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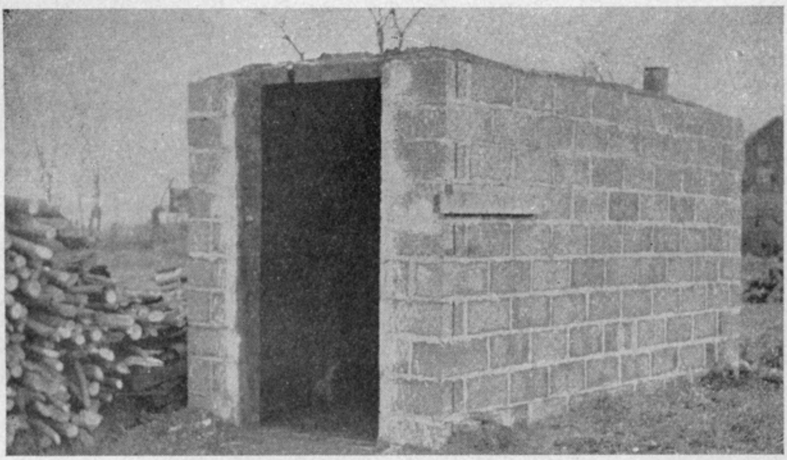

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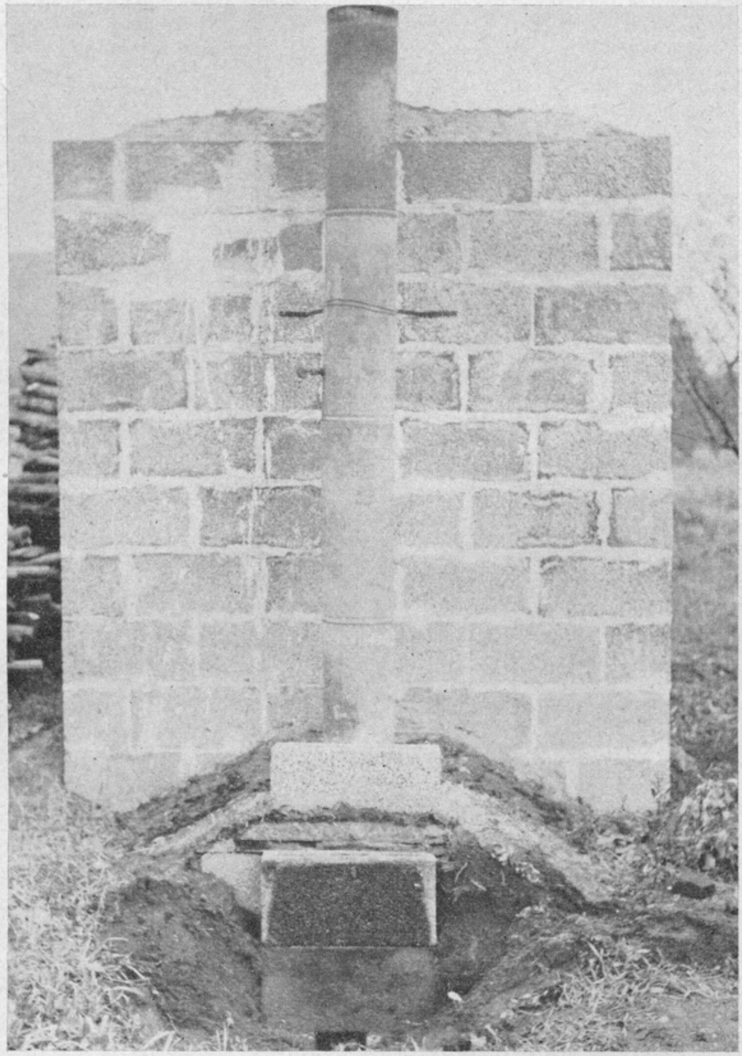

Front view of two-cord kiln with the chimney in place and the chimney stove banked with earth except at the front end.

A CHARCOAL KILN MADE OF CINDER-CONCRETE BLOCKS[1]

A. Richard Olson and Henry W. Hicock

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 limited, combustion is incomplete and the wood is carbonized or charred. The volatile elements are driven off as "smoke" and charcoal and ash remain as solid residues.

The smoke formed under conditions of incomplete combustion is made up of a considerable 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 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. Well-burned charcoal contains from 75 per cent to 95 per cent carbon plus a small amount of ash derived 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, throughout the ages, a great many devices have been developed for accomplishing it. Wood has been carbonized in pits dug in the ground, in heaps covered with sod and in masonry and steel structures. The quantity carbonized in one operation has varied from less than one cord to nearly 100 cords.

