THE CONNECTICUT CHARCOAL KILN

CONNECTICUT AGRICULTURAL EXPERIMENT STATION

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This bulletin supersedes Station Bulletin 494, "A Charcoal Kiln Made of Cinder-Concrete Blocks", which was published in February, 1946. The issue of the latter was exhausted early in 1948. This publication contains essentially the same information as that in Bulletin 494, together with certain additional features based on experiments performed and observations made on kilns in use during the last two years.

Front view of two-cord kiln with the chimney in place and the stove banked with earth except at the front end.

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by

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PRINCIPLES OF CARBONIZATION

The art of making charcoal is a very old one and has been practiced in many parts of the world since long before the Christian era. The basic principle underlying the process is that of incomplete combustion. When wood is heated to a temperature of about 250° C. (482° F.) or higher, it quickly decomposes to form gases, vapors and solids. If heating takes place in the presence of sufficient air, combustion is complete or nearly so and the only residue is ash. If, however, the air supply to the heated wood is restricted, combustion is incomplete, the volatile elements are driven off as "smoke" and charcoal and ash remain as solid residues.

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The smoke formed under conditions of incomplete combustion is made up of a number of non-condensable gases and condensable vapors. The principal gases emitted are carbon monoxide, hydrogen, methane, carbon dioxide, oxygen and nitrogen. The first three are combustible and may be recovered and burned to produce heat or light. The vapors are water, acids, alcohols, tars, oils and other organic compounds. After removal of water, the other vapors may be condensed, separated and refined for industrial use or may be used as fuel. Well-burned charcoal contains from 75 to 95 per cent carbon plus a small amount of ash made from the inorganic minerals in the wood. The wood from which it is derived contains about 50 per cent carbon.

Since carbonization is based on limiting the air supply to the wood while it is being heated, it is understandable why a great many devices have been developed throughout the ages for accomplishing it. Wood has been carbonized in pits dug in the ground, in heaps covered with sod and earth, and in masonry and steel structures. The quantity carbonized in one operation has varied from less than one cord to more than 100 cords.

It is beyond the scope of this paper to discuss the many types of carbonizing apparatus which have been developed. However, a general classification based on four methods of carbonization which cover most conditions, is given to show the relationship of the kilns described in this paper to other types of apparatus. The methods are as follows:

(a) Carbonization by the admission of air to the wood. Initially, a portion of the wood is subjected to free burning with excess air to raise it to carbonizing temperature. The air supply is then restricted and so regulated that carbonization progresses through the wood mass in response to the air supply until all is reduced to charcoal.

(b) Carbonization by circulating hot furnace gases through the wood mass. These gases, which contain only a small amount of oxygen, are generated outside the carbonizing equipment, usually by burning waste wood. Control of the operation is somewhat better than in (a), but the structure is more complicated.

(c) Carbonization by applying heat to the outside of air-tight chambers in which the wood is enclosed and to which neither air nor furnace gases are admitted.

(d) Carbonization in heavily insulated chambers, in which the raw wood is passed continuously through an "exothermic" zone (Badger-Stafford Process).

The apparatus used for methods (a) and (b) is generally called a kiln. It is usually operated primarily for the production of charcoal, although some of the volatile elements may also be recovered. The wood is in the form of sticks or billets. The apparatus used for methods (c) and (d) is generally called a retort or oven. Its primary function is the recovery of condensable acids, alcohols, tars, etc., charcoal production being of secondary importance. The wood may be in the form of billets or in more finely divided forms such as sawdust, chips and hogged wood.

There are some types of apparatus that employ more than one of the methods described above and other types which cannot be categorically fitted into the above classification.

HISTORICAL REVIEW

The following brief historical sketch is presented to give perspective on the Station's work with small kilns. In post-colonial days charcoal was made almost wholly for local markets in "sod" or "pit" kilns and, in spite of intense competition from more refined equipment, much charcoal is still produced in this way. Only native materials are needed to construct sod or pit kilns but a great deal of skill and attention are required to assemble these materials and to coal the wood. Recovery of volatile products is seldom attempted.

During the early development of the iron resources in the Lake States region, vast amounts of charcoal were needed for smelting. Much of this was made in brick beehive kilns of large capacity. These were a marked improvement over the sod kilns but they also required an experienced operator. While charcoal was the principal product, methanol and other condensable elements were recovered in some cases. With the substitution of coal for charcoal in smelting this great market for charcoal was lost.

The expanding wood-distillation industry, which operated primarily for the recovery of methanol, acetic acid, acetone and other products, made charcoal as a secondary product. Since charcoal made in beehive kilns ordinarily could not compete in price with that made as a by-product of wood distillation, many operators of such kilns were forced out of business.

Between World War I and World War II chemical research resulted in methods of manufacturing methanol, acetic acid and acetone commercially from materials other than wood. With such methods no charcoal is produced. These developments have been countered to some extent in the wood-distillation industry by the adoption of greatly improved techniques of making and refining the primary products.

During World War II the great demand for charcoal and other products of wood carbonization brought all types of carbonizing apparatus back into the picture. For the future, economics will determine whether methanol, acetic acid and acetone will be derived from wood or from other materials. If from the latter, some means must be provided to furnish the charcoal which is so essential in many industries. Retorts require a heavy capital investment and it seems doubtful if they could be operated solely for charcoal production. Large beehive kilns, while less expensive than retorts, are also costly. Moreover, they require a highly skilled operator to obtain good and uniform production. The necessary investment in retorts and large kilns can only be justified where an assured supply of inexpensive wood is available. Such conditions are to be found in relatively few areas in the United States.

It would appear, therefore, that there is a place for a small kiln which is inexpensive to build, easy to operate and which can be readily moved from place to place to coal small lots of wood, thus reducing the cost of handling and transportation.

Over a period of 10 years the Station's efforts have been centered on the development of such a kiln. Station Bulletin 448[1] describes two rectangular kilns, formed of steel panels, which were the result of early investigations. The smaller kiln was quite satisfactory and accomplished most of the objectives sought when used with seasoned or semi-seasoned hardwoods. With unseasoned hardwoods, the yield was only fair. With unseasoned conifers, the results were unsatisfactory, apparently due to a combination of high wood-moisture content and excessive heat losses through the metal shell. The larger kiln gave about the same results, but was somewhat more difficult to operate because it was too wide.

Subsequently, other construction materials were investigated and, after some tests, cinder-concrete blocks were chosen as the most feasible. Later use demonstrated that the blocks were entirely satisfactory.

The balance of this report is devoted to a description of the construction and operation of kilns built of this material. Some features, not found in the steel kilns, are incorporated in the design of the new apparatus. The yield of charcoal from the latter is higher than from the steel kilns and operation is easier. The cost of a cinder-concrete kiln is much less than that of a steel kiln of equal capacity. Wood of any moisture content can be coaled successfully, but the yield from wood with a moisture content in excess of about 80 per cent (oven dry basis) is low. The cinder-concrete kiln is not portable in the same sense as the steel panel kiln but, if properly assembled, it can be easily dismantled and rebuilt at a new site.

THE CINDER BLOCK KILNS

Kilns of one-cord and two-cord capacity have been built and operated experimentally by the Station. Both are of the chimney type, i.e., all the smoke is drawn out through one opening, and both are designed for four-foot wood. The one-cord kiln (net capacity 1.1 cords) houses a 4 x 4½ x 8 foot pile of wood with the necessary allowance for clearance and for air and smoke passages. The two-cord kiln (net capacity 1.9 cords) is 16 inches higher and 32 inches longer than the one-cord kiln. The design of both kilns is such that, if the coaling operation is started at the proper time, all labor operations can be performed during the usual daylight working hours. Detailed instructions are given for the building and operation of these kilns. In a separate section some information is also presented on kilns of the same general design, but of larger capacity.

Materials of Construction

The materials needed for construction of the one-cord and two-cord kilns, as shown in the diagrams (pages 32 to 37), are cinder-concrete blocks, sand, cement, lime, a small amount of steel plate, furnace flue pipe, new or used iron or steel pipe and a few miscellaneous items. These materials are later listed under Bill of Materials on page 31. The number of cinder blocks listed includes the actual number needed to construct that portion of the

[1] A Portable Charcoal Kiln Using the Chimney Principle. October, 1941.

chamber, including the parapet, which is above ground line, to build all of the chimney stove, and to line the trench within the chamber. Any other blocks suggested for the foundations will be in addition to those listed. For certain parts of the kilns alternative materials are suggested but are not included in the Bill of Materials.

Cinder-concrete blocks are fabricated from screened cinders and a fast-setting cement, according to A. S. T. M. specification #C-90-44. They are a standard building material with sufficient strength and adequate heat resistance for kiln construction. Blocks of the same type, made by different manufacturers, will vary somewhat in dimensions, contour, and number and position of the holes. The cost will vary with the locality and the distance from the source of manufacture.

Five stock sizes of blocks, all of the hollow type, are used. All of these are shown in Figure 4C, except the 6 x 8 x 16 inch parapet blocks. Standard 8 x 8 x 16 inch blocks are used for most of the construction. Two sizes of pier blocks (both ends square), 8 x 8 x 16 inches and 8 x 8 x 8 inches, are used to turn corners and to face the doorway at the rear end. The door is laid up with 8 x 8 x 16 inch pier blocks. The top is formed of 4 x 8 x 16 inch partition blocks. The sizes given are nominal and allow for a ¼ inch mortar joint. The kilns are so designed that they may be assembled almost entirely of whole blocks and, for this reason, the measurements on the sketches are also nominal and will vary somewhat with the actual dimensions of the blocks and the thickness of the mortar joints.

The arrangement of the several parts of a kiln are of more importance than the material used in its construction. If steel, brick, field stone or concrete can be assembled into a leak proof unit more cheaply than can cinder blocks, there is no reason why such material should not be used. If unseasoned wood is to be coaled, steel is not satisfactory unless it is insulated.

KILN CONSTRUCTION

The kilns, exclusive of the foundations which are not shown except in Figures 3A and 3B, are made up of three parts: a coaling chamber, a chimney and a chimney stove. The chamber houses the wood during carbonization. The chimney, which connects with both chamber and stove, maintains a draft while the wood charge is being raised to coaling temperature and acts as a smoke outlet during coaling. The stove abuts on the wall at the front end of the coaling chamber but is not bonded to this wall. In it wood is burned to induce draft in the chimney.

The materials may be assembled into a kiln with ordinary labor and without special tools. The time of assembly will vary with the type of foundation but, exclusive of the foundations, two men should be able to build the one-cord kiln in about two days and the two-cord kiln in three days.

Kiln Site and Foundation

The kiln should be set up on a well-drained site which is fairly level. The floor of the kiln is of native earth which may be covered to a depth of several inches with coarse sand or cinders if desired.

A level surface on which to start laying the cinder blocks is essential. If the kiln is to stand on a location less than two years, a wood foundation will be adequate. This may be made in the form of a frame of any wood available. The frame members should be 8 inches wide (the width of a block) and about 6 inches deep. They may be 6 x 8 inch sawed timbers or they may be built up of any used lumber which is 8 inches wide and 1 inch or more in thickness. Alternatively, the frame may be made of round timbers which have been hewed or sawed on one side to provide a flat bearing surface 8 inches wide. The frame should be assembled above ground and sunk in a trench with the bearing surface level and 8 inches below ground line. The corners should be square and the outside dimensions of the frame should be the same as the outside dimensions of the kiln. One extra tier of 8 x 8 x 16 inch standard blocks (not included in the Bill of Materials) will be needed above the timber frame to bring the foundations up to ground line (Figure 3A).

