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Unique Boiler Designs and Firing Methods for Cellulose Fuels

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WOOD AS A FUEL

Today the United States uses wood to supply over 1.1 quads of energy. Four-fifths of that is used in wood process plants and the pulp and paper industry. Wood burning provides the equivalent of 140,000 barrels per day of oil in the U. S.. The Department of Energy (DOE) predicts that this figure could double by the year 2000.

In addition to its costs, the advantages of wood include its availability, the fact that it can be replenished, the fact that it is clean environmentally, and that maintenance costs are lower. This is especially true if we compare wood to coal firing. The availability of the wood can be misleading, because while there are over three-quarters of a million acres of forest and land in the United States, it is uneconomical to ship more than about 40 or 50 miles to the plant.

Wood for fuel can come not only from the trees directly, but from the slash, (tops and limbs left in the forest after harvesting), trees cut for right of ways or building and expansion, dead trees from fire, disease or other natural occurrences, and waste products from various wood process plants.

On the economic side, wood contains about 17,000,000 Btu's per ton. However, wood is made up of about 50 percent water. Thus on a delivered basis, wood costs between 1 and 2 dollars per million Btu's. By comparison fuel oil is running between $2.50 and $3.50 per million Btu's, while coal is averaging about $2 per million Btu's. Projections by the Department of Natural Resources and Community Development for the state of North Carolina indicate that by 1990 coal will cost $5 per million Btu's and oil will be in the $6 to $8 range. Wood, however, is expected to remain relatively constant around the $2 per million Btu value.

In a paper presented to the Northeast Regional Public Power Annual Conference in Chatham on Cape Cod, Massachusetts in 1978, Charles T. Main, Inc. demonstrated that low quality eastern butiminous coal at $40 per ton and wood at $12 per ton were comparative in fuel cost at approximately 2 cents per gross kilowatt hour.

The American Boiler Manufacturer's Association reports wood to be a major factor in industrial steam generation. Per Table I, one-fourth of the 1980 boilers above 40,000 PPH were wood fired.

Due to uncertainties in the hogged wood supply, it is advantageous to fire both wood and coal alternately or simultaneously. This can be accomplished with pulverized coal burners and a spreader stoker for wood or a combination feeder for spreader stoker firing coal and wood; see Figure 1. Wood, being relatively low in bulk density and wet is best fed by pneumatic distributors while the coal is fed with mechanical distributors.

60 Solid Fuel Boilers Reported Above 40,000 PPH

Size:	**24 between 40,000 to 100,000 PPH**
Firing:	**31 Spreader Stoker**
	15 Pulverized Coal
	7 Hopper Fed Stoker
Fuel:	**38 Coal**
	15 Wood
	5 Bagasse
	2 Bulk Refuse

Table I ABMA 1980 Industrial Review

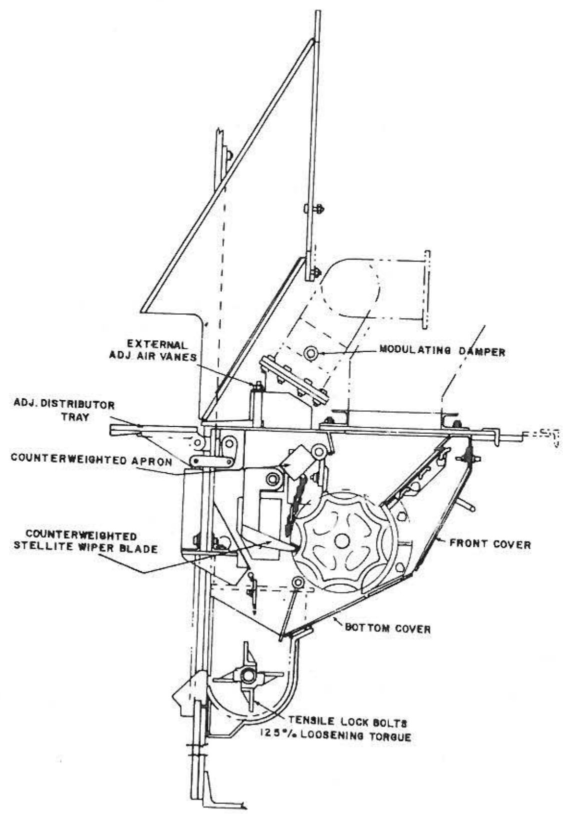


Figure 1 Multi-Flex Feeder for Coal and Wood Spreader Stoker Firing

A comparison of coal and wood analyses is given in Table II. The differences show wood to be advantageous with low sulfur and ash quantitites, and high ash fusion temperatures. Coal has the advantage of low moisture and less bulk material handling concerns.

- **Proximate Analysis, Percent by Weight, As Fired**

	Hogged Wood	Hogged Bark	Shavings	Med. Volatile Bituminous	High Volatile B Bituminous
Moisture	45.1	50.0	28.0	1.5	5.8
Volatile Matter	43.6	36.4	54.1	23.4	36.2
Fixed Carbon	11.0	12.1	17.6	64.9	46.3
Ash	0.3	1.4	0.3	10.2	11.7
Sulfur	0.0	0.1	0.0	2.2	2.7
• Heating Value Btu/Pound, As Fired					
	5,012	4,515	6,332	13,800	11,910
• Ash Fusion Temperature					
	2,750	2,240	2,360	2,450	2,160
• Sulfur, Pounds per Million Btu As Fired					
	0.0	0.22	0.0	1.6	2.3

Table II Fuel Analyses, Wood and Coal Comparison

Though laboratory analysis shows that most species of wood and bark have approximately the same chemical composition on a dry basis, moisture content can vary over a broad range. This affects heating value and boiler efficiency as well as combustion stability. When moisture contents rise above 60%, efficiency diminishes rapidly and the use of stabilizing burners becomes more of a necessity. Some plants dry the wood prior to admission into the furnace. The effect of moisture on boiler efficiency is shown in Figure 2.

