7989	314·4726	871·9635	0·9839
4	108·5	300	14	59·7	111·3	27·7061	79·4009	315·1081	871·5156	1·0006
5	111·0	300	14	62·9	110·6	30·9082	78·6985	316·6632	870·4192	0·9031
Proportion of dry steam .. .. 92·7 per cent.								Total		4·6839
Proportion of moisture (1,000—0·927) .. .. .. 7·3 per cent.								Average		0·927

"The oil fire was practically noiseless and smokeless, and there was no evidence, in the way of leaks or odour, to indicate that petroleum was burning.

"It is probable that the high temperature and quantity of the steam supplied to the atomiser was more than sufficient to wholly volatilise all the oil, and that the heated air later supplied in the pipe was also of sufficiently high temperature to prevent any condensation, so that the fire was really a gas flame. Just what these temperatures were the board had no means of accurately determining, but the superheated steam pipe, 30 inches distant from its passage through the boiler front, was sufficiently hot to quickly melt and vaporise zinc, while at the atomiser it readily melted lead; hence the temperature of the steam must have been near 800° Fah., while the temperature of the heated air, judging by the touch, must have been above 200° Fah. within the pipe.

"The quantity of air and steam required for the atomiser could not have been large, for the former was all delivered through a one-sixteenth inch orifice under a pressure of 57·7 lbs., and a moderate motion of the air-pump supplied it, while the latter, together with the entire oil supply for the fire, was delivered through a one-eighth inch orifice, the pressure being 107·5 lbs., and the difference of pressure on the two sides causing the flow being necessarily less than this.

"A sample of oil taken from the tank during the progress of the trial was, by the courtesy of Surgeon-General J. M. Brownie, U.S.N., chief of the bureau of medicine and surgery, submitted to the chemist of the Naval Museum of Hygiene for analysis, with the following result:

C = 84·08	Specific gravity, 0·822.
H = 14·40	Flashing point, 64° Fah.
O = 1·52	
N = Trace.	
100·00	

"With the chemical composition of the fuel and the following formula, based on the experimental determinations of Messrs. Favre and Silbermann, we are able to compute the number of heat units that its complete and perfect combustion will produce:—

$$h = 14500\left[C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right]$$

This gives

$$h = 21010 \cdot 326.$$

The equivalent evaporation from and at 212° is

$$E = \frac{h}{965 \cdot 7}$$

which gives

$$E = 21 \cdot 756 = \text{lbs. of water.}$$

"Whence it appears that there was realised with petroleum in the device tested 77·8 per cent. of the total heat of evaporation of which it was theoretically capable, which is a much larger proportion than is possible under any conditions of actual working practice with the best quality of coal.

"The facility of handling petroleum and manipulating the fires is very decidedly in its favour, and a much smaller force would be required for that purpose than with coal.

"The trial was not of sufficient duration to absolutely demonstrate the permanent efficiency of the device for burning petroleum, but an examination after its conclusion showed no evidence of any deposit of carbon in the pipes or burners, and certainly the heat and evaporative efficiency were as great at the conclusion as at the beginning.

"The representative of the company informed us that the device experimented with had been in use for three years that it had not been cleaned, and that there had never been any evidence of carbon deposit.

"The question of safety in stowing and handling has not been decided, but in the opinion of the Board this could be satisfactorily provided for by the use of closed tanks, water-jacketed, with vent pipes overboard, and by careful workmanship in connecting pipes, fittings, and valves.

"We are of the opinion that the system could be advantageously adopted on board torpedo-boats and coast-defence vessels, if safety in stowage and handling can be clearly arranged, and think the device of the Petroleum Fuel and Motor Company, of Washington, D.C., worthy of a trial, particularly as it can be applied without interference with the coal-burning arrangements."

"Very respectfully, your obedient servants,

A. S. GREENE,
Chief Engineer, U.S.N.

C. W. RAE,
Passed Assistant Engineer, U.S.A.

R. S. GRIFFIN,
Assistant Engineer, U.S.N.

"Engineer-in-Chief GEORGE W. MELVILLE, U.S.N.
Chief of the Bureau of Steam Engineering.
Navy Department, Washington, D. C."

CHAPTER XI.

SOME INDUSTRIAL APPLICATIONS OF LIQUID FUEL.

Burning Brick by Oil.—In a paper read by S. P. Crafts before the National Association of Brickmakers at Memphis, United States of America, the cost of the various fuels employed in Southern New England is given, and it is stated that: "One cord of beech wood, worth $4·00, contains 17,065,000 heat units; one (American) ton of bituminous coal, at $4·00, contains 31,227,000 heat units; four barrels of fuel oil, 40 gallons each, at $1·00 per barrel, at 6 pounds to the gallon, gives us 20,160,000 heat units. Here then," says Mr. Crafts, "we have data based on the cost and heat values for one locality, the variation from which will not be large from any of the brick manufacturing centres in that region, in which I include the Hudson River, New Jersey, &c.