If the set is to be permanent, a more stable foundation should be provided. This may be done by digging a trench 8 inches wide and 2 feet or more deep and filling to ground level with field stone. A concrete mix should be floated on top of the field stone to provide a level bearing surface 8 inches wide (Figure 3B). It will be noted in Figure 3A that there is a hole in the foundation directly beneath the center of the front wall. This hole, which is 12 inches wide and 8 inches deep, is the smoke outlet from the chamber to the chimney. It should be provided for regardless of the type of foundation used.

An alternative method of making a permanent foundation is to use extra blocks instead of field stone below the ground line. These may be laid without mortar. No foundation is needed under the chimney stove.

Since it is below ground line, the "trench" shown in Figures 1A and 1C may be considered a part of the foundation. This trench is an extension of the smoke outlet through the foundation into the chamber. It is 16 inches long and 12 inches wide. It is formed by excavating the kiln floor to a depth of 8 inches directly in back of the smoke outlet and lining the excavation with three blocks marked X, Figure 1C. The tops of these blocks are level with the top of the foundation, i. e., they are at ground line.

Building the Coaling Chamber (for four foot wood)

After completing the foundation, the next step is to lay up the walls of the coaling chamber. The blocks are laid with mortar. If the structure is to be permanent, the mortar may be of cement, lime and sand. If, however, it is to be taken down and re-assembled at another place, the mortar should contain only lime and sand. After assembling, the interior surfaces of the walls should be given one or more brush coats of lime mortar of a creamy consistency to seal the pores in the blocks and any small leaks.

It will be noted in Figure 2B that a part of the rear wall of the chamber is cross-hatched. This is the door, to form which the blocks are laid individually *without mortar* after the kiln is loaded.

The over-all width of both the one-cord and two-cord chambers is the same, 4½ standard block lengths, nominally 72 inches. The height of the one-cord chamber is the sum of the heights of eight standard blocks, nominally 64 inches; that of the two-cord kiln is the sum of the heights of 10 such blocks, nominally 80 inches. The over-all length of the one-cord chamber is the sum of the lengths of seven standard blocks, nominally 112 inches; that of the two-cord chamber is the sum of the lengths of nine standard blocks, nominally 144 inches. The walls are eight inches thick. Unless otherwise noted, all blocks in the wall are laid with the holes vertical.

It is very important that the first tier of blocks in the chamber walls be laid carefully. If this is done, the balance of the walls can be laid without cutting blocks and with joints perfectly broken except for two instances which will be noted later. The following suggestions are made on the assumption that a ¼ inch mortar joint will be used between blocks.

Begin at the rear end by laying up the lower five blocks (all 8 x 8 x 16 inch pier) of the door as shown in Figure 2B. This unit of blocks will occupy a space 40 inches wide, 16 inches high and 8 inches thick. Center this unit over the center of the foundation. Now lay all blocks in the first tier without mortar, spacing them ¼ inch apart and proceeding as follows: Place pier block A (Figures 2A and 2B), allowing ¼ inch between it and the adjacent door block. Place pier block B, spacing it ¼ inch from its adjacent door block. Place pier block C on its side (with holes horizontal) to form "Air Inlet B". Place half block D. Place either three or five standard blocks E, depending on whether the chamber is for one or two cords. Place half block F. Place pier block G on its side to form "Air Inlet A". Place half block H. This completes one side.

Beginning adjacent to block A on the other side (Figure 2A), place pier block N on its side to form second "Air Inlet B". Place four or six standard blocks M, depending on whether the chamber is for one or two cords. Place pier block K on its side to form second "Air Inlet A". Place standard block J to turn the corner. This completes the second side.

To complete the front end (see Figure 3A), plug the holes in pier block X with mortar, lay it on its side and center it over the smoke passage in the foundation. Place standard block O. Lastly, fill the two spaces marked Y either with cut blocks or with brick, mortar or any other materials available.

This completes the initial laying of blocks in the first tier. The next step should be to line up the blocks, square the corners of the wall and then cement the blocks to each other and to the foundation with mortar. The holes, which are nearest the end wall in pier blocks C, G, N and K, serve as air inlets at each corner. The other hole (or holes, if the block has more than two) should be plugged. This is most easily done before these blocks are cemented in place. Before laying in mortar, it is desirable to check the position of all blocks in the tier and also to see that the over-all dimensions are approximately those shown on the sketches.

If the first tier is laid as indicated above, all succeeding tiers can be laid without cutting blocks and with perfect breaking of the joints except in Tier 2 near the two air inlets (Figure 2B). As the tiers are laid up, the holes in the blocks should be filled with fine sand.

It may be well at this time to emphasize the fact that the purpose of the sand, which is used to fill the holes in the blocks as the walls are built up, is to provide an additional seal against air leaks. When the kiln is operated, the sand dries out and settles, and for a time *it will be necessary to replenish the supply.* After a few burns, the sand will cease to settle.

After the walls have been completed as indicated, an additional tier of 6 x 8 x 16 inch blocks should be laid on top of them to form a parapet. The 8 inch faces of the parapet blocks should be laid flush with the outer walls. The parapet (not shown in the drawings) serves to hold the pipes supporting the roof in place and to keep the sand (or soil), used to seal the roof, from blowing away.

Since the blocks in the door are not locked to the rest of the structure, a tie rod should be provided to keep the side walls from spreading when heated. This is accomplished by spiking two pieces of 2 x 8 inch plank, 3 feet long, to the side walls as shown in Figure 3B, allowing them to extend about 6 inches. The tie, which may be either a threaded ¾ inch rod or two ¾ inch eye bolts connected by a chain, passes through holes or slots in the protruding ends of the planks. After the door blocks are in place, the nuts on the tie should be drawn snug but should not be forced enough to crack the side walls.

If it is so desired, a door frame and door may be fabricated out of angle iron and a steel plate. The latter should be sufficiently reinforced to keep it from warping when heated. A steel door can be taken down and replaced more quickly than the blocks, but it will be more costly and it also presents the problem of unequal expansion between metal and the adjacent wall blocks. Moreover, it will not have the insulating properties of the cinder blocks.

Under some operating conditions, it may be desirable to place the door opening in the middle of one side instead of at the end. If this is done, it will be necessary to provide a lintel to span the top of the doorway and to support the section of roof adjacent to it.

Modified Chambers for Five Foot Wood

The inside width of the chambers shown in the several sketches is 56 inches. This will accommodate 4 foot wood with 8 inches clearance. Should the builder wish to use 5 foot instead of 4 foot wood, he may do so by increasing the outside width from 72 to 80 inches (the length of 5 instead of 4½ blocks). This will result in an inside width of 64 inches and a clearance of 4 inches. This smaller clearance will require a little more care in cutting the 5 foot wood. No sketches are included for a kiln of increased width, but a careful study of the drawings will indicate how the change may be made. The smoke passage should be centered on the new width. The doorway should be increased in width to 48 inches. The air inlets should be in the same relative positions as in the drawings.

It is suggested that the first tier be started by centering a block (with holes horizontal) over the smoke passage in the foundation. Two whole blocks laid on either side of the center block will complete the first tier at the front end. The sides are then filled in and the back end turned to form the doorway, using uncut standard and pier blocks. The four side blocks in this tier which lie nearest to the end walls are turned on their sides to form air inlets as previously described. The second tier can then be laid upon the first, using uncut standard, pier and half blocks, and all joints will break perfectly. Except for the fact that no provision need be made for air inlets, the third and succeeding odd tiers are exact replicates of the first tier; the fourth and succeeding even tiers are exact replicates of the second tier. The position and type of blocks in the same tier, but on opposite sides, are identical.

The modification of the kilns as described above will not appreciably change the operations schedules given in Tables 1 and 2.

Building the Top

The top or roof of the kiln is formed of 4 x 8 x 16 inch partition blocks and 60-inch lengths of 1¼ inch iron or steel pipe. The two outside holes in the blocks are reamed out and seven blocks are threaded on two lengths of pipe to form a panel 16 inches wide and approximately 56 inches long. To assemble a panel, place seven[1] blocks, side by side, on a plank laid across the side walls, push the two pipes through the reamed holes and then slide the whole panel into place with the pipe ends resting on the side walls. This will be found much easier than assembling on the ground and lifting into place. The center block in the front panel (labeled "Inspection Block" in Figure 2B) rests on top of the pipes and is easily removed. This block serves several purposes. It may be removed for inspection while the kiln is in operation. It should be removed before the kiln is opened after cooling to make sure there is no fire in the charcoal. It should be left off while discharging charcoal to provide ventilation.

Reaming out the holes is a rather tedious job. However, the work can be greatly facilitated by use of a tool made by filing saw teeth in one end of a piece of 1½ inch iron pipe, 18 inches long. To ream the holes, place the block on the ground (not on a hard surface), start the tool at the small end of the hole in the block and continue reaming by striking the end of the tool lightly with a hammer. The tool should be rotated slightly after each blow. Somewhat less reaming will be required if three pieces of 1 inch pipe are substituted for two pieces of 1¼ inch pipe in each panel.

After all the panels are in position, the blocks should be spaced evenly on the pipes. Their top surfaces should then be plastered with a 1 inch coat of lime mortar, over which is placed a 2 to 3 inch layer of sand or soil to provide an additional seal.

A top so constructed will bear the weight of two or three men. However, it is advisable to lay two planks lengthwise of the kiln on top of the sand to serve as a cat walk. This will distribute any moving loads more evenly and prevent failures which might occur from local overloading.

[1] If the top is for a chamber to house five foot wood, eight blocks will be needed for each panel.

As a substitute for the 4 x 8 x 16 inch partition blocks, 20 or 22 gauge sheet metal may be used for the roof. The sheets may be of any size convenient to handle and, if sufficient overlap is allowed, they need not be welded. The edges of all sheets should be well weighted down to prevent warping and leakage. Sheet metal permits the use of pipe of larger diameter for supports than would be possible if the blocks were "threaded" on pipe as described above.

Completing the Chamber for Operation

To complete the chamber for operation it will be necessary to drill holes for the firing ports in each side wall just above ground line, and to provide means of reducing the size of the holes in Blocks C, G, N and K (see Figures 2A and 2B) to conform to the size of opening specified in Tables 1 and 2.

The ports are drilled just large enough to accommodate a piece of 1½ inch pipe, 9 inches long, which is cemented in place. The position of the ports relative to the ends of the kiln is shown in Figures 2A and 2B.

Figure 6A shows a method of reducing the size of the core opening in Block K (for location of which see Figure 2A) to a specified size. Cement the 4 inch faces of two common red bricks, a and b, to Cinder Blocks J and K. The tops of the bricks should be level with the top of the opening in Block K and the distance between them should be great enough so that Brick c, which is placed with its edge against Block K, can be moved up or down to vary the size of the opening, z, as desired. Brick c is held in position by banking soil around its base.

Figure 6B, which represents a vertical section through x-x (Figure 6A), but with Bricks a and b not shown, indicates a method of making an automatic air-inlet closer. A piece of light sheet metal (r), bent to a right angle, is attached to the cinder block wall by a hinge as indicated. While the kiln is coaling, the closer is propped in an open position with a long, thin piece of wood (q) as shown. When coaling has progressed to a point where glowing occurs near the inlet, stick (q) will burn off, permitting the closer to drop down over the inlet. Closure will not be complete. However, sufficient air will be shut off so that an excessive amount of charcoal will not be burned should the operator not be on hand to bank the inlet as soon as the charcoal begins to glow. The outer edge of the metal closer should be weighted.

