PRODUCTION OF CHARCOAL IN A
MASONRY BLOCK KILN - STRUCTURE
AND OPERATION

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MADISON S. WISCONSIN
Acknowledgment

This report provides the initial results of the Forest Service Research program on charcoal production. Forest Service personnel intimately connected with the project are: Southeastern Forest Experiment Station, Walton R. Smith and Ralph Peter; Lake States Forest Experiment Station, Arlie W. Toole, Carl Arbogast, and Paul H. Lane; Forest Products Laboratory, Edward G. Locke, Edward Beglinger, E. C. O. Erickson, Spencer M. Munson, Boyd M. Witherow, and Arthur L. Koster. Much of the success of this project is due to the excellent cooperation of many organizations, such as: Minnesota Iron Range Resources and Rehabilitation Commission; St. John's University, Collegeville, Minn.; Cliffs-Dow Chemical Company; North Carolina Conservation and Development Commission; Kingsford Chemical Company; the University of Minnesota; and the University of Georgia.
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PRODUCTION OF CHARCOAL IN A MASONRY BLOCK KILN--

STRUCTURE AND OPERATION

Compiled by the Forest Products Laboratory

SUMMARY

Plans, construction details, a bill of materials, and operational procedures for a square, double-walled, masonry block structure of 7-cord capacity are presented. The structure includes three smoke stacks, a single front entry for regulated air input, steel doors, a sectional steel ceiling, and a protective roof on independent supports. The kiln is sufficiently large to permit end-to-end loading of three tiers of 4-foot wood or two tiers of 5-foot wood. Satisfactory yields of market quality charcoal are obtained with comparatively short coaling periods and at minimum coaling temperatures. Kiln temperature can be observed with low-cost instruments.

CHARCOAL DEMAND AND PRODUCTION

Numerous large and small kilns of various types produce charcoal commercially. In general practice, these units are of masonry block, reinforced concrete, sectional sheet metal (1, 4, 5, 23), and, for the larger beehive type, of brick or ceramic tile construction. Over one-third of the present total yearly production of charcoal is estimated to be by the kiln method. Although byproduct plant facilities are limited, flexible methods of kiln production can keep pace with the growing recreational needs for charcoal. As this expansion occurs, there should be greater possibilities for the integration of kiln production with forest management for the fuller utilization of noncommercial forest species and mill residues.

FOREST SERVICE INTEREST AND INVESTIGATIONS

The pressure for increased charcoal production (1, 2, 6) has created the need for masonry block kilns of larger than 1- and 2-cord capacities. However,

Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Underlined numbers in parentheses refer to literature cited at the end of the text.

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little recent information has been published on masonry block kiln design other than that on the small units developed and reported by H. W. Hicock and associates of the Connecticut Agricultural Experiment Station (9, 10, 14, 15).

Commercial kiln inspections conducted in recent years have further established the need for improved kiln facilities and operational procedures. Lacking basic information on the design, operation, and production economics of the moderate-size kilns of 5- to 10-cord capacities, the Forest Service considers further experimental work on these subjects essential. During the past 2-1/2 years, the Forest Service has initiated a number of cooperative field studies utilizing 2-, 3-, 7-, and 10-cord experimental kilns, in order to examine (1) the behavior characteristics of various structural materials, methods of construction, and structural components; (2) the development of operational procedures and controls; and (3) the effects of the use of various types of raw material on operating methods and yields. These studies are in progress at the following locations:

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While these studies are not complete, they are sufficient to provide the initial structural and operational recommendations included in this report. Revision of these recommendations will be made as more complete data are developed.

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This report incorporates information obtained from the several experiments into a single kiln design that provides extended application and flexibility of use, minimum maintenance, and reliability of control. This design conforms closely to the experimental unit located at Athens, Ga., which is also square in plan and of 7-cord capacity. The results so far obtained are from a series of 16 runs, 12 of which utilized seasoned and 4 unseasoned charge material. The results dealing most importantly with the species, coaling times, and charcoal yields are shown in table 6. The most prominent variables in the investigations thus far are wood moisture content, air volume input and location, chimney location, ignition and coaling temperatures, and ignition fuel amount and procedure. Another experimental kiln of similar design and capacity is operating in the Dukes Experimental Forest near Marquette, Mich. Investigations have recently been started at this location and as yet only limited operating data are available. On the basis of preliminary results, it is expected that an operation comparable to that of the Athens kiln will be obtainable. Both kilns are of double-wall, masonry block construction with multiple stacks and a sectional metal ceiling unit. The walls and ceiling are sealed against passage of volatiles by a layer of fine sand. The kiln proper is protected from the weather by a pitched roof.

WOOD CARBONIZATION IN KILNS

In the direct or kiln-burning method of producing charcoal, the primary heat necessary for carbonization is furnished by partial combustion of the wood. Additional amounts are subsequently provided by the reaction heat during the course of conversion. Combustion is retarded as needed by limiting and regulating the amount of air admitted into the kiln.

After an initial surface zone of dry wood has been established, and upon addition of further heat, the wood decomposes and charcoal is formed. In addition to the heat given off as the wood decomposes, the heat required for carbonization or coaling conditions is supplied both by combustion of the wood decomposition gases and vapors and by the portion of the wood that carbonizes. Similar conditions occur progressively throughout a kiln charge of wood. Water vapor and other volatiles that are supplied with too little oxygen for complete combustion escape as smoke through the kiln stacks. The most important ingredients of this smoke are acetic acid, methanol, and tars. Recovery of these chemicals would be impractical, because of the small amounts of these crude condensed volatiles that would be recoverable from kiln operations, and because of the heavy investment required for condensing and refining equipment.

On the average, carbon for charcoal production is available in wood up to about 50 percent of the dry weight. At least as much is available in hardwood barks, but softwood barks contain somewhat less carbon on the average than does wood. Yields of charcoal from the bark may therefore be similar to or probably greater than the amount recovered from the wood.
The charcoals made by controlled kiln burning and in externally heated recovery-plant ovens have properties in common. The amounts of moisture (2 to 4 percent), volatiles (18 to 23 percent), ash (2 to 4 percent), and fixed carbon (74 to 81 percent) in charcoal largely determine its quality for general market acceptance. Production of charcoal with these amounts of components assures not only good quality but a maximum yield per kiln charge as well. Charcoals produced with somewhat lower amounts of volatiles and correspondingly higher amounts of fixed carbon are more desirable for specialized industrial uses. These charcoals may be produced with overall kiln temperatures somewhat higher than those within the recommended operating range of 850° to 950° F. Their production will result in reduced yields and possibly shorter kiln life.

KILN CONSTRUCTION

General

Plans for the erection of a 7-cord charcoal kiln of concrete masonry blocks are presented in figures 1 to 8. Figure 9 shows a scale model of this kiln. The coaling chamber is 13 feet 4 inches by 12 feet 8 inches, enclosed by a 24-inch thick wall comprised of two 8-inch masonry walls with an 8-inch fill between. The kiln has two side-hinged steel doors, a sand-covered sectional-type steel ceiling, and a metal roof carried on simple wooden trusses and independent wood pole supports. Three chimneys or smoke stacks are located one each at the center of each side and back wall of the kiln. Each stack is simply supported on steel plates placed on loose concrete blocks that abut the main structure but are not bonded to it; the chimney blocks rest directly on the ground. Ordinarily, very little weight is imposed on the blocks, so that no formed foundation is needed. The only requirement is that blocks abutting the kiln proper be removable. In some cases, however, soil conditions may require a footing or some form of foundation under these chimney blocks.

The plans are believed to provide sufficient detail to enable an average handyman to build a satisfactory structure. Also included are instructions for building the kiln and a complete list of the materials required. It is assumed that all of the items specified under Bill of Materials, tables 1 to 3, will be readily available in most localities.

The average cost of building the kiln illustrated in figure 9 with side-hinged steel doors is estimated at $1,800 ($1,000 for material, $800 for labor), based on present-day material costs and labor rates in the Midwest. The actual cost in other areas may vary as much as 10 percent or more, depending upon location and accessibility of material.

Local conditions of weather or availability may require some construction changes, such as depth or type of footing, pitch of roof, type of ceiling...
Each of the basic design features of the kiln presented here has proven satisfactory in a few operations of various experimental units. The structural plans given here have been proven only in about a dozen experimental runs. Thus, the life expectancy or permanence of this structure can be predicated only upon the excellent performance of similar materials as used in many commercial kilns and in many coaling operations. For example, cinder concrete masonry units in single-wall rectangular structures of 7-cord capacity have continued in service through 150 to 200 coaling operations under normal operating maintenance. The sheet metal ceiling suspended from exterior supports, the multiple stacks, and the double-wall feature, all designed to reduce the continual maintenance requirements of single-wall structures, have been used successfully in commercial-size kilns.

A study of both commercial and experimental kilns has indicated that the life expectancy of masonry-type kilns is largely dependent on two conditions: the quality of the masonry units and the operation at lowest efficient coaling temperature (12, 13, 21, 22). Operating temperatures are discussed under operating procedures elsewhere in the report, so only quality of units will be discussed here.

**Quality of Masonry Units**

Cinder concrete units—comprised of screened and graded cinder aggregates obtained by crushing bituminous coal clinkers—have given the best performance of any of the materials commonly used in masonry block kilns. Other lightweight aggregates obtained by crushing clinkers of expanded steel mill slag (Waylite) or of native shale (Haydite and Shalite) and, to a lesser degree, the standard sand and gravel units (American Society for Testing Materials designation C90-44) have been used in some operating kilns. However, the expansion of these aggregates is greater than that of the cinders, when exposed to the high kiln temperatures, so that the cinder concrete is favored because of less contraction and expansion and cracking of wall units, and consequently less continual maintenance.

Graded cinder aggregate and screenings have been combined with Portland cement in various formulas. Many block manufacturers have their own proven formulations, some based on weight, and some on volume. One such 14-cubic-foot batch of cinders at 5 to 10 percent moisture content combined the following components: 25 to 35 percent of 5/8-inch aggregate; 25 to 35 percent of 1/4- to 3/8-inch aggregate; 30 to 50 percent of less than 1/4-inch aggregate; 1-1/2 sacks of air-entrained Portland cement; 2 tablespoons of a plastic additive; and 5 to 6 gallons of water.
In localities where limestone is available, limestone screenings have been combined with graded cinders and standard Portland cement to form a dense, moist-cured block of exceptional performance. For example, blocks of the following formulation have given satisfactory service through more than 150 coaling cycles, under commercial operating conditions: 440 pounds of graded cinders; 100 pounds of 1/8-inch limestone aggregate; 200 pounds of limestone screenings; 100 pounds of Portland cement; and just enough clean water to make a workable mix.