"Now which shall we use?" Mr. Crafts asks his audience. . . "The most cost for labour in burning, and the least cost for fitting up is with wood, but it involves the greatest cost for fuel. The greatest cost for fitting up, and a smaller cost for labour in burning is with coal, but with the least cost for fuel if you could realise all the heat it contains. With oil the cost of fitting up is more than with wood, but less than with coal, unless you build permanent walls, and even then it is somewhat less, and the labour in burning is least of all. But the cost of burning with oil is less than with wood, but more than with coal, unless you can utilise a much greater percentage of the heat of the oil than that of coal. Now it is claimed that you can get all the heat there is in the oil, at least 19,000 out of the 20,200 units, and that with coal you get but 8000 or 8500 out of the 14,300 units. You must remember, however, that these are claimed as proportions in the pound weights of the two fuels. When we consider the cost they more nearly approach each other; 12 lbs. of oil costs 5 cents and 12 lbs. of coal costs 2 1-7 cents; therefore, to get at the relative values we must estimate the work of 12 lbs. of oil and the work of 28 lbs. of coal; 12 lbs. of oil at 19,000 heat units gives 228,000 heat units, as against 224,000 at 8000 or 238,000 at 8500.

"From this it seems that there is very little difference between the cost of coal or oil unless some other consideration intervenes. But there is a consideration of the lesser expense of fitting for oil, the saving of time in burning, the fewer hands required, and the ease with which you can increase the heat. You may keep your bricks at a dull red and fail to burn them hard; but if you can in a shorter time with oil get the requisite temperature, then you do the work in less time and at a saving of fuel, for the radiation of the heat of a kiln in six or seven days is no small item. It seems to me that in this shortening of time and saving thereby is the principal argument in favour of oil over coal; but it becomes us to consider whether the difference of the percentage of heat utilised under a boiler when burning oil or coal, will hold good when diffused in and through a kiln of brick. I do not think it will, for a kiln seems to take up all the heat of combustion in either case, certainly until the last stage of burning, when the blanket of steam ceases to hold down the heat as in the earlier stages, a condition very different from the smoke-stack of a boiler. In summing up, I should say that wood is the simplest and most expensive fuel in most localities, certainly in localities where the greatest number of bricks are made, but that between coal and oil it is an open question."

During the discussion on this paper Mr. D. V. Purington read a letter from a friend, and made, besides, some forcible and eloquent observations which we will do him the justice to reproduce in his own idiomatic language: "Just before I left home I happened to receive from my superintendent of the yard in Indiana a little note relative to a kiln of 250,000, giving the facts of the difference between wood and oil. . . . He does not give the cost of labour; he simply gives the difference in labour in favour of oil. Kiln of 250,000 using wood and coal: 40 cords of wood at \$2.50 = \$100; hauling to kiln at 25 cents per cord = \$10; 90 tons of coal at \$3 = \$270; unloading same, \$7.50; cleaning up the ashes, \$5; difference in labour, \$10; total \$402.50 = \$1.61 per 1000 for fuel and the extra labour. That, of course, seems a little forced. He should have either not given the labour at all, or given the entire cost of labour. At this place, where we make pressed brick, we have been unable to find any burner we could dry off sufficiently slow with oil to get the steam off without commencing to burn the brick, so we have dried off partially with wood. Same sized kiln with oil: 15 cords of wood at \$2.50 = \$37.50 (against 40 cords of wood); 350 barrels of oil at 62 cents per barrel, \$217; making steam 10 tons of coal at \$3 = \$30; hauling 15 cords of wood at 25 cents = \$3.75; unloading coal, 75 cents; total \$289·00, or \$1.15 per 1000; saving = \$113.50. The above figures are about as close as I can get them, and nearly accurate. I have figured the cost of coal at \$3 and the oil at 62 cents, which may not be exact. Now, in our yard in Chicago, common brick—and I want to say right here that efflorescence in our Chicago modern brick does not bother us any; you cannot see it if it does come out; you do not care anything about it—I have burnt this year a little over 28,000,000, without using a stick of wood or a pound of coal, entirely with oil. Of course my bricks are artificially dried. We have taken out of each brick, from the time it was made till it was set in the kiln, 1¼ lb. of water, so they are about as dry as can be got, practically. We start one side of the kiln three or four hours before we do the other, and we get the heat up just as fast as we can get the draft started. When we first start, of course without the arches being heated at the sides to form a combustion, we have to burn more oil. Our fire is oil, and we burn on an average 4 days, when the average was about 7½ days before. I burn in kilns of twenty-four arches each, and where we used five men we now use two. We have no ashes to haul away, no coal to unload. We unload all our fuel with a little steam pump, and it is then ready to be drawn by gravitation from the tank to the kiln. I can state unequivocally that I know of no inducement, other than a pecuniary one, that would lead me to go back to burning common brick artificially dried with wood or coal. I am not up in heat units, and shall endeavour to talk in a language that brick makers can all understand. I do not know a unit of heat; would not know a dozen if I were to see them right here. The cost for fuel has been, for oil, an average of 36½ cents per 1000. In the beginning, before we understood oil and its uses, we used a great deal more, and we are all the time improving upon it. Any science so new as the burning of brick with crude oil is susceptible of great changes, and I expect it to improve for the next ten years. The exact total cost of burning brick, so far with me I have been unable to ascertain, for this reason—I take my steam from a stack of three boilers, and the same steam from the three boilers is used for running my machines in the day time, and also for my kilns, and for burning brick, so I have been unable to divide the amount of steam I use for burning brick, and the only way I can get at it is relatively, and my figures show the total cost for labour, fuel, oil and coal for burning brick this year has been 53⅓ cents as compared last year with 92 cents using wood and coal. If the cost of fuel was the same; if it cost me just as much for oil and wood to make steam, as it did for wood and coal, I would still burn with oil. My arch bricks, aside from the first 18 inches, are the best I have in the kiln. To use a burner with an aperture sufficiently small to make a light fire results in clogging that aperture with carbon. The hydrocarbon burner is in many respects, I think, the most complete oil burner I have ever seen. There are five apertures about the size of a knitting-needle in it." In answer to a question whether he found any difficulty in handling the fires with oil and getting at the centres, outside corners and ends, and throwing the heat into any desired part of the kiln, Mr. Purington replied in the negative, and explained that to get the heat he lets one side go very light, and fires the other heavily, so that the two flames, instead of meeting in the centre, faced each other. He also stated that he could get any heat he wanted inside of two minutes. After the fire was started and the brick began to sweat, there was no difficulty in getting the fire to penetrate, besides in firing there was this advantage over coal, that the kiln could not possibly be choked, and there were no ashes and no dust. On being asked the average cost per arch to arrange a kiln to burn with oil, taking into consideration the pipe, burners, truck, &c., Mr. Purington stated that to fit up a yard for making 35,000,000 of bricks, about $2500 was requisite.