[1] The authors wish to make the following acknowledgements:

Of the aid and support given to these investigations by Clifford Ongley, who until his untimely death in September, 1944, was Superintendent of the White Memorial Foundation, Litchfield, Connecticut. His interest in the project was keen and his efforts to bring it to fruition, untiring.

To the White Memorial Foundation, Litchfield, Connecticut, which cooperated in the development of the kilns by furnishing working space and all the supplies, materials, and labor required in the experiments.

To Civilingeniör Hilding Bergström, Stockholm, Sweden, for the use of information included in his two booklets, Kolning i Mila Skorstenmilor (Carbonization in Kilns and Chimney Kilns) and Kolning i Ugn (Carbonization in Ovens), which has been modified for use in the kilns herein described.

To T. Robert Swanback of this Station for translating Bergström's manuals from the Swedish.

It is beyond the scope of this paper to discuss all types of apparatus but a general classification, based on three methods of carbonization, which will cover most conditions, is given to show the relationship of the kilns described in this paper to other kinds 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 limited 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 Group (a), but the structure is more complicated.

(c) Carbonization by heating wood in enclosed chambers to which no air or furnace gases are admitted.

Apparatus in Groups (a) and (b) is generally called a kiln and is usually operated for the production of charcoal, although some of the volatile products in the smoke may also be recovered. Apparatus in Group (c) is generally known as a retort or an oven and is used primarily in the wood-acid industry for the recovery of the condensable acids, alcohols, tars, etc., charcoal production being of secondary importance. The kilns which will be described later in this bulletin are in Group (a).

THE LOCAL SITUATION

Connecticut's annual needs for charcoal are between 10,000 and 20,000 tons. A large part of this is used by the tobacco growers for curing tobacco. The balance is used by many small industries for a miscellany of purposes and by individuals for domestic and camp fires.

Formerly, all the charcoal for local needs was made within the State in sod or pit kilns and many people earned a livelihood in this way. Only native materials were needed to construct a kiln but a great deal of skill was required to assemble these materials and to coal the wood. With the rise of the wood-acid industry in New York and Pennsylvania, charcoal was produced in increasing quantities as a by-product and at a price which forced practically all of the local charcoal burners out of business.

In 1935 a survey was made of the sources of charcoal to supply local needs. The results indicated the desirability of again making charcoal from native woods. Improved methods had been developed for producing acetic acid, methanol, and acetone from materials other than wood and the wood-acid industry appeared to be in a rather precarious position. It was greatly stimulated during the war but, at the present time, operations appear to be at a rather low ebb. There is a current shortage of charcoal for local needs and the desirability of filling these needs by coaling native woods seems to be as great as in 1935.

The initial work with native woods was carried on by the State Forester's office. Several 50 cord brick kilns of the beehive type were built and operated. Later, a private company with large holdings constructed a number of similar kilns.

Work with these kilns indicated that, if the price of charcoal was competitive, the undertaking would return costs but would not show a profit. This was due primarily to the high cost of cutting and transporting wood in an industrial region where labor rates are high. The kilns were quite expensive to build and the monthly capacity was rather low. Furthermore, personnel with the necessary skill to operate these kilns was very difficult to obtain.

In 1940 the Station began experimenting with small kilns. The objective sought was a kiln which could be moved from place to place to accommodate relatively small quantities of wood, which was inexpensive to build, which required a minimum of labor and skill to operate and which would produce good yields.

Station Bulletin 448, published in 1941, describes two rectangular kilns, formed of steel panels, which were the result of these 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.

Shortly after Bulletin 448 was published, priorities were placed on steel and experiments were initiated to develop a kiln, similar to the steel kiln, but built of available materials. After some tests, cinder-concrete blocks were chosen as the most feasible construction material. The balance of this report is devoted to a description of the construction and operation of two kilns built of this material. Some features, not found in the steel kilns, are incorporated in the design of the new kilns. 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 for 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 it is properly assembled, it can be easily dismantled and rebuilt at a new site.

THE CINDER BLOCK KILNS

Kilns of two sizes are described. 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) is shaped to house a 4 x 4 x 8 foot cord, plus the necessary clearances for long sticks 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 capacity of either of these kilns may be increased 25 per cent by increasing the width eight inches to accommodate five foot instead of four foot wood. This will not change appreciably the operations schedule given below. Greater widths are not recommended.

