Charcoal—Its Manufacture and Use

Charcoal is the most ancient of manufactured plant products, dating from early prehistoric times. In 1956 there were 265,000 tons produced. The heavier uses included those as recreational and domestic fuels and chemical raw material.

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Introduction

The charcoal industry provides a positive means for large-scale utilization of forest and mill residues. The place of this industry as a silvicultural aid in forest management cannot be over emphasized.

Processes are available for handling either large quantities of raw material from extensive integrated operations or limited amounts from small farm woodlots. A market for second-growth stand-improvement cuttings that are not suitable for other uses can be provided. Because of this scavenger-like nature, cull logs, top and limbs discarded in logging and cutting operations provide the chief source of raw material. Other types of suitable raw material include mill slabs, edgings and larger block sections. Sawdust, shavings and similar wood fines are being commercially converted in only limited quantities because of processing and economic obstacles not yet entirely overcome. These latter kinds of wood residues are potentially, however, an abundant and relatively cheap source of raw material for future large-scale conversion.

Both hardwoods and softwoods can be used for raw material. The availability and practical worth of such hardwood species, beech, birch, maple, hickory, sweetgum, ash and oaks, make them generally preferred for chemical conversion. Similarly, among the softwood species, the old stumpwood from longleaf and slash pines is preferred because of availability and its high resin content.

An outline of domestic charcoal production would include, chronologically, use of the primitive dirt or sod kiln (2, 16), the brick beehive kiln, the small retort of 50 to 75 years ago, and the present concrete-block and sheet-metal kiln structures, ovens and vertical-tube retorts. More efficient processing has accompanied these steps, as a rule, both within the scope of the kiln operations that produce only charcoal, and the chemical plants that recover charcoal and associated byproducts. Current charcoal production still represents a cross section of all of these methods. Progressive improvements in methods and operational control account largely for any significant differences that may be present in the uniformity or properties of the charcoal obtained from kilns and from recovery planks.

Some properties of the wood itself, regardless of the method applied, are directly related to those of the resulting charcoal. The hardness and density of maple, oak and hickory are readily apparent in the charcoal they produce, as
Fig. 1 (Upper). Early dirt charcoal kiln in process of unloading or "drawing". "U.S. Forest Service".

Fig. 2 (Lower). Brick beehive kiln—large scale kiln conversion of wood wastes to charcoal.
are the relative softness and light weight of charcoal from willow and alder. The bark of many hardwoods is quite dense and rich in carbon, and would be expected to yield as much charcoal as an equal weight of the clear wood. Among the softwood species, this condition exists to a lesser degree. Aside from a few types of charcoal that have specific properties that meet the needs of specialty use, all, in general, satisfy the usual market requirements. Charcoal of good quality has a fixed carbon content of 78 to 82 percent (8).

**Production in Kilns**

Formation of charcoal by “burning” takes place when wood is heated in a kiln in the presence of regulated but limited amounts of air. The initial heat required to start the process of wood drying and decomposition is supplied by igniting part of the charge. Retarded combustion, or coaling, proceeds with air added in sufficient amounts to maintain a glowing progressive fire zone throughout the charge. Volatile products formed by combustion and distillation of the wood escape through stacks or directly from wall ports. The charcoal, usually with small amounts of ash, remains as the residue.

Numerous kilns of both fixed and portable design (1, 4, 5, 15) have been developed and operated commercially in accordance with the general principle described. In the forming and operation of earth kilns, important considerations are wood accessibility, sheltered location and character of soil. Sound, seasoned hardwood pieces, about four feet long and six to eight inches in cross section, are usually piled in mounds of as much as 50 to 90 cords. A substantial layer of earth is placed over the wood to provide an enclosure. A period of about 20 days is needed to convert a wood charge of 50 cords by this method. Yields of 700 to 750 pounds of marketable charcoal per cord are obtained. Despite the reduced yields expected from kilns of this type, a low initial investment gives a favorable effect for limited current production.

Another type of kiln used since early days is the so-called “beehive” (10) brick unit. Kilns of this design provided more efficient operation and production of greater amounts of carbon required for early charcoal-iron manufacture. Beehive kilns now in use include both very old and fairly recent units of typical construction. Old ceramic kilns of the same general design have been converted to charcoal production. These kilns are roughly dome-shaped and range in capacity from 50 to 80 cords of forest or slab wood. Most beehive installations operate with from three to 18 units. Each kiln represents an estimated investment of $6,000 to $8,000. About 800 pounds of marketable charcoal and 50 pounds of unsalable fines per cord of dry wood are obtained on the average. These fines may subsequently be made into briquettes at charcoal-producing plants with briquetting facilities or at other briquetting plants.