Armour-plate bending by Liquid Fuel.—At Woolwich most remarkable results have been obtained with liquid fuel in the manufacture of armour plates. We are indebted for the following particulars to Mr. B. J. Carew's 'Practical Treatise on Petroleum.'

Under ordinary circumstances the armour-plate bending furnace is lighted from four to five hours before the plate is placed in it. The time occupied in heating the plate for bending depends upon its thickness, one hour per inch of thickness being allowed. Taking then a 6-inch plate, we get from ten to eleven hours from the time of starting before the plate is ready for bending. Let us now see what the liquid fuel will do. The cold furnace is lighted, and after an hour is deemed sufficiently heated. A 6-inch armour-plate, 7 feet 6 inches long by 3 feet wide, is then consigned to the furnace, and after an hour and a half is drawn and thoroughly heated and ready for bending. Thus in two hours and a half we have the work of ten or eleven hours completely and satisfactorily performed. Nor is this all; the advantages of the system do not stop here. The plate is remarkably free from scale, which can only be accounted for by the absence of the deteriorating influence of the products of combustion in the ordinary furnace. Another valuable result arises from this cause. Thin plates, when heated by liquid fuel and bent double, show no signs of cracking, as they usually do when heated in the coal furnace. This important feature is said to save ten shillings per ton on the metal, which amount it would lose in value by deterioration under the ordinary method of treatment. The fuel in a vaporised condition is supplied from the generator to the furnace by six jets, which are led in through small openings, by which means just a sufficient quantity of atmospheric air is admitted to support combustion. This method of supplying heat also offers another advantage; it can be applied to the whole or any portion of the plate. Thus, if a plate requires to be bent to one end only then the heat is directed to that part. Further, the rate at which the metal is heated can be regulated to a nicety by increasing or diminishing the number of jets. Close beside the armour-plate furnace is another one for heating thinner ones, which have been regularly at work for some time past. It is heated by four jets, and is supplied from the same generator which is placed between the two. The average time occupied in heating is seven minutes; with the ordinary furnace it takes from twelve to fifteen minutes for each plate.

Manufacture of Iron by the "Eames Process."—This is an American process and consists of an ordinary re-heating furnace, with a generator and a steam boiler attached to it. The generator consists of a cast-iron vessel with alternate projecting shelves attached to its sides. The oil trickles over the shelves and is swept off by a jet of superheated steam. The maximum amount of oil required for this furnace is 30 gallons, or 200 lbs., per hour; it can work charges of 3000 lbs., and make steam for the rollers besides. "The trickling oil is met by a jet of steam moving in the opposite direction, and is at once completely vaporised under a pressure of about 10 lbs., and is carried into an adjoining furnace. Air subsequently mingles with the steam and oil vapour and passes the furnace bridge and burns within the furnace, and then runs beneath the boilers to the flue and stack. The old bridge is completely bricked up excepting a space which extends across the furnace, closed only by fire-bricks placed on end, and it is found that if the combustion chamber has a horizontal thickness of more than 18 inches, the fire-bricks are fused."

The working of the apparatus is thus described by Professor Wurtz :—" It is quite easy to determine with precision, with the arrangements at Jersey City, the relations of consumption of oil to iron produced, and time, labour and material occupied in any special case. The oil was fed from a tank sunk in the ground, which had a horizontal section throughout of four feet square. Each inch in depth therefore corresponded to 2304 cubic inches, or closely enough to ten N. S. gallons of 231 cubic inches. By gauging with a graduated rod each hour, therefore, the hourly consumption of oil was readily followed up. It was thus determined by me, that, starting with a cold furnace and a boiler full of cold water, 45 minutes was a maximum time, with oil fed at the rate of 30 gallons per hour, or 22·5 gallons in this time, to bring the whole fire space to a dazzling white heat. Six piles of boiler scrap averaging 500 lbs., or 3000 lbs. in all, being then introduced, 35 minutes more at the same rate of consumption not only brought the piles to a high melting heat, but raised the steam in the boiler to 90 lbs. pressure, being that required to operate the rolls. The time required after the furnace was heated and steam up for each charge of 3000 lbs. averaged at most 80 minutes, and as the brickwork became heated throughout it was apparent the feed oil might be somewhat diminished. Thus in a working day of ten hours, just seven such charges could be worked off, averaging 2500 lbs. of rolled iron each; total 8 tons per day of boiler-sheet from one such furnace, with an average consumption as a maximum of 30 gallons (200 lbs.) of oil per hour, or 300 gallons (2000 lbs.) in all. To this must be added, however, the fuel used under the generator and small supplementary boiler, which together was 500 lbs. per day. It is admissible that the generator and one boiler will operate several furnaces, the inventor says five. If we say four it will diminish the small addendum of cost. As to the working this furnace with coal, it was ascertained from the testimony of the operators, that by keeping up the fire all night, so that a heat could be had at a reasonable time in the morning, the maximum product of finished sheet might be, with superior work, allowing 90 minutes for each heat, 6 American tons, with a consumption of at least $5\frac{1}{2}$ American tons of coal, 12,320 lbs., or 2053 lbs. of coal per ton.*