Any dense, moist-cured cinder concrete unit will be acceptable. In fact, if cinders are not available, any of the masonry blocks using other lightweight aggregates may be used. They will, of course, be more apt to crack and will be likely to disintegrate earlier than blocks of cinder concrete.

With whatever material is used, complete shrinkage of units before laying is important. If the units are artificially dried after the usual damp curing and drying below the normal moisture content, they will be less apt to shrink and crack when exposed to kiln temperatures.

**Workmanship in Laying Masonry Units**

Good workmanship in laying the block is next in importance to quality itself. Careful tooling of mortar joints will assure tight joints either concave or V-shaped; raked, stripped, or struck joints are not acceptable. Joints should be uniform and not over 3/8 inch thick. If an experienced mason is not available for laying up the masonry block, a good construction reference should be consulted; one such reference is A.I.A. File No. C, "Facts about Concrete Masonry," published by the National Concrete Masonry Association, 38 South Dearborn Street, Chicago 3, Ill. If neither a mason nor reference data are obtainable, the following general instructions for building the kiln may serve as a guide.

**Selection of Site**

Choose a site that has good drainage and is nearly level. This will insure a dry work area with a minimum of heaving from frost action and a minimum of grading and leveling. If the kiln is set up on a slope, excavate deeply enough at the back when leveling the floor to permit the front end footing to rest on undisturbed soil rather than on compacted fill.

**Footings**

Stake out the kiln on the ground to the exact dimensions shown on the footing plan (fig. 1). Set up batter boards at the kiln corners, and stretch...
lines between boards directly over the outside edge of the footing. Bring
tops of boards to the same level, so that depth measurements can be made
from these lines. Corners may be squared either by laying out 6- by 8- by
10-foot triangles with the 6- and 8-foot dimensions at the corner (or any
multiple of 3, 4, and 5), or by adjusting opposite corners to equal diagonal
dimensions. Using the lines as guides, excavate a trench for the 24-inch-
wide and 32-inch-wide segments of the 12-inch-deep perimeter footing.

If full-depth side forms are used, trenches must be a few inches wider than
the final footing. When the soil is firm enough to serve as side forms, a
raw trench may suffice; however, forming at least the top 3 or 4 inches will
prove helpful in striking off the top of the concrete and establishing a true
level surface at top of footing. Side forms may be 1-inch boards or plywood,
supported by 2 by 4 stakes spaced about 2 feet apart. Place reinforcing bars
as shown on plans either by supporting each on standard bar chairs and
wiring to forms or by pouring the bottom 4 inches of concrete and then plac-
ing bars on top of this layer before completing the pour.

If footings deeper than those shown on the plans are needed to extend below
the frostline (in areas where the ground freezes or to conform to local
requirements), the lower portions may consist of local rock or coarse
aggregate in a mix leaner than the 1:2:4 upper portion. Do not pour con-
crete on frozen ground. If the footing is poured in cold weather, heat the
water, sand, and aggregate before mixing, and protect the green concrete
from freezing for at least 48 hours.

The 8-1/2-inch square chimney tile smoke outlets must be installed with
their bottom inside surface flush with the top of the footing in order to stay
within the nominal 8-inch height of the first course of masonry. This may
be done either by working each tile into its proper position after striking off
the top of the footing and before the concrete sets up, or by inserting 8-1/2-
by 5/8-inch boards anchored to side forms when leveling the top of the
footing.

The kiln floor may be of earth as shown, or a 3- to 4-inch thickness of con-
crete may be added any time after the kiln has been completed. If a poured
concrete floor is added, be sure to provide some wire-mesh reinforcing at
midthickness; also, make allowance for expansion of the slab against the
inside edge of the footing. This can be done before pouring the floor by
tacking strips of fiberboard sheathing or any removable strips of 1/2-inch
material along the edge of the footing.

Walls

All of the cinder-concrete masonry units used in the walls are nominal 8-
by 8- by 16-inch hollow blocks. Three types of the standard three-core
oval units are recommended: stretcher, corner, and pier types. Pier or
stretcher blocks could be used throughout if other types are not available. Likewise, solid or two-core units could be used, but the three-core oval type with full mortar bedding is recommended.

Mortar joints may vary from 1/4 to 3/8 inch between blocks; the thickness will be determined by the block dimensions required to build to an 8-inch vertical module and a 16-inch horizontal unit of measurement. Use a good grade of masonry mortar with two parts of mortar sand, or prepare the following mix as needed: one volume of Portland cement; one volume of lime putty or hydrated lime; and four to six volumes of damp, loose mortar sand. Add just enough water to produce (after thorough mixing) a moderately stiff mixture which can be easily worked. Do not use any mortar that has begun to set up before it can be properly bedded and pressed into final position.

The base course of the masonry walls is shown on the footing plan (fig. 1); it is very important that this first tier of blocks be carefully laid as indicated. If the base and second courses are accurately laid, the balance of the blocks will fall into place with all joints perfectly broken. All blocks are laid with the hollow cores vertical, except for the three second-tier blocks between the walls and over the three chimney tile, which are laid with the hollow cores horizontal (fig. 2).

It will be advantageous to have an experienced mason lay the masonry walls. However, if a mason is not available, the following procedure may be followed.

Lay out the base course in the dry (i.e., without mortar) to check position of blocks and measured dimensions. Mortar the base course accurately to the footing. Press blocks carefully into the mortar and level accurately lengthwise and crosswise. Above the base course, stretch guide strings between vertical corner posts, rather than between the batter boards. Keep blocks being laid about 1/16 inch away from the guide string.

When large blocks are used, it is customary to stand them on end and butter one end of each block before laying it in the wall. Press each block firmly against the blocks previously placed. Vertical head joints and horizontal bed joints will average from 1/4 to 3/8 inch. Excess mortar that is squeezed out between joints as the units are placed should be struck off flush. The mortar should be compacted firmly against the blocks with a small trowel or pointing tool. Pointing helps to produce tight, strong joints and should be carefully done on both sides of each wall. Be sure to keep masonry units dry until they are laid in the wall.

Wire wall ties are shown in position on the second course of blocks (fig. 2). These wire ties should be carefully made, and placed as shown on top of the second, fourth, sixth, eighth, and tenth courses as the laying of courses progresses. Also, strips of wire mesh are called for at the tops of the tenth and eleventh courses of the inside and outside walls, respectively. This wire mesh will support the mortar filling used to seal up the cores of
the top courses. Be sure to provide the 3/4-inch clearance required between the angle iron doorway lintel and the adjacent front wall blocks (fig. 3).

Neat cement may be used to level off the tops of the front wall blocks against which the bottom of the lintel must bear lightly in order to seal off the ceiling cover. Use a piece of bright sheet metal flashing between the lintel and the top of the wall to permit the lintel to slide easily along the wall during the first few coaling cycles.

It will also be necessary to provide some means of retaining the sand at the ends of the angle lintel. This may be done either with glass wool, or by placing a sheet-metal corner flashing against the blocks at the ends of the lintel. A simple sheet-metal corner unit consisting of a bottom and two adjacent sides could be cut from the common 1-gallon can.

Construction of the outer and inner walls should be carried forward at the same time. When four or five courses have been laid and the mortar set up, add dry loose soil or sand, a little at a time. The dry fill should be lightly rodded or tamped with a pointed rod or small pipe to consolidate the fill and to prevent it from lumping and arching between walls. This fill should extend a few inches above the inner wall and become a part of the ceiling cover. After the kiln has been completed and the mortar fully cured, a brush coat of Portland cement paste applied to the inner wall is recommended to help seal the surface.

**Metal Ceiling**

A plan view of the steel ceiling over the coaling chamber is shown in figure 3. It consists of I-beam supports, pipe supports and pipe hangers, a tri-rib type of steel roof decking, and an angle iron doorway lintel.

The 6-inch, 12.5-pound I-beam supports for the steel ceiling are shown centered over 8- by 8-inch bearing plates that have been bedded and leveled in mortar cement. This beam size is the minimum allowable for strength requirements at the spacing shown. Other means of support—such as pole-type beams, timber beams, or second-hand railroad rails or steel beams—could be used. However, any substitutions made must be at least equal in strength to the beams shown; otherwise, beams must be spaced closer together. Under no circumstances should the spacing between beams be increased or the size of supporting pipe reduced. Beams and bearing plates are left loose and not restrained by any anchor bolts.

If some form of tri-rib steel decking is not available, use 18-gage corrugated sheet-metal roofing or the equivalent. Likewise, if the more desirable full-length 14-foot sheets are not available, 8-foot lengths may be lapped from 18 to 24 inches at the center of their width. If neither of these is available, a last alternative would be 7-foot lengths lapped about 6 inches.
When 14-foot sheets are used, the ends of cover No. 1 should be cut back about 1/2 inch in order to provide the same amount of end clearance shown for the lintel (fig. 3).

The four smoke outlets or ceiling ports indicated on the plans are most easily made before installing the ceiling sheets in which they occur. First, cut the ends of each 5- by 17-inch opening almost to the full width between ribs, and then either make two lengthwise cuts to complete the opening, or, make a single lengthwise cut down the center, and bend up each half vertically to form the sides of the opening. Construct the metal sleeves for adjustable vent caps as detailed in figure 3, and bolt or weld each sleeve in place. Welding or bolting of sleeves may be avoided by forming the outlet with the single lengthwise cut and by extending the horizontal end legs of the sleeve from 2 to 3 inches, relying on the sand cover to hold the sleeve in place.

Ceiling elements are installed in the following manner and sequence:

1. Install the I-beams on the bearing plates and attach the angle lintel to the adjacent I-beam as detailed in figure 7.

2. Temporarily hang the pipe hangers on the second and rear I-beams. Slide the 2-inch pipe supports through these hangers and place the pipes in the exact spacing shown on the plans.

3. Slip the front ceiling sheet into place over the pipes and lintel flange and place exactly as indicated on the ceiling plan. Invert the front row of five hangers over the front I-beam in proper position over the pipes, and mark the locations of the holes in the ceiling steel through which the legs of the "U" bolt will pass. Number each pair of holes and their corresponding "U" hangers for proper orientation when reinstalling.