Only meager data are available for kilns of the same design but of larger capacity. These indicate that the ratio of length to height is important and should be about two to one, or perhaps eight to five. One kiln of about five-cord capacity has been built and successfully operated in Connecticut. Its width is sufficient for five foot wood and the ratio of length to height is approximately two to one. The operator, who has had experience in charcoal making in sod kilns, feels that this ratio should be decreased by increasing the height. In summation of the fragmentary information available, it would seem that the capacity of kilns of this type might be increased to about 10 cords. The cost of construction of one 10-cord kiln would be less than five two-cord kilns, but it is doubtful if the monthly output would equal that of the latter.

In the opinion of the authors, an increase in plant capacity can be better accomplished by increasing the number of kilns rather than by increasing the size of the kiln except for the increase in width already noted.

Materials of Construction

The materials used in construction of the kilns are cinder-concrete blocks, sand, cement, lime, a small amount of steel plate, furnace pipe, new or used steel or iron pipe and a few miscellaneous items (see Bill of Materials).

The cinder-concrete blocks are fabricated from screened cinders and 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.

Four stock sizes, all of the hollow type, were used in the experimental kilns (Figure 4 C). The greater part of the construction is of standard 8 x 8 x 16 inch blocks. Two sizes of pier type 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 1/4 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 recommended unless it can be 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. The stove abuts on the front wall of the coaling chamber but is not bonded to this wall. It houses the wood burned to induce draft in the chimney.

Bills of material for the two sizes of kilns described will be presented later. The number of cinder blocks specified therein includes the actual number needed to construct that portion of the chamber 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.

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 desirable. 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 width of the frame members should be eight inches (the width of a block) and the depth about six inches. Such a frame may be built up of any used lumber which is eight inches wide and one inch or more in thickness. Alternatively, it may be made of round timbers which have been hewed or sawed to provide a flat bearing surface eight inches wide. The frame should be assembled above ground and sunk in a trench with the flat bearing surface level and eight 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 foundation 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 eight inches wide and two 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 eight 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 eight 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 purchase extra blocks instead of field stone for use 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 eight 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. This may be done in either of two ways:

(a) The blocks may be laid up dry, i. e., without mortar. When all are in place, the inside surfaces are given a ¼ inch plaster coat of lime mortar and the outside joints are pointed with the same material to prevent leaks.

(b) The blocks may be laid with mortar as the structure goes up. This is considered the best method and is the one herein described in detail. 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 surface is given one or more brush coats of creamy lime mortar to seal the pores in the blocks and any other 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 eight 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 and cement them to each other and to the foundation with mortar. The hole, which is nearest the end wall in pier blocks C, G, N, and K, serves as the air inlet 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 the blocks 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.

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, three feet long, to the side walls as shown in Figure 3B, allowing them to extend about six 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.

Modified Chambers for Five Foot Wood

The net width of the chambers shown in the several sketches is 56 inches. This will accommodate four foot wood with eight inches clearance. Should the builder wish to use five foot instead of four foot wood, he may do so by increasing the outside width from 72 to 80 inches (the length of five instead of 4½ blocks). This will result in an inside width of 64 inches and a clearance of four inches. This smaller clearance will require a little more care in cutting the five 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.

Construction is really easier for a five foot than for a four foot width because the former is an even multiple of whole block lengths instead of half block lengths (16 inches x 5 whole blocks vs. 8 inches x 9 half blocks). It is suggested that the first tier be started by centering a block over the smoke passage in the foundation. Two whole blocks laid on either side of the center block will complete 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. The third tier is an exact replica of the first; the fourth, of the second and so on. The position and type of the blocks in the same tier, but on opposite sides of the chamber, are identical.

Building the Top

The top or roof of the kiln is formed of 4 x 8 x 16 inch partition blocks and 64-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 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 several hours 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.

After all the panels are in place, the blocks should be spaced evenly on the pipes and their top surfaces plastered with a one inch coat of lime mortar. The entire top should then be covered with a layer of fine sand or soil two inches thick to complete the seal. This layer should be maintained at all times.

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 catwalk. This will distribute any moving loads more evenly and prevent failures which might occur from local overloading.

To complete the chamber for operation, it will be necessary to drill holes for firing ports in each side wall just above ground line and to provide a metering device for the air inlets. The ports drilled are just large enough to accommodate a piece of 1½ inch pipe, nine inches long, which is cemented in place. The position of the ports

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

relative to the ends of the kilns is shown in Figures 2A and 2B. The purpose of the metering device is to provide an opening of known cross-sectional area for each air inlet. This may be done in a variety of ways. Perhaps the simplest is to rabbet the edges of two strips of wood, each ¾ x 2 x 10 inches, to accommodate a thin metal slide. Nail these strips on either side of the inlet opening with their edges vertical and parallel and cut a thin metal slide to fit the rabbet. Make sure that no air enters the inlet except through the opening formed by the slide.