Considerable progress has been made in the development of small concrete-block kilns. Numerous kiln installations of this general type are commercially producing charcoal with satisfactory results. Their advantages are comparatively low investment per cord of capacity, simplicity of construction, and favorable charcoal yields. The investment required for concrete-block construction is estimated at $125 to $150 per cord of capacity. Controlled operation in such equipment gives charcoal yields of about 850 pounds, 750 pounds, and 650 pounds a cord from, respectively, the denser seasoned hardwoods, green hardwoods and softwoods. Sizes of these kilns are generally from two to ten cords.
Fig. 3. Brick, beehive type, kiln. Large-scale kiln production of charcoal in converted ceramic kilns.
Production in Hardwood Byproduct-Recovery Plants

Nearly half of the nation’s charcoal output is from a group of six hardwood distillation plants located chiefly in areas with stands predominately of maple, birch, sweetgum and oak. These plants also include facilities for the recovery of acetic acid and methanol. Production is conducted in part by conventional oven carbonization and by other carbonization methods quite different in principle and application. All plants have in common, however, two main operating steps in which (a) the wood is predried and carbonized and (b) the crude liquid products obtained are refined.

Oven Processing. The conventional oven operation is a batch process. The sheet-steel ovens hold approximately ten cords of cord-size wood. The ovens are commonly set in pairs, and heat is applied externally from separate fire boxes. Steel rails on the floor of the oven and in line with yard and cooler tracks allow fast charging and discharging of the ovens by means of steel buggies. Full cross-section swinging doors at both ends of the oven are made gas-tight with steel wedges that engage the door frame. Excessive heat radiation is prevented by an additional outside door. Distillation volatiles leave the oven through sideward vapor take-offs to water-cooled copper condensers.

Coal and manufactured and natural gases are the chief fuels used for firing. Controlled heating of the ovens to an end temperature of about 800° F. assures optimum yields of low-volatile charcoal and refined liquid byproducts. Distillation cycles vary from 18 to 22 hours and may be so timed that charging and discharging of a number of ovens can be accomplished at staggered intervals. The hot charcoal is withdrawn to gas-tight, sheet-steel coolers at the same time a new charge of wood enters the ovens from the yard or from predriers. A minimum time of 48 hours in the coolers and 48 hours in covered sheds is required for conditioning the charcoal before it is shipped. From 1,000 to 1,100 pounds of charcoal is generally obtained from a cord of wood in oven processing.

Stafford Retort Processing. The Stafford retort (9) has little resemblance structurally or operationally to the conventional ovens. Processing in this type of unit is continuous. Wood that has been hogged or is in small blocks or chips is utilized, rather than cord or long block lengths. Production in one domestic plant started almost 30 years ago and has since been maintained continuously. It is of interest to note that where low-cost scrap from an adjacent mill initially provided all of the raw material, the greater part now required is from forest hardwoods and sawmill residues.

Efficient predrying and related low moisture content of the wood are important factors to the Stafford carbonizing operation. The wood from the rotary driers is fed to the retorts at a predetermined rate and at a moisture content not exceeding 0.5 percent. Flue gases from the power plant supply the heat to the predriers supplemented by non-condensible wood gas.

The Stafford retort operates vertically, is about 40 feet high and ten feet in diameter, and is heavily encased overall with insulation. Adequate provision against heat losses must be made, since a critical heat balance within the retort is a controlling factor for proper operation. Automatic barrel-type valves at the top and bottom ends of the retort prevent the introduction of air with the wood feed, and also prevent the escape of volatiles at these points. The preheated wood enters the retort at a temperature of about 300° F. As the wood continuously moves downward, carbonization conditions are maintained by utilizing reaction heat available at about mid-point in the retort. The average tem-
Fig. 4. Sheet metal kilns, operating battery-wise near mill slab waste supply.
perature in this central zone is about 950° F. and gradually decreases with charcoal formation to about 480° F. at the base. Volatile materials pass from outlets at the top of the retort to four evenly spaced condensers. The charcoal is discharged continuously to air-tight coolers and conditioners. The small-size charcoal produced has restricted markets as such, but, on the other hand, needs only limited grinding for briquette production. About 1,000 pounds of charcoal are obtained from each cord of wood. The entire output of about 130 tons of charcoal per day is converted to briquettes. An additional plant using the Stafford principle has recently been reported under construction. This plant is estimated to cost two and a quarter million dollars and will utilize woods and mill residues in chipped form.