Scrap Welding Furnaces.—These furnaces are in use at the Borisoglebsk works on the Griazi-Tzaritzin Railway, in Russia, and are described by Mr. Urquhart, in his supplementary paper on the use of "Petroleum Refuse" read in January 1889 before the Institution of Mechanical Engineers. The body of these furnaces is of the usual reverberatory form, and in place of a fire-grate it has three air spray injectors at the firing end, which are placed almost on a level with the bridge. Through these three blast injectors the whole of the air required for combustion is supplied. As no unconsumable particles exist in the fuel, no ash-pit is required, and no clearing is necessary during working, hence the furnace can work continuously so long as the roof does not get burnt out. It also slags very freely, thus proving that quite sufficient heat is available for all practical purposes. The blast used is cold, and from the ordinary smithy main. It was at one time contemplated to heat the air by the waste heat from the furnace itself; but being short of boiler power Mr. Urquhart had to utilise the waste heat from both these welding furnaces for heating a large elephant boiler erected close by, which now supplies almost sufficient steam for the steam-hammers and rolling mill. The petroleum reservoir is placed right above the larger furnace, in order that during winter the refuse may be kept in a liquid state by the heat radiating from the furnace; it supplies both furnaces through a separate pipe to each. Besides a main cock on the pipe to each furnace, there are also three half-inch cocks for regulating minutely the supply of fuel to the three spray injectors of the larger furnace. The liquid trickling from these cocks spreads into a thin film upon an inclined shoot cast in one piece with the blast pipe, which terminates at the furnace end in a wide flat tuyere. The blast issuing from this broad rectangular orifice carries with it, in the form of spray, the thin flat film of petroleum dropping

* J. B. Carew, 'Practical Treatise on Petroleum.'

from the orifice above; and the jet striking against the low bridge, half a brick high, produces a thorough mixture of air and gas, the proportions of which are so accurately regulated that a perfect white welding heat is maintained in the furnace without any smoke being emitted. The larger furnace has three blast injectors while the smaller requires only two. The same construction of blast injector is now used also in the tire fires in place of circular tuyere nozzles.

The great simplicity of the appliances for thoroughly utilising liquid fuel for metallurgical purposes, even for forgings of the largest size, commends itself in any country where this fuel can be had at a cheap rate. As no trace of sulphur exists in petroleum refuse, no deteriorating effect can take place upon the iron. With coal, especially Russian bituminous from the Donetz coal basin in South Russia which is rich in sulphur, it is impossible to get iron of first-rate quality. In tests made on iron rolled from poor unwashed scrap welded with liquid fuel it was invariably found that a very homogeneous ductile metal of high quality was produced. As compared with coal a saving is effected of 40 per cent. in weight of fuel, besides the output being considerably increased.

On Monday mornings 3½ hours are required for heating the larger furnace up to a white heat, with a total consumption of 540 lbs. of petroleum refuse. On all other days in the week 1¾ hours are required, with a consumption of 125 lbs. To make one ton of blooms in the larger furnace alone from small unwashed scrap three times welded requires a consumption of 17 cwts. of petroleum, with a loss of iron of from 18 to 20 per cent. In practice, however, both furnaces are at work at the same time, and the blooms are passed from one to the other when being hammered, thus keeping the heat up in blooms and furnaces, and reducing the consumption of petroleum to 13 cwts. per ton of rolled bars of light section.

Brass-melting Fires.—Mr. Urquhart also describes in the same paper two brass-melting furnaces using liquid fuel, which he has had in daily work about three years with entire satisfaction. The same fires were formerly used with coke as fuel; they are of the well-known make having drop bottoms, which however are not now used, as no unconsumed residue remains in the furnace. The same blast tuyere is used here as in the welding furnaces and tire fires; one is quite sufficient for each brass fire, and is set tangentially to it, thereby giving a whirling motion to the flame, which coming in contact with the white-hot fire-brick lining ensures complete combustion of all the particles it contains. The blast used is cold, and supplied from an ordinary fan. Besides occasioning a much cleaner foundry, free from sulphurous fumes, the adoption of petroleum in place of coke has resulted in a sensible economy in fuel, as well as a saving of time in melting. The results are as follows :—with coke, 40 lbs. of brass castings were made with 35 lbs. of fuel and 10 per cent. loss of metal ; while with petroleum refuse 40 lbs. of brass castings are made with 18 lbs. of fuel and only 6 to 7 per cent. loss of metal, and with 25 per cent. saving in time.