A very desirable adjunct to a kiln is an "A" roof made out of light sheet metal which will shed water during heavy rain or snowstorms. It is suggested that this auxiliary roof be made in sections so that it may be easily removed to allow ready performance of any repairs to the top that may be necessary.

Building the Chimney Stove

The chimney stove is a rectangular box which abuts the front end of the chamber and whose interior dimensions are length, 48 inches; depth, 16 inches, and width, 12 inches. It will be noted from Figure 2A that one half its depth is below ground line. It is divided into two unequal parts by a baffle. The front part serves as a fuel chamber where fire is maintained during part of the burn to induce chimney draft. The back part forms a connecting passage between the smoke outlet under the chamber wall and the chimney. See Figures 1A, 1C and 4B.

The upper block in the front wall is removable for fueling the stove, and air is admitted through a hole dug under the lower block in the same wall to maintain fire.

The top of the chimney stove is made up of four 4 x 8 x 16 inch cinder blocks and a piece of sheet steel, ¼ x 20 x 32 inches, in which a hole is cut to admit 8 inch furnace flue pipe. The top of the chimney should extend 10 inches above the coaling chamber walls, regardless of the height of these walls. When the burn is in progress, the chimney pipe sets over the hole in the steel plate. To prevent the chimney from sliding through the plate, cut three pairs of slits, about 1 inch long, in the lower end of the pipe parallel to its axis. The slits making up a pair should be about 1 inch apart and the pairs should be spaced about equally around the perimeter of the pipe. After cutting, bend the 1 inch pieces outward at right angles to form "ears" which will rest on the plate and prevent the chimney from sliding through the plate. A piece of ⅛ x ½ inch strap iron, nailed to the front wall of the chamber (Figure 3A), will hold the chimney in a vertical position. Since the chimney is removed during the cooling period, it should not be permanently fastened to the bracing iron. When the chimney is not in place, the hole in the steel plate may be covered by any small metal plate that will span the gap. To prevent leaks, the entire stove, except the front end, is covered with sand or soil (see page 3).

KILN OPERATION

Process of Coaling

In kilns operated by the admission of air, the process of coaling is a progressive one. It consists in first bringing a relatively small portion of the charge up to charring temperature by direct firing. This results in the initiation of a "coaling zone" which then moves through the wood mass in response to air admitted to the kiln. This start of a coaling zone is always at some point near the top of the kiln. The shape of the zone will vary with the shape of the kiln and its direction of movement will always be toward the source of air supply. In kilns of rectangular shape, the coaling zone (or zones) has the shape of a thin bent plane. If fired near the middle, as in the kilns herein described, two such coaling zones are developed. Movement of these is outward toward the ends of the kiln and also downward toward the air inlets. The two pairs of solid lines marked "1" in Figure 4A indicate the relative positions of the two coaling zones in a two-cord kiln after several hours of operation. Coaling started at point X directly above the firing ports. Later the zones moved farther away from each other. Successive positions of the two zones during the burn are marked 2, 3, etc.

The coaling zones are only a few inches thick and, for that reason, the amount of wood actually being charred at any one time is a relatively small percentage of the whole charge. Ahead of the zone, as it moves, is uncharred wood; behind it is charcoal, which occupies a little more than half the space originally occupied by the wood.

The objective sought in coaling is to have the two zones approach the forward and rear air inlets at approximately the same time, leaving an even bed of charcoal the entire length of the kiln. This is accomplished by regulating the amount of air admitted at these inlets. To compensate for the chimney being located at one end, the firing ports are off center, fore and aft. Since the volume of wood aft of the firing ports is less than that forward, the rear (B) air inlets are regulated to admit less air than the front (A) air inlets. The rate of coaling for the charge as a whole is governed by the amount of chimney draft.

Loading

In loading the kiln the following points should always be observed:

(a) Stringers should be laid on the floor to permit free circulation of air underneath the charge (See Figure 4B).

(b) Provision should be made for an unobstructed smoke passage down the front (chimney end) wall and out the smoke outlet. This may be accomplished by the use of struts (Figure 4B) or by piling the wood as will be described later.

(c) The wood should be packed as closely as possible to allow a minimum of air space.

(d) Care should be taken to see that the air inlets do not become blocked with wood or with bark and other refuse while loading.

Loading will be described for two types of wood as follows:

(a) For 4 foot or 5 foot cordwood or slabs.

(b) For pieces of wood up to 16 inches long, either cut-up cordwood or other short pieces of various kinds. The latter should be air-seasoned and not kiln-dried.

Prior to loading, 4 foot or 5 foot cordwood or slabs should be rough-graded into three sizes and used as follows:

(a) Small, including sticks 2 to 3 inches in diameter, *which should always be piled just above the stringers to a depth of a foot or more* (see Figure 4B). *The placing of small wood in this zone is highly important regardless of the size of kiln or the method of piling employed.*

(b) Medium, including sticks 4 to 5 inches in diameter, which may be used anywhere in the kiln, except where small wood is specified.

(c) Large, including sticks 6 inches and over in diameter, which should be placed above the middle of the kiln and near the end walls. All sticks over 7 inches in diameter should be split.

The following suggestions for piling wood in the kiln apply specifically to the one-cord and two-cord kilns as shown in Figures 2A and 2B. Although the above kilns, with chambers increased in width to 64 inches, inside, to take 5 foot wood, crosswise, are of somewhat greater capacity (1.5 and 2.4 cords, respectively) they are still classed as one-cord and two-cord kilns as far as piling is concerned.

Cross-piling, as shown in Figure 4B, is the only feasible piling method for the one-cord kiln regardless of the width of chamber or whether the wood is 4 feet or 5 feet long. It is also the only feasible method with the two-cord kiln when 5 foot wood is to be coaled.

In the two-cord kiln with a chamber 56 inches wide, inside, 4 foot wood may all be piled crosswise (Figure 4B) or a part of it may be piled lengthwise of the kiln and a part of it crosswise as described below. Regardless of how the wood may be piled elsewhere in a kiln, piling should be *crosswise* between the firing ports and in the zone immediately above them.

Loading 4 foot or 5 foot sticks by either piling method is begun by laying two wooden stringers, 4 inches in diameter, on the floor of the kiln, parallel to the side walls and about 18 inches from them. These stringers are discontinuous in front of the firing ports (Figure 4B). Stand a 16 x 20 inch piece of heavy (12 gauge) hardware cloth, with ½ inch mesh, slantwise against the front wall to prevent falling charcoal from blocking the smoke outlet.

In all-crosswise piling, as illustrated in Figure 4B, proceed as follows: Stand two struts against the wall at the chimney end. Start piling against these struts and pile upward and toward the firing ports. When the latter are reached, lay oil-soaked rags and kindling between them and, immediately above the kindling, pile brands, dry wood and small wood to a depth of about three feet. Then continue piling toward the top and the doorway using the sizes of wood suggested above for different sections of the kiln. Crosswise piling to *heights greater than 7 feet is not advisable* because the wood may slide and injure the loader.

If part of the wood is to be piled lengthwise, proceed as follows:

(a) Lay the stringers as described for all-crosswise piling.

(b) Beginning 6 inches from the front (chimney end) wall, place several layers of *small diameter* wood on the stringers and at right angles to them. This layer should "floor" the stringers and be continuous except for the narrow zone reserved for kindling between the firing ports.

(c) On top of the "floor" at the chimney end, lay up Pile 1 (Figure 5A) with the sticks laid lengthwise of the kiln and the pile extending from side-wall to side-wall, *but be sure to leave four inches between the ends of the sticks and the front wall for a smoke passage.*

(d) Place oil-soaked rags and kindling between the firing ports. Above the kindling build up Pile 2 *to a depth of about 4 feet with brands, dry wood and small wood laid crosswise.*

(e) Lay up Pile 3 to a depth of about 2 feet with the sticks lengthwise as in Pile 1 and their outer ends flush with the inner face of the doorway.

(f) Continue loading by laying up Pile 2 and Pile 3 simultaneously until the top is reached.

Care should be taken to maintain as close contact as possible between the crosswise pile in the middle of the kiln and the lengthwise piles adjacent to it.

Loading of wood of cordwood length will be greatly facilitated, if it can be brought to the door, or even part way into the kiln, on a "dolly".

If sticks of shorter length (up to 16 inches) are to be used they may be thrown into the kiln without piling. It will be necessary to face the struts and surface the stringers with slabs, longer wood, or old boards, spaced 1 to 2 inches apart, to prevent the thrown pieces from blocking the air passages. Next place oil-soaked rags and kindling between the firing ports and, immediately above them, pile brands and small pieces of dry wood to a depth of about 3 feet. The remainder of the charge is thrown in at random.

Thrown wood will have more voids than if regularly piled and will, consequently, yield less charcoal per kiln. It is believed that there should not be too great variation in the size and shape of the pieces used in any one charge; for instance, slender edging pieces and short heavy blocks. Short length material lends itself to movement by conveyor and, with some modification, the kiln could be loaded through a hole in the roof.

When charging is completed, lay the door blocks in position without mortar as shown in Figure 2B. Point up the joints on the outer face of these blocks and the joint between the top tier of blocks and the roof with lime mortar. Lay bricks over the holes in the top tier of blocks and cover with sand. Snug up the tie rod. The kiln is now ready to fire.

Firing

A complete operations schedule (Tables 1 and 2) is presented on pages 22-23 for the one-cord and two-cord kilns when used with *seasoned hardwoods*. Firing takes 45 minutes and the procedure is the same for both kilns. Its purpose is to bring a portion of the wood in the chamber up to coaling temperature in preparation for the formation and later movement of the coaling zones. Firing is done in two steps:

(1) With all air inlets and firing ports closed and the chimney damper fully open, the chimney stove is charged with wood, fired and allowed to burn *strongly* to induce a good draft in the chimney.

(2) After 15 minutes the firing ports are opened and the charge in the chamber is ignited by pushing a lighted taper through them. The ports are left open for 30 minutes. During this period *all air inlets are closed and the chimney damper is in a fully-open position.* Fuel should be added to the chimney stove as needed to maintain a strong chimney draft.

At the end of the firing period both firing ports are closed and banked with sand or soil. The temperature of the wood immediately above the firing ports should now be high enough for coaling to begin.

Coaling

The objective from this point is to develop the coaling zones and conduct them through the wood at such a rate that the burn will be completed at both ends of the kiln at approximately the same time. The time required to coal differs for the two sizes of kiln but the steps in the procedure are the same for both. They are as follows:

(1) Initial coaling period. The chimney damper remains *wide open* and a *strong* fire is maintained in the chimney stove throughout the period. At the beginning of the period, both B air inlets are opened; later (see Tables 1 and 2) the A air inlets are opened. It usually requires about 3½ hours to initiate coaling in the one-cord kiln and about 5 hours in the two-cord kiln.

Once coaling is well started, its action is strong enough to maintain sufficient chimney draft and the chimney stove can be closed and banked and the damper set in a *half-open* position.

(2) Final coaling period. With the air inlet openings and damper set as described at the end of the initial coaling period, the kiln should now be ready to coal through without further attention. This will require about 20 hours for the one-cord kiln and 37 hours for the two-cord kiln. As the end of this period approaches, the operator should be on hand to close the kiln.

Once one has learned to evaluate it, the character of the smoke issuing from the chimney is a good indicator both of whether coaling has been properly started and whether, once started, it is progressing satisfactorily. While the chimney stove is in operation during the initial coaling period, the smoke is thin and bluish in color. At the end of the first hour of the final coaling period (one hour after the stove has been closed) the smoke should have become dense and grayish white in color and be emitted in good volume. If the volume decreases within one hour, indications are that coaling has *not* been properly started and the stove should be opened, refueled and allowed to burn strongly for one to two hours with the damper wide open but *without changing* the air inlet settings. It should then be closed again and another observation made of the smoke one hour later.