Converted Hardwood Byproduct-Recovery Plants. Some of the more marginal plants have been forced by economic conditions to curtail full by-product manufacture to the recovery of charcoal alone. Such retractive measures have resulted in better plant returns, and better plant position for future charcoal production.

Conversion of these plants is accomplished by eliminating the highly specialized equipment for the recovery and refining of the liquid byproducts and leaving intact the carbonizing facilities. The change-over from full recovery processing is quite simple and requires only that the retort gases be vented from the condensers to the atmosphere, to an outside combustion furnace, or to the oven fire boxes for use as supplementary fuel. Either of the latter two means for disposal of volatiles is preferred, since direct bleeding to the atmosphere may create both a nuisance and a possible health hazard. Charcoal yields comparable to those from oven byproduct plants are obtained, and at reduced cost.

Gas-Circulating Processes. A marked change from conventional oven-carbonization methods is evident in the more recent commercial techniques developed in Germany by Reichert (7, 11, 12) and in Belgium by Lambiotte (6). These techniques may help overcome the persistent economic barriers of high wood and labor costs in the United States. One large oven plant has already been partially converted, and full conversion of another is contemplated.

In principle, the carbonization methods employed by Reichert and Lambiotte are similar, but they differ from other systems in that they use a hot, inert gas media for transfer of heat to the wood. Although the Reichert operation has been essentially batchwise and that of Lambiotte continuous, it is reportedly possible to make the Reichert process continuous without undue difficulty. With the further exception that the heating gas in the Reichert retort flows downward with the direction of the wood through the retort, and countercurrently to the wood travel in the Lambiotte retort, both methods may be described briefly together. The retorts are cylindrical with conical end sections, and are mounted vertically as individual units or in batteries. Both top and bottom sections of the Lambiotte retort are equipped with special valves to permit loading and discharging without intake of air or loss of wood gases and vapors. In operation, heated wood gases enter the retorts through valved openings, spread throughout the charge, and are subsequently emitted along with distillation vapors to condensers. A portion of the dried gases from the condensers is blown under slight pressure through furnace tubes and is heated to a predetermined temperature by combustion of the remainder of the condenser gases. Passage of the heated gas from the furnace to the retort completes the cycle. Conditions of gas recycling and circulation within the retort
Fig. 5. Sheet metal kilns, readily portable for location at various sources of wood supply.
are automatically maintained with a minimum of attention. The yield of charcoal per cord is comparable to that obtained by other commercial processes with similar hardwood species. As yet, domestic charcoal production from this type of operation is limited.

**Production in Resinous-Wood Byproduct-Recovery Plants**

At the outset, the recovery of charcoal at resinous-wood byproduct-recovery plants was of secondary importance, marketwise, to the recovery of the distillate containing pine tars and oils. While both products are now equally important, the nature of the raw material that must be used restricts location of the plants to areas of abundant supply. These areas contain the desired "pitchy" stumpwood from old, logged-over southern pine stands, and are confined chiefly to the region along the Gulf Coast. Unlike the perpetual supplies of raw material that are available for plants in the hardwood-distillation group, progressively decreasing supplies are generally the outlook for resinous-wood operations. On the basis of proportionate plant return, charcoal has become increasingly important, however, and might make possible the use of softwood raw material now considered inferior.

Southern stumpwood is generally carbonized in batches in horizontally mounted, cylindrical steel retorts (3). Fire boxes are located at one or both ends of the retort, depending upon its length. In a few operations the retorts are sufficiently large for car loading, but most are charged and discharged by hand. Two plants vary the process by using concrete retorts with inside flue-pipe heating. Processing has been further varied by not heating the bottom of the retort, so that much of the higher boiling liquid can be drawn off at the bottom and vapor fractions can be passed through side outlets to condensers, Other than for the oil heating applied to the concrete retorts, firing methods are similar to those used in the hardwood-distillation industry. The charcoal is removed to an air-tight receiver after it has been heated for about 24 hours. It is then put in open-shed storage.