It is of course quite possible that a better arrangement could be made for this purpose ; but, as in the case of locomotives, the plan described is the simplest and most direct method of applying liquid fuel under existing circumstances, and Mr. Urquhart has been so satisfied with the results that he has not seen any necessity for further experimenting.

CHAPTER XII.

CONCLUSION.

In addition to those that have been adduced in their favour in the preceding pages, the advantages of liquid fuels as compared with coal, especially those that are of weight in connection with modern fast steam men-of-war, may be summed up in the following order :—

(1) The rapidity and cheapness with which they can be brought on board, which, according to Tweddell,* are so great that the steamers of the Caspian can ship from 800 to 1000 tons of fuel in from three to four hours, a period which could be still more reduced if a few arrangements still wanting were introduced. A torpedo boat, therefore, which required at most about twenty tons of liquid fuel could be made ready in a few minutes, and a whole flotilla would require no more time than it takes to coal a single boat at present.

(2) The storage of the oil in such parts of the vessel as are unfit for cargo. Such parts are the water ballast tanks of large cargo-carrying steamers, the double bottoms of ironclads as well as the keel spaces fore and aft of boilers and engines on all steamers. Besides, by filling up these spaces it will become possible to make the engine rooms more convenient and spacious, by reducing the bunkers, especially in the case of smaller vessels.

(3) The diminution of the staff of stokers and of the physical fatigue of stokers. As the oil is sent out of the bunkers into tanks above the furnaces by means of a steam

* 'Journal' of the Royal United Service Institution, May, 1885, p. 698.

pump, from whence it flows of itself into the furnaces, coal trimmers are not required. Besides, only one stoker is wanted for each watch for every furnace on board, who has to regulate the sprinkler taps and see that the water in the boilers is at the right height. Tweddell states that the steamers of the Caspian have usually only one stoker and two boys for each watch. The largest steamers that have communicating furnaces would therefore require no more than one stoker and three or four boys for each watch, and would consequently want no more than three stokers and ten or twelve boys altogether, whereas at present they employ a staff of stokers amounting to from sixty to eighty men, which must cost steamship companies at least 60*l.* per annum per man in wages and keep. What sums steamship companies would save through reducing their stoking staff can be easily calculated. On board torpedo boats one stoker would suffice instead of the two that are the rule now for each watch; and as the stoker will have little physical work to do, the men will keep better health in bad weather, whereas at present it is well known that the leading stokers are the first to get exhausted.

(4) The greater power of evaporation of liquid fuels, which is in the proportion of 7 to 4 to that of coals, enables steamers either to reduce the weight of the fuel they take on board when the same distance is to be steamed as in the case of coal fuel, or else enables steamers to steam a longer distance when the same quantity of liquid fuel is taken as would have been required if coal had been used. A modern torpedo boat, which, for example, at a given speed could go 4000 knots, would, if instead of coal it had the same weight of oil on board, be able to go 7000 knots; and if it filled an equal space with oil as the coals would have occupied, it would be able to go 7500 knots, because one ton of coal occupies 44 cubic feet on board, whereas one ton of oil residuals occupies 39·2 cubic feet. By means of liquid fuel, therefore, the sphere of action of a torpedo boat can be nearly doubled.

(5) The more perfect combustion of liquid fuel prevents

the formation of residuals and smoke. Consequently, ashes and cinders do not occur, and the furnaces need not be cleaned, nor need the flues be swept. The first circumstance is of the greatest importance with regard to torpedo boats, which generally have only one furnace, the grates of which after a six hours' coal-fire, at most after ten, are covered with clinker. It then becomes imperative to clean the grates if the steam pressure and speed are to be kept up. Such a cleaning is not, however, easily accomplished. The grate surface is generally about 6 feet 7 inches square, on which during ten hours about 8 tons of coal have been burned, leaving, even under favourable conditions, at least 175 lbs. to 225 lbs. of clinker. Besides, during the operation of cleaning, the boat must lose a considerable amount of speed owing to arrested evaporation. A further loss of speed is incurred by the attachment of "swallows' nests" (rings) to the mouths of the tubes, and as the grates must be cleared at short intervals—especially if the journey be rapid, for the grates cannot be kept free of clinker—it is clear that a vessel chasing a torpedo boat may easily overtake it without attaining as great a speed as the latter, for her fires can be cleaned at each watch, and she need not therefore lose so much speed. If the torpedo boat, however, should burn liquid fuel instead of coal it can go on for days without rest or loss of speed, and must necessarily distance any larger craft chasing it. But there are two other important factors that have never been taken into consideration. The first is the advantage that is derived from doing away with the very cumbersome and exceedingly filthy process of throwing the ashes and cinders overboard, which is indeed quite impracticable during action; and the second, the immunity from exposure to a singeing of clothes and body by sparks and cinders flying out of the short funnel, when the speed is at all rapid. People who have been any time on board a torpedo boat can scarcely have a very pleasant recollection of their experience. On the other hand, the abolition of smoke is of the greatest tactical importance. The torpedo boat that does not betray itself by a column of smoke is very difficult to discover on the horizon, and will, therefore, have an enormous advantage, as it will itself be able to distinguish all larger vessels by their smoke columns. How these masses of smoke issuing from the chimneys, even though the best coal be used, betray the movements of vessels when a sudden increase of speed is laid on and artificial draught applied, English naval authorities have had brought home to them during the recent naval manœuvres. As, however, a sudden stoppage of the air current will produce enormous dense smoke columns in cases where liquid fuel is used, Captain Curtis, R.N.,* has suggested that this circumstance should be utilised with a view to establishing a code of smoke signals for long distances, on the Morse system.