If coaling has been well started and the smoke thins out *at some time later during the final coaling period,* indications are that coaling is probably progressing too slowly and the damper should be opened slightly. The volume of the smoke should remain fairly constant until near the end of the final coaling period when it normally tends to thin out and turn bluish. This indicates that the burn is nearly completed.

If, during the final coaling period, the smoke has a distinctly yellowish color, coaling is progressing too rapidly and the damper should be closed slightly. (See Discussion on pages 27 to 29.)

On some locations, draft conditions may be encountered which are either abnormally low or high. These may be compensated for by increasing or decreasing the damper opening.

Closing and Cooling

If the wood has been properly stacked in the kiln and the air inlet openings are the right size, the coaling zones should reach all air inlets within an hour. As the zone approaches an inlet, glowing charcoal will be visible and the inlet should be closed and banked with soil. The other inlets should be closed and banked as soon as a glow is visible but, if any fails to glow within an hour, all should be closed and banked to prevent local burning of charcoal.

After all the inlets have been closed, the chimney should be removed and the hole in the steel plate covered and banked with soil.

It is imperative that *all leakage of air into the kiln be prevented during the cooling period.* Even slight leakage may provide enough air to continue combustion of the charcoal which, in turn, will prevent cooling. Walls and top should be inspected very carefully for leaks immediately after closure. Leaks in the top may be stopped with sand, those in the walls by brushing with lime mortar of a creamy consistency.

The kiln must now cool down. This will require three days for the one-cord and five days for the two-cord kiln. This cooling period may be reduced 60 per cent by introducing water into the kiln in the form of a fine mist as soon as it is closed. If water is used, one block near the top of the door panel should be laid with the holes horizontal. One of these holes should be plugged firmly. Into the other, cement a short piece of pipe of sufficient diameter to accommodate the spray nozzle and to permit steam to escape (see Figure 3B). The pipe should be plugged when not in use. The water should be introduced under sufficient pressure to insure a very fine mist and pumping should cease when steam formation ceases. It will take about 50 gallons of water for the one-cord and 80 gallons for the two-cord kiln. If mist is used, the one-cord may be opened and discharged after 24 hours of cooling. The two-cord kiln will require 48 hours to cool.

Opening the Kiln

The schedules on pages 22-23 indicate the approximate time at which the kiln may be opened but experience and tests made under actual operating conditions are the only real guides. The kiln should not be opened until the charcoal is cooled enough so that it will not take fire when air is admitted. A fire can always be quenched with water but this causes deterioration of the charcoal and is considered poor practice.

About an hour before the kiln is considered ready for opening, remove the top blocks in the door panel and the inspection block. Open the air inlets and firing ports and take the interior temperature[1] at some point. If there is no rise in temperature after one hour, the kiln is probably ready to open. If the temperature does rise, reseal the kiln and wait another 24 to 48 hours.

If the kiln seems ready to open, take down the door panel and, if possible, let the kiln air out for an hour or so. This is to clear out any carbon monoxide fumes that may be present and is particularly important if the charge appears hot. It is good practice to keep several pails of water or a spray pump on hand.

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[1] A thermometer reading to 400° F. should be used.

After taking down the door panel, observe the depth and evenness of the charcoal bed and, while unloading, note the location and amount of brands and ash pockets. Such observations will be helpful in correcting future burns.

A coke fork is a satisfactory tool for unloading the kiln. If the charcoal is to be bagged, a bag holder should be provided.

Charcoal will sometimes ignite after removal from the kiln and, for this reason, it is advisable to store it in the open for at least 48 hours before it is placed in more permanent storage or is shipped. Charcoal in open storage should be covered with a tarpaulin.

After 48 or more hours in the open, charcoal should be moved to more permanent storage where it can be kept dry. To minimize the danger of spontaneous combustion, the storage house should be well ventilated and divided into relatively small compartments so that the charcoal will never be assembled in large deep masses. If the charcoal is to be sold in bags, it should be bagged as it leaves the kiln. Loose piling of the bagged coal in the storage house will provide adequate ventilation. If possible, floor the storage space and provide ventilation under the floor.

Common carriers have regulations governing the shipment of charcoal. These should be strictly adhered to.

SCHEDULE OF OPERATIONS

Tables 1 and 2 give complete operations schedules which have proved satisfactory in coaling oak, maple, birch and other dense woods when the pieces ranged from 3 to 7 inches in diameter and had a moisture content of 20 to 40 per cent. Such wood may be classed as seasoned.

These schedules should be used by the operator as a guide. It should be remembered that wood is an extremely variable substance. No two lots are ever quite alike even though they may appear to be. The human element must also be taken into account, since people do not react alike to instructions or conditions. In the last analysis, the operator must modify the instructions to suit his own conditions. Modification of the schedules for woods of other kinds and of other moisture content are discussed on pages 28-29. The schedules may be so arranged that practically all the labor required can be done within the limits of the ordinary work day.

The time required to charge with wood and unload the charcoal is approximately five man-hours for the one-cord kiln and eight man-hours for the two-cord kiln. If several kilns are operated as a battery, the intermittent labor required during the firing and initial coaling periods can be performed on one kiln while another is being charged or discharged.

TABLE 1. SCHEDULE OF OPERATIONS

One-Cord Kiln (Seasoned Hardwoods)

Sticks 3 to 7 Inches in Diameter

Operation		Duration (hours)	Typical time schedule	Air inlet openings (square inches) "A" Inlets (each)	"B" Inlets (each)	Chimney damper position	Firing ports	Chimney stove	Remarks
Firing	Step 1	¼	Monday 1:00 to 1:15 P.M.	0	0	Fully open	Closed	Strong fire	Kiln ignited through firing ports at 1:15 P.M.
	Step 2	½	1:15 to 1:45 P.M.	0	0	Fully open	Open	Strong fire	
Coaling	Initial period	2	1:45 to 3:45 P.M.	0	2.5	Fully open	Closed	Strong fire	
		1½	3:45 to 5:15 P.M.	3.0	2.5	Fully open	Closed	Strong fire	
	Final period	19¾	5:15 P.M., Monday to about 1:00 P.M., Tuesday	3.0	2.5	Half open	Closed	Closed	
Closing		....	About 1:00 P.M., Tuesday	Closed	Closed	Closed	Closed	Closed	Kiln sealed for cooling
Cooling	With water[1]	24	1:00 P.M., Tuesday to 1:00 P.M., Wednesday	....	....	....	....	....	Kiln opened at 1:00 P.M., Wednesday
	Without water	72	1:00 P.M., Tuesday to 1:00 P.M., Friday	....	....	....	....	....	Kiln opened at 1:00 P.M., Friday

[1] Fifty gallons of water introduced as fine mist.

TABLE 2. SCHEDULE OF OPERATIONS

Two-Cord Kiln (Seasoned Hardwoods)

Sticks 3 to 7 Inches in Diameter

	Operation	Duration (hours)	Typical time schedule	Air inlet openings (square inches)		Chimney damper position	Firing ports	Chimney stove	Remarks
				"A" Inlets (each)	"B" Inlets (each)				
Firing	Step 1	¼	Monday 1:00 to 1:15 P.M.	0	0	Fully open	Closed	Strong fire	Kiln ignited through firing ports at 1:15 P.M.
Firing	Step 2	½	1:15 to 1:45 P.M.	0	0	Fully open	Open	Strong fire	
Coaling	Initial period	3	1:45 to 4:45 P.M.	0	3.0	Fully open	Closed	Strong fire	
Coaling	Initial period	2	4:45 to 6:45 P.M.	4.0	3.0	Fully open	Closed	Strong fire	
Coaling	Final period	37½	6:45 P.M., Monday to about 8:00 A.M., Wednesday	4.0	3.0	Half open	Closed	Closed	
Closing		....	About 8:00 A.M., Wednesday	Closed	Closed	Closed	Closed	Closed	Kiln sealed for cooling
Cooling	With water[1]	48	8:00 A.M., Wednesday to 8:00 A.M., Friday	....	....	....	....	....	Kiln opened at 8:00 A.M., Friday
Cooling	Without water	120	8:00 A.M., Wednesday to 8:00 A.M., Monday	....	....	....	....	....	Kiln opened at 8:00 A.M., Monday

[1] Eighty gallons of water introduced as fine mist.

KILNS OF LARGER CAPACITY

Since Bulletin 494 was published, observations have been made on a number of kilns of the same general design as those described above but with a capacity of more than two cords. The following statements represent the best summary of the results obtained with larger kilns that can be made at the present time. They are intended as a guide to the person who feels that a kiln of larger capacity will better satisfy his needs.

(a) Initial cost, yields, and cost of operation.

Construction costs per volume of wood contained will be less for one large kiln than for a battery of several smaller kilns of equal total capacity, unless the former is so large that a more elaborate and costly roof is required.

There is some evidence that, up to a certain point, yields of charcoal per cord from the same kind of wood will increase as the size of the kiln increases.

The larger the kiln, the longer will be the time required to load and to unload and to coal and cool off. In the absence of definite time schedules for the several operations, it is impossible to make accurate comparisons of the cost of operating large versus small kilns. It is known that schedules for a battery of the latter may be so arranged that labor will be quite fully utilized and little overtime work will be required. Moreover, the monthly output of charcoal from a battery is high because of the short coaling and cooling cycle of the individual kilns. It is conceivable, therefore, that the advantages of a lower capital investment in and increased yields per cord of wood from a large kiln may be more than offset by higher labor costs per ton of charcoal produced and a lower rate of production per annum.

(b) Shape, size and interior dimensions of larger kilns.

Kilns of less than 20-cord capacity are better adapted to loading and close piling if the ground plan is rectangular rather than circular or elliptical and also if the walls are vertical rather than sloping as in beehive kilns. Only kilns with rectangular ground plan and vertical walls are discussed in this paper.

The authors are of the opinion that kilns of the type described should not have an interior width[1] greater than is necessary to accommodate a 5 foot stick crosswise since it is somewhat difficult to start coaling in kilns of greater width. Moreover, wider kilns will require heavier roof construction which will be more costly.

The height of a kiln should be at least half, and preferably more than half, its length. The latter should probably not be much in excess of 18 feet.

Based on the above statements the dimensions for the two-cord kiln, as shown in Figure 2B, may be increased to a width of 5 1/3 feet, a length of about 13 feet and a height of about 7 feet, thus giving it a capacity of about three cords. By further increasing the height to 9 feet[2] the capacity could

[1] All further statements regarding dimensions will refer to interior measurements.
[2] Chamber walls more than 7 feet in height should be firmly braced to prevent spreading.

be increased to more than four cords. The duration of the several operations would be longer in each case than those described for the two-cord kiln, but no changes in construction, other than increased dimensions, would be necessary. The three-cord kiln would lend itself to all-crosswise piling with 5 foot wood. In either the three-cord or four-cord kiln, 4 foot or 5 foot wood could be piled lengthwise *in one rank* at either end, as shown in Figure 5A, the middle section above the firing ports being filled in with wood piled crosswise. All-crosswise piling is not feasible for the four-cord kiln because of its height.