4. Remove the inverted "U" bolts and place the marked sheet on top of the I-beam; cut out the holes with a cold chisel or by any preferred method.

5. Replace the steel sheet and insert the "U" hangers from underneath, straddling the pipe by placing "U" ends through the corresponding numbered pair of holes. Place washers on each leg of the "U" so they will rest against the top of the ceiling steel and thus prevent the ceiling sand from running through the holes (a packing of glass wool around legs of the "U" bolts will also help to prevent flow of sand). Then place the 5/16-inch strap iron supports over the I-beam with the legs of the "U" bolt passing through the holes in the strap; turn the nuts down sufficiently on the ends of the "U" bolt legs to lift the 2-inch pipe until it just touches the bottom of the lintel.

6. Place the succeeding sheets in turn in the order indicated on the plans and repeat the operations described above for each row of hangers, tightening the hangers firmly against the 2-inch pipes. Note that sheet No. 7 must be installed with the ribs down, so that it may serve as a puff plate.
that will be easily lifted or forced upward for instant relief of small internal explosions. It is desirable that the ends of this inverted sheet be packed with glass wool to minimize sifting of sand into the kiln.

(7) After installing the caps on the four ceiling openings, spread no more than 3 inches of dry sand on top of the ceiling. Then bank sand around the edges of the ceiling with bank sloping upward to the top of the outer wall.

**Roof Structure**

A good roof will keep driven rain from adding weight to the ceiling loads and from wetting and corroding the metal components. A corrugated metal roof over purlins on simple wood trusses with nailed joints is recommended (fig. 4). The trusses are designed for a snow load of 30 pounds per square foot and stress-graded lumber with a bending stress rating of 1,400 pounds per square inch. Roof supports independent of kiln walls are recommended as shown in the plans.

Poles pressure treated with coal tar creosote will give longer service than untreated poles. They should be ordered about 2 feet longer than the minimum dimensions shown on the plans to allow for deeper holes where soil of poor load-bearing quality is encountered. A minimum top diameter of 4 inches and a length of 16 feet should be ample. Holes should be from 6 to 8 inches larger in diameter than the butt of the pole to allow for tamping of fill after tops have been aligned and fixed into position. Make sure the bottom of the hole is clean and in firm ground; otherwise the pole may settle after erection.

Poles may be plumbed either on the outside—with all the taper left on the inside—or vice versa. Each pole can be held in the desired plane by a temporary brace from about midheight to an adjacent side stake driven into the ground. The 2- by 4-inch stringers used for pole alignment and support of trusses are nailed to the poles, and further reinforced with vertical 2- by 4- by 24-inch seat cleats nailed to each face of the pole.

Note the two positions of the roof purlins at the eaves as shown in Sections AA and BB (figs. 5 and 6). The left half of section AA has been taken at the centerline of the left side chimney and shows the eave purlin set back just enough to clear the chimney. The right half of section AA was taken further back in the adjacent roof bay to show the normal position of purlins at the eave line outside the chimney area.

**Chimneys**

The three chimney bases are constructed from loose pier-type cinder concrete blocks placed directly on the ground, with loose steel plates resting
on the blocks. Each of the outside plates is used to support an 8-inch-diameter metal chimney with insulation to a height of 3 to 4 feet around the base of the stack. This insulation may consist of a thin collar of earth held in place by small steel drums from which the ends have been removed, or by whatever other means may be at hand. A discussion of the functional use of these chimney bases is included in the section covering operational procedures.

Doors

This kiln has a wide door opening designed to accommodate mechanical equipment and platform trucks. The smooth front face of the kiln permits use of steel doors held flush against the angle lintel over the doorway opening and the blocks at each side.

Details for the fabrication of twin doors of single sheet steel and angle frame construction are given in figures 7 and 8. Fourteen-gage sheets are reinforced by small angle iron; the door sheets and framing angles are combined by means of spot or tack welding. Intermittent tack or spot welding rather than continuous fillet welds is recommended, in order to minimize the buildup of internal stresses from assembly welding. The buildup of welding stresses would increase the warping and racking tendency of these lightweight doors when exposed to coaling temperatures; to avoid this danger, the welding should be done by an experienced welder.

It is important that the door sheets project 1/4 inch beyond the framing angles at the sides and top of each door as shown, except along the continuous weld connecting the door-stop angle to the right-hand door. This slight projection of sheets will permit tight sealing between the doors and face of the kiln along the edges where door plate and frame are only spot- or tack-welded.

Alternate methods of suspension and closure of these metal doors are shown in figures 7 and 8. In figure 7, the doors are shown hung on side hinges that are fastened to the walls of the kiln by means of bolts. Experimental attempts with other forms of metal door-closing systems used with the masonry blocks have indicated that any rigid restraint against the natural warping tendency of these steel doors will contribute to the fracture of the retaining masonry. This hinged method has been reasonably acceptable when carefully installed. The most important and exacting part of this method of suspension is the placement of strap hinges and supporting bars.

The weight of the doors should be supported by the vertical bars, which are merely held in place by the anchor bolts through the wall. The actual weight will be carried by the inside bars adjacent to the hinge, so these bars must be in good bearing on top of the footing. This weight will be counterbalanced at the outer bars by the collective weight of the walls on the anchor bolts, or by means of direct anchorage of the outer bars to the
footing. Effective anchorage of bars to the footing (not shown in the figure) would be advantageous. Anchorage could consist of an angle or bent plate with the horizontal leg attached to the footing by a 1/2-inch expansion anchor and bolt, and the vertical leg attached to the bar by a 1/2-inch pin or bolt. Use of a template to space, aline, and hold the bolts in their respective positions in the mortar course will prove helpful when laying blocks, and later when marking holes in bars and strap hinges.

When hanging the doors, it may be necessary to shim the screw hooks at the hinges to bring equal pressure to each strap hinge and to bend the strap portion of each hinge slightly outward to provide swing clearance for the projecting edge of the door plate. Fabrication details for alternate methods of holding the top of closed doors against the sealing material at face of kiln, and details for anchoring the steel doorway lintel are also shown in figure 7. From time to time, it will be necessary to adjust both the loose clip and the drop-pin type of snubby shown, in order to maintain the desired 1/4-inch door clearance at the seal.

The steel doors may be suspended from an overhead trolley track that is bolted to the bottom chord of the roof truss (fig. 8). This sliding door closure is simpler to fabricate and install than the side-hinged type. Its chief advantage is its independent means of support, which eliminates all restraint to the masonry block in the doorway area. The necessary track, hangers, and suspender chains are commercially available.

This type of door should be only lightly held against the face of the kiln. If tightly held or restrained, it will warp and bow badly, causing considerable difficulty in maintaining a tight seal during cooling. When lightly held, however, by means of the drop pins at the top, pipe props at the sides, and a few loose blocks and some earth across the bottom, it should function properly. Each door will behave differently with respect to release of welding stresses and normal warping when heated. In some cases, therefore, the top and bottom snubbing and the restraint from the bent plate through the door handles may be sufficient to maintain a tight seal, and the diagonal pipe props at the sides may possibly be omitted.

Some commercial operators save labor by using a single-piece door of 3/8-inch-thick corrugated steel plate that weighs as much as 500 pounds and is held in place by pipe props. Others prefer to lay up dry standard-size masonry block in the doorway opening, and then plaster tight the outside face with a lime paste. If you choose to lay up dry wall by hand (about 77 standard pier-type units), it would be advisable to make a change in the 2-inch ceiling support pipes: shorten the pipes by 7 inches, so that they end 9 inches from the front face. This change will permit the lay-up of doorway block in the plane of the front face right up to the bottom of the lintel, without interference from the ceiling pipe.
OPERATION

Charcoal kiln operation has been generally based on observed volume and color of chimney smoke and on varying time schedules. Wood and other factors remaining closely alike, by close observation experienced operators can roughly correlate these properties of the smoke with the progress and completion of the burn. A more accurate indication of the coaling operation under all conditions can be made, however, by measurement of kiln temperatures with relation to time. The application of the temperature-time method has been found to give uniform results and reliable control throughout the coaling and cooling cycles. Control of temperature at moderate levels extends the useful life of the structure and insures maximum yields of good-quality charcoal.

Temperature Instrumentation

Kiln-operating temperatures have been measured by means of a simple, low-cost system developed at the Athens-Macon Research Center of the Southeastern Forest Experiment Station (17). The two principal parts of the system are: (1) a high-resistance microammeter calibrated for kiln application, and (2) flexible stainless steel overbraided iron constantan thermocouple wires, installed as shown in figure 10.

Raw Materials

The weight of charcoal obtained from each charge is dependent chiefly upon wood species, wood size and form, and wood moisture content. The following recommendations for the charge should produce an optimum yield of charcoal.

For raw material, the heavier or denser hardwood species (8, 11, 26) are preferred. The oaks and hickories, for example, produce correspondingly greater yields of charcoal than lighter species under similar conditions. Dry weights per cubic foot of a number of hardwood and softwood species are shown in table 4.

The charcoal yield will vary directly with the cord volume of solid wood. A cord of straight, 4-foot forest wood about 8 inches in diameter or larger has the greatest actual solid wood content per cord of piled wood, or about 105 cubic feet (7). The solid cubic content of stacked wood varies over a wide range. The introduction of crooked, knotty, excessively tapered and smaller diameter sticks will reduce the solid wood content. In extreme cases, the solid wood content may drop to 65 cubic feet or less. It is advisable for proper coaling and ease of handling to limit the stick diameter to not more than 10 inches. Mill residue (in the form of slabs, edgings, and trim) and cull boards provide suitable raw material as well. Yieldwise,
this material is about equal to forest wood, but in general it is economically superior because of the low cost at which it can be obtained.

Slab stock generally includes a greater percentage of bark per charge than does forest wood. While hardwood bark will produce a yield of charcoal by weight similar to that from clear wood, the bark charcoal is less firm and more easily broken and will usually produce a greater amount of fines.

For good operating conditions, it is preferable to use wood of about 20 to 40 percent moisture content. Wood at a lower average moisture content coals at a faster rate, and requires generally greater attention and more frequent measurements for prevention of excessive kiln temperatures. Although green wood yields less charcoal, it can be satisfactorily coaled if extra fuel is added for the development of a well-sustained ignition zone. Charges of green wood require longer coaling times than seasoned wood.