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 eight-inch chimney 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 is set in place over the hole in the steel plate. To prevent the chimney from sliding through the plate, cut three pairs of slits, about one inch long, in the lower end of the pipe parallel to its axis. The slits making up a pair should be about one inch apart and the pairs should be spaced about equally around the perimeter of the pipe. After cutting, bend the one inch pieces outward at right angles to form "ears" which will rest on the plate and prevent the chimney from sliding through. A piece of ⅛ x ½ inch strap iron, nailed to the front wall of the chamber, will hold the chimney in a vertical position (Figure 3A). 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 inside front cover).

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 though 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 was initiated at point X directly above the firing ports. Later the zones move 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

Loading is begun by laying two wooden stringers, four 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). Next stand two struts, three to four inches in diameter, against the front wall to permit a free passage for the smoke to the smoke outlet under this wall. Stand a 16 x 20 inch piece of heavy (12 guage) hardware cloth with ½ inch mesh slantwise against the front wall to prevent falling charcoal from blocking the smoke outlet.

For stacking in the kiln, the wood should be rough-graded into three sizes and used as follows:

(a) Small, including sticks two to three inches in diameter, which should be placed on the stringers to a depth of 12 inches and in the zone directly above the kindling (see Figure 4B).

(b) Medium, including sticks four to five inches in diameter, which may be used anywhere in the kiln.

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

All wood is piled at right angles to the stringers and should be packed as closely as possible (Figure 4B). Piling should be started against the struts and proceed toward the firing ports. When these are reached, lay kindling and oil soaked rags between them. Above the kindling, pile brands, dry wood and small wood to half the height of the kiln. Continue piling toward the rear end, using the several sizes of wood as recommended above. While loading, be sure that the air inlets and firing ports do not become clogged with bark or other material.

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 I and II) will be presented later for both sizes of kiln when used with seasoned hardwoods. Firing procedure, which extends over a period of 45 minutes is the same for both. 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 accomplished 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 the two ports which are left open for ½ hour. During this period the air inlets are closed and the chimney damper is in a fully open position. Fuel is added to the chimney stove as needed to maintain a good chimney draft.

This completes the firing period at the end of which both firing ports are closed and banked with sand or soil. The kiln is now ready to start coaling.

Coaling

The object from now on will be to develop the coaling zones and to conduct them through the wood at a rate which will result in completion of the burn at both ends of the kiln at approximately the same time. The time required to coal is different 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. At the beginning of this period, both B Air Inlets are opened; later the A Air Inlets are opened. (See Tables I and II). This period lasts 3½ hours for the one-cord and five hours for the two-cord kiln. When it is over, the chimney damper is set in a "half open" position. Coaling action is now strong enough to maintain its own draft without fire in the chimney stove and the latter is closed and banked.

(2) Final coaling period. With the air inlet openings and damper set as described at the end of the initial coaling period, the kiln is now 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.

Closing and Cooling

If the wood has been properly stacked in the kiln and the air inlet openings have been of the right size, the coaling zones should reach all the 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 the inlets have all been closed, the chimney should be removed and the hole in the steel plate covered and banked with soil. The kiln should be inspected carefully for leaks in the walls and top. Leaks in the latter may be stopped with sand. Leaks in the walls may be plugged by brushing with creamy lime mortar.

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 given below 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. If a thermometer is available, take the interior temperature 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.

After taking down the door panel, observe the depth and eveness 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

The following tables give complete operations schedules for the one-cord and two-cord kilns when used for coaling oak, maple, birch

Table 1. Schedule of Operations

One-Cord Kiln (Seasoned Hardwoods)

Operation		Duration (hours)	Typical time schedule	Air inlet openings (square inches) "A" Inlets (each)	Air inlet openings (square inches) "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.
Firing	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	
Coaling	Initial period	1½	3:45 to 5:15 P.M.	3.0	2.5	Fully open	Closed	Strong fire	
Coaling	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
Cooling	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)

	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.
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 A. M., Friday
Cooling	Without Water	120	8:00 A. M., Wednesday to 8:00 A. M., Monday	....	....	....	....	....	Kiln opened at 8 A. M., Monday

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

and other dense woods cut in the winter and seasoned in the pile during the following summer. The moisture content ranged from 30 to 40 per cent (dry basis). The sticks ranged in diameter from three to seven inches and the material could be classified as grade 1 hardwood fuel.