A further enlargement can be made by keeping the width at 5 1/3 feet but making the length 18 feet and the height 10 or 12 feet. With a 10 foot height the capacity would be nearly 7 cords; with a 12 foot height, about 8 cords. The following methods of piling are suggested:

(a) *Two ranks* of 4 foot wood may be piled lengthwise at *either* end as it is piled at the front end in Figure 5B, the middle section being filled with wood piled crosswise, or

(b) If the wood is quite straight, sticks 8 feet long may be piled *in one rank* lengthwise at *either* end as it is piled at the rear end in Figure 5B, the middle section being piled crosswise with 4 foot or 5 foot wood.

If the length of a kiln is increased beyond about 13 feet, a pair of additional air inlets should be placed in each sidewall, near ground line and halfway between the firing ports and the corner air inlets A and B. During the early part of the burn the new air inlets are used in the manner previously described for the A and B inlets, respectively. When the charcoal begins to glow at the new inlets, they should be closed and the A and B air inlets opened.

Kilns with a capacity of more than three cords should be provided with a chimney pipe which is at least 9, and preferably 10, inches in diameter. The cross-sectional area of the smoke outlet under the wall at the chimney end should be fully as large as that specified for the two-cord kiln. The size of the chimney stove should be increased to permit less frequent firing. This can be easily done by increasing the height of the stove and the height of the baffle by 8 inches (the depth of one block).

The suggestions made thus far regarding kilns of more than two-cord capacity are based on numerous observations and are believed to be quite feasible. If the reader wishes to experiment in further increasing the size of kiln, the following are suggestions which he may try:

(a) Keep the width to between 5 and 6 feet, increase the length to 24 feet and the height to 12 to 15 feet; place a doorway in the middle of the side, and a chimney at either end. In effect this would be joining two kilns end to end. Firing would be done in the middle and the coaling zones would move toward the chimneys.

(b) Make the length 18 feet, the height 10 or 12 feet and increase the width to 8 feet. A kiln of these dimensions will probably be somewhat difficult to start but, otherwise, the technique of operation should be little different from that described above for a kiln of the same length and height but only 5 1/3 feet wide.

The authors advise the person who wishes to experiment with a kiln of greater capacity than two cords to first build a two-cord kiln with a chamber wide enough to take 5 foot wood, crosswise. After gaining experience with this kiln, he can quite easily increase the height and length (and even the width) to form a kiln of the capacity he desires.

COALING LONG-LENGTH WOOD

The following method is suggested for adapting a kiln to coal wood up to 12 feet long. It is based partly on the technique of coaling used in European horizontal kilns and partly on previous experience with a coaling method slightly different from that described in this paper. The sticks should be reasonably straight and may be either slabs or round or split wood.

(a) Build a kiln which is 5 1/3 feet wide, 14 feet long and 8 feet high with chimney stove as previously described, but in place of the firing ports, install an extra pair of air inlets (designated C).

(b) Lay two stringers lengthwise of the kiln. On top of these lay four stringers crosswise and space them equally as shown in Figure 5C.

(c) Pile the wood lengthwise of the kiln leaving a 4 inch space at the chimney end for a smoke passage. This will leave a space about 2 feet long between the end of the pile and the door.

(d) Place oil soaked rags and kindling on the floor just inside the doorway and, above the kindling, pile brands and dry wood to fill the space between the piled wood and the door.

(e) Use the chimney stove to create draft as indicated for the two-cord kiln, and about 15 minutes later ignite the kindling through the rear (B) air inlets which now are used as firing ports.

(f) At the end of about one hour, close and bank the B air inlets and open the C air inlets. The A air inlets are kept closed until glowing appears at the C air inlets. The latter are then closed and the A air inlets opened. Further timing of operations will have to be worked out by experiment.

The object of the above operations is to start coaling near the top of the door at the rear end and to develop one coaling zone at this end instead of two zones at the point marked "X" in Figure 4A. In response to air admitted at air inlets C, and later at air inlets A, this zone will move forward toward the chimney end and finally downward toward air inlets A. Since this one zone will have to travel the full length of the kiln instead of about half this distance as indicated in Figure 4A, the time required for coaling will probably be somewhat more than twice that given in Table 2 for the two-cord kiln.

DISCUSSION

Under this heading are included a number of more or less unrelated statements, based on experience, which may help the operator in gauging his operation.

Rate of Coaling

A good burn is characterized by an even bed of firm, black charcoal which does not break up readily, which has a low percentage of small pieces or dust, and which contains few or no brands or ashes.

Charcoal produced from the denser woods such as oak, maple, birch and ash will, under the same coaling conditions, be heavier than charcoal from light woods such as basswood, aspen and most conifers. Weight per unit of volume is, consequently, not always an indication of a poor burn. If, however, the charcoal is not only light in weight, but also breaks up readily into small pieces, it is an almost certain indication that the burn was made too quickly. As previously stated, too fast coaling is indicated by smoke which is distinctly yellowish in color.

A burn which is conducted too slowly will continue to burn for a time with a decreasing volume of smoke and may finally go out entirely. When the kiln is opened, there will usually be a pocket of ashes near the firing ports and an excessive amount of brands or uncharred wood at the ends of the kiln. Apparently, what happens is that the amount of air, which is drawn in through the air inlets by the chimney draft, is insufficient to keep the coaling zones moving but is sufficient to cause local burning.

The range between the coaling rate of a burn that has been run too fast and one that has been run too slowly is comparatively small. For his first few burns, the beginner is advised to use deliberately *more chimney draft* than is indicated for the kind, size and moisture content of the wood which is being coaled. By so doing, he can be almost certain that the charge will coal through and that he will avoid the difficulties that arise when a burn is run too slowly. The charcoal produced will be light and will break up easily but this can be corrected by gradually decreasing the chimney draft on subsequent burns.

If, after several trial burns, a kiln persistently coals out at the rear (doorway) end before it does at the chimney end, the A air inlets should be opened somewhat sooner than is indicated in Tables 1 and 2.

Chimney Draft

The amount of chimney draft and, consequently, the speed of the burn, is governed by the damper setting. After the chimney stove has been closed, this setting varies between one-half open and full-open and, in the absence of instruments, is gauged by the position of the damper handle relative to a quadrant scribed on the chimney. One side of the quadrant should be parallel to the long axis of the chimney.

Experimental evidence indicates that during coaling the draft should be equivalent to about 0.02 to 0.03 inch of water pressure. If a draft gauge is available, much more consistent results will be obtained if the damper is set to conform with a desired draft gauge reading than if it is set by quadrant.

While the chimney stove is in operation, i. e., until the end of the initial coaling period, an extra foot of flue pipe may be used on the chimney. This will create a stronger draft and shorten the period during which the stove must be operated.

Tar Formation

Toward the end of the burn, tar collects in increasing quantities on the inside surface of the chimney pipe near its base. Here, it is coked into a fairly hard, highly porous mass which may entirely block the chimney. Blocking usually manifests itself by a lessening of the volume of smoke, without a change to a bluish color, before glowing appears at the air inlets. *The coked tar mass must be removed.* This may be done by running a long slender pole down the chimney pipe. It is a good practice to perform this operation several times during the latter part of the final coaling period to make sure the chimney is clear.

Brands

An ideal burn would be one entirely free of brands. Such a condition is seldom attained. As the coaling zones approach the air inlets, the charcoal formed begins to glow in response to the incoming air. Glowing usually occurs before the wood is all coaled through. If it continues until all the wood is coaled, an appreciable loss of charcoal may take place through combustion. It is better, therefore, to close the kiln within an hour after glowing is visible at any air inlet. By this practice, a few brands will be found near the end walls, but these can be coaled on the next burn. The total volume of brands left in a good burn in either the one-cord or the two-cord kiln should be one-tenth of a cord or less.

Brands may also result from mixing green or dozy wood with seasoned wood, from attempting to coal too large sticks or from conducting a burn too slowly. A correction in operational technique will eliminate an excess of brands arising from these causes.

Size and Shape and Moisture Content of Wood

All sizes of wood up to 7 inches in diameter can be coaled successfully. Larger pieces should be split. The sticks should be reasonably straight to facilitate close piling in the kiln. A cord of wood made up of sticks of small diameter will contain much less wood substance and, consequently, produce much less charcoal than a cord composed of sticks of large diameter. The wood should be sound.

If the wood has a moisture content approximating that indicated in Tables 1 and 2, but the sticks are of smaller average diameter (2 to 4 inches), it should be coaled with slightly smaller air inlet openings and slightly less chimney draft than is indicated in the tables. Larger diameter sticks (5 to 7 inches) require slightly larger air inlet openings and slightly more chimney draft than is indicated in the tables.

Coniferous and hardwood slabs can be coaled with good yields, the operational procedure being much the same as for cordwood of about the same moisture content.

Wood of any moisture content can be carbonized but, from a practical standpoint, the moisture content should probably be between 20 and 80 per cent. The lower figure will be about the minimum for thoroughly air-dried wood in the northeastern United States. The higher figure is about the average for unseasoned northern hardwoods. The best yields will be obtained when coaling wood with a moisture content of between 20 and 40 per cent. Good yields will result from coaling unseasoned hardwoods and partially seasoned conifers (moisture content from 65 to 85 per cent). Unseasoned conifers, especially those comprised largely of sapwood, which may have a moisture content of 150 to 200 per cent and contain up to 400 gallons of water per cord, can be coaled but the yields are very low. These can be improved very materially by one to two months of summer seasoning. In one case where this was done with Scotch pine, the yield of charcoal was increased 55 per cent.

When coaling unseasoned hardwoods and semi-seasoned conifers, it may be necessary to increase the size of the air inlet openings by as much as 50 per cent more than the values given in the tables and to have the chimney damper three-quarters instead of one-half open. For unseasoned conifers of very high moisture content it may be necessary, not only to increase the air inlet openings, but also to maintain the damper in a position between three-quarters open and fully open.

Although no wood of low moisture content (below 20 per cent) has been coaled by the authors, the literature on carbonization indicates that such wood does not coal readily or produce good yields in this type of apparatus. Kiln dried material would fall in this category.

Since carbonization in kilns is based on the movement of air (or in some cases furnace gases) through the wood mass, sawdust shavings and other finely divided material cannot be successfully coaled in them because the pieces pack so closely together that circulation is almost completely shut off.

It is not considered good practice to mix seasoned and unseasoned wood in the same charge nor to coal wood which has become "dozy".

Table 3 shows the yields obtained with a number of different species and from woods of different moisture contents.

Inspection and Care of the Coaling Chamber

The coaling chamber requires little care beyond keeping it sealed tightly during the coaling and cooling periods, except for air purposely admitted through the air inlets and firing ports. Without adding greatly to the cost of construction, it would be almost impossible to make the chamber permanently leak proof. Nor is this necessary. Small leaks will develop from time to time but these can be very easily closed and need cause no trouble if the kiln is inspected systematically. This is particularly important during the first half dozen burns. Sand settles in the core holes in the blocks and small leaks develop due to poor mortar joints or to porosity

TABLE 3. YIELDS

Wood coaled	Estimated moisture content (oven dry basis) (per cent)	Yield per cord[1]		Number of burns
		In bushels[2]	In pounds	
Seasoned mixed hardwoods	20 - 40	46	920	10
Unseasoned mixed hardwoods ..	80	38	760	4
Semi-seasoned Scotch pine	65 - 75	29	580	4
Unseasoned Scotch pine	More than 150	19	380	3
Unseasoned white pine slabwood	65 - 75	33	660	1
Unseasoned white pine topwood	65 - 75	26	520	4

[1] Net yield of lump charcoal, excluding uncoaled wood (brands) and fine charcoal.