(6) The improved ventilation of the firing space, which is said to be caused by the admixture of air in the sprinkler, and also by the fewer rays of heat. According to Tweddell,† if one goes below into the engine room when the thermometer is 104° Fah. in the shade, an increase of temperature as compared to that on deck is scarcely noticeable when oil is the fuel ; whereas with the coal fires, with natural draught, the temperature rises under similar conditions to 131° and 149° Fah. Besides, in the former case the stokers need not exert themselves at all, whereas where coals are used they have to work very hard, and must come on deck every few minutes to get a breath of air. For tropical climates, therefore, liquid fuel is strongly to be recommended.

(7) The greater manœuvring capacity of the engines, which is attained by the possibility of suddenly increasing, reducing, or stopping the fire. In the case of coal fires, if it be desired suddenly to shut off the steam, and the safety valve is not to be used, the fire and smoke-box doors have to be opened, and the cold air must be admitted directly into the boiler, which is exceedingly bad for the latter. Further, a considerable time must elapse before a fire thus extinguished can be made

* 'Journal' Royal United Service Institution, May, 1885, p. 696.

† 'Verhandlung des Vereins zur Beförderung des Gewerbfleisses,' 1887, p. 546.

to burn again. But both can be quickly accomplished in the case of sprinklers by simply closing or opening the steam and oil valves.

(8) The longer life of the boilers, which is chiefly to be ascribed to the fact that the fire-doors need only be seldom opened, and consequently the entrance of cold air into the furnace and the resultant cooling of the boiler-plates is completely avoided. It is perhaps of less importance that mineral oils contain no sulphur,* and that consequently the plates of the fire-box are not so severely taxed as in the case of coal, the sulphur of which, owing to the formation of sulphurous acid, acts destructively on the iron.

(9) The ease and exactitude with which the oil can be measured when it is taken on board, as well as when it is being burned, should silence complaints of short weight in coals which one hears so frequently now, and should also insure a better verification of the consumption of fuel during trial. Those advantages, of which 3, 4, and 5, are the most brilliant, must be considered in connection with certain disadvantages which the use of liquid fuel entails, and which cannot be passed over. These are :—

(1) The erection of oil tanks and supply pipes in the place of existing coal stations, so as to insure the rapidity of taking oil on board alluded to above. These oil stations need not be so numerous, however, as the coal stations, because steamers burning oil do not require fuelling so frequently as those that use coal. The cost of erection and maintenance of such stations with good oil-tight iron trucks, with pumping machinery for filling as well as a system of supply pipes for emptying them, by means of which as many vessels may be served at one and the same time as feasible, would probably not exceed the expenditure on coal stations, which must be provided with sheds in good repair, landing jetties, tipping appliances, &c. The staff of workmen, on the other hand, would be remarkably small at an oil station, as compared with the number required at a coal station, for the trans-

* 'Journal' of the Royal United Service Institution, May 1885, p. 697.

mission of oil can be worked mechanically, whereas the transport of coal must of necessity entail a great deal of manual labour. If the tactical advantages of liquid fuel be considered of sufficient importance, the slight additional expenditure in oil stations will not stand in its way.

(2) The loud noise occasioned by sprinklers, which is exceedingly inconvenient in the case of passenger steamers, would be downright fatal for torpedo boats. If it is realised, however, that this noise, according to d'Allest's experiments, resembles strongly that of a large fan, and as the fan engines fitted to torpedo boats which use artificial air currents do not work particularly noiselessly, it will be admitted that the difference is not very great. Besides, a torpedo boat making a night attack would travel very slowly so as to avoid all possible noise, and a sprinkler worked with a pressure of 0·5 atmosphere makes very little noise indeed, according to French experiments; and it is very probable that even this slight noise would be lost in the general noise of the pumps and engines.

(3) The combustibility of oil, which might occasion an explosion in the event of a shell hitting the tanks. This objection may be met by the statement that the oil can be easily stored under the water-line, where it would be comparatively safe; besides which it will yet have to be proved whether oil in a tank is really likely to ignite if pierced by the splinter of a shell. Of course all idea of getting protection out of the oil tanks, as in the case of coal bunkers, must be relinquished; but this sacrifice is not so great as would at first appear. The very thin bunker walls, and the far from thick layer of coal that surround the boiler at present, can scarcely be seriously regarded as much protection against the penetrating power of modern projectiles and shells. Nor should we forget that Admiral Selwyn is not in favour of using oil that has a lower specific gravity than from 1·050 to 1·060, therefore possessing a higher specific gravity than sea water—1·026. The advantages of such oil are self-evident. The dense, heavy oil is less easily ignited, contains no volatile gases, and burns more economically on account of its

density than thin oil, and does not flow off into the sea at once as soon as the tank under water-line has been pierced by a projectile, as is the case with the lighter oils. The remaining oil could in such circumstances be still used for fuel, while the water that had entered through the aperture made by the projectile could be allowed to remain floating on the top; and as it would be lighter than the oil it had replaced, the buoyancy of the vessel would be increased instead of being reduced. A coal bunker that has been riddled must, on the other hand, be instantly shut off; its contents are no longer of any use, and the water that enters it reduces the buoyancy of the vessel.