These schedules should be used by the operator as a guide. They have been employed successfully with the kind of wood described above and, with minor modifications, on wood of other species, sizes and moisture content. It should be remembered, however, 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 to conditions. So, in the last analysis, the operator must modify the instructions to suit his own conditions. The schedules have been 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.

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 small percentage of fines, 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 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. To remedy this, close the chimney damper slightly on the next burn.

A burn which has been conducted too slowly will usually have a pocket of ashes near the firing ports and an excessive amount of brands near the ends of the kiln. Apparently what happens is that the air supply coming in at the air inlets is insufficient to keep the coaling zones moving but is sufficient to cause local burning of charcoal already formed. The remedy is to open the chimney damper slightly on the next burn.

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. A burn conducted at a fast rate will be successful in that most of the wood will be coaled. The charcoal, however, will be light. It may be entirely satisfactory for some uses, but it is unsatisfactory to the producer who sells by weight instead of by volume. A burn which is conducted too slowly will, as indicated above, not only coal badly or not at all, but will also burn up the charcoal as fast as it is made. Such a condition should be avoided at all costs.

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 ½ and ¾ 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 the draft should be equivalent to about 0.02 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.

Character of the Smoke

Color and volume of the smoke issuing from the chimney about one hour after the chimney stove has been closed and banked are good indicators of coaling progress, once one has learned to evaluate them. When the kiln is coaling satisfactorily, there should be a good volume of grayish-white smoke. If the volume of smoke is small, coaling is probably progressing too slowly and the damper opening should be increased. An appreciable amount of yellow color in the smoke indicates that coaling is progressing too rapidly and the damper opening should be decreased. The volume and color of the smoke should remain fairly constant until near the end of the final coaling period, at which time the smoke tends to thin out and turn bluish. This indicates that it is nearly time to close the kiln.

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 tar mass may be removed by running a long slender pole down the chimney pipe. It is a good practice to perform this operation two or three times during the last two hours 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 takes place through combustion. It is better, therefore, to close the kiln within an hour after glowing is visible. 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 brands arising from these causes.

Size and Shape of Wood

All sizes of wood up to seven 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.

With wood of a moisture content approximating that indicated in the tables above, sticks of smaller average diameter (two to four inches) should be coaled with slightly smaller air inlet openings and slightly less chimney draft than is indicated in the tables. Larger diameter sticks (five to seven 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.

The two following statements are estimates by the authors and are not based on experience.

(1) It should be possible to use the kilns to coal odd shaped pieces of refuse wood such as trimmings, blocks, etc., which accumulate around wood working establishments, provided the moisture content is not too low and the pieces do not vary too much in size. It would be necessary to floor the stringers with scrap boards (spaced 1 inch apart) and to face the struts with the same material. It might also be necessary to bridge the air inlets on the inside to prevent stoppage with small pieces of wood.

It will probably not be feasible to hand pack material of this kind. It would seem that the most satisfactory method of loading would be to remove the center top panel and dump the pieces through the opening, raking them as they fall to settle them into place. Under these conditions the pieces would not be very closely packed and the yields would, consequently, be rather low. An operations schedule would have to be worked out.

(2) It seems almost certain that sawdust, shavings, hogged wood and similar small waste cannot be coaled in these kilns. Circulation of air is necessary to the movement of the coaling zones. Fine material packs so tightly that such circulation would be almost completely shut off.

Moisture Content (dry basis)

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.

Although no wood of low moisture content (below 20 per cent) was coaled in the kilns described, the literature on carbonization indicates that such wood does not coal readily or produce good yields. Kiln dried scrap lumber would fall in this category.

The best results with the kilns were obtained when coaling wood with less than 40 per cent moisture. Good results were also obtained with unseasoned hardwoods (moisture content about 80 per cent), the yields being about 80 per cent of those from the same kinds of wood which had been seasoned during one summer. Unseasoned conifers generally have a much higher moisture content than hardwoods (in some cases 150 to 200 per cent or 400 gallons of water per cord) and, while they can be coaled, the yields are very low. These can be improved very materially by one to two months of summer seasoning in the open. In one case where this was done with Scotch pine, the yield was increased from 19 to 29 bushels per cord or about 55 per cent.

When coaling unseasoned hardwoods and semi-seasoned conifers, it was found necessary to increase the size of the air inlet openings by approximately 50 per cent over the values given in the tables and to have the chimney damper three-quarters instead of one-half open.

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

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	30 – 40	46	920	6
Unseasoned hardwoods (Oak)	80	38	760	2
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.

adding greatly to the cost of construction, it would be almost impossible to make the chamber absolutely 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 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. Small leaks in vertical surfaces and around the door blocks are easily stopped by brushing over with creamy lime mortar, a pail of which should be on hand at all times. 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 discernible 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. They are very important during the cooling period, when no air should be allowed to leak into the kiln, and should be guarded against by all possible means.