[2] In Connecticut, a legal bushel of charcoal weighs 20 pounds.

in the blocks themselves. The core holes should be refilled until the sand ceases to settle. The top should also be kept covered with a layer of sand at all times.

Small leaks in vertical surfaces and around the door blocks are easily stopped by brushing over with lime mortar of a creamy consistency, a pail of which should always be kept on hand. Leaks will become less frequent as time goes on, due to plugging from the inside with tar. This, however, does not do away with the need for frequent inspections. The best time to make these is within an hour after the kiln is closed and banked for cooling. Action continues for a while after the air is shut off and apparently a slight pressure is developed which forces the smoke out through small leaks which are not discernable during coaling.

Leaks are not particularly important during the coaling period unless they are too large or too numerous. In such cases they act as added air inlets and disrupt the schedule. During the cooling period, when no air should be allowed to enter the kiln, they are very important and should be guarded against by all possible means.

Life of the Kilns

Some of the kilns under observation have been used for more than 100 burns without deterioration except for a little erosion on the inner surfaces of several blocks adjacent to the firing ports. These blocks are still serviceable but would have to be replaced if the kiln were moved. On the basis of this experience, it is estimated that the kilns should remain serviceable for 150 or more burns if they are not moved. If they are dismantled and rebuilt, there would undoubtedly be some breakage. The excellent condition of door blocks, which have been taken down and relaid more than 100 times, indicates that deterioration should be relatively small.

Winter Operation

Experience with the kilns indicates that they are most easily operated when the temperature is above about 20° F. If they must be operated at lower temperatures, the kilns should be housed and provision made to keep the wood reasonably dry. The chimney should be insulated and the ground around the kiln should be ditched to provide good drainage.

BILL OF MATERIALS

(For Kilns with an Interior Width of 56 Inches)

Kind of material	Nominal dimension	Number of pieces	
		One-cord kiln	Two-cord kiln
Cinder-concrete blocks (Hollow type)			
Standard	8″ x 8″ x 16″	145[1]	225[1]
Standard	6″ x 8″ x 16″[3]	19[1, 3]	23[1, 3]
Pier	8″ x 8″ x 16″	34[1]	35[1]
Half-block	8″ x 8″ x 8″	9[1]	11[1]
Partition	4″ x 8″ x 16″	48[1]	62[1]
1¼″ iron or steel pipe[2]	64″ long	12	16
1½″ iron or steel pipe[2]	9″ long	2	2
2″ iron or steel pipe[2]	9″ long	1	1
Strap iron (chimney brace)	⅛″ x ½″ x 40″	1	1
Steel plate	¼″ x 20″ x 32″	1	1
Wire cloth, ¾″ mesh 12 ga. wire	16″ x 20″	1	1
Tie rod—¾″ rod or chain with eye bolts	for 76″ span	1	1
8″ furnace flue pipe (metal)		5 2/3 linear feet	7 linear feet
Flue pipe damper	for 8″ flue pipe	1	1
Wood plank	2″ x 8″ x 36″	2	2
Sand	....	2½ cubic yards	3 cubic yards
Lime	....	160 pounds	240 pounds
Cement (optional)	....	....	....

[1] The number of blocks which are needed to contsruct that portion of the chamber, including the parapet, which is above ground line, to build all of the chimney stove, and to line the trench within the chamber. Any blocks used in the foundations will be in addition to those listed. To allow for breakage, it is recommended that the number specified be increased as follows: standard and pier blocks combined, five; half blocks, two, and partition blocks, ten.

[2] New or used.

[3] For building the parapet.

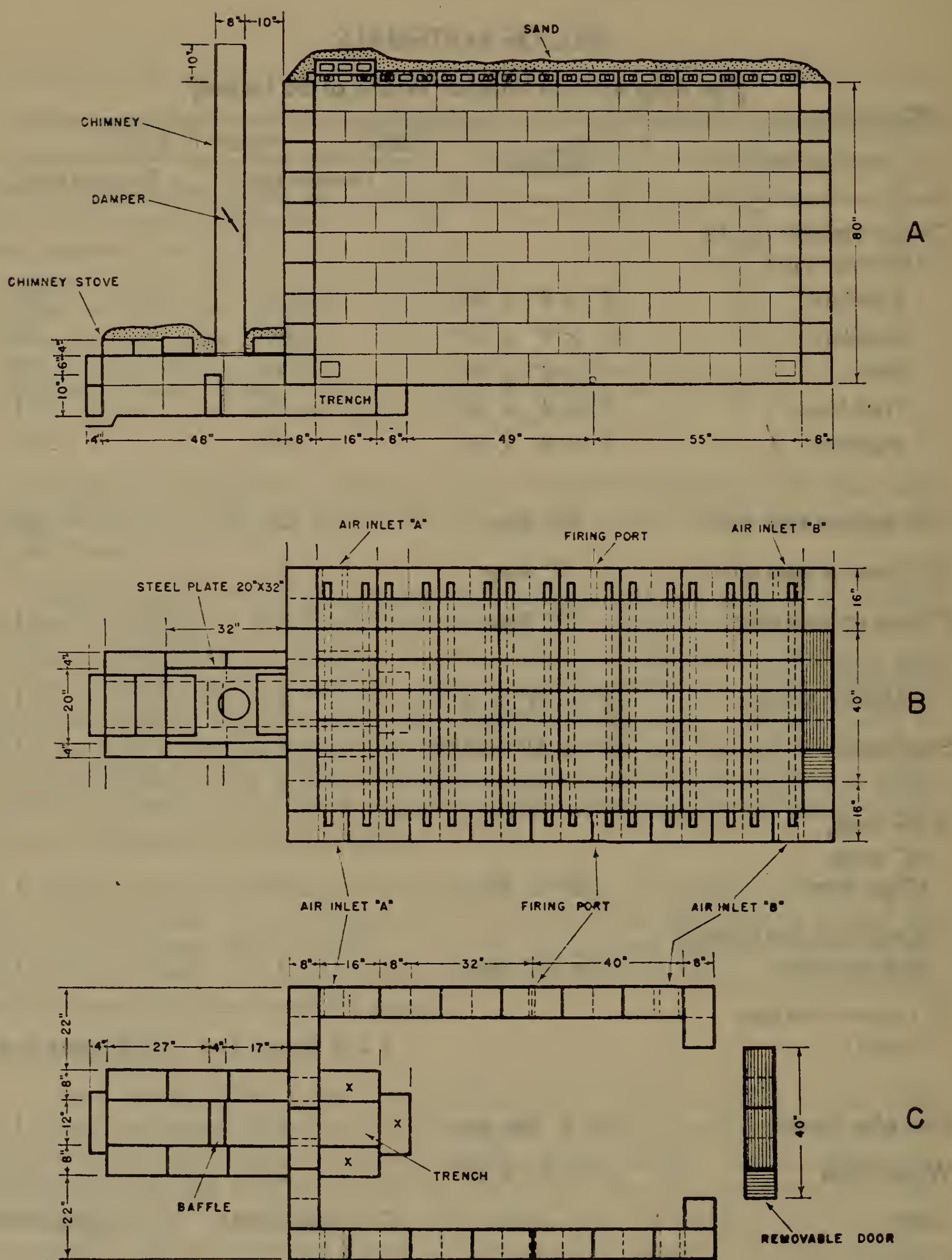

FIGURE 1

A. Vertical section through two-cord kiln. Elements cut by the plane of section are shown in heavy lines, background features in light lines.

B. Plan view of two-cord kiln, fully assembled.

C. Plan view of one-cord kiln with the chimney, the top of the chimney stove and the roof of the coaling chamber removed. The removable door is shown assembled but offset from the chamber walls.