Kiln Charging

Select stringers from the wood to be charged and space them crosswise about each 2 feet to raise the charge from the kiln floor. The diameter of the stringers is not critical, although pieces about 6 inches in diameter will provide both adequate operational conditions and wood charge space.

Wood of 4-foot lengths in three tiers or 5-foot lengths in two tiers is placed lengthwise on the stringers. The wood should be tightly stacked for maximum charge weight. Wood of larger diameter should be placed at or near the top of the charge, where the temperatures are higher. Leave a space of 2 to 4 inches between the rear wall and the kiln charge and one of about 6 inches between the top of the charge and the ceiling. No space need be left along the side walls. The space remaining between the load and the kiln door is utilized as the ignition area.

Ignition Fuel and Insulation

Dry kindling and fuel wood should be crib-piled forward of the kiln charge and away from the metal door. A charge of seasoned wood requires an ignition crib of wood approximately 18 inches deep, 20 inches high, and 8 feet wide, as shown in figure 11. The wood fuel for a charge of green wood should be at least twice this amount. The wood must be piled to provide a stable crib. When the fuel crib has been prepared, place crumpled paper at various points and pour about 1-1/2 gallons of fuel oil over the piled fuel. Spread another 1-1/2 gallons of fuel oil over the face of the charge.

In both the open-door and closed-door methods of ignition, the snug fit of the doors to the kiln face after ignition is essential. Adequate sealing can be provided by pasting glass-fiber insulation in varying thicknesses along
the inside perimeter face of the door. The insulation should be sufficiently thick to be partly compressed when the door is in place. The packing can be attached with roofing tar and may be reused or be replaced when necessary between operations. The doors are held in place with drop pins as shown in figure 7. Wedging or similar forced sealing should not be used because of the danger of transmission of heating stresses from the metal door to the kiln wall.

Open-Door Method

In the application of this procedure, certain routine checks and precautions should be taken. All chimneys and ceiling ports should be open and the port covers readily accessible without need of reaching over the openings. Drop pins, bolts, and props should be within easy reach for door closure. Other materials which should be conveniently located include glass-fiber insulation for door packing, and a trowel, large brush, slaked lime, sand, and water for grouting. The fuel crib should receive a final inspection to insure that it is firm and will not fall while the door is open.

In the use of a highly combustible material such as fuel oil, considerable care must be taken during the periods of both lighting and subsequent rapid combustion of the ignition fuels. The use of a taper is advisable for the lighting, and heavy gloves should be worn during kiln operation.

Ignition and Precoaling Period

Ignite the fuel with the doors fully open and the masonry blocks open and in place at the base of the door opening. Within a very short time, there is active burning of the fuel bed with vigorous flaming and later active combustion of the fuel oil over the face of the charge, as shown in figure 12. The open rear ceiling ports create a maximum draft to draw much of the flaming and heat over the top of the charge. Whereas limited flaming occurs through the front ceiling ports from time to time, only flame-free gases are emitted through the rear ceiling ports.

Keep the door open until the fuel oil has been consumed and ignition well established across the face of the charge. Seasoned wood requires 3 to 8 minutes to establish this condition, after which time the door should be closed without sealing. After the doors have been closed, the air ports in the masonry blocks under the door should remain open.

While the door is open, a temperature as high as 1,400° F. may be indicated by thermocouple No. 1 (fig. 10). After the door is closed, there will be a rapid reduction of temperature during a period of 10 minutes to about 700° to 900° F., and within 1/2 hour to 500° to 600° F. This precoaling temperature of 500° to 600° F. is based on the average temperatures indicated by thermocouples Nos. 1, 2, and 3. It is highly desirable to
maintain this average temperature over the top of the charge, because the
time schedule for closing the ceiling ports is based on maintaining this
temperature.

The air control action guide (fig. 13) applies most specifically to the con-
version of seasoned wood having a moisture content from 25 to 40 percent.
The ignition heat can be conserved by closing and covering the front ceiling
ports with sand 10 minutes after the door is closed. Partially close the
rear ceiling ports with metal slide covers within 30 to 60 minutes after
the door has been closed; within a further period of 30 to 60 minutes there-
after, complete the closure and seal them with sand. Keep all ceiling
ports closed as long as there is an average temperature of 500° to 600° F.
ad the top of the charge. Should this temperature drop below about
500° F., partially open the rear ceiling ports to increase the temperature,
and then close them when this coaling temperature has been regained.

Smoke will be forced to the chimney outlets and escape through one or all
chimneys after the rear ceiling ports are partially closed. All should be
emitting smoke soon after the ports are completely closed. With cooler
air temperatures, it may occasionally be necessary to create a chimney
draft. Ignition of oil-soaked paper in the opening at the base of the chim-
neys will usually do this.

Closed-Door Method

The routine precautions outlined for the open-door method apply also for
this method, and similar amounts of crib fuel and fuel oil are used. You
will need to scatter additional crumpled, oil-soaked paper between the
fuel crib and door, however, for convenient firing. In the closed-door
method, the door is shut and sealed, and no concrete blocks are used at
the base of the door. Thus there will be a full 9-inch air entry space
between the bottom of the door and the footing, for firing and establishing
ignition.

Ignition and Precoaling Period

After the doors have been closed, ignite the fuel by means of the fuel oil-
soaked paper leading to the crib (fig. 11). Shortly after it is lighted, the
entire fuel crib should be burning. Make sure there is complete ignition
across the face of the charge.

The average temperature across the top of the charge (measured by thermo-
couples 1, 2, and 3) will not be as high initially as that indicated for the
open-door method. After the initial combustion phase, this average tem-
perature may drop to about 300° F. Ignition should be continued by regulation
of the ceiling ports (as outlined for the open-door method) until the tempera-
tures average 500° to 600° F. At this time place the masonry blocks under
the door to provide regulated air intake.

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For both the open- and closed-door methods of ignition, the door edges and the space between the door panels should be grouted when a ceiling temperature of 850° to 950° F. has been established. Then, brush slaked lime-water mixture, without sand and of heavy cream consistency, along the edges of the door and over the glass fiber in the center door joint. A better seal can sometimes be obtained with a heavier mixture applied with a small trowel.

Coaling Period

Coaling begins at or near the ceiling, with temperatures gradually increasing from the range of about 500° to 600° F. The preferred maximum coaling temperatures of the average range of 850° to 950° F. (as indicated by thermocouples 1, 2, and 3) should be maintained for the greater part of the coaling period. If temperatures in excess of 950° F. are sustained for lengthy periods of time, abnormal kiln deterioration may result.

Temperature Control

To maintain the temperature control range of 850° to 950° F., regulate the air input through the block ports at the base of the door. No one temperature control schedule for optimum coaling conditions can be indicated, because the size and moisture content of wood, the bulk density of the charge, wind direction and velocity, and the pattern of ignition all vary. However, until the operator can better gage the effect of such variables through experience, the action guide (fig. 13) will be helpful. This guide indicates that 5 to 10 hours are needed to increase the temperature of seasoned wood from the range of 500° to 600° F. to the recommended coaling temperature of 850° to 950° F.

When the coaling temperature has been reached, reduce the air intake area by closing the 1-inch space between the door bottom and the masonry air-port blocks; this reduces the initial total of 370 square inches of air-intake opening to about 270 square inches. To maintain a temperature range of 850° to 950° F. at the ceiling, it may be necessary to adjust air-port closure within the time limits indicated by the shaded area surrounding the broken line of the action guide. The closing of too many air ports will produce a noticeable temperature drop within a period of 15 to 30 minutes; temperature can be raised again by simply reopening the air ports. On the other hand, if there is not sufficient air reduction, the temperature will continue to increase slowly. Four to six closure steps will be required on the average to maintain an optimum temperature condition. After the last step only 15 to 30 square inches of air-port area remain open until the run has been completed (fig. 14). Each of the three openings in a block provides an air intake area of 15 square inches.

Since the temperature control action for green wood coaling will take place after a greater time interval from the precoaling condition (500° to 600° F.),
it would be represented in the action guide to the right of the shaded area (fig. 13). Close observation of operating procedure will enable the operator to predict within reasonable limits the necessary temperature control action required. To obtain the recommended coaling temperature of 850° to 950° F. with green wood, it may be necessary to remove several of the air-port cinder blocks to permit more air to enter. When the desired temperature is reached, replace the blocks and seal additional air ports as required. Bricks, for example, may be placed at the air-port openings; after it becomes certain that these ports will remain closed, they can be sealed in place with dirt.

Coaling Pattern

The coaling pattern develops from the top of the charge downward and from the front to the rear, in the form of a shallow arc. Settling takes place as the charcoal is formed, so that the final bed of charcoal is approximately two-thirds the initial height of the wood charge. During the latter part of the burn, the thermocouples along the ceiling are several feet above the charcoal bed, and at that time the average recorded temperature along the ceiling is expected to drop at least 50° F. No additional air ports should be opened so long as the temperature indicated on thermocouples 4 and 5 is 825° F., or a trend of increasing temperature is indicated. Figure 15 illustrates an expected temperature pattern for three zones of the kiln during various phases of coaling.

The base of the kiln charge toward the rear is expected to coal out last. Therefore, when thermocouple No. 5 has indicated a temperature of about 800° to 825° F. for several hours with the same temperature indicated on thermocouple No. 4, the coaling cycle is considered complete, even though there may still be some volume of smoke from the chimneys. Much of this smoke probably originates from a few partially coaled pieces; more complete coaling would require several additional hours of kiln time for the recovery of very little additional charcoal.

Hot Spots

The temperature throughout the coaling zone is not uniform but includes rather localized areas of increased temperature, or hot spots. With use of only five thermocouples many of these hot spots will go undetected. If a hot spot of 1,100° to 1,300° F. develops near the kiln wall, it would be advisable to reduce air entry for a short period of time to lower this excessive temperature.

Air-Port Blowback

In some kiln runs, smoke may occasionally puff out forcefully through the air intake ports. Reduction of air input for about an hour usually will reduce
the puffing even though temperature control conditions do not warrant such action. The puffing is probably due in part to localized accelerated coaling that develops either from uneven ignition or from wood of widely different moisture content. A normal amount of light puffing from the air ports may be disregarded.