Life of the Kilns

The experimental kilns have been used for more than 50 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 100 or more burns if they are not moved. If they are dismantled and rebuilt, there would undoubtedly be some breakage. The excellent condition of the door blocks, which have been taken down and relaid more than 50 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

Kind of material	Nominal dimension	Number of pieces	
		One-cord kiln	Two-cord kiln
Cinder-concrete blocks[1] (Hollow type)			
Standard	8″ x 8″ x 16″	145[1]	225[1]
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″ 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 specified is the actual number needed to construct that portion of the chamber 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.

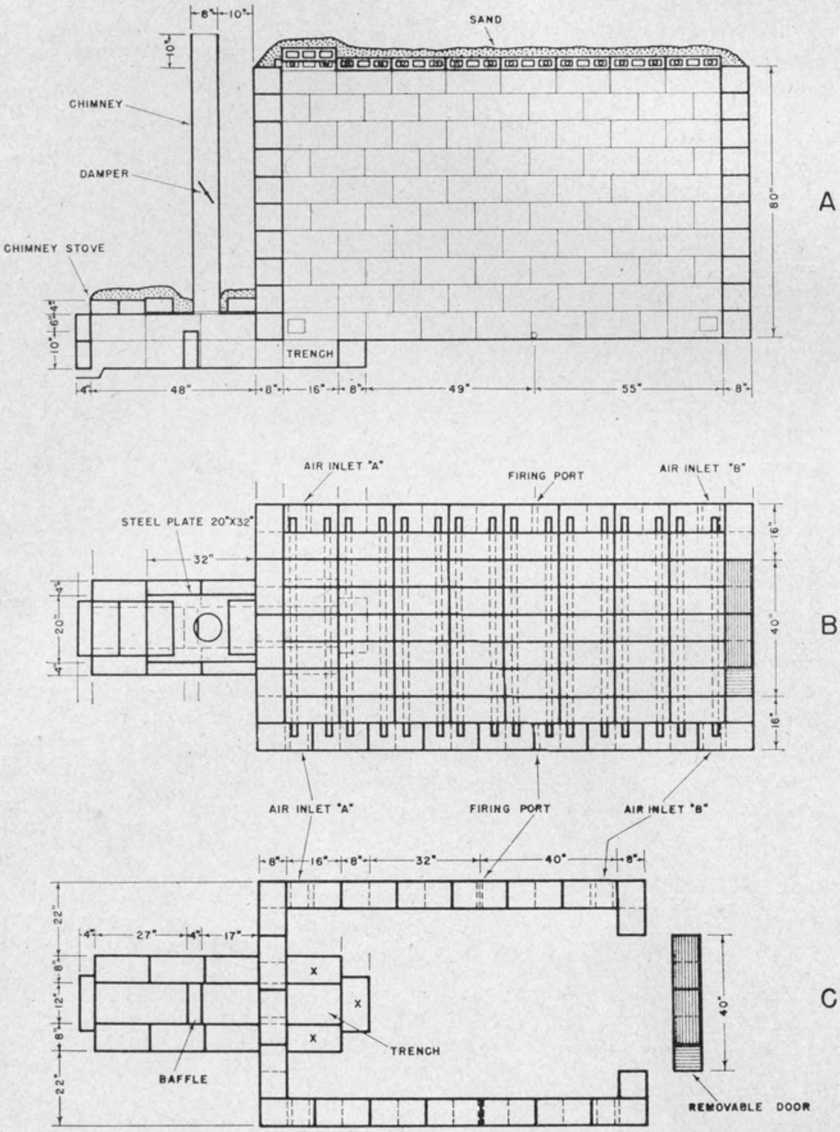

FIGURE 1

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.