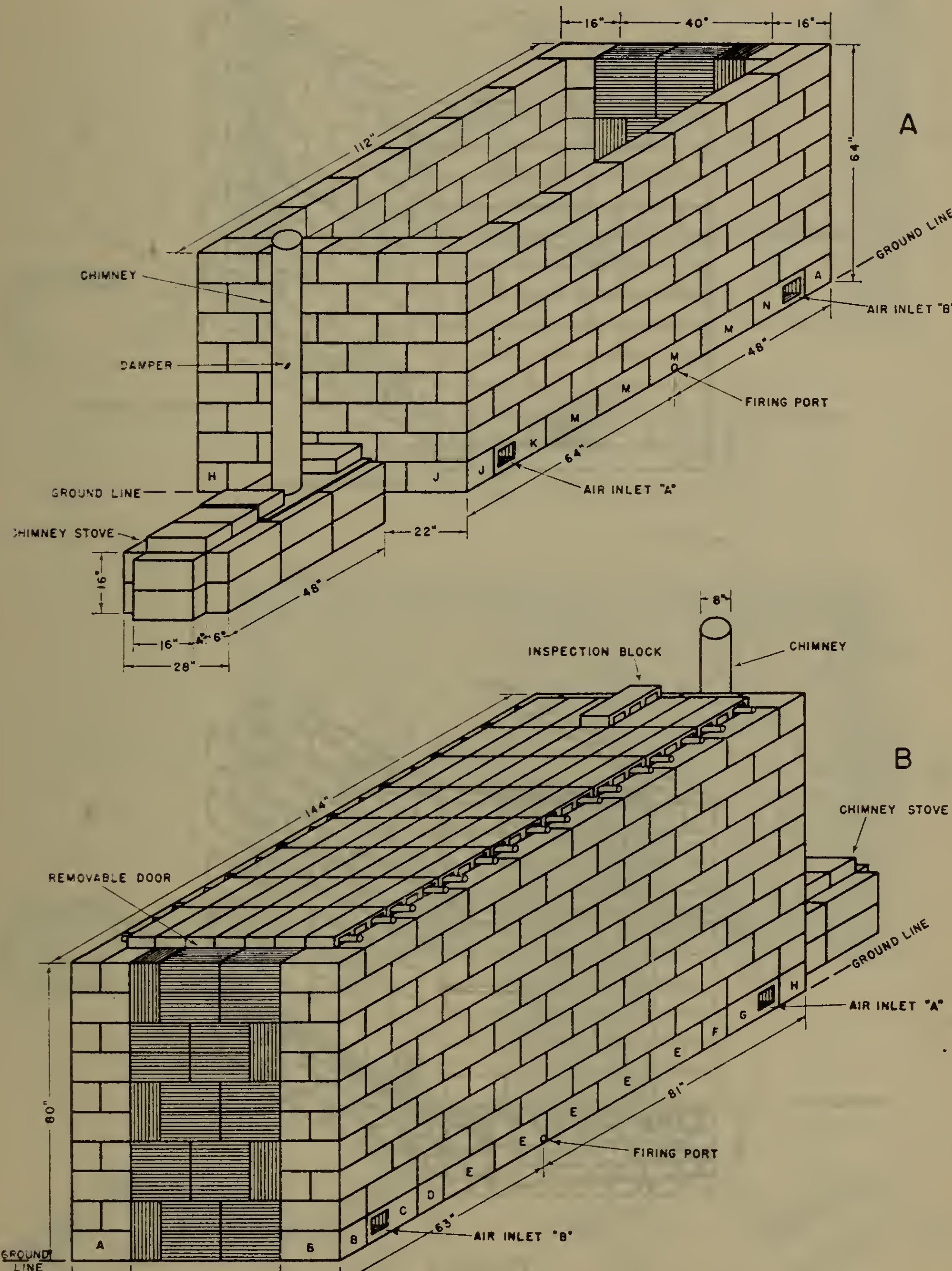

FIGURE 2

A. Isometric drawing of one-cord kiln with the roof of the coaling chamber removed.

B. Isometric drawing of two-cord kiln fully assembled. The blocks which make up the removable door are shaded.

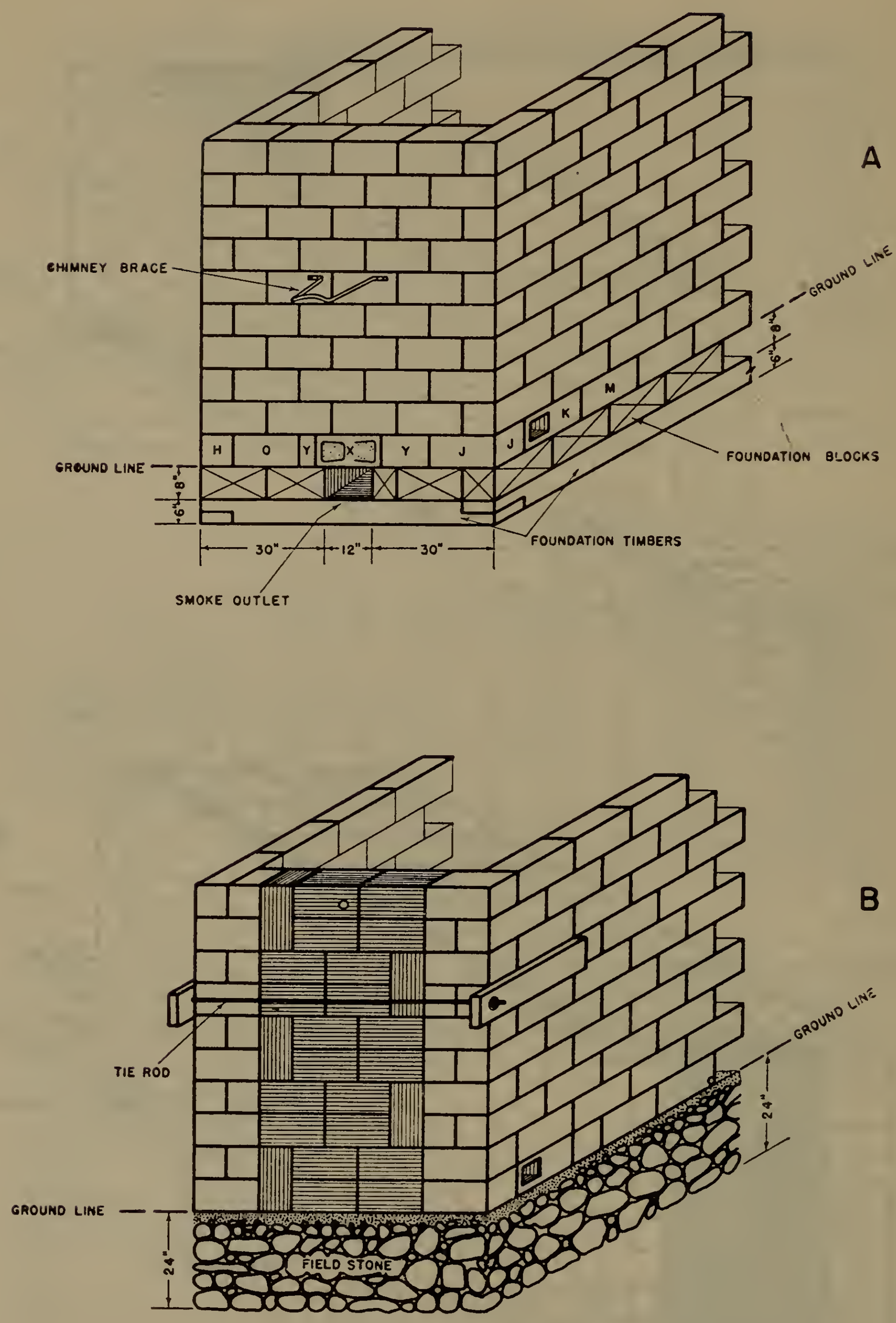

FIGURE 3

A. Isometric drawing of the front end of two-cord kiln with chimney stove removed. The foundations are for a temporary installation and consist of timbers and an extra tier of blocks. Note the smoke outlet through the foundation and the chimney brace.

B. Isometric drawing of the rear end of two-cord kiln showing removable door and tie rod. Foundations of field stone and concrete are for a permanent installation. The hole near the top of the door is for the admission of water during cooling.

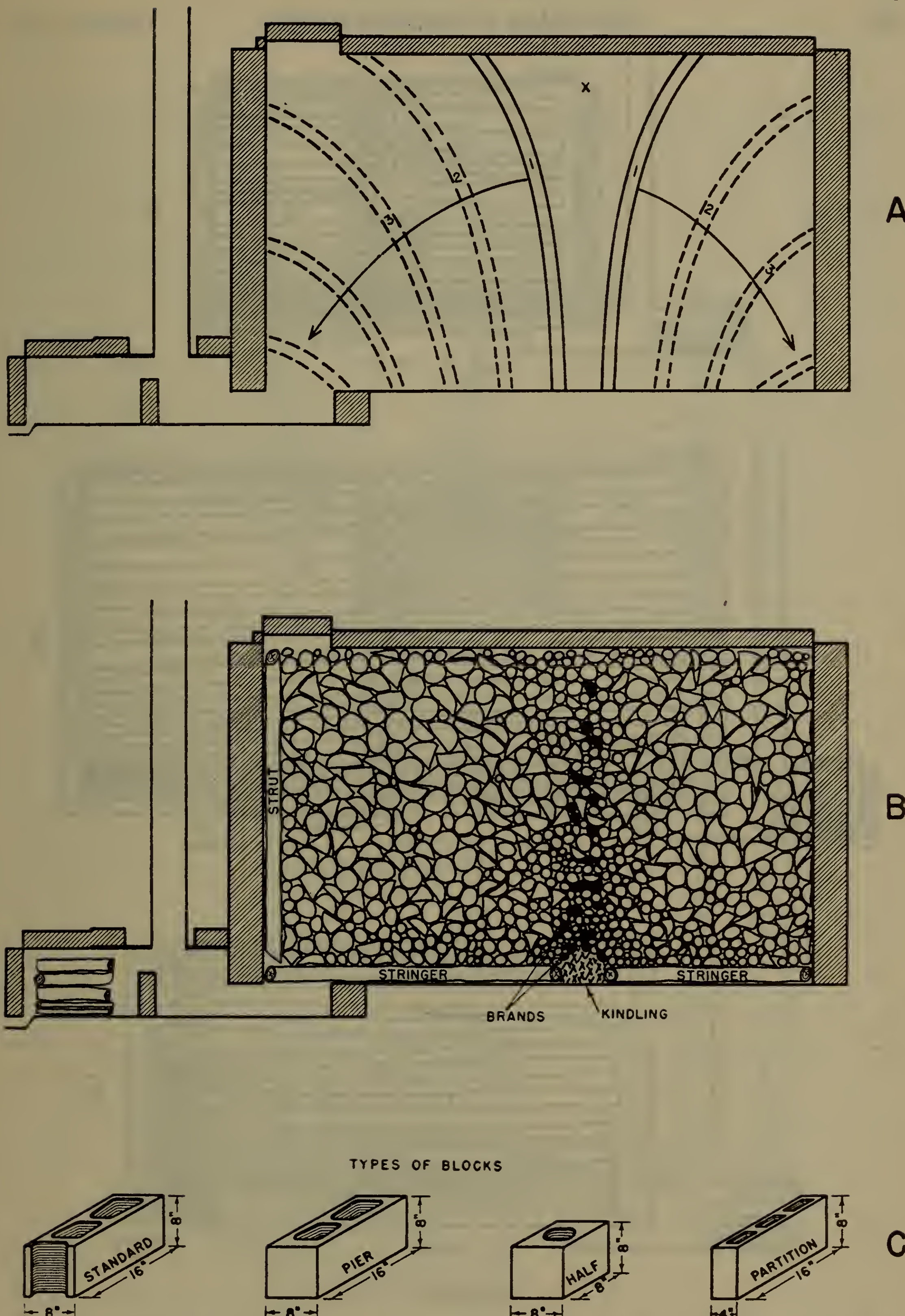

FIGURE 4

A. Vertical section through two-cord kiln illustrating movement of the coaling zones through the wood mass during carbonization.

B. Vertical section through two-cord kiln showing position of stringers and struts and placement of the kindling and the several sizes of wood. Brands are shown in solid black.

C. Isometric drawings of the four types of cinder-concrete blocks used in construction of the kilns. Dimensions shown are nominal.

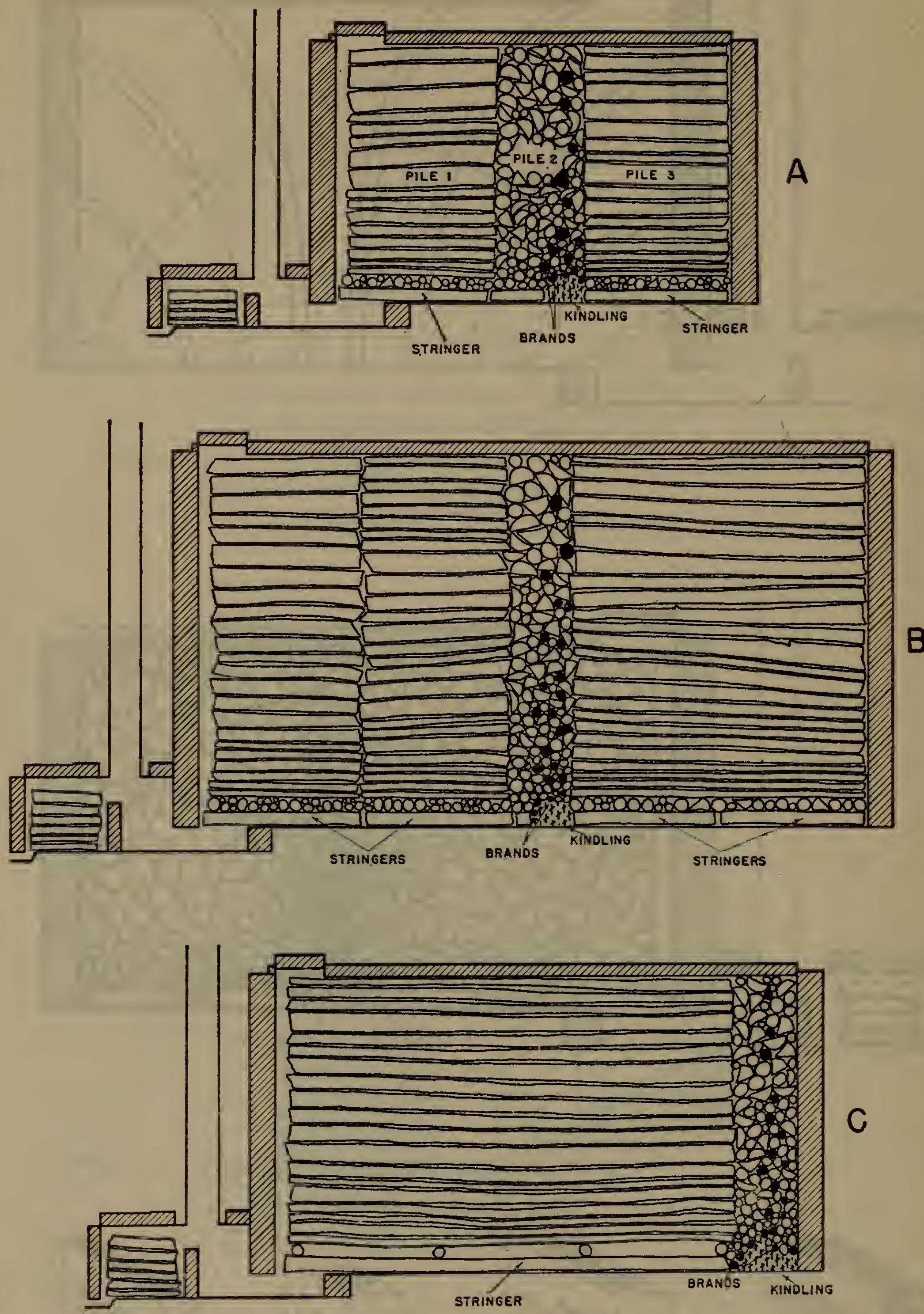

FIGURE 5.