General

Combustion of the ignition fuel produces a dark, heavy chimney smoke, which changes to a light gray-yellow as the seasoned wood in the charge begins to coal. If the wood in the charge is green or has relatively high moisture content, the smoke will be "steamy" and slightly gray-yellow. As the wood changes to coal, the products of wood decomposition will gradually darken the smoke. During this time, a liquid consisting mainly of water and tar will collect at the chimney base, diminishing toward the final stages of coaling. Heavy accumulation of tar and coke occurs with operation; when the kiln is not in operation, remove the chimneys from the kiln and burn them out periodically. This will insure maximum draft in subsequent operation.

After a 24- to 28-hour period of coaling seasoned wood, one or two of the chimneys may stop smoking. When this occurs, seal the inactive chimney by removing the back plate of the chimney base and filling the chimney port with dirt to prevent intake of air. It is possible, however, that all chimneys will remain active until the end of the coaling period, as previously noted.

It is important not to permit entry of large amounts of uncontrolled air into the kiln during the coaling cycle. The accelerated effect of strong and variable winds blowing directly into the air intake ports can be modified by baffling them away from and in front of the air ports by means of a plank placed vertically approximately 12 inches from the face of the openings. During the course of the first few burns, inspect the kiln ceiling frequently, because there is a tendency for the dirt or sand fill between the two walls to settle. This settling may expose a portion of the metal ceiling and permit air leakage between the ceiling and inner wall. When settling has occurred, add sand. Sand fill may sift also into the ceiling holes through which the "U" bolt ceiling supports pass if the holes have not been properly sealed with glass fiber packing.

Minor maintenance measures will be required after the door has been properly packed and grouted. Limited air leakage through small openings at the door perimeter is not critical during the coaling period, but the larger openings should be grout-sealed. Some door warping will occur during kiln heating and cooling, but the door remains quite stable after coaling temperatures are reached. Changes in the fit of the door to the kiln face caused by warpage can be readily remedied with glass fiber packing.
Cooling Period

The cooling of the charcoal for discharge will be accomplished most directly by suitable sealing of the kiln. At the end of the coaling period seal the remaining open air ports with dirt; also seal any active chimney with dirt, as previously described. Leave one chimney open for approximately 2 hours after sealing the air ports to permit escape of smoke before the kiln is completely sealed and to prevent development of internal gas pressures.

Check walls for cracks or other possible sources of air entry that will need sealing. The door perimeter seal should extend below the banked dirt covering the air ports. Check the sand seal behind the lintel and on the ceiling, and completely cover the ceiling ports with several inches of sand. All dirt seals for the air or chimney ports should be firm and well packed. The ceiling should be checked thoroughly for any source of air entry.

It is very important that the smallest source of air entry be sealed, if cooling is to be completed within 3 to 4 days. The kiln should be checked and resealed where needed at least twice a day during the first 2 days of cooling, and as needed for the remaining period.

The end of the cooling period or the time for charcoal discharge may be largely determined by temperature indication throughout the kiln. A temperature of 150° F. or less for all thermocouples is considered suitable indication. Before opening, test for possible hot spots in the charcoal bed by opening the rear ceiling ports and several air ports. If there is no indicated rise of temperature or evidence of smoke or heat at the rear ceiling ports within a 2-hour period, the kiln may be opened. If a heating condition is indicated, reseal the kiln and check for air entry; after 48 hours, retest for temperature.

As an alternate procedure, the kiln may be opened immediately after the temperature is below 150° F. without checking for a possible hot spot. If a fire does develop, simply close and reseal the kiln door.

The bed of charcoal produced will be approximately two-thirds the height of the wood charged, usually with some ashing of the front face (fig. 16). Also, the top of the charcoal bed may occasionally be covered with a fine ash, but the presence or absence of the ash does not indicate either poor- or good-quality charcoal.

Kiln Discharging

Basically, kiln discharging is a manual operation, since no specific type of equipment has been designed for this purpose. It is recognized, however, that some form of mechanization might well be used for greater operational
efficiency. Some has already been done in field studies and by many commercial producers, including the use of mechanical scoops, belt conveyors, live and dead rolls, and endless chains. The individual operator should evaluate his own needs. If mechanically inclined, he can improvise equipment; or he can obtain that which is best suited from available markets. Similar mechanization can be used to charge kilns.

If the charcoal is not produced for briquetting, screen it for separation of dust and fines. No standard screen has been adopted; the mesh size employed may vary from 3/8 inch to 3/4 inch or more. Different operators usually devise their own types of bins and bagging arrangements.

Safety Precautions

In kiln operations as in any work, safety measures and safe work habits are of supreme importance. A number of safety features are included in the design of the kiln and should not be overlooked. Utilize them as indicated and plan your operations carefully to avoid accidents.

1. The draft diverters on the top of the chimneys prevent sudden downdrafts of wind into the kiln. Unless these preventive measures are properly applied, accelerated coaling and explosion are possible. As an additional safety feature, the center section of the ceiling is so placed that it will lift off in case of explosion and thus reduce the pressure against the kiln structure.

2. In case of severe air port puffing, all ports should be closed for a short time and gradually reopened to admit the former air supply.

3. The insulation at the base of the chimney has a twofold purpose. The chimney base may become sufficiently hot to cause the accumulated tars to smoke. The insulation will help to prevent possible chimney fires and to maintain suitable chimney draft by reducing tar accumulation.

4. If fuel oil is used for ignition purposes, pour the oil over the fuel bed immediately before igniting it. The oil fumes should not be allowed to accumulate, particularly in a closed kiln. Gasoline or similar fuels with a low flash point should never be used.

5. Place the ceiling port covers in a location where it will not be necessary to reach over the open ports. The hot gases from these ports during kiln operation can burn human skin, and the throat and lungs as well if breathed in excess.

6. Some toxic gases are present in the cooled kiln after coaling. It is highly important, therefore, to provide and maintain adequate ventilation before entering the kiln.

7. The sand on the kiln ceiling becomes hot during the coaling period. Heavy gloves should be worn for protection from burns by the hot sand or
hot metal. When it becomes necessary to do some maintenance in the ceiling area, use at least 6-foot planking for distribution of the workman's weight on the sheet-metal ceiling. Such planking may be stored across the ceiling support beams when not in use.

(8) Also wear gloves when working near the kiln door. Take precautions at all times to avoid tripping or falling against the extremely hot door during the coaling period. It is good safety practice to keep away from the kiln door area whenever possible.

(9) Do not allow sustained kiln temperatures of 1,000°F or more. Such excessively high temperatures are detrimental to the structure. If for any reason you suspect a dangerous condition within the kiln, seal all of the air ports and the two side chimneys. Leave the rear chimney open to prevent development of excessive gas pressure.

(10) An adequate first-aid kit should be readily available.

(11) Kiln explosions occur sometimes with rather serious results. Although their cause is not clearly understood, it is probably related to critical gas mixtures formed mostly either by hydrogen or methane with the entering air, or by some combination of these gases. Since varying amounts of these gases are undoubtedly present during most of the coaling action, it is possible to prevent the formation of explosive gas mixtures by efficient use of the air admitted. The following figures show the ranges within which hydrogen and methane gases form explosive mixtures with air (16).

<table>
<thead>
<tr>
<th>Gas</th>
<th>Lower percent</th>
<th>Upper percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>4.1</td>
<td>74.2</td>
</tr>
<tr>
<td>Methane</td>
<td>5.3</td>
<td>14.0</td>
</tr>
</tbody>
</table>

The range within which critical hydrogen and air mixtures are formed is wide and indicates a large potential for explosion effect. Somewhat more favorable conditions are indicated, however, in the narrower range for methane and air. The entry of air through ports or by structure leakage—excess of that required for uniform and progressive coaling action—may thus create a primary condition for explosive gas mixtures. The fact that kiln explosions happen very infrequently would suggest that average operating conditions are satisfactory; the few explosions that do occur are probably the result of the input of unregulated amounts of air.

Since excessive temperatures indicate an oversupply of air that provides possible causes of explosive action, it is advantageous to measure temperature for kiln operational control. This can be done simply and inexpensively, as described in this report.

As mentioned previously in this report under Operation, good coaling control has been obtained in Forest Service field experiments by the establishment
of a uniform ignition zone and of suitable conditions for the efficient use of entering air. By means of a stack located midway on each of three walls, the air is spread efficiently throughout the kiln from a single front point of air entry. The danger of introducing excess air and forming critical gas mixtures is therefore greatly reduced.

Other factors that promote unbalanced ignition or coaling conditions and in turn upset good air control are (1) the use of mixed wet and dry wood charges, and (2) stack backdraft. The former can be avoided by careful selection of the wood, and the problem of excess air by stack backdraft can be overcome by use of anti-downdraft pipe caps (fig. 5).

Related Production Factors

The general practice for determining charcoal yields is based on pounds obtained from a cord of wood. Some operators have been confused because they misunderstood this basis for evaluation of yield. Some variables in this connection should be considered.

Wood Species

It is well known that the heavier woods produce on a volume basis the greater yield of charcoal in pounds. As a suitable base value, the weight of the wood is the dry weight, measured after all the moisture has been removed. Even within species (or more specifically among the oaks and hickories), there is wide variation in dry weight per cubic foot. The comparative values in table 5 show the oven-dry weight of southern red oak to be 39 pounds per cubic foot, while that of white oak is 44 pounds per cubic foot. The various hickory species weigh from 42 to 52 pounds per cubic foot. Variations in these wood weights can easily result in different charcoal weight yields, as shown for the calculated amounts in table 5. The weights per cubic foot for other species are shown in table 4 as well, and may be useful as a species selection guide.

Yield Evaluation

The measure of charcoal conversion is based on the calculated oven-dry weight of the wood charge divided into the weight of the charcoal recovered. A charcoal yield of 30 to 34 percent from a masonry block kiln is considered satisfactory, and the spread of charcoal yields in pounds per cord (table 5) is based on this factor. If the conversion of seasoned wood is much below 30 percent, some improvement in kiln operation might well be indicated. However, if the conversion is much above 34 percent, there would be good possibility of reduction in charcoal quality with greater amount of volatiles and a resultant increase in charcoal weight (28).
Method for Determining Percent Charcoal Conversion

Wood moisture content.--If the wood is well seasoned, moisture content may be determined by using a moisture meter. This instrument has reasonable accuracy within a moisture content range of about 7 to 30 percent. Another method is to cut moisture samples 1 inch thick from a representative number of the pieces charged. Weigh these sections immediately after cutting, or wrap them in foil or plastic to keep moisture content constant until they can be weighed. Record the weights to the nearest tenth or ounce fraction of a pound. The greater the weight accuracy, the more accurate will be the moisture determination.

