FURNACE-TYPE LUMBER DRY KILN

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During World War II, the need for drying facilities increased at small sawmills operated with gas, Diesel engines, or electric power. Such mills lacked steam for the more conventional steam-heated type of lumber dry kiln. Because of the difficulties of control and the increased fire hazard, most of the dry-kiln companies and engineers providing steam kilns had avoided the design and construction of furnace-type kilns. To learn what could be done about these problems, and to provide information and data on design and operation of kilns of this general type, the Laboratory undertook to do some design and test work in this field. The kiln type described in this report is intended for use only where steam is not readily available.

A small experimental unit was built on the Laboratory grounds during the early months of 1944 and was in operation approximately 1 year. The general design did not differ a great deal from conventional steam kilns of the internal-fan, cross-circulation type except in the methods used to supply heat and humidification. A commercial sawdust burner was used in order to utilize a fuel that is considered waste at many mills, but a gas or oil burner or a coal-burning furnace could be substituted. The heating plant also included a secondary combustion chamber and a multiple-return-bend type of smoke pipe which provided the necessary radiating surface. The desired temperature was maintained automatically with a thermostat and a damper motor connected to the draft door of the burner. Relative humidity was controlled automatically with a wood-element hygrostat and a second damper motor. The building itself was of wood and was insulated with dry sawdust. Its capacity was approximately 7,500 board feet of 1-inch lumber. The drying of several northern softwoods and hardwoods, including 4/4 green oak, proved to be satisfactory both as to drying time and drying degrade.

Following this work, a commercial kiln having a capacity four times that of the Laboratory unit was constructed by a Wisconsin lumber company at Merrill, Wis., in cooperation with the War Production Board and the Forest Products Laboratory. The kiln has been in continuous operation since February 1945, except for three reconstruction periods when fires damaged portions of the roof and furnace room. These fires were due, at least in part, to the use of dry sawdust and shavings. This fuel burned too vigorously and did not feed properly through the hopper. As there was not
a continuous supply of green sawdust, the company decided to replace the sawdust burner with an industrial-type oil burner. Large amounts of northern Wisconsin hardwoods and softwoods have been kiln dried, and the drying results have been good.

A smaller commercial unit, similar in size and design to the Laboratory unit, was built by a firm at Grand Marais, Minn., in 1946. A first attempt to burn dry planing-mill shavings resulted in a fire. Later, however, a method was devised that safely fed this fuel into the burner. After 2 years, this firm believes that dry shavings are better than sawdust that is not at the proper moisture content.

These tests and experiences have indicated that this design is susceptible to good control of drying conditions and that a sawdust burner can be satisfactorily and safely used. Overheating to obtain high temperatures quickly must be avoided. Consequently, the drying temperatures used must be consistent with moderate demands on the heating equipment, which, of course, is best not only to guard against fire, but also to permit better control of drying conditions. Careful attention in both construction and operation is worthwhile with any kiln operation, but particularly with furnace-type kilns, which require both equipment and technique that are not yet common in this field. Considerable experience is necessary to attain a degree of control comparable to that readily obtainable in a good steam kiln. Therefore, to use the words "cheap" and "inexpensive" too freely in connection with these kilns might be misleading if all factors are not considered. In sum, the evidence is that, if properly constructed and operated, this type of kiln is suitable for use at small sawmills and planing mills where a steam supply is not available, or where its use would be especially inconvenient and expensive.

Description of Experimental Laboratory Unit

Figure 1 shows a furnace-type kiln design that is similar to the original unit made and tested at the Forest Products Laboratory. Figure 2 is an exterior view showing the door and its hardware, the openings in the eaves that vent the attic space above the insulated ceiling of the drying compartment, and the sticker rack, which can be picked up by a lift truck and moved where needed. Figure 3 shows a burner, and figure 4 the secondary combustion chamber and the return-bend type of smoke pipe and radiating surface used in the Laboratory kiln.

Construction

The commercial sawdust burner used has a grate area of about 4 square feet. It is of a type used rather commonly for home heating in the Pacific Northwest and the Northeastern States. The sawdust is placed in a large hopper and feeds by gravity to inclined grates and horizontal toe grates (fig. 5). The hot gases pass from the adjustable step grates and horizontal toe grates to the combustion chamber, where they are mixed with additional oxygen supplied by the secondary air and are then completely burned. From the combustion chamber, the hot flue gases pass through the long return-bend smoke pipe (fig. 4) to the chimney. The interior of the burner is lined with fire brick, with diatomite insulation between the brick and the cast-iron shell. The fire is controlled.
by operating the draft door with a small electric motor, such as is commonly used in furnace installations. The motor is set in motion by a bimetallic or gas-operated thermostat that projects through the wall into the drying chamber (on the entering-air side of the load), but is regulated from the furnace-room side.

The general design of this furnace-type lumber dry kiln lends itself to the use of coal, oil, gas, or even wood burners. The most important consideration regarding any burner is its ability to provide a wide range of heat output under good control. Another is its effect on the ultimate cost of drying the lumber.

The secondary combustion chamber has a volume of approximately 25 cubic feet. This volume, approximately 6 cubic feet per square foot of grate area, gives good results, but it is possible that smaller ratios of volume to grate area might also give entirely satisfactory results, particularly when only a low fire is needed. The chamber is connected directly to the open back of the burner and is also lined with fire brick and insulated. Its exterior is of common brick. The top, consisting of a cement slab cast upon a fire-brick arch, has not proved entirely satisfactory because of the development of cracks due to expansion and contraction. A refractory cement slab could be used in place of the ordinary cement slab and fire brick, but the best top construction would be of regenerator tiles which simply span crosswise of the chamber. Some allowance, however, must be made for expansion and contraction. As originally constructed, the secondary combustion chamber was located within the drying compartment. Since the loss of heat is not great, however, it can be located in the furnace room with only one end projecting slightly into the drying chamber, as shown in figure 1. In this location, it would not interfere with the air circulation through the load, although the amount of interference that occurred was found to be of no great importance.

The combined smoke pipe and radiating surface is 15 inches in diameter and made of 16-gage metal. The first length from the combustion chamber gets very hot and probably should be of heavier metal. For the first 4 to 6 feet, high-temperature stainless steel would be very good. If desired, the diameter can be adjusted somewhat to conform to standard sheet sizes. Approximately 40 to 50 square feet of radiating surface are believed desirable for each square foot of grate area, but possibly somewhat less would work satisfactorily. The smoke pipe is built in sections butt jointed together in the center of each bend. A wide metal band with bolted flanges encloses the joint. By enlarging the pipe to get the required amount of radiating surface, the number of runs could be reduced to three, in which case the chimney would be located at the door end of the kiln. The pipes are supported on metal brackets fastened to the vertical angle iron posts. Strap hangers suspended from cross bars (as shown in fig. 1) afford another satisfactory means of support, but, in any case, provision should be made for dismounting the pipes for cleaning.