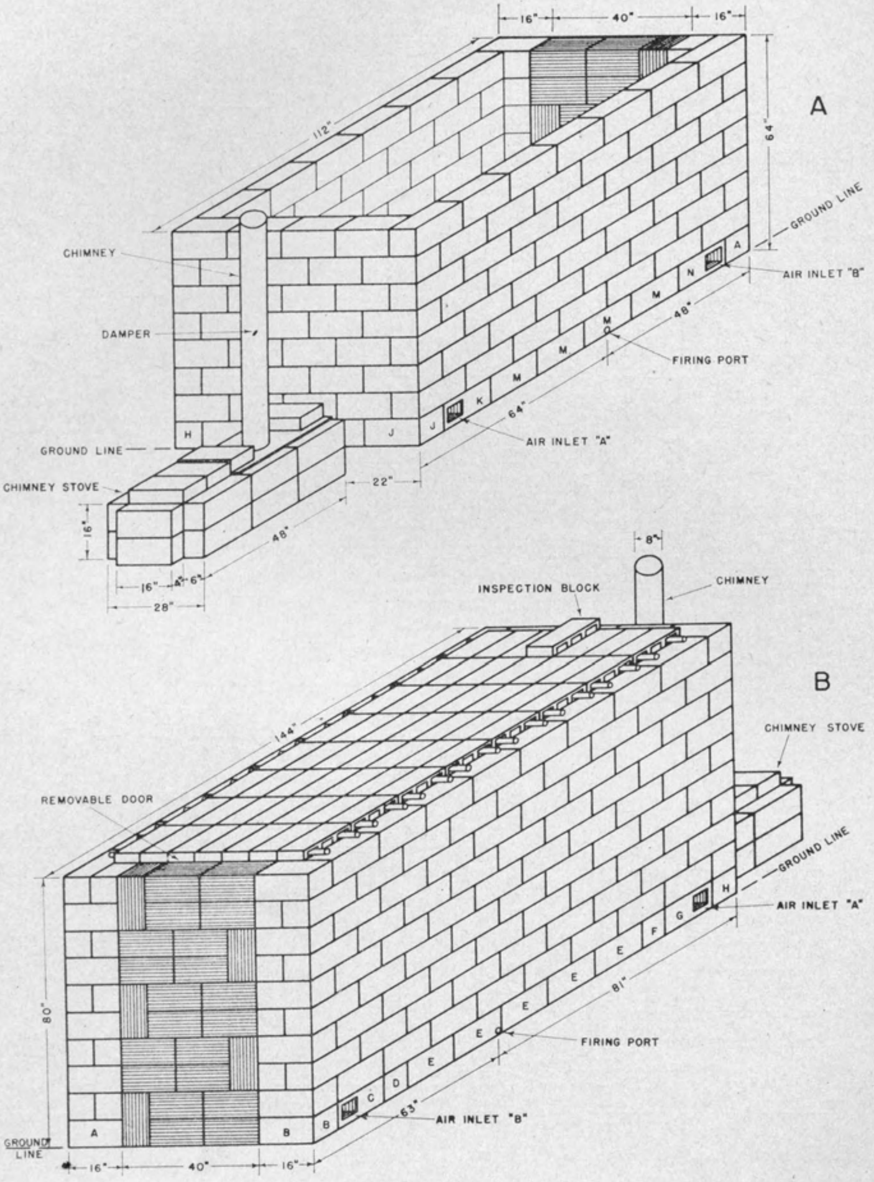

FIGURE 2

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.