**Status of the Carbonization Industry**

The annual charcoal production in the United States for 1956 was 265,000 tons (17). Table I shows the approximate annual production of charcoal by process classifications, with the corresponding amounts of raw material consumed.

<table>
<thead>
<tr>
<th>Plant Process</th>
<th>Charcoal Produced</th>
<th>Wood Consumed</th>
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<tbody>
<tr>
<td>Kiln</td>
<td>55,000</td>
<td>121,000</td>
</tr>
<tr>
<td>Hardwood - byproduct recovery</td>
<td>159,500</td>
<td>351,000</td>
</tr>
<tr>
<td>Hardwood - converted byproduct recovery</td>
<td>14,500</td>
<td>32,000</td>
</tr>
<tr>
<td>Resinous - wood byproduct recovery</td>
<td>36,000</td>
<td>71,000</td>
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The carbonization industry has a less favorable economic condition now than about 25 years ago. In the intervening period, wood costs have more than doubled, and labor costs, on the average, have increased to at least an equal or greater degree. Charcoal prices, however, did not increase proportionately. In the mid 1930's, upwards of 50 recovery plants were producing charcoal. The present recovery-plants, all of which have fixed locations and potentially unfavorable wood costs, now provide the bulk of the charcoal. Because it would cost an estimated $25,000 per cord of capacity to construct a new hardwood recovery plant, it cannot be foreseen that any large or continued expansion of the
Fig. 6 (Upper). Two-wall, 7-cord, masonry block kiln—recently developed unit providing features for operational efficiency and increased uniformity of product.

Fig. 7 (Lower). Commercial 9-cord, concrete block kiln—both large and small units are operated singly or in groups to provide flexible charcoal production amounts.
charcoal industry will take place in this conventional manner.

Utilization of wood residues for charcoal cannot be overlooked, even though past commercial efforts have been largely unsuccessful. Mill refuse can be made available for conversion at a cost considerably below that of forest wood, and is available now at a cost of about only one-half that of forest wood. Satisfactory commercial conversion in the past has been retarded primarily because of excessive equipment and maintenance costs and the lack of markets for small particles of charcoal. More recent developments in this field indicate that mill residues can be utilized in practical operations. One of these developments is a semi-commercial unit (13) designed at the Oregon Forest Products Laboratory, Corvallis, Oregon, and constructed to operate on Douglas-fir mill fines. This unit includes the essential factor of continuous feed input, and has been further designed for recovery of all the byproducts. Briquette research was carried on at the same time in order to establish the practicability of a combined operation.

Other carbonization research on wood-waste fines includes the application of a fluidized-bed technique. In this method wood particles are continuously fed to a cell containing inert gas as a heating medium. The particles are kept agitated by controlled input and upward movement of the gas stream until they are completely converted to charcoal. The results of exploratory investigations conducted at the Georgia Institute of Technology, Atlanta, Georgia, the Oregon Forest Products Laboratory, Corvallis, Oregon, and the Stanford Research Institute, Stanford, California, indicate promise for commercial expansion of the fluidized-bed technique in the future.

Utilization

During the past several years, charcoal markets have been increasingly active, with demand oftentimes exceeding production. Charcoal is both a chemical raw material and a fuel, and its consumption in these two major fields determines the operational pattern of the industry. Uses of charcoal in metallurgy and in associated applications can be rated considerably less important. Charcoal is consumed in the form of lumps, briquettes, screenings, powder and activated charcoal. It is used primarily as domestic and specialized fuel, and in the metallurgical, chemical and allied fields. The market for charcoal as a recreational fuel is tremendously active. These uses, without relation to individual tonnage consumption, are shown under three groupings in Table 11. Despite the widely different produc-
TABLE II