The brick chimney has an 18-inch square flue lining. A by-pass damper was installed in the chimney for use in starting fires and in controlling the heat within the drying chamber. It was found, however, that the draft was sufficient through the long pipe and that good control of temperature was obtained without using the by-pass. For this reason, it can be eliminated.

In the furnace room a balcony was installed for sawdust storage so as to facilitate the loading of the hopper.
The vent system has dampers for controlling the amount of venting. The dampers are connected to a small motor of the furnace draft-door regulating type, which is set in motion by a wood-element hygrostat employing a microtype switch for electrical contact. By this means, the evaporated moisture is used to provide humidification. With sufficient attention, hand operation of the vent dampers is satisfactory, but instrument control is more desirable, especially in the initial stages of drying. As constructed in the experimental kiln, a vent duct on one side serves as inlet and one on the other side as outlet. As shown in figure 1, metal ducts pass directly through the side walls of the kiln, eliminating condensation trouble that has been experienced in the furnace room of the experimental unit, where the ducts pass through that room. Two 8-inch diameter pipe vents through each side wall provide sufficient venting capacity for this size of kiln.

The water sprays impinge upwards against the second run of pipe and then drop to the lower pipe. They are used mainly at the end of the drying period to provide sufficient humidification for the relief of case-hardening stresses; if needed, however, they can be used at other times to increase the relative humidity.

Two direct-connected motor-fan units consist of 1-1/2 horsepower, glass-wound motors and 3-foot, disk-type fans. Each has a rated capacity of approximately 15,000 cubic feet of air a minute at free delivery. The installation provides for reversible circulation, but best uniformity of temperature was obtained with the air passing upwards on the pipe side, and for that reason only one-way circulation is needed. Other types of fan installations can be used, such as disk-type fans mounted on a single longitudinal shaft with the electric motor (or possibly a gas or Diesel engine) located outside the drying chamber, and a special duct enclosing the fans to direct the air through the fans from the heating area to the entering-air side of the load.

The suspended ceiling has 2 by 4 joists and is filled with sawdust for insulation. Fifty-five-pound (per 108 square feet) roll roofing is placed on the lower side of the ceiling joists as a moisture barrier and rests on the 1-inch ceiling boards. The sawdust is left exposed on the top side so that any escaping moisture can pass through it into the ventilated attic space above. The side walls have 2 by 4 studs and are filled with dried sawdust insulation. The inside surface of the studs is also covered with 55-pound roll roofing as a moisture barrier. The roll roofing is put on vertically with overlapping joints sealed together at studs when the inside sheathing was nailed on. For more permanent installations, brick, tile, or light-weight cement blocks are recommended.

The kiln door is 2-1/4 inches thick, 10 feet, 4 inches wide, and 11 feet high. It is constructed of 2-1/4-inch solid stiles and rails, 3/4-inch braces, insulation, and 3/4-inch tongued and grooved boards installed vertically, on both sides. It is mounted on an overhead track with regular kiln-door hardware. A felt strip wrapped in heavy canvas is used as a gasket on the door jamb.
The lumber pile is 8 feet wide, 10 feet high, and 16 feet long. Such a pile will hold approximately 7,500 board feet of full-length, 4/4 lumber piled on 3/4- or 7/8-inch stickers. The capacity for random-length, box-piled stock is less and is governed by the average length of the boards. A track system to permit piling the lumber outside the drying chamber on regular kiln trucks is preferable to inside piling on a fixed foundation.

A baffle directs the air to the entering-air side of the load and prevents short circuiting of the air through the fans. It is made of canvas mounted on a frame, and is hinged to the motor platform so that it rests on the top of the load, but is lifted to provide overhead clearance during loading and unloading.

The clear glass tile windows (regular building block material 4 by 7-3/4 by 7-3/4 inches in size) are located in the walls above the small inspection doors as a means of reading, from outside, a wet- and dry-bulb hygrometer mounted on the inside wall. A window made with two blocks set vertically gives greater vision than one made with a single block for reading a hygrometer made with long thermometers of the precision type. Caulking compound or other types of mastic that will stand up under high temperatures can be used to seal the joints against vapor leaks.

Operation of Heating System

The method of maintaining the desired dry-bulb temperature in the furnace-type lumber dry kiln is distinctly different from that used in steam-heated kilns. When operating the latter type, steam is admitted to the radiating system within the kiln by valves manually or automatically operated to maintain the desired temperature. The heat is obtained by using the required amount of steam from a large supply. In operating the furnace-type kiln, the total heat developed by the burner is used at all times and the desired temperature is maintained by controlling the rate of burning. The rate of burning in the sawdust burner used in the Laboratory experimental kiln is extremely flexible and a high degree of control is obtained by controlling the supply of air and fuel.

Starting the fire.--Conventionally, the fire is started by tipping the hopper forward and laying paper and kindling on the grate before filling the hopper with fuel. An easier method is to fill the bottom of the hopper with dry shavings and light the fire from the ash pit below the inclined grates. The latter method is particularly advantageous if the hopper has been extended upward into a fuel-storage space so that it cannot be readily tipped forward for laying a fire on the grate.

Controlling the temperature.--The desired kiln temperature is maintained by the automatic control of the draft door of the burner and by keeping enough fuel in the hopper.

Two devices for governing the amount of air admitted to the burner are the draft door in the front of the burner and the secondary-air port on top of the burner toward the rear. In practice, part of the primary air entering through the draft door may bypass the fuel bed and thus become in effect secondary air.
Primary air is air that passes through the fuel bed. Its volume is controlled both by a thumbscrew adjustment of the draft door that maintains a minimum opening and by automatic opening and closing of the draft door. The temperature is controlled automatically by a thermostat that activates a damper motor through a three-wire, 20-volt electric circuit. As the temperature falls below the setting on the thermostat, the damper motor opens the draft door; when the desired temperature is reached, the motor closes the door. Thus a constant dry-bulb temperature is maintained within the range of heat output of the burner.

The slope of the inclined grates also governs the amount of air that passes through the fuel bed. When the grates are tilted down, less air passes through the fuel bed than when the grates are in a horizontal position. The volume of air that is thus directed is, of course, governed initially by the volume admitted through the draft door.