A. Vertical section through two-cord kiln showing the wood piled lengthwise of the kiln at either end and crosswise in the central section.

B. Vertical section through a seven or eight-cord kiln showing suggested method of piling 4-foot wood (left) or 8-foot wood (right) lengthwise of the kiln at the ends and crosswise in the central section.

C. Vertical section through a kiln showing a suggested method of piling wood and placing kindling when coaling wood or slabs up to 12 feet in length.

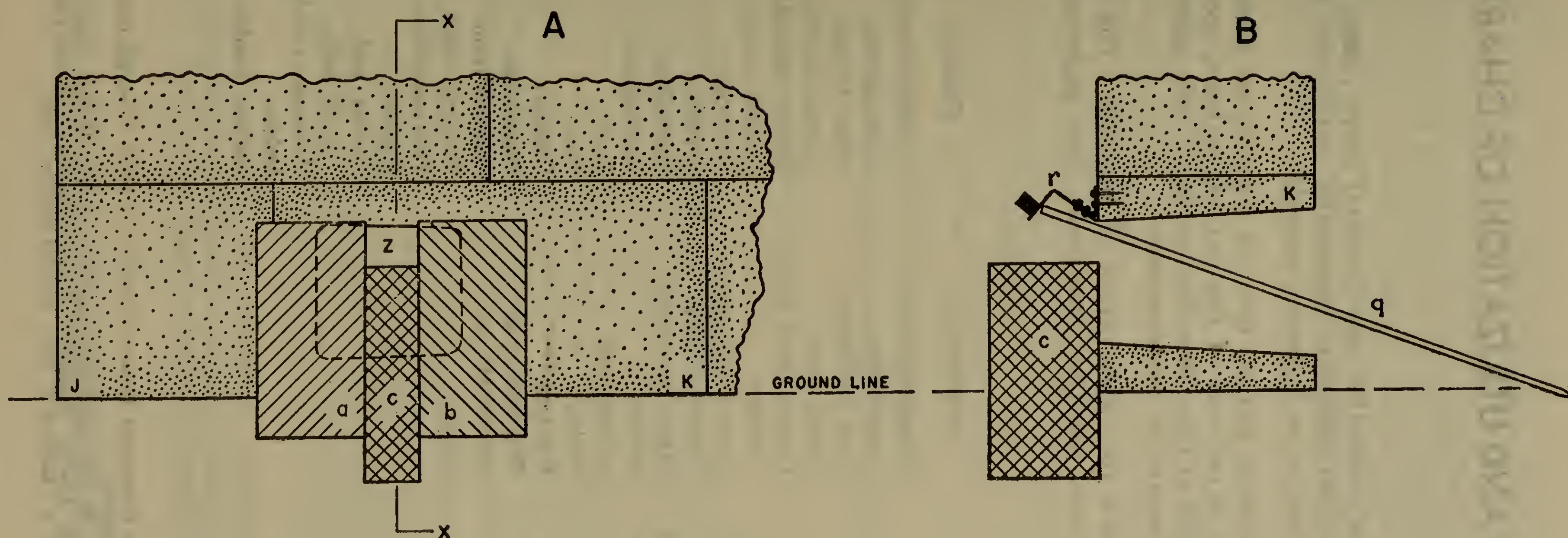

FIGURE 6.

A. Showing a method of reducing the size of the core opening in Block K, Figure 2A, to a specified size.

B. A vertical section, X——X, through Figure 6A (with red bricks *a* and *b* omitted) showing the arrangement of parts of an automatic air inlet closer.

MANUFACTURE AND UTILIZATION OF CHARCOAL[1]

National

In the United States, charcoal in any of several forms (lump, screened, powdered or briquets) is an important commodity and is used for many purposes both as a fuel and as an industrial material.

It is estimated that about 350,000 tons[2] of charcoal are produced and used annually. Almost 20 per cent of this is made in kilns, operating on the same general principle as those described earlier in this bulletin; most of the balance is manufactured in closed retorts.

Charcoal is used for a very wide variety of purposes. The following table[2] lists some of the more important ones under three major categories:

Domestic and Specialized Fuel	*Metallurgical*	*Chemical*
Citrus growers	Aluminum metal	Activated carbon
Domestic	Armor plate	Black powder
Foundries	Case hardening	Brake linings
Incinerators	Cobalt metal	Carbon disulfide
Laundries	Copper, brass and bronze	Carbon monoxide
Meat and fish curing	Electro manganese	Catalyst reactor
Railroad dining cars	Foundry molds	Electrodes
Shipyards	Magnesium metal	Fertilizer
Tinning and plumbing	Mining	Galvanizing
Tobacco curing	Molybdenum	Gas cylinders
	Nickel	Glass
	Pig iron	Glues
	Powdered iron	Graphite
	Special alloys	Magnesium
	Steel	Molding resins
		Nursery mulch
		Pharmaceuticals
		Plastics
		Poultry and stock feeds
		Potassium cyanide
		Rubber
		Sodium cyanide

[1] The Connecticut Agricultural Experiment Station is not in a position to supply information on specific markets for or uses of charcoal.

[2] The nationwide figures on charcoal production and use in the United States are from CHARCOAL PRODUCTION by Edward Beglinger. Report #R1666-11. Forest Products Laboratory, Forest Service, U. S. D. A., Madison 5, Wis. Revised October, 1947.

Local

In 1947 a canvass was made to determine the total amount of charcoal used annually in Connecticut, the purposes for which it was employed and the extent to which the consumers were supplied by charcoal produced locally. It was found that the total annual consumption of charcoal within the State averages between 15,000 and 20,000 tons. An estimated 25 per cent of this is in the form of briquets, the remainder mostly lump charcoal. The following table shows the more important types of use and the annual consumption in each.

Type of Use	*Current Annual Consumption in Tons*
A. General and specialized fuel use—lump and briquet form:	
1. Tobacco curing	
a. Shade grown tobacco	6,000 to 10,000
b. Open grown tobacco	up to 5,000[1]
2. Domestic, picnic and restaurant use	2,000
B. In metallurgy—lump and screened charcoal:	
1. Non-ferrous industries (copper, brass, bronze and silver)	2,500
C. All other miscellaneous uses	500

The estimated potential production of known kilns in the State is not over 3,000 tons annually. The actual production of these kilns, about half of which have a capacity of five cords or under, is less than 2,000 tons. That is, the ratio of local consumption to native production is approximately 10 to 1. This wide divergence has naturally resulted in the dependence by Connecticut users, for their charcoal requirements, on outside sources such as Pennsylvania, Tennessee, Michigan and other states. Opportunity exists for a considerable expansion of wood charcoal production in Connecticut.

From the standpoint of the prospective producer there is a large, local demand for charcoal for numerous applications in large and in small quantities. This demand does not fluctuate markedly from year to year, and is concentrated in a small area. A less favorable factor is the high cost of cutting and transporting wood in an industrial region where labor rates are high.

In Connecticut there are relatively few areas where wood can be assembled in sufficient volume to warrant a large capital investment in a permanent carbonization plant without incurring unduly high costs for

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[1] The amount of charcoal used for curing open grown tobacco will vary widely from year to year depending on weather conditions in the late summer. Occasionally it may not be necessary to burn any charcoal; other years the requirements will be high.

transportation. Small kilns of the type described earlier in this bulletin can be set up near the source of wood supply and, when transportation costs become too great, the kilns can be readily moved to a new site. A battery of five or more kilns can be made to produce a high annual yield with a comparatively low capital investment. A single kiln is a satisfactory unit for the small producer who does not wish to make charcoal in large quantities or who wishes to operate intermittently.

COSTS OF PRODUCTION

Costs of manufacturing charcoal vary with each operator's conditions. Some guide for the prospective operator, however, may be obtained from the following example. The cost figures, labor rates and price of charcoal are for southern New England as of 1947. The yields are from Table 3 in the earlier section of this bulletin and assume an average burn using the two-cord kiln.

Cost of 2 cords of seasoned mixed hardwoods delivered at the kiln @ $12.00	$24.00
Loading the kiln, 3 man hours @ $1.25	3.75
Unloading charcoal and bagging in gunny sacks, 5 man hours @ $1.25	6.25
Attention while coaling, 1 man hour @ $1.25	1.25
Depreciation of kiln @ $1.00 per burn	1.00
Total	$36.25
Returns from 1800 lbs. of charcoal (900 lbs. per cord) @ 2½¢[1]	$45.00
Net return $8.75 or $4.38 per cord.	

The prospective charcoal kiln operator will readily see how the greatest returns can be made. Each operation done without cash outlay represents a greater cash return than shown. For instance, if the operator supplies his own wood, loads and attends the kiln, and bags the charcoal, the only expenditure would be depreciation on the kiln. Gross returns per cord could then amount to $22.00 instead of $4.38.

If, in the above example, unseasoned mixed hardwoods are coaled, a yield of only 1,500 lbs. of charcoal (See Table 3) may be expected. If the costs remain as tabulated above, the operation will just about break even; if conifers are coaled, it will be carried on at a loss.

In connection with the balance sheet given above, it should be pointed out that, regardless of species, wood loses approximately 50 per cent of its volume and 70 to 80 per cent of its dry weight when it is reduced to charcoal. Dense woods like black and yellow birch, oak, hickory and maple have a greater dry weight per cord than such light woods as aspen, basswood

[1] Average wholesale price in Connecticut, 1947.

and most conifers and, therefore, will yield much more charcoal per cord by weight than the latter. The volume of charcoal produced per cord is about the same for dense woods as for light woods. Consequently, if the charcoal is sold by volume instead of by weight, the lighter woods are in a much more favorable position than is indicated in the examples above.

The conversion of slabs, edgings and woods waste into charcoal offers a much better opportunity for a profitable operation than when wood is cut specifically for charcoal production. Frequently such waste is not readily salable and, in some cases, is a liability to the mill owner because he must pay to dispose of it. If such waste can be delivered to the kiln for the cost of reducing it to lengths suitable for coaling, instead of the $12.00 per cord cited above, a gross profit may be realized from almost any kind of wood.

SUMMARY

Charcoal is an essential material for many extremely diversified users. For some there is no acceptable substitute. Except for a few very specialized purposes, it has been, and probably will continue to be, derived largely from wood. It may be manufactured in apparatus which varies from very simple and inexpensive kilns to very elaborate and costly wood distillation plants. Conversion of wood to charcoal creates an added outlet for low quality wood and wood waste for which there is a rather limited demand. The costs of its production in kilns and other simple apparatus are mostly for labor. The returns are not high, but, if the producer studies the conditions surrounding his operation and carefully conducts the coaling process, he should be able to obtain a greater return from his wood than if he sells it as a raw product. Charcoal consumption in Connecticut is about 10 times greater than production. Some of this consumption could be satisfied by an increase in production in Connecticut.