Uses of Charcoal

<table>
<thead>
<tr>
<th>Domestic and specialized fuel</th>
<th>Metallurgical</th>
<th>Chemical</th>
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<tbody>
<tr>
<td>Recreational</td>
<td>Copper</td>
<td>Carbon disulfide</td>
</tr>
<tr>
<td>Curing tobacco, meat, and fish</td>
<td>Brass</td>
<td>Calcium carbide</td>
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<tr>
<td>Heating and cooking in dining cars</td>
<td>Pig iron</td>
<td>Silicon carbide</td>
</tr>
<tr>
<td>Heating foundry, tinnery, and plumbing equipment</td>
<td>Steel</td>
<td>Sodium cyanide</td>
</tr>
<tr>
<td>Heating houses, laundries, and incinerators</td>
<td>Nickel</td>
<td>Potassium cyanide</td>
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<tr>
<td>Heating salamanders in shipyards and citrus groves</td>
<td>Aluminum</td>
<td>Carbon monoxide</td>
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<td></td>
<td>Electro manganese</td>
<td>Activated carbon</td>
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<td></td>
<td>Armor plate</td>
<td>Black powder</td>
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<td></td>
<td>Foundry molds</td>
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<td>Fire works</td>
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<td>Catalyst reactor</td>
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<td>Rubber</td>
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<td>Brake linings</td>
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<td></td>
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<td>Molding resins</td>
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<td>Gas-cylinder absorbent</td>
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<td>Paint pigment</td>
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<td></td>
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<td>Crayons</td>
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<td></td>
<td></td>
<td>Nursery mulch</td>
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<td></td>
<td></td>
<td>Pharmaceuticals</td>
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<tr>
<td></td>
<td></td>
<td>Poultry and stock feeds</td>
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</table>

tion processes, the product is surprisingly uniform in properties, and rigid consumer specifications are not generally required. Its marketability for industrial and fuel uses is determined by its bulk weight and percentage of volatile matter. Limiting maximum values for volatiles and moisture content are about 20 percent and two percent, respectively. There are economic limitations associated with further expansion in the recovery-type operations. It is apparent that additional facilities for charcoal production will stem largely through the development of processing equipment for wood fines and the more extensive application of kiln operations for forest and heavy mill residues. As waste utilization tools, their wide development would afford excellent opportunity for greater and cheaper production.

Despite the existing favorable aspects of kiln production, research in this field could be gainfully applied. Kiln production provides a means of immediate money return to the farm woodlot owner, and industrial opportunities for others interested in comparatively large-scale production. Additional basic information relating to kiln structural performance and elements of operational control is needed, however. Field kiln studies are being conducted by the U.S. Forest Products Laboratory in cooperation with associated Forest Experiment Stations. The results are expected to provide a more adequate guide for technical and economic development and commercial expansion of this method of wood-waste conversion.

Kiln operations strategically located with respect to wood and charcoal markets already produce substantial tonnage. It is not difficult to forecast that, with additional similar facilities, production could be expanded almost at will. However, it would seem desirable in this event that production stabilize itself around a lower-priced material. A trend in this direction would relieve a growing danger of charcoal pricing itself off the market, and also establish a position for retaking a number of outlets now lost to cheaper carbons.

The wood carbonization industry as a whole will no doubt operate with a meas-
FIG. 8 (Upper). Hardwood by-product recovery plant—includes carbonization and refining facilities for the production of chiefly acetic acid, methanol, and charcoal in lump, briquette and activated forms.

ure of profit for some time to come. It will expand, however, only through further technological and economic research in connection with existing production techniques and in the development of more suitable ones as well.

Literature Cited

Utilization Abstract

Pine-gum Research. The U. S. Department of Agriculture Naval Stores Research Station, Olustee, Fla., is active in the study of methods of production and new products from pine-gum. One of the outstanding improvements in production methods of turpentine and rosin worked out by this station is the continuous distillation process which saves about half the steam needed to operate batch stills.

Research on derivatives of crude pine-gum has shown that maleo-pimaric acid is valuable in industrial applications as printers' ink, paper sizing, alkyd resins, and photographic chemicals. From turpentine, preparations of esters of pinic acid are excellent lubricants for engines of jet aircraft; as additives to plasticizers, these esters give to plastics the desirable qualities of low temperature flexibility, durability and permanence. Pinane hydroperoxide, derived from turpentine, is useful as a catalyst in the production of cold rubber.

From rosin, with the addition of lead and magnesium to aldehyde-modified rosin, improved metal resinsates are produced, with good paint-drying qualities. A new acid has been discovered in rosin, resistant to crystallization. Palustric acid, first identified in Pinus palustris, has already found use in paper sizing, and has promise of other industrial utilization. (Anon., Chemurgic Digest 15(10): 4–5. 1956.)

17. U. S. Forest Service. 1957. Charcoal Production in the U. S.