Secondary air furnishes the oxygen needed to continue the burning of the unburned gases in the combustion chamber. This air enters the burner through a secondary-air port or through the draft door and under or around the grates into the combustion chamber. The supply of air is controlled manually by adjusting the position of the cover of the secondary-air port as well as by the opening and closing of the draft door. Apparently, the supply of secondary air is seldom more than is required for complete burning, and the secondary-air port may remain open during normal operation.

To hold a desired kiln temperature with the minimum variation, a thumbscrew on the draft door can be manually adjusted to provide a small opening in order to maintain a minimum fire that will nearly furnish the heat required. The size of the opening when the draft door is opened by the electric control motor is then adjusted by moving the point of attachment of the connecting chain along the motor arm, or by leaving much or little slack in the connecting chain when the draft door is closed. The desirable adjustment is to have the rate of burning, when the draft door is open, safely above that required to maintain the desired temperature, but not enough to increase the temperature dangerously. Then, even though the mechanism were to fail, the temperature would not go far below or far above that desired.

Temperature variations recorded in the Laboratory kiln unit while operating under thermostatic control were not great, usually being about 2° F. On occasion, temperature variations were even less, indicating that the burning rate of the furnace as governed by the draft is sufficiently flexible for accurate control between certain temperature limits. The sensitivity of the thermostat seems to be the most important limiting factor.

The adjustments for controlling the depth of the fuel bed on the grate are made by hand, usually only when there is a change in the type of fuel being used. Only a thin layer of a heavy fuel, such as green hardwood sawdust, is required for satisfactory burning; for drier fuel, a thicker layer is required. The fuel baffle is suspended from two threaded studs that extend upward through the top casting of the burner. By turning the nuts on these studs, the baffle is raised or lowered. The angle of the inclined grates
also governs the depth of fuel as well as the amount of air that passes through
the fuel bed. As the grates are tilted downward, the depth of the fuel bed be-
comes greater, and as they are tilted back to a horizontal position, the depth
of the fuel bed is lessened.

In general, a bed of fuel that is too thick causes much smoke and incomplete
burning of the gases in the combustion chamber, while a bed that is too thin
allows the draft to rush through the burner, carrying sparks and ash into the
combustion chamber. Probably the ideal adjustment is to have the fuel bed as
thick as possible while maintaining satisfactory combustion as indicated by
the absence of smoke.

Removal of ash.--Limited experience indicates that the burner can be operated
continuously during a kiln run as long as 3 weeks if the ash pit is cleaned out
daily or every other day. The amount of ash that accumulates from approximately
700 pounds of green hardwood sawdust during a 24-hour period is less than 0.5
bushel. Between runs, the secondary combustion chamber and the burner are
cleaned thoroughly. Approximately 0.4 bushel of ash accumulates back of the
grates and in the combustion chamber during 1 week of operation. The removal
of this ash presents no special problem. Ash accumulates very slowly in the
heating pipe, but occasionally the lower run should be removed and cleaned.

Kinds of wood waste used.--Sawdust, shavings, and chips were burned in the
Laboratory unit with varying degrees of success. The size, shape, and
moisture content of the fuel determine its acceptability. Both have a direct
bearing on the heat value of a given volume of fuel and on the manner in which
the fuel will feed down from the hopper into the burner. Granular sawdust
feeds much better than either shavings or chips, which, because of their
shape and light weight, tend to arch and clog in the hopper. Green or partly
dry sawdust has less available heat than dry material because of the amount
needed to evaporate the water before it can burn, but, being somewhat heavier
per unit volume, it feeds better through the hopper.

During the experimental kiln runs there was no difficulty in holding a fire,
even with green oak sawdust. When burning light, dry shavings or chips that
do not feed well, the fire burned back into the hopper. Green hardwood or
softwood sawdust fed well, burned well, and its heat value was sufficiently
high per unit of volume. A mixture of sawdust and shavings or chips burned
less satisfactorily as the proportion of shavings or chips was increased. A
mixture of 50 percent green sawdust by volume (moisture content 60 to 100
percent based on the oven-dry weight) and 50 percent dry shavings (moisture
content 10 to 15 percent) burned fairly well. Oak sawdust having a moisture
content of about 40 to 60 percent burned best of the several types of fuel
used.

Quantity of sawdust fuel needed.--The limited data available on fuel con-
sumption permit only a rough estimate of the quantity required for con-
tinuous operation. During 12 kiln runs in the Laboratory experimental unit,
68,150 board feet of lumber were dried. Records of the weight and moisture
content of fuel burned and the pounds of water evaporated from the lumber
being dried showed that the kiln operates at an over-all efficiency of
between 15 and 30 percent. This efficiency figure was obtained by dividing
the number of British thermal units required to evaporate the water from the lumber by the number of B.T.U. in the fuel burned and includes all heat losses, such as those up the stack and through the building and vents. A wide range of material was dried, including 3/4 and 4/4 Western redcedar, 4/4 ponderosa pine, Eastern white pine, Douglas-fir, commercial red and white oak, and hard maple. The highest efficiency figures were recorded when drying fast-drying species that had a high original moisture content. The drying time for these species ranged from 3 to 10 days. Small sawmills in one part of the South produced from 0.80 to 0.89 pound of sawdust (oven-dry weight) per board foot sawed, or enough fuel to kiln dry up to 75 percent of all the lumber manufactured.

In burning green, or very nearly green oak sawdust, the burning rate ranged from about 20 to 80 pounds per hour under draft door control and under a draft pressure of about 0.1 inch of water.

**Operation of Relative Humidity System**

The furnace-type kiln was designed to provide humidification without the use of steam. In steam-heated kilns the desired relative humidity is obtained by maintaining definite dry-bulb and wet-bulb temperatures. The dry-bulb temperature is maintained through control of the steam supply to the heating coils, and the wet-bulb temperature is maintained through control of the steam spray and the vents. In the Laboratory's furnace-type kiln, the desired relative humidity is maintained by automatic control of the vents and a water spray by means of a wood-element hygrostat developed at the Forest Products Laboratory (6). This instrument is capable of maintaining the desired relative humidity independently of the dry-bulb temperature. It is fairly easy to construct and is capable of controlling relative-humidity conditions within an equilibrium moisture content of wood of approximately 1 percent. In adjusting it to maintain any particular condition, however, an hour or two is required for the wood element to attain the proper moisture content. It is mounted on the wall near the thermostat on the entering-air side of the load (the side opposite the heating pipes).

There are two methods of maintaining the desired relative humidity: (1) by utilizing the moisture from the wood being dried, as is generally done in commercial kilns, and (2) by the use of water sprays to increase the relative humidity of the air. The water sprays are used as are steam sprays in a commercial kiln.