After the sections have been weighed, dry them at a controlled oven temperature of approximately 200° F. If the sections do not change weight after any two consecutive weighings, all the moisture has been removed.

Calculation.--The moisture content in percent for each section is calculated as follows:

\[
M.C. = \frac{\text{Weight when cut} - \text{ovendry weight}}{\text{ovendry weight}} \times 100
\]

The average moisture content for all the sections is then determined.

Weigh the charge as it is loaded into the kiln. This weight is needed to calculate the ovendry weight of the load, using the average moisture content previously determined. This calculation is as follows:

\[
\text{Calculated ovendry weight of wood in kiln} = \frac{\text{weight of wood in kiln}}{\text{average moisture content of sections} + 100} \times 100
\]

After the charcoal has been weighed, divide the calculated ovendry weight of the wood into the weight of the charcoal and multiply the value obtained by 100. This value is the charcoal yield in percent, and will provide a correct relationship between the dry weight of the wood coaled and the charcoal produced from that wood on a percentage basis.

Charcoal Quality

Good-quality charcoal contains 75 percent or more of fixed carbon; the remaining amount comprises fractions of volatiles and ash. The volatiles, if present in larger amounts than about 24 percent, will cause charcoal smoking when burned. These determinations can be made only with analytical equipment. A rough quality test for volatiles can be made by burning samples of charcoal to determine the absence or extent of smoke. A metallic ring noted when a piece of charcoal is dropped onto a hard surface

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provides a further rough test for good quality. Too rapid coaling at high
temperatures causes friable charcoal to be produced with consequent easy
breakage to small lumps and fines. The species of wood coaled does not
influence the quality of charcoal. In general, the lump charcoal obtained
from the medium dense hardwoods is considered cleaner because it does
not break or dust so easily in handling as the charcoal from most of the
softwoods and lighter hardwoods.

PLANT STORAGE

Considerable care must be exercised when storing charcoal. Although the
product is very stable when properly cooled, it can be hazardous when
handled otherwise. The most prevalent danger is that it might cause a fire
in the storage area.

Although spontaneous combustion (self-ignition by the production of heat
through the chemical action of its own constituents) is always a possibility,
the most common cause of such fires is "hot" charcoal, a term that des-
cribes charcoal that has just been removed from the kiln and, although
considered to be adequately cooled, may contain some glowing or burning
pieces. Spontaneous combustion may also occur in charcoal that has been
sprayed with water to cool it quickly. Therefore, it should be placed in
the open air away from previously cooled charcoal for at least 24 hours
after removal from the kiln. During this time it should be exposed to good
air circulation and be protected from the weather, preferably in an open
shed rather than under a tarpaulin. If there is no evidence of heat or active
fire after this cooling period, it may be placed in the warehouse.

Piled charcoal dust or tightly packed fines are more subject to spontaneous
combustion than the larger lump material. They should be exposed to the
air but protected from the weather for not less than 5 days before storage
or shipment. Preferably, they should be stored separate from the lump
charcoal.

Accidental fires due to inadequate cooling times and improper storage pro-
cedures can be prevented. Do not rush or slight these important phases of
your operation.

MARKETS AND MARKETING

The recovery plant charcoal production group is best equipped on the
average for the larger industrial bulk deliveries and in position to indicate
general charcoal market prices. Such prices usually quoted in current
market reports become a roughly established selling base for charcoal.
Such a price pattern is less effective in the widely scattered and larger overall recreational markets because of heavy seasonal demands and consequent shortages of charcoal. These conditions in turn create to a large extent a market price pattern of considerable variability. All prospective producers should explore marketing possibilities before locating in any particular area since overproduction will have adverse effects on local markets.

Established outlets for kiln production include wholesalers and fuel dealers in cities, who buy sizable quantities for resale to industry or for packaging for domestic markets (19, 24, 25, 27, 29). Within areas near the kiln operation, the operator may sell bulk or bagged charcoal directly to local outlets. For domestic fuel and recreational markets, the screened 3/4-inch to about 3-inch lump charcoal is packaged in burlap, multi-wall paper bags, or paperboard boxes. The burlap bags are usually 50-pound size, while the commonly used paper containers for the retail trade are generally in sizes of 4, 5, 10, and 20 pounds. The increased production cost for bagging is estimated to be $10.00 to $15.00 per ton, which is balanced off as a rule by the considerably higher selling price for a packaged product.

Additional outlets for new or already established kiln operations have been developed with the production of briquettes. Kiln operations and briquette production have become associated in several different ways: (1) kiln production with briquetting facilities; (2) kiln production from a number of operations providing the sole source of charcoal supply to the briquetting plant; and (3) kiln production providing part charcoal supply to recovery plants with briquetting facilities, and to briquetting plants formerly manufacturing coal briquettes. There is growing interest in production of charcoal in briquette form. The marketing of briquettes has advantages of less package volume in storing and transport and of handling for household and picnic broiling.

The equipment for producing charcoal briquettes is highly specialized. It requires powered units for charcoal dry grinding and for wet mixing with water and starch, for press-forming the mix, and finally for drying the green briquettes to low moisture content for storage and use (18, 20). The smallest briquette press manufactured has a capacity of about 1 ton per hour and costs about $8,000. The equipment investment required for a complete plant at operating capacity of 8 to 10 tons per day is estimated to be $100,000. During the past several years, the number of charcoal briquetting operations has increased from 4 to 24, located in various parts of the country. Eighteen of them are supplied by kiln producers usually on a term contract basis and at a charcoal lump price of $40 to $50 a ton. An advantage to the kiln producer in this case is that he may dispose of all of his production, including the "fines," which generally amount to about 10 percent of his production by weight. Briquettes command a substantially higher market price than does lump charcoal, over and above the cost of manufacture. Figure 17 shows a flow diagram of processing for charcoal briquette manufacture.
TRANSPORTATION REGULATIONS

Several precautions must be observed when transporting charcoal, especially for considerable distances and between States. The Interstate Commerce Commission has definite regulations pertaining to the movement of hazardous materials. It considers charcoal as one of these, and lists it in the group of flammable solids and oxidizing materials which are "liable, under conditions incident to transportation, to cause fires through friction, through absorption of moisture, through spontaneous chemical changes, or as a result of retained heat from the manufacturing or processing."

Properly cooled charcoal very rarely exhibits these dangerous characteristics. The Interstate Commerce Commission has recognized the value of proper cooling of charcoal and the regulations have been written accordingly. Specific examples are:

49CFR 73.162 (j)(3) Charcoal burned in pits or kilns must be thoroughly cooled in the sealed kilns. After the kilns are opened, the charcoal must be allowed to stand in the open kiln or elsewhere exposed to the air for not less than 24 hours before loading in a freight car. Charcoal burned in kilns may be loaded in open cars or in box cars, but after loading in box cars, the cars must be allowed to stand not less than 24 hours with doors open before shipment.

49CFR 73.162 (k)(3) Screenings, or ground, crushed, granulated, or pulverized charcoal, from pit or kiln burned charcoal, are considered as non-hazardous, provided the screenings or the material from which the ground charcoal is made has been exposed to the air for not less than 5 days prior to shipment or grinding.

There are additional regulations covering practically all parts of the transportation phase of the industry, such as packaging and marking; drying specifications for briquettes before transporting them; handling of lump charcoal and screenings; and instructions for loading boxcars, motor carriers, and other carriers. The regulations specifically spell out that charcoal, as a combustible solid in its many forms, can be dangerous if not properly handled. For example, Sec. 77.838 (b)(3)

Articles to be kept dry. Special care shall be taken in the loading of any motor vehicle with flammable solids or oxidizing materials which are likely to become hazardous to transport when wet, to keep them from being wetted during the loading process and to keep them dry during transit. Special care shall also be taken in the loading of any motor vehicle with flammable solids or oxidizing materials, which are likely to become more hazardous to transport by wetting, to keep them from being wetted during the loading process and to keep them dry during transit. Examples
of such dangerous materials are charcoal screenings, ground, crushed, or pulverized charcoal, and lump charcoal.

The paragraphs quoted here are but a few of the regulations covering the transportation of charcoal. Persons contemplating entering the business should consult an Interstate Commerce Commission representative, who can usually be located by contacting the local postmaster.

CONCLUSION

Charcoal has been an important domestic product for many years. Primary outlets for charcoal were in metallurgy; later more important tonnage markets developed chiefly in the chemical and allied fields and in the use of charcoal as a recreational fuel. The largest amount now produced by both the highly specialized recovery plants and the simple kiln operations is consumed in household, recreational, and picnic use.

Charcoal recovery by means of flexible, low-investment kiln conversion creates raw material markets for low-value forest wood and mill residues. Although kiln production does not return a large profit, with efficient operation a reasonable profit may be realized; also, the stands supplying the raw material will increase in value. Profits are likewise possible in the utilization of coarse mill residues by conversion of unwanted material to a salable product.

In the kiln production of charcoal, equal emphasis must be placed upon markets and marketing. Several procedures commonly employed that provide the more promising outlets are (1) wholesale of bulk charcoal; (2) contracted sales through an established company or organization, using the organization's trade name; and (3) the development of an individual complete marketing organization.

As a commercial enterprise kiln production promotes good forest and wood management practices and utilization, and provides the opportunity for a measure of business profit.
1. Anonymous.  

2.  

3.  

4. Baldwin, H. I.  

5. , and Weld, E. A.  

6. Beglinger, E.  


9. Hicock, H. W., and Olson, A. R.  

10. , , and Callward, F. M.  

11. Kotok, E. S.  
1955. The Production of Charcoal from Arizona Mesquite.  
Rocky Mountain Res. Note No. 15. Fort Collins, Colo.
12. Lane, P. H., and Sprenger, G. E.
1956. Design of an Experimental Charcoal Kiln. Lake States
Forest Experiment Station Tech. Note No. 471.
St. Paul, Minn.

Lake States Forest Experiment Station Tech. Note No. 494. St. Paul, Minn.