(4) The very small number of oils which can be used as fuel. If estimated at a maximum, the annual output of all the natural oil of the world amounts to about six millions of tons of mineral oil, three-quarters of a million tons of tar oil, and a quarter of a million tons of slate or shale oil—altogether seven million tons. Modern industry, which transforms these into liquid fuel, lubricating oils, benzol, paraffin, &c., cannot spare them; at most it can leave us about 20 per cent. of the original weight in residuals, which, however, would only represent a fifth part of the fuel required annually by the steam navigation of the world. On the other hand, the latter absorbs about a thirty-third of the annual output of 400 million tons of coal of the world, or 12 million tons.

(5) The enormous cost of liquid fuel at present is, however, the rock on which all attempts at introducing its use more widely in merchant vessels must founder. According to the present prices of coal and oil residuals, the latter, notwithstanding their higher power of evaporation, are about three times as dear as coal. The saving in stokers, the cheapness of loading, and the other enumerated advantages, do not materially alter their proportion. Not until new oilfields have been discovered, cheaper methods of transport introduced, and oil residuals brought down in price to about double that of coal, will it be at all possible for them to compete with the latter in Western Europe. Whether such a competition could last very long even then is very doubtful

in view of the experience we have had in the rise of the price of oil in England as soon as its general adoption for steam propulsion seemed probable, necessitating a return to coal. Of course, the war navies, which are not so dependent on prices as the merchant marine, will reserve their verdict until they see, after the termination of the experiments still going on in England, Russia, and France, whether the much vaunted tactical superiority of oil over coal is justified by the result. Should this be the case, as is probable, these nations, and perhaps the United States, will possibly introduce liquid fuel on their torpedo boats. Further, liquid fuel, if Laval's experiments prove to be practicable, will very probably be adopted for submarine vessels to an important extent; and finally, it is very possible, as indeed has been the case recently in North America, that liquid fuel will find adopters among the proprietors of pleasure yachts, for in all these cases economy is only a secondary consideration.

The question whether the economical interests of Germany would make a more universal adoption of liquid fuel desirable must be answered in the negative. The condition of the very extensive but exceedingly depressed German coal trade would probably become more deplorable if German steamers were all gradually to adopt liquid fuel.

The German navy will have to await the adoption of liquid fuel for torpedo boats in foreign countries without following suit, for the simple reason that native oil, under existing circumstances, could be obtained only at an enormous increase of cost, and in inadequate quantities; and the purchase of oil from foreign countries would involve great expenditure in oil-stations, and would place the Government at the mercy of a foreign Power in the event of war.

Russia and the United States, on the other hand, who are largely blessed with mineral oil, and England, which could easily procure a shale oil at a reasonable price from its own bituminous slate clay, have every reason to seriously consider the adoption of liquid fuel by their navies, especially now that its technical adaptability has been clearly demonstrated. If France should adopt liquid fuel, although it has but a few important oil wells in the Sevennes, near Pezenas, and in the department of Hérault, the reason for this may be found in the fact that the coal seams of France might, in the event of a war, prove inadequate for the demands of her railways and fleet, as the mobilisation of the 17th Army Corps is said to have proved. France would, therefore, be wise to provide an important section of her fleet, the torpedo boats, with furnaces for liquid fuel. From whence the French are going to get their liquid fuel it is impossible to say. In the meantime d'Allest seems to promise us an answer at a future period.

We cannot do better than conclude this treatise by repeating the moderate and pregnant words of Mr. Carew, quoted in our introductory chapter at p. 3: "We must look for the best results from petroleum, both economically and technically, in those uses where the improved product of the manufactured article, more than counterbalances the difference in price of the two kinds of fuel."

APPENDIX I.

Date 1868.	Duration of Experiment.	Total consumption during experiment.		Water at $140\frac{1}{2}^{\circ}$ F. evaporated per 1 lb. of fuel.	Approximate steam consumption of Sprinkler.	Usefully evaporated water per 1 lb. of fuel after deducting 6 per cent. for sprinkler.	Time requisite for opening steam	Fuel requisite for this purpose.	During Experiment.			Fuel used.
		Water.	Fuel.						Smoke.	Ash.	Slack.	
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
	hrs. min.	lb.	lb.	lb.	lb.	lb.	hrs. min.	lbs.		lb.	lb.	
28 April	5 40	4642·7	494·25	9·76	275·58	9·18	1 10	59·95—wood	0	0	0	Tar oil.
29 April	5 55	3869·9	549·85	7·31	..	6·87	1 2	55·98—coal	very clear	104·03	14·105	Welsh coal.
4 May	7 40	3869·9	422·18	9·52	233·84	8·95	1 15	59·95—wood	0	0	0	Tar oil.
6 May	3 30	2824	313·91	9·36	169·47	8·78	1 9	55·98—wood	0	0	0	Tar oil.
11 May	6 47	5416·3	530·33	10·51	324·37	9·88	1 30	40·99—wood	0	0	0	Tar oil.
14 May	7 40	5416·3	759·78	7·40	..	6·96	1 10	40·99—coal	very clear	119·9	14·99	Welsh coal.