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2Underlined numbers in parentheses refer to literature cited at end of this report. Publications referred to can be obtained by writing to the Forest Products Laboratory, Madison 5, Wis. A complete list of reports on seasoning is given in FPL List No. R446.
To utilize the moisture given up by the lumber being dried requires that the kiln be as vapor-tight as possible. During the first part of a kiln run, a high relative humidity is necessary to prevent excessive shrinkage of and tension in the surface fibers. If the moisture given up by the wood is more than sufficient to maintain the desired relative humidity, some is exhausted through the vents. As the drying progresses, less and less moisture is extracted from the wood, but, at the same time, a lower relative humidity is desired. This fortunate circumstance makes the control of relative humidity comparatively easy. Especially is this true when drying thin sizes of species that dry readily.

When a higher relative humidity is desired than can be attained by closing the vents to utilize the moisture from the wood, vapor is added to the air by spraying a fine mist of water upon the hot flue pipes from spray nozzles. A city water supply maintained at a 60-pound pressure gives a fairly fine spray, but pressures perhaps as high as 150 pounds per square inch are more effective. When city water is not available, water can be supplied from a well or driven point by means of a small, automatic, electric pulping unit of the high-pressure type.

Both the vents and the water spray can be operated automatically with an electric control motor through a three-wire, 20-volt circuit and the wood-element hygrostat. During the first part of the kiln run, when there is more than sufficient moisture in the air, the hygrostat circuit is switched to the control motor that operates the vent dampers. In this manner the relative humidity is kept down to that desired by venting the excess. When the moisture given up by the lumber being dried no longer maintains the desired relative humidity, the hygrostat circuit is switched to the control motor that opens the water valve or activates the high-pressure pump, and water is sprayed onto the hot flue pipe, thus increasing the relative humidity to that desired.

Several kiln runs were satisfactorily dried in the Laboratory unit without automatic control of relative humidity. In this moisture-tight kiln sudden changes of relative humidity do not take place as drying progresses. The relative humidity remains steady, slowly falling as less moisture is given up from the wood.

Figure 6 shows the kiln conditions and the drying rate of the lumber for a kiln run consisting of 4/4 commercial red and white oak. During the first 6 days the wood-element hygrostat held the relative humidity to a maximum of 80 percent (except for the first day while the control was being established). Thereafter the vents remained closed and the relative humidity gradually dropped to 10 or 12 percent during the final days of drying. After the lumber had dried to a moisture content of 5 percent, a conditioning treatment for the relief of case-hardening stresses was given the oak by increasing the temperature to 165° F. and the relative humidity to 65 percent for 6 hours by means of the water sprays. As the temperature dropped during the night, the relative humidity increased to 90 percent. This conditioning treatment completely relieved the stresses (3).
In another kiln run, consisting of 4/4 hard maple, the fans were left on continuously, but the fire was maintained during daylight hours only, and consequently the drying conditions, especially the temperature, varied considerably from the control setting. This is shown in figure 7, which gives the complete drying data for this particular run. These schedules follow, in a very general way, the Laboratory's basic schedules (2).

Regulating and Indicating Instruments

Besides the bimetal (or vapor-bulb) thermostat for regulating the temperature, and the wood-element hygrostat for controlling the relative humidity, inexpensive wall hygrometers are used to determine the conditions of temperature and relative humidity. One is placed on each side of the kiln and is visible through the glass-block inspection port above each of the rear access doors. By reading the dry- and wet-bulb thermometers of each instrument, the kiln operator is able to determine the temperature and relative humidity within the kiln, and thus to regulate the drying conditions according to the moisture content of the kiln samples as prescribed by the kiln schedule being followed (4).

Costs

The Laboratory experimental kiln unit cost $3,000, of which $800 was for equipment. Complete cost figures, including depreciation, maintenance, interest, insurance, and other factors of interest to commercial operators, are not available. Operating cost figures of interest to anyone contemplating the building and operation of the furnace-type lumber dry kiln, can, however, be estimated fairly closely.

The Laboratory kiln has two 1-1/2-horsepower fans that use about 2 kilowatts an hour. At $0.02 a kilowatt-hour, cost of power is about $1 a day.

The burner uses green oak sawdust at the rate of 70 to 80 pounds per hour at the start of a kiln run when the kiln and the lumber are being heated, and at only a slightly lower rate during the early stages of drying, when considerable moisture is evaporated from the wood. Especially is this true when drying a fast-drying species. As drying continues and an even temperature is being maintained, the burning rate drops rather sharply to 20 to 30 pounds of green oak sawdust per hour. The over-all average burning rate is approximately 40 pounds per hour. If the cost of sawdust is $1 per ton, the cost of fuel will be approximately $0.50 per day.

The kiln requires 1 to 1-1/2 man-hours per day for maintaining the fire and weighing kiln samples. While common labor can be used for filling the hopper (which has to be done once or twice daily), the kiln operator should be a skilled technician. These costs will vary considerably, but might be $0.60 for the laborer (1 hour) and $0.60 for the operator (1/2 hour), or $1.20 per day. The following summary shows estimated daily operating costs.
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<tr>
<td><strong>Total</strong></td>
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</tr>
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</table>

Daily operating cost for 1,000 board feet of lumber in a kiln containing 6,000 board feet would be $2.70 divided by 6, or $0.45.

These figures are based on only a short period of operation of an experimental unit, and operating costs of a commercial unit may be quite different.

**Commercial Units**

At Merrill, Wis.

On the basis of the experience gained in the operation of the experimental Laboratory unit, a lumber dry kiln large enough to hold from 20,000 to 30,000 board feet was designed, constructed, and operated in cooperation with the War Production Board and the Wausau Lumber Sales Company, Wausau, Wis., at the company's electric mill in Merrill, Wis. This kiln was constructed during the winter of 1944-45 and was put in operation February 24, 1945. It was still in use at the date of this publication.

The plan shown in figure 8 is a slight modification of the original plan used for this installation. In this drawing, the secondary combustion chamber has been moved almost completely out of the drying room into the furnace room; metal supports are shown for the roof and fans, and a brick chimney receives the smoke pipe to eliminate condensation problems in the attic space due to leakage around the smoke pipe. In the kiln as built, the pipe extends upward through the ceiling and roof. The use of a brick chimney would also lessen the fire hazard. Figure 9 is an exterior view, figure 10 shows the heating pipe located between the loads, and figure 11 is a view of one of the water sprays directed upwards against the second run of pipe.