1946. A Charcoal Kiln Made of Cinder Concrete Blocks.
Connecticut Agricultural Experiment Station Bulletin 494. New Haven.

Experiment Station Bulletin 448. New Haven.

16. Perry, J. H.
Book Company, Inc. New York, N. Y.

17. Peter, Ralph.
1956. An Inexpensive Method for Measuring Charcoal Kiln
Temperatures. Southeastern Forest Experiment
Station Paper No. 73. Asheville, N. C.

1944. Charcoal--Industrial Fuel from Controlled Pyrolysis of
Sawmill Wastes, Part II. Oregon Forest Products
Lab., Oregon State College, Corvallis, Oreg.

1955. A Review of the Charcoal Production and Marketing
Situations in the U. S. with Reference to Minnesota.
School of Forestry Mimeographed Report, University
of Minnesota.

20. Stillman, A. L.

21. Troxell, H. E., and Barney, C. W.
1956. The Colorado Experimental Charcoal Kiln. School of
Forestry Res. Note No. 3, Colorado A and M College,
Fort Collins, Colorado.

22. 1956. Time-Temperature Study in Small Charcoal Kiln. School
of Forestry Res. Note No. 4, Colorado A and M
College, Fort Collins, Colorado.

Rept. No. 2084 -31-
23. Tryon, H. H.
   No. 4. Cornwall-on-the-Hudson, New York, N. Y.

24. Warner, J. R., and Lord, W. B.
   Lake States Forest Experiment Station Paper 46, St. Paul, Minn.

25. 1957. How Large is the Charcoal Market?
     Lake States Forest Experiment Station Tech. Note No. 477. St. Paul, Minn.

26. Webber, L. E.
   Northeastern Forest Experiment Station. Upper Darby, Pa.

27. Witherow, B. M.
   1956. Information about the Charcoal Industry in the Southeast.
   Southeastern Forest Experiment Station. Asheville, N. C.

28. , and Smith, Walton R.
   Southeastern Forest Experiment Station Paper No. 79. Asheville, N. C.

   1956. Retail Marketing of Charcoal in Iowa. Iowa Agricultural
Table 1.--Bill of materials for kiln proper

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Material</th>
<th>Nominal size</th>
<th>Where used</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 pieces</td>
<td>Reinforcing bars</td>
<td>1/2&quot; round by 16'3&quot;</td>
<td>Footing</td>
</tr>
<tr>
<td>6 pieces</td>
<td>Reinforcing bars</td>
<td>1/2&quot; round by 17'6&quot;</td>
<td>Footing</td>
</tr>
<tr>
<td>25 sq. ft.</td>
<td>6&quot; by 6&quot; #4 wire fabric</td>
<td>Style #66-44</td>
<td>Footing</td>
</tr>
<tr>
<td>4.1 cu. yds.</td>
<td>Portland cement concrete</td>
<td>1:2:4 mix</td>
<td>Footing</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Chimney tile</td>
<td>8-1/2&quot; square by 24&quot; long</td>
<td>Chimney outlet</td>
</tr>
<tr>
<td>60 cu. ft.</td>
<td>Masonry mortar</td>
<td></td>
<td>Walls</td>
</tr>
<tr>
<td>180 cu. ft.</td>
<td>Mortar sand</td>
<td></td>
<td>Walls</td>
</tr>
<tr>
<td>801 units</td>
<td>Standard stretcher type</td>
<td>8&quot; by 8&quot; by 16&quot;</td>
<td>Walls</td>
</tr>
<tr>
<td>98 units</td>
<td>Corner type</td>
<td>8&quot; by 8&quot; by 16&quot;</td>
<td>Smoke outlet and doorway</td>
</tr>
<tr>
<td>22 units</td>
<td>Pier type</td>
<td>8&quot; by 8&quot; by 16&quot;</td>
<td></td>
</tr>
<tr>
<td>320 cu. ft.</td>
<td>Dry sandy soil or fine sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 pieces</td>
<td>Standard black iron pipe</td>
<td>2&quot; O.D. by 15'</td>
<td>Ceiling</td>
</tr>
<tr>
<td>11 pieces</td>
<td>Steel decking</td>
<td>18 gage 18&quot; by 168&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>4 pieces</td>
<td>Standard I beam</td>
<td>6&quot;--12.5 lb. by 16'8&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>8 pieces</td>
<td>Bearing plates</td>
<td>8&quot; by 8&quot; by 1/4&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>1 piece</td>
<td>Angle iron lintel</td>
<td>6&quot; by 4&quot; by 5/16&quot; by 13'11&quot;</td>
<td>Doorway</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Bent plate lintel supports</td>
<td>2-1/2&quot; by 5/16&quot; by 19&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>20 pieces</td>
<td>Hanger rod plates</td>
<td>2-1/2&quot; by 5/16&quot; by 10&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>20 pieces</td>
<td>Hanger rod, with washers</td>
<td>1/2&quot; round by 3'6&quot;</td>
<td>Ceiling</td>
</tr>
<tr>
<td>430 ft.</td>
<td>Noncorrosive wire</td>
<td>#6 gage</td>
<td>Wall ties</td>
</tr>
<tr>
<td>100 ft.</td>
<td>Wire mesh (or joint reinforcement)</td>
<td>6&quot; wide strips</td>
<td>Top</td>
</tr>
<tr>
<td>4 units</td>
<td>Sheet metal sleeve and cap</td>
<td>24 gage</td>
<td>Smoke outlet</td>
</tr>
<tr>
<td>6 pieces</td>
<td>Steel plate</td>
<td>16&quot; by 3/8&quot; by 20&quot;</td>
<td>Chimney base</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Metal smoke pipe</td>
<td>8&quot; by 16'</td>
<td>Chimney top</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Chimney thimble or cap</td>
<td>8&quot;</td>
<td></td>
</tr>
<tr>
<td>3 pieces</td>
<td>Pipe cap (nondown draft)</td>
<td>8&quot;</td>
<td></td>
</tr>
</tbody>
</table>

\[1\] These quantities do not provide for any extra units in case of breakage.

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<table>
<thead>
<tr>
<th>Quantity</th>
<th>Material</th>
<th>Nominal size</th>
<th>Where used</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>16' wood poles (pressure treated)</td>
<td>4&quot; min. top diam.</td>
<td>Roof supports</td>
</tr>
<tr>
<td>8 pieces</td>
<td>Stress-grade lumber, 1400 f minimum</td>
<td>1&quot; by 6&quot; by 20'</td>
<td>Bottom chords</td>
</tr>
<tr>
<td>8 pieces</td>
<td>do</td>
<td>2&quot; by 6&quot; by 12'</td>
<td>Rafters</td>
</tr>
<tr>
<td>8 pieces</td>
<td>do</td>
<td>1&quot; by 4&quot; by 6'</td>
<td>Diagonals</td>
</tr>
<tr>
<td>8 pieces</td>
<td>do</td>
<td>1&quot; by 4&quot; by 3'6&quot;</td>
<td>Diagonals</td>
</tr>
<tr>
<td>8 pieces</td>
<td>do</td>
<td>2&quot; by 4&quot; by 20'</td>
<td>Purlins</td>
</tr>
<tr>
<td>4 pieces</td>
<td>do</td>
<td>2&quot; by 4&quot; by 18'</td>
<td>Stringers</td>
</tr>
<tr>
<td>16 pieces</td>
<td>do</td>
<td>2&quot; by 4&quot; by 2'</td>
<td>Str. seat</td>
</tr>
<tr>
<td>8 pieces</td>
<td>do</td>
<td>2&quot; by 4&quot; by 4'</td>
<td>Brace</td>
</tr>
<tr>
<td>4 pieces</td>
<td>do</td>
<td>1&quot; by 4&quot; by 3'</td>
<td>Brace</td>
</tr>
<tr>
<td>4 pieces</td>
<td>do</td>
<td>1&quot; by 4&quot; by 8'</td>
<td>Brace</td>
</tr>
<tr>
<td>4 pieces</td>
<td>do</td>
<td>1&quot; by 6&quot; by 8'</td>
<td>Collar beam</td>
</tr>
<tr>
<td>20 pieces</td>
<td>Corrugated roofing or equivalent</td>
<td>No. 24 by 26&quot; by 144&quot;</td>
<td></td>
</tr>
<tr>
<td>20 ft.</td>
<td>Metal ridge roll</td>
<td>29 gage 12&quot;</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Bolts</td>
<td>1/2&quot; round by 10&quot;</td>
<td></td>
</tr>
<tr>
<td>5 lb.</td>
<td>Standard bright wire nails: 40d common</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 lb.</td>
<td>do</td>
<td>16d common</td>
<td></td>
</tr>
<tr>
<td>5 lb.</td>
<td>do</td>
<td>12d common</td>
<td></td>
</tr>
<tr>
<td>2 lb.</td>
<td>do</td>
<td>10d common</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. -- Bill of materials for steel doors and alternate methods of door closure