APPENDIX II.

Experiments.			Consumption of fuel.			Water evaporated.					Temperature.				Wind pressure.			
Manner and year in which conducted.	Number of	Duration of	Total consumption.	Per hour.	Per 1 sq. yard of grate surface per hour.	Total.	Per hour.	Per 1 sq. yard of heating surface per hour.	Per 1 lb. of fuel.	Per 1 lb. of fuel calculated on water at 212° F.	Of the feed water.	In the smoke chamber.	In the heating space.	Boiler pressure.	In supply channel inches of water column.	In the fire-pipes inches of water columns.	Quantity of air for 1 lb. of fuel.	Remarks.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
		Hrs. Min.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	°	°	°	lb. sq. in.			cub. ft.	
d'Allest oil residuals with natural draught, 1887.	1	4 15	573·68	134·97	128·22	6832·4	1606·7	68·9	11·90	13·81	73·4	..	..	39·66	..	..	..	1 lb. of oil evaporated on the average 11·83 lbs. of feed-water, or 13·65 lbs. of water at 212° Fahr.
	2	4 10	464·01	110·25	105·79	5950·8	1428·1	61·24	12·82	14·85	75·2	..	..	39·66	..	..	..	
	3	3 58	534·18	134·66	127·92	6391·6	1611·1	69·07	11·96	13·77	82·4	..	..	39·66	..	..	..	
	4	3 06	404·96	130·63	124·11	4628·4	1492·2	63·96	11·42	13·15	82·4	..	..	39·66	..	..	..	
	5	5 20	624·30	117·05	111·21	7493·6	1403·9	60·19	11·99	13·83	80·6	..	..	39·66	..	..	..	
	6	6 28	843·65	130·45	123·92	9752·7	1507·5	64·63	11·55	13·30	82·4	..	..	39·66	..	..	..	
	7	4 00	539·98	134·99	128·25	6171·2	1542·8	66·14	11·42	13·15	82·4	..	..	39·66	..	..	..	
	8	4 36	590·56	128·38	121·97	6832·4	1483·3	65·69	11·55	13·32	80·6	..	..	39·66	..	..	..	
	9	2 07	236·22	111·59	106·01	2865·2	1353·3	58·02	12·12	13·98	80·6	..	..	39·66	..	..	..	
	10	5 20	742·42	139·20	132·25	8595·6	1611·1	69·07	11·57	13·32	82·4	..	..	39·66	..	..	..	
d'Allest oil residuals with forced draught, 1887.	1	1 30	471·48	314·31	681·12	4848·8	3226·6	134·91	10·27	12·01	60·8	662	..	39·66	1·77	0·39	..	1 lb. of oil evaporated on the average 11·33 lbs. of feed-water, or 13·25 lbs. of water at 212°.
	2	4 30	1341·00	298·00	655·05	15690	3486·7	145·78	11·70	13·68	64·4	575½	..	39·66	1·65	0·31	..	
	3	6 00	1729·43	286·92	634·29	20788	3464·7	144·86	12·02	14·06	62·6	716	..	39·66	1·77	0·31	..	
Guillaume Anzin briquettes with forced draught, 1885.	1	5 00	14568·00	2913·69	369·82	121645	24329	67·08	8·35	9·85	66·2	824	82·95	79·98	0·79	0·06	343·63	1 lb. of briquettes evaporated on the average 8·06 lbs. of feed-water, or 9·28 lbs. of water at 212°.
	2	5 00	181499·40	3629·99	460·75	150280	30056	82·89	8·28	9·77	73·4	915·8	93·2	79·98	1·00	0·23	363·76	
	3	4 35	19864·65	4334·16	550·13	154547	33717	92·99	7·78	..	73·4	897·8	..	78·13	2·61	..	399·1	
	4	5 03	21995·92	4355·95	552·90	173562	34369	94·97	7·89	9·47	52·7	975·2	78·8	79·58	2·70	0·344	362·7	
	5	5 15	23869·32	4357·97	557·55	183721	34994	96·45	8·03	9·64	51·8	957·2	73·4	79·45	2·55	0·34	340·45	
Thornycroft Nixon's navigation coals with forced draught, 1880.	1	2 00	1833·74	916·86	436·79	12969	6479·7	94·36	7·06	8·21	53·6	1072·4	75·02	108·4	1·97	1·33	..	1 lb. of coal evaporated on the average 6·32 lbs. of feed-water, or 7·54 lbs. of water at 212°.
	2	2 07	2468·48	1165·92	556·59	16310	7705·2	110·58	6·60	7·65	57·2	1191·2	85·1	108·4	2·95	1·84	..	
	3	1 30	2188·57	1459·45	696·65	10566	7444	134·72	6·33	7·36	53·6	1259·6	77·9	106·68	3·94	2·95	..	
	4	1 27	2607·33	1801·73	858·84	15479	10751	156 47	5·97	6·93	55·95	1443·2	81·86	106·68	5·90	4·26	..	

INDEX.

ERRATA.

Page 76, line 18 from top, after "water" insert an asterisk, and at the bottom of the page the following footnote: "See Appendix II."

Pages 76 and 77, *for* "Thorneycroft" *read* "Thornycroft."

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