The sawdust burner was of a commercial type having a grate area of approximately 13 square feet and a heat output capacity of about 2,000 B.t.u. an hour. A conveyor was used to lift the sawdust from the storage pile at the rear of the kiln building to the storage bin above the furnace room. The secondary combustion chamber was larger, in proportion to grate area, than that built in the smaller Laboratory unit, but after some operating experiences it was felt that a smaller volume would have functioned better under slow fires because of relatively higher temperatures. The water-spray system consisted of a driven point with a fine screen and a 220-volt, 1-horsepower, high-pressure rotary pump that was controlled by the wood-element hygrostat through a magnetic relay switch.
The original cost of this unit was approximately $9,000, roughly subdivided as follows: $3,000 for the building, $3,000 for the heating and humidifying system, $1,500 for motor-fan units and baffles, and $1,500 for track, trucks, and laboratory equipment such as small weighing scales, drying oven, and band saw. Most of the work was done by the regular mill crew, which was inexperienced in the construction of lumber dry kilns. This fact, plus some extremely cold weather, probably increased the labor cost of the building and installation of equipment.

The company has dried a large amount of northern Wisconsin hardwoods and softwoods from both the green and the air-dried condition. Drying results have been good and, during initial operation in the spring of 1945, operating and fixed costs were estimated at $1 a day for 1,000 board feet.

Trouble with fire at this plant has been due partly to the fact that sawdust was stored outdoors and, when it became too soggy to burn satisfactorily, dry sawdust and shavings from a planing mill were used to increase the heat output. This lightweight fuel did not feed properly through the hopper, burned back into the hopper, and overheated the furnace and the first portion of the elongated smoke pipe. As the sawmill is operated only part time, a continuous supply of fresh sawdust is not available. Consequently, it was decided to eliminate this trouble by replacing the sawdust burner with an industrial oil burner, having a B.t.u. output capacity of over 2,000,000 B.t.u. per hour when burning No. 4 or 5 oil, at the maximum rate of about 15 gallons per hour. The average burning rate, however, in drying air-dried basswood, maple, ash, and pine from about 24 to 7 percent moisture content, was 3 gallons of No. 4 oil a day for each 1,000 board feet of a charge. With a kiln charge of 24,000 board feet of lumber, this would mean an average burning rate of 3 gallons an hour. The average drying time was nearly 6 days for each run, making a total fuel consumption of about 18 gallons for 1,000 board feet. Assuming a cost of 10 cents a gallon, the fuel cost for 1,000 board feet of such lumber would be $1.80. The cost of drying green material would be a great deal more, the increase being somewhat in proportion to the amount of water evaporated.

At Grand Marais, Minn.

A kiln similar in size and design to the experimental unit shown in figure 1 was built by Andrew Hedstrom & Sons, Grand Marais, Minn., in cooperation with the Forest Products Laboratory. This unit was completed and put into operation during June 1946 and, at the date of this publication, was still in operation and giving satisfactory service.

Two 48-inch disk fans were mounted overhead on individual shafts that extended through the side walls to the outside, where they were connected to two 1-horsepower motors by means of twin V-belts. Figure 12 shows these fans set in a fan baffle that prevents short circuiting of the air from the pressure to the vacuum side. For the same purpose, a second baffle is hinged onto the lower edge of the fan baffle so that it can be lowered to the top of the load. Figure 13 shows the heat shield on each side of the first run of heating pipe. Figure 9 gives an exterior view of the loading track and transfer system. This method has since been discarded in favor of lift trucks. Lumber is piled on pallets wherever convenient and transported with lift.
trucks to the kiln trucks at the kiln door. Figure 14 shows the operating equipment, consisting of a drying oven, triple-beam balance, and weighing scale.

As the Grand Marais sawmill is some miles from its planing mill, the firm developed a successful method of burning planing-mill shavings.

A first attempt was made to feed shavings into the burner with a stoker-type coal screw directly from a storage bin into the fire through the front plate of the burner. Fire broke out when the screw was not running, allowing flame to work back through the screw into the shaving bin. This source of danger was eliminated by raising the bin to bring its bottom level with the top of the metal hopper on the sawdust burner so that the shavings drop several feet from the screw to the fire below (fig. 15). The feed is at such a rate that the shavings burn as they reach the grates and do not accumulate or build up in the hopper. A down draft through the burner hopper carries the flames horizontally into the secondary combustion chamber and away from the feed screw. This down draft exists, due to leakage, even though a lid is kept on the hopper.

The fuel bin is approximately 4 feet wide, 8 feet long, and 5 feet high. To prevent the shavings from arching above the feed screw, the lower half of one sloping side wall is hinged to the upper half, so that two arms extending to it from ball-bearing cams on a horizontal shaft can move this hinged section in and out an inch or two to break up arching of the shavings. The owners consider this arrangement better than a horizontal shaft with perpendicularly mounted iron pin arms that rotate within the hopper directly above the feed screw.

The storage bin could be much larger to hold fuel for use when the planer mill is not running. Added safety from fire would be gained by locating the bin outside the kiln, with the feed screw leading from it through the kiln wall to the burner hopper.

The shaving bin is filled by means of a pipe that taps the main pipe leading from the planing mill blower to the waste burner. With a directional damper operated manually, shavings are diverted to the bin whenever needed.

The feed screw, about 4 inches in diameter, runs lengthwise along the bottom of the shaving bin and through a metal pipe to the burner hopper, entering it directly below the lid.

Both the fuel feed screw and the cam shaft that moves the hinged side of the shaving bin are driven by a 1/4-horsepower electric motor through a series of reduction pulleys and a reduction gear box. A variable-speed pulley on the motor permits automatic adjustment of speed; at high speed, the feed screw turns at 18 revolutions per minute and at low speed 6 revolutions per minute. The cam shaft turns much more slowly, approximately 3 revolutions per minute at high speed and 1 revolution per minute at slow speed. The adjustment is made automatically through the combined action of a thermostat and damper motor that moves the motor back and forth on a sliding base so as to vary the effective diameter of the motor pulley. When the thermostat calls for heat, the damper motor not only moves the driving motor but also opens the draft door of the burner.

Report No. D1474
Heat Requirements

About 1,000 B.t.u. are required to evaporate 1 pound of water at kiln temperatures. Additional heat is required to take care of heat losses through the vents and through the kiln structure. This amount varies a great deal in different kilns, but usually it is best to allow at least another 1,000 B.t.u. for every pound of water evaporated (8). In table 1, the values are given in pounds of water and pounds of steam, but for all practical purposes it is sufficiently correct to assume that 1 pound of condensed steam will provide 1,000 B.t.u.