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Material</th>
<th>Nominal size</th>
<th>Where used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel Doors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 pieces</td>
<td>Steel plate (drop pins)</td>
<td>2-1/2&quot; by 5/16&quot; by 10&quot;</td>
<td>Doorway</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Standard black iron pipe</td>
<td>2&quot; O.D. by 2&quot;</td>
<td>Doorway</td>
</tr>
<tr>
<td>3 pieces</td>
<td>Bent rod (drop pins)</td>
<td>1/2&quot; round by 17&quot;</td>
<td>Doorway</td>
</tr>
<tr>
<td>2 pieces</td>
<td>14 gage hot rolled sheet</td>
<td>14 gage 56&quot; by 84&quot;</td>
<td>Steel doors</td>
</tr>
<tr>
<td>1 piece</td>
<td>Angle iron (door stop)</td>
<td>2&quot; by 2&quot; by 3/16&quot; by 6'6-1/2&quot;</td>
<td>Steel doors</td>
</tr>
<tr>
<td></td>
<td>Steel doors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 pieces</td>
<td>Angle iron frame (bent)</td>
<td>1-1/2&quot; by 1-1/2&quot; by 3/16&quot; by 11'6&quot;</td>
<td>Steel doors</td>
</tr>
<tr>
<td>4 pieces</td>
<td>Angle iron diagonals</td>
<td>1-1/2&quot; by 1-1/2&quot; by 3/16&quot; by 8'3&quot;</td>
<td>Steel doors</td>
</tr>
<tr>
<td></td>
<td>Steel Required for Side-Hinged Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>of Door Suspension Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bars</td>
<td>2&quot; by 1/4&quot; by 7'0&quot;</td>
<td>Door supports</td>
</tr>
<tr>
<td>12</td>
<td>Plates</td>
<td>4&quot; by 4&quot; by 1/8&quot;</td>
<td>Door supports</td>
</tr>
<tr>
<td>12</td>
<td>Bolts--anchor</td>
<td>3/8&quot; round by 26&quot;</td>
<td>Door supports</td>
</tr>
<tr>
<td>6</td>
<td>Strap hinges</td>
<td>1-3/4&quot; by 1/4&quot; by 18&quot;</td>
<td>Door supports</td>
</tr>
<tr>
<td>6</td>
<td>Screw hooks (for strap hinges)</td>
<td>3/4&quot; by 6&quot;</td>
<td>Door supports</td>
</tr>
<tr>
<td></td>
<td>Steel Required for Overhead Trolley</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Track, Sliding-Door Method of Suspension Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 ft.</td>
<td>Trolley type track</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>4</td>
<td>Sliding door hangers</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>12 ft.</td>
<td>Electric welded chain</td>
<td>No. 2</td>
<td>:</td>
</tr>
<tr>
<td>2 pieces</td>
<td>Standard black iron pipe</td>
<td>1-1/2&quot; O.D. by 8'0&quot;</td>
<td>Door prop.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Species</th>
<th>Lbs. per cu. ft.</th>
<th>Species</th>
<th>Lbs. per cu. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alder, red</td>
<td>27</td>
<td>Sweetgum</td>
<td>34</td>
</tr>
<tr>
<td>Ash, white</td>
<td>40</td>
<td>Oaks</td>
<td>42-52</td>
</tr>
<tr>
<td>Beech</td>
<td>42</td>
<td>Tupelo</td>
<td>34</td>
</tr>
<tr>
<td>Birch, yellow</td>
<td>41</td>
<td>Douglas-fir (coast)</td>
<td>32</td>
</tr>
<tr>
<td>Aspen</td>
<td>26</td>
<td>Hemlock, east.</td>
<td>27</td>
</tr>
<tr>
<td>Cottonwood, east.</td>
<td>27</td>
<td>Loblolly pine</td>
<td>34</td>
</tr>
<tr>
<td>Hickories</td>
<td>42-52</td>
<td>Longleaf pine</td>
<td>39</td>
</tr>
<tr>
<td>Maple, red</td>
<td>34</td>
<td>Shortleaf pine</td>
<td>33</td>
</tr>
<tr>
<td>Maple, sugar</td>
<td>43</td>
<td>Slash pine</td>
<td>41</td>
</tr>
</tbody>
</table>

1 USDA, Forest Products Laboratory 1955 Wood Handbook No. 72, Madison, Wis.
2 Average resin content approximates 6 to 8 percent.

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Table 5. -- Relationship of calculated wood volume-charcoal yields by various species

<table>
<thead>
<tr>
<th>Species</th>
<th>65 cubic feet of solid wood per cord</th>
<th>85 cubic feet of solid wood per cord</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds: Pounds: Pounds</td>
<td>Pounds: Pounds: Pounds</td>
</tr>
<tr>
<td>Southern red oak</td>
<td>39 : 2,535 : 810</td>
<td>39 : 3,315 : 1,060</td>
</tr>
<tr>
<td>White oak</td>
<td>44 : 2,860 : 915</td>
<td>44 : 3,740 : 1,195</td>
</tr>
<tr>
<td>Pignut hickory</td>
<td>52 : 3,380 : 1,080</td>
<td>52 : 4,420 : 1,415</td>
</tr>
<tr>
<td>Live oak</td>
<td>52 : 3,380 : 1,080</td>
<td>52 : 4,420 : 1,415</td>
</tr>
<tr>
<td>Sycamore</td>
<td>35 : 2,275 : 728</td>
<td>35 : 2,975 : 952</td>
</tr>
<tr>
<td>Beech</td>
<td>42 : 2,730 : 875</td>
<td>42 : 3,570 : 1,140</td>
</tr>
<tr>
<td>Yellow birch</td>
<td>41 : 2,665 : 855</td>
<td>41 : 3,485 : 1,115</td>
</tr>
<tr>
<td>Sugar maple</td>
<td>42 : 2,730 : 875</td>
<td>42 : 3,570 : 1,140</td>
</tr>
<tr>
<td>Aspen</td>
<td>25 : 1,625 : 520</td>
<td>25 : 2,125 : 680</td>
</tr>
<tr>
<td>Red alder</td>
<td>27 : 1,755 : 560</td>
<td>27 : 2,295 : 735</td>
</tr>
</tbody>
</table>

1 Calculated at 32 percent average conversion.
Table 6. --Production data from experimental 7-cord, double-wall kiln

<table>
<thead>
<tr>
<th>Wood charged</th>
<th>Moisture content of seasoned wood</th>
<th>Weight of charge</th>
<th>Calculated oven dry weight of charge</th>
<th>Charcoal yield Conversion:</th>
<th>Brands:</th>
<th>Carbon: Ignition content: and coal:ing time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Pounds</td>
<td>Percent</td>
<td>Pounds</td>
<td>Percent</td>
<td>Hours</td>
</tr>
<tr>
<td>Oak</td>
<td>36</td>
<td>23,060</td>
<td>16,955</td>
<td>33.1</td>
<td>5,210</td>
<td>400</td>
</tr>
<tr>
<td>Oak and sycamore</td>
<td>32.5</td>
<td>20,230</td>
<td>15,270</td>
<td>34.0</td>
<td>4,750</td>
<td>435</td>
</tr>
<tr>
<td>Miscellaneous soft hardwoods</td>
<td>33</td>
<td>18,105</td>
<td>13,615</td>
<td>31.1</td>
<td>3,925</td>
<td>310</td>
</tr>
<tr>
<td>Do .................</td>
<td>21</td>
<td>17,665</td>
<td>14,600</td>
<td>30.5</td>
<td>4,150</td>
<td>310</td>
</tr>
<tr>
<td>Do .................</td>
<td>25</td>
<td>18,625</td>
<td>14,900</td>
<td>31.1</td>
<td>4,390</td>
<td>240</td>
</tr>
<tr>
<td>Oak</td>
<td>40</td>
<td>22,970</td>
<td>16,405</td>
<td>31.5</td>
<td>4,841</td>
<td>320</td>
</tr>
<tr>
<td>Oak</td>
<td>43</td>
<td>23,200</td>
<td>16,225</td>
<td>25.3</td>
<td>3,781</td>
<td>317</td>
</tr>
<tr>
<td>Oak</td>
<td>56</td>
<td>31,680</td>
<td>20,310</td>
<td>26.0</td>
<td>4,818</td>
<td>463</td>
</tr>
<tr>
<td>Hickory</td>
<td>57</td>
<td>30,775</td>
<td>19,600</td>
<td>27.9</td>
<td>4,822</td>
<td>648</td>
</tr>
<tr>
<td>Oak</td>
<td>1.69</td>
<td>32,080</td>
<td>18,980</td>
<td>27.6</td>
<td>4,900</td>
<td>345</td>
</tr>
<tr>
<td>Oak and hickory</td>
<td>1.67</td>
<td>30,070</td>
<td>18,005</td>
<td>27.9</td>
<td>4,370</td>
<td>660</td>
</tr>
</tbody>
</table>

1 Green, unseasoned wood.
Figure 1. Plan view showing concrete footing, bottom course of masonry blocks, loose blocks at chimney outlets, and position of pole roof supports.

M 111 536
TIE WALLS TOGETHER WITH 4" x 16" CLOSED RECTANGULAR TIES OF NO. 6 GAUGE 4' LONG NON-CORROSIVE WIRE, SPACED 2'-4" CENTERS AS SHOWN, AT TOP OF 2nd, 4th, 6th, 8th, AND 10th COURSES.

PLACE 6"-WIDE STRIPS OF WIRE MESH OR STANDARD JOINT REINFORCEMENT AT TOP OF 10th COURSE OF INSIDE WALL AND AT TOP OF 11th COURSE OF OUTSIDE WALL TO SUPPORT MORTAR FILLING IN THE CORES OF THE TOP COURSES 11 AND 12 RESPECTIVELY.

2nd COURSE CINDER-CONCRETE MASONRY
69 - 8" x 8" x 16" STRETCHER UNITS
6 - 8" x 8" x 16" CORNER UNITS (C)
3 - 8" x 8" x 16" STRETCHER UNITS OVER CHIMNEY TILE WITH HOLLOW CORES HORIZONTAL (H).

Figure 2. Plan view at top of second course of masonry blocks showing position of wall ties.
Figure 3. -- Plan view of steel ceiling and details of smoke outlets.
Figure 4. -- Front elevation of kiln and roof details.

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Figure 5. -- Section AA of figure 1, showing side walls, ceiling, and typical chimney and roof details.
Figure 6. — Longitudinal section BB of figure 1, showing front and back wall details, ceiling supports, and inside elevation of side wall.
Figure 7. -- Fabrication details of steel doors, side hinge suspension and closure, lintel attachment, and ceiling supports.
Figure 8.--Fabrication details of steel doors and overhead suspension for sliding door closure.
Figure 9. -- Scale model of a 7-cord, masonry block kiln.
Figure 10. -- Detail of thermocouple assembly and locations of thermocouples on the lengthwise centerline of kiln with approximate distance from the kiln floor.
Figure 11. --Fuel volume for ignition of seasoned wood.

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Figure 12. --Ignition--open-door method. Air input through block openings (air ports); all ports remain open during early coaling phase.
Figure 13. -- Time-air control action guide for maintaining optimum coaling temperatures (based on use of seasoned hardwoods with 25 - 40 percent moisture content).
Figure 14. --Late coaling phase showing limited airport area required to maintain coaling conditions. Note drop pin at upper center of door opening to hold door in place.
Figure 15. -- Side view of kiln showing a coaling temperature pattern in three zones relating to open door ignition for wood (based on experimental kiln gridded with 36 thermocouples at 25 - 40 percent moisture content).
Figure 16. -- Undisturbed charcoal. Note thermocouples in center of kiln; also, rockwool insulation along edges of doors.
Figure 17. --Flow diagram for charcoal briquette manufacture.