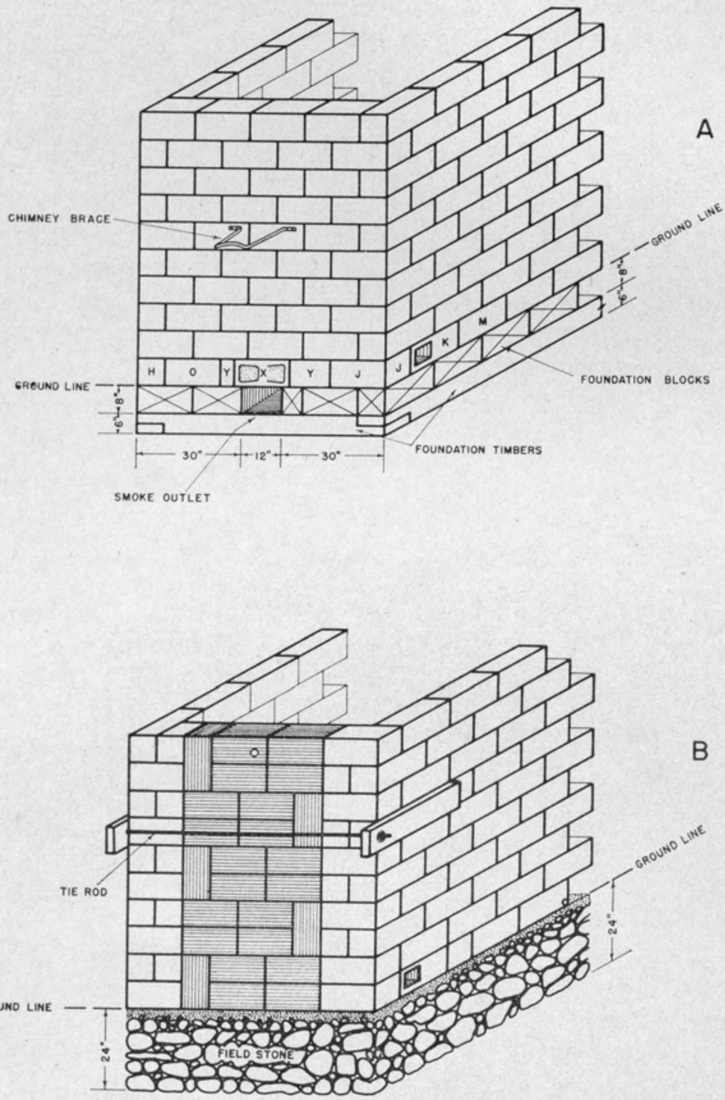

FIGURE 3

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.

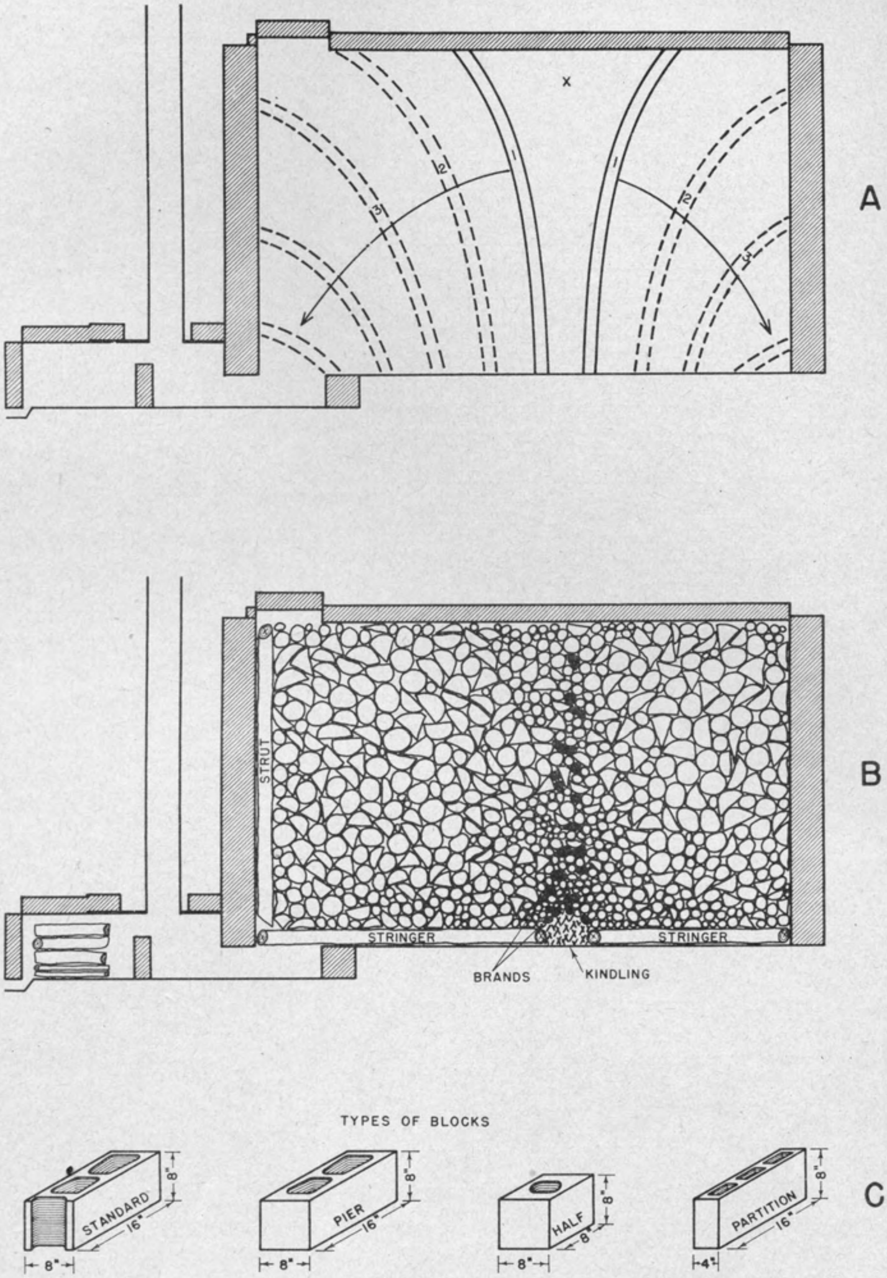

FIGURE 4

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.