Another problem in estimating heat requirements is the rate at which the water evaporates from the lumber. This varies from less than 0.1 to possibly more than 1 percent an hour, depending upon the species and item being dried, its moisture content, the efficiency of the kiln, and the drying schedule used. Assuming a 1 percent hourly rate for fast-drying, low-density species, the moisture evaporated would be approximately 20 pounds an hour for 1,000 board feet of lumber. At an over-all heat requirement of 2,000 B.t.u. to evaporate a pound of water, the hourly demand would then be 40,000 B.t.u. for 1,000 board feet. Air-dried oak, on the other hand, may require less than 10,000 B.t.u. an hour.

As the heat requirement is much greater at the beginning of a run on green material than it is toward the end, the drying time is often increased by the inability of a small heating plant to furnish sufficient heat to attain permissible drying temperatures quickly. It is somewhat doubtful whether or not it would be economical to provide a great deal of surplus heating capacity to take care of this need; but if this capacity is available without too great a first cost and loss in over-all efficiency, a definite saving in drying time may be made possible, particularly where high initial temperatures and low initial relative humidities are not damaging to the lumber.

Circulation Requirements

Ventilation is often confused with circulation in the kiln drying of lumber. Ventilation refers to the passage of air into and out of the drying compartment to dispose of the evaporated moisture. Circulation refers to the internal movement of air to carry heat from the heating surfaces to where it is used for the evaporation of moisture, and for the replacement of heat lost through the structure and vents. Uniformity of drying conditions depends upon the rate at which the heat is delivered to the various locations where needed to maintain constant conditions of both temperature and relative humidity. Theoretically, perfect uniformity can be accomplished only by an infinite air velocity, but for all practical purposes an air velocity of about 300 feet a minute through one 8-foot wide load (or two 8-foot loads if heat is provided between them) is sufficient to give a satisfactory drying rate for most species and items of green lumber. The need for fast air circulation, however, diminishes with the moisture of the stock, and for well air-dried lumber it is desirable but not nearly so essential. In other words, a fan delivery that will provide about 3 or 4 cubic feet of air a minute for each board foot of green lumber in the kiln will give a satisfactory drying rate even with a rather long air travel through the lumber piles. Lower air velocities will
also dry green lumber satisfactorily, but the drying time will be increased. The loss of time will occur mostly during the initial stages of drying, when the drying rate and heat requirements are greatest.

Venting Requirements

The optimum vent opening for any particular kiln is difficult to determine. Fast drying at low temperatures and low relative humidities requires high venting capacity. On the other hand, air-dried lumber can often be dried, especially under high temperatures, in a kiln without vents, leakage being sufficient to provide a satisfactory amount of venting. For general lumber drying, however, it is best to have a tight kiln with ample vent openings. Although opinions and experience differ widely as to the proper size and number of vents, it is believed sufficiently satisfactory for most operations if inlets total an amount equivalent to about 20 to 30 square inches for each 1,000 board feet of lumber, and outlets about the same amount.

Each vent should be provided with a tight-fitting lid or damper operated either manually or automatically to produce the results desired. They will function fairly well in any location because of the usually big difference between the vapor pressure within and that outside of the kiln. The greatest exchange of air takes place where the vents are located on each side of the recirculating fans so as to take full advantage of the pressure differential between the two sides of the fan and fan baffle. Because of this pressure differential in a fan kiln, no special stacks or chimneys need be provided.

As water sprays are not so convenient and effective as steam sprays in controlling the relative humidity, it is particularly important that furnace-type kilns be constructed with a good vapor barrier and well-fitted doors, so that full advantage can be taken of the evaporated moisture for humidity control. For this reason, too many leaky vents may prove to be a detriment with regard to quality of drying, and should be guarded against (2).

Humidification Requirements

When the relative humidity is not increased sufficiently by closing the vents, water sprays can be used to supply whatever moisture is needed. Knowing the air volume and the amount of lumber in the kiln, the amount of moisture needed at the end of the run to raise the moisture content of the lumber about 1 or 2 percent for the relief of case-hardening stresses can be computed. The loss of moisture due to leakage must also be provided for, but even when a liberal estimate is made for this, the total requirement is considerably less than 0.1 gallon a minute for 1,000 board feet of lumber. The water supply, however, must be greater than this because only a part of the water spray vaporizes.

A spray nozzle using from 0.25 to 0.50 gallon of water per minute under normal city water pressures, when directed upwards against the second run of heating pipe, appears to be sufficient for about 3,000 to 4,000 board feet of lumber. More sprays will do no particular harm and may be needed occasionally. It is best, however, to install the sprays so that some of them can be turned off from the outside if not needed.
The sprays would be more effective in raising the relative humidity if hot water were used. Some additional equipment, however, would be needed to heat the water before it enters the spray supply line. Steam from a small, low-pressure boiler would be even more effective and convenient, but would cost more. Such equipment might be considered where good control is particularly desirable.

Special Considerations

Several aspects of the construction and operation of the furnace-type kiln differ from those encountered in the construction and operation of a steam kiln.

Fire Hazard

First among these special considerations is the possibility of a fire. Steam-heated kilns are safely separated from the boiler room, but the furnace-type kiln is a closely coupled unit, with the fire box an integral part of the kiln. The fire is usually near the inflammable fuel storage bin and the lumber in the kiln. The source of fire may be either the burner in the control room or the heating pipe within the kiln. When adequate attention is given to the problem of preventing fire, however, successful results are obtained. A few simple precautions are highly effective.

A fire from the burner may originate at the draft door from which sparks sometimes fly when the burner puffs and backfires due to incomplete burning in the combustion chamber. The danger is greatly lessened if the ash-pit door is screened. The backfiring may occur when the combustion chamber is not sufficiently hot, as after a long period with the draft door closed or when the fire is being started. The former is common if the burner is too large for the heat requirements and must be operated at a low burning rate. There is no backfiring if the burner is operated at a brisk rate of burning. A shield around the front of the burner, or a fireproof furnace room, would eliminate this fire hazard.

Sawdust may ignite in the hopper if the fuel does not feed down readily, thus allowing the fire to work back into the hopper. The proper precaution is to keep the hopper well-filled with green or only partially dry sawdust and covered with a metal lid except when loading it. Dry planing-mill sawdust and shavings can be burned without danger if dropped directly to the grates from the upper part of the burner hopper at a rate that will not let the fire get too hot or the dry fuel accumulate in the hopper.

The metal heating pipe inside the kiln is also a potential source of fire, since it becomes hot during operation. The section adjacent to the combustion chamber becomes sufficiently hot to ignite any wood that might come in contact with it. The area about the heating pipe must, therefore, be kept clean and free of all wood waste. Further to overcome this fire hazard, a long tunnel-shaped combustion chamber was tried as a means of dissipating some of the heat, before the hot gases enter the first section of pipe. The heat output and heat control, however, were not so good as with the rectangular-shaped combustion
chamber and the additional metal radiating surface. Wood partitions, of course, should not come in direct contact with the walls of the secondary combustion chamber. A space should be left and filled with masonry or other fireproofing material.

Loading and Unloading Arrangements

To use the kiln to best advantage, it should be in operation as much of the time as possible. If the lumber is loaded directly into the kiln, the kiln will be down the length of time required to unload and reload. The use of tracks and kiln trucks will shorten the loading time somewhat, for one charge can be loaded while the kiln is operating, and the time between runs will be only the time required to remove and unstack the dry lumber and push the trucks of green lumber into the kiln. A transfer track system further reduces the loss in drying time by eliminating the time needed for unstacking.

If a transfer car system is too expensive for a small kiln operation, loading and unloading can be facilitated by building a kiln with a door at each end, with loading tracks running from one end and unloading tracks from the other. The furnace and operation room would then be on one side, as shown in figure 16. In this sketch, the building construction differs from the experimental design and represents a more permanent type of construction.

The use of a lift truck is becoming more common and might be considered as a means of eliminating the need for transfer tracks or doors at each end of the kiln.

Control Equipment

Temperature is difficult to control, within the limits desired in a lumber dry kiln, with any hand-fed wood or coal furnace even though a thermostat is used. The use of gas, oil, or stoker-fed coal largely eliminates this difficulty, and even the sawdust burner with its gravity feed of sawdust from the hopper was found to control kiln temperatures much better than a hand-fired, coal-burning furnace controlled with the same type of thermostat. Without good temperature control, some form of hygrostat is particularly helpful in operating the vent dampers and water or steam sprays.

If satisfactory humidity conditions are not obtained in this manner, the hygrostat can be connected to the furnace, thereby securing the desired humidity by regulating the temperature. The vents and sprays would be set by hand and used only when needed. The drying would be done according to an equilibrium moisture content schedule. Disadvantages of this system are that the resulting temperatures may be lower than necessary for some species, prolonging drying time, or possibly too high for other species, such as green oak, increasing drying defects. As a safeguard, a thermostat in the drying compartment, and possibly a limit or dome switch in or near the furnace to prevent overheating, should be connected into the temperature-control circuit.

If good temperature control is possible, a wet-bulb thermostat can be used in place of a wood-element hygrostat. This thermostat can be connected to
a motor valve on the water-spray line or, during the early stages of drying, to a damper motor on the vents and then, during the latter part of the run, to the motor valve on the spray line. Since, however, the relative humidity obtained depends upon the difference between the wet-bulb and dry-bulb temperatures, steady control of the dry-bulb temperature is essential.

Size of Kiln Unit

The size of a kiln unit is governed by its required output capacity and the time required to dry each kiln charge. Easily dried species, such as 4/4 pine, can be kiln dried green from the saw in 3 to 5 days. Species such as 4/4 basswood and aspen dry in 4 to 7 days, while beech, birch, and maple usually require 10 to 15 days. Green oak is one of the slowest-drying species; 3 to 4 weeks are require for 1-inch stock. Slow-drying items commonly are air-dried first in order to reduce the time required for kiln drying (1).

Small kilns can be quickly loaded with one species and thickness, but for general commercial drying larger kilns are cheaper. It would cost considerably more to build and operate four units of 5,000-board-foot capacity than one with a capacity of 20,000 board feet. On the other hand, the smaller units would be more flexible where the mill output consisted of a number of species and thicknesses.

Costs

Furnace-type kilns, such as described here, are cheaper to build than steam kilns only with respect to the cost of the complete heating system and the simpler control instruments. Buildings, equipment for loading and unloading the lumber, and fans cost as much as for a steam kiln of similar capacity and standards.

Equipment Used in Experimental Units

Sawdust Burners

There are several patented commercial sawdust burners on the market. The burner used in the Laboratory kiln had a grate area of about 4 square feet while that used in the 4-truck kiln at Merrill, Wis., had a grate area of about 13 square feet. The larger furnace heated up rather slowly when cold, but worked well when the secondary combustion chamber was hot. Although this combustion chamber may be larger than necessary, nevertheless continuous operation tended to eliminate this starting difficulty. The smaller burner in the Laboratory unit has given less trouble in starting, but this may have been due to a difference in draft or fuel.
Fans

The following specifications were used in purchasing the motor-fan units:

"Each motor shall be a 1-1/2-horsepower, three-phase, 220-volt, 60-cycle, reversible glass insulated motor suitable for use in a lumber dry kiln under temperatures as high as 220° F. and relative humidities up to 100 percent. For further protection, each motor shall be equipped with a Bakelite slot wedge and a vaporproof terminal box. The motor shall be direct connected to a 36-inch propeller-type fan and shall turn at approximately 1,140 revolutions per minute. The total air delivery of each unit shall be at least 15,000 cubic feet per minute at free delivery. Each unit shall be equipped with a motor stand or fan ring for support, a manual starting switch, and an automatic overload switch for motor protection. Sealed conduit and fittings or a special electric cable capable of withstanding the temperature and relative humidity conditions above specified shall be provided for use within the kiln."

Units of this nature can be purchased from kiln companies, ventilating equipment concerns, or producers of other types of fan equipment.

Disk fans mounted on individual shafts crosswise of the kiln or else on a single longitudinal shaft within a deflecting duct can be used and can also be obtained from kiln companies as well as from manufacturers of such equipment (5).

Door Hardware and Door Carrier

Special dry-kiln door hardware and door carriers are manufactured by a firm that markets them either direct or through various dry kiln companies and engineers at standard prices. As the door, door hardware, and door carriers must correspond in dimensions, complete doors, or else blueprints for the construction of doors, should be obtained with the door equipment. Although not so satisfactory, doors can also be hung on heavy hinges. This arrangement is cheaper, but care must be taken to see that the doors are strongly built and well-fitted.

Kiln Trucks

Kiln trucks can be obtained from the various dry-kiln companies. Those purchased for the Merrill kiln were 6 feet in length with two 8-inch wheels on each unit. Four are required for each 16-foot kiln load. Other truck lengths are available also and may be more appropriate for loads of different lengths. Combinations of 4- and 6-foot trucks would be desirable where the lumber is sorted for length or where close sticker spacings are used.
Thermostat

Both bimetal and vapor-bulb thermostats were used satisfactorily. In purchasing such equipment, the following specifications can be used as a guide:

"1. Element shall be mounted so as to extend through a 6-inch wall into the drying compartment and be at least 16 inches from the case. The case should be mounted in the operating room.

"2. Operation shall be through contact points or a small electric switch.

"3. The thermostat shall be suitable for operating a 20-volt electric control motor through a temperature range of 90° to 210° F. The sensitivity shall be such that the temperature differential is not greater than 3° F. and the calibration shall be at least equal to the 3° F. sensitivity with set mechanism for easy adjustments."

Various companies produce equipment that is believed to meet these requirements. (Forest Products Laboratory Report TP-26.)

Hygrometers

Two hygrometers should be provided for each kiln unit. Hygrometers and thermometers of kinds suitable for the purpose can be obtained from instrument companies and from kiln companies (5).

Control Motors

Two damper control motors are needed, one for the draft door of the furnace, which works off the thermostat, and one for the vent damper and water sprays, which works off the wood-element hygrostat. Many furnace draft-door motors on the market are suitable for this purpose. They should be of the two-position type with a two- or three-wire circuit (to correspond with the thermostat), and should operate on 20-volt, 60-cycle current obtainable through use of a transformer from regular 110-volt current.

Hygrostat

A wood-element hygrostat, equipped with a micro-type electric switch, can be built by anyone handy with machinist tools (6). A less efficient and less desirable design, shown in figure 17, has been used successfully, however, and is somewhat simpler to construct.

Spray Nozzles

The most desirable spray nozzle is one that delivers a small amount of water in a very fine spray or mist. Many nozzles of this type are on the market.
Equipment Needed for Moisture Content Determinations

Forest Products Laboratory report TP-49 lists various companies that have equipment of this kind:

**Triple-beam balance.**--One balance is needed for weighing moisture content sections. It should be sensitive to 0.01 gram and have a total capacity of at least 200 grams. A capacity of 500 grams or more is often desirable.

**Scales.**--One scale is needed for weighing kiln samples (4). It should be sensitive to 0.01 pound and have a total capacity of 25 pounds or more.

**Electric oven.**--One oven is needed for drying moisture content sections. It should have a capacity of at least 1 cubic foot and be capable of automatically controlling temperatures up to 220° F.

**Bandsaw.**--One bandsaw is needed for cutting moisture content sections and stress sections. Any of the small home-workshop saws having at least 14-inch wheels and a 1/2-horsepower motor will be satisfactory. At the time of purchase, extra blades should be included.
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   partments. FPL Rept. No. R1265, 7 pp., illus.
Table 1.--Estimated steam consumption for 1-inch lumber in commercial kilns

<table>
<thead>
<tr>
<th>Species</th>
<th>Condition: Time of drying</th>
<th>Water evaporated per pound : Days</th>
<th>Steam per M of water : Pounds</th>
<th>Steam per M board feet : Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak</td>
<td>Air-dried: 8 to 12</td>
<td>600 : 3 to 4.5</td>
<td>1,800 to 2,700</td>
<td></td>
</tr>
<tr>
<td>Birch and maple</td>
<td>Air-dried: 6 to 8</td>
<td>575 : 2.5 to 4.5</td>
<td>1,450 to 2,350</td>
<td></td>
</tr>
<tr>
<td>Sweetgum</td>
<td>Air-dried: 7 to 10</td>
<td>450 : 2.5 to 4.5</td>
<td>1,100 to 1,800</td>
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<tr>
<td>Douglas-fir</td>
<td>Green: 3 to 4</td>
<td>750 : 2 to 2.75</td>
<td>1,500 to 2,050</td>
<td></td>
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<tr>
<td>Longleaf pine</td>
<td>Green: 4</td>
<td>2,000 : 2 to 2.75</td>
<td>4,000 to 5,500</td>
<td></td>
</tr>
<tr>
<td>Shortleaf pine</td>
<td>Green: 4</td>
<td>2,500 : 2 to 2.75</td>
<td>5,100 to 7,000</td>
<td></td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>Green: 4</td>
<td>1,800 : 2 to 2.75</td>
<td>3,600 to 5,000</td>
<td></td>
</tr>
</tbody>
</table>

1 From "Steam requirements in lumber dry kilns," FPL Rept. No. R1478.
Figure 1.—Improved design of Forest Products Laboratory furnace—type dry kiln.
Figure 2.--An exterior view of the experimental furnace-type kiln on the grounds of the Forest Products Laboratory.
Figure 3.—The commercial sawdust burner used in the Laboratory kiln.
Figure 4.—The return-bend type of elongated smoke pipe that is used for radiation in the laboratory kiln.

ZM 78600 F.
SECTION SHOWING TYPICAL TWO-PIECE FEED GRATE.

SECTION SHOWING TYPICAL MULTIPLE SHELF FEED GRATES.

Figure 5.--Cross-sectional views of two typical sawdust burners that are adaptable for use in heating a furnace-type lumber dry kiln.

2 M 225°F
Figure 6.--Drying conditions and resulting drying rate of 4/4 oak from southern Wisconsin, obtained in the Laboratory kiln under full-time operation.
Figure 7.—Drying conditions and resulting drying rate of 4/4 hard maple, as obtained in the Laboratory kiln under daytime firing only.
Figure 9.--Commercial furnace-type lumber dry kilns at (top) Merrill, Wis.; (center) Grand Marais, Minn.; and (bottom) Beaver Bay, Minn.
Figure 10.--Centrally located 24-inch smoke and heating pipe as used in the Merrill kiln. Metal instead of wood supports for roof and motor-fan units would lessen the fire hazard.
Figure 11.--Water spray directed upwards against the second run of heating pipe to provide humidification in the Merrill kiln. Water is provided by an automatic electric pump from a driven-point well located in the furnace room. It is controlled by a wood-element hygrostat located on the entering-air side of the load.
Figure 12.--Two 48-inch disk fans in the Grand Marais kiln. Hinged baffle board drops from the fan baffle to top of load to prevent short circuiting of air. Top run of 16-inch smoke and heating pipe enters brick chimney near the ceiling. All supporting members near pipe are of metal.
Figure 13.--Lower portion of pipe in Grand Marais kiln. Metal heat shield is provided around lower run of pipe. The secondary combustion chamber is built into the lower part of the chimney and extends back into the furnace room.
Figure 14.—Operating equipment used at the Grand Marais kiln. Left to right, small electric oven, triple-beam balance, and weighing scale.
Figure 15.--Arrangement designed to feed planing-mill shavings into kiln furnace. Eccentric arms move hinged side wall of shaving bin slowly to prevent arching of shavings. Screw feed carries shavings to burner.
Figure 16.—A proposed design of a 2-truck unit with a door at each end of the kiln for quick unloading and loading.
Figure 17.--One form of wood-element hygrostat developed at the Laboratory and used successfully in controlling humidity in small storage rooms as well as in the Laboratory's furnace-type kiln.