The higher the moisture content, the more need for uniform fuel distribution, which in turn affects air distribution through the grate. For difficult applications a higher grate air differential pressure may be helpful.

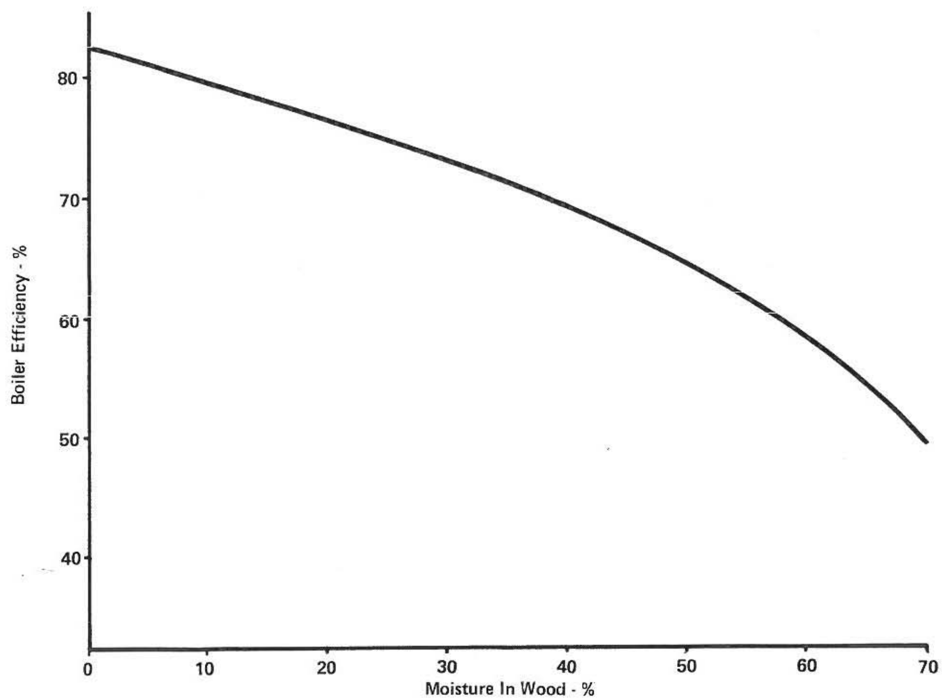
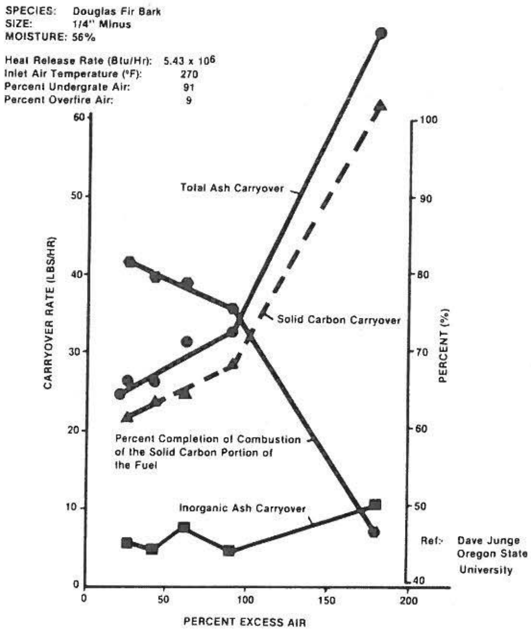
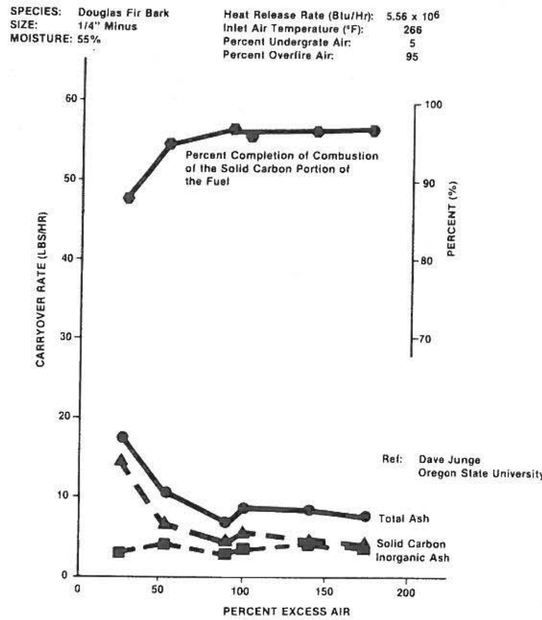


Figure 2 Effect of Wood Moisture on Boiler Efficiency

This increased grate air differential pressure (i.e. velocity) would normally markedly increase fly ash carryover. This effect has been counteracted by hot overfire air systems delivering up to 50% of the total combustion air at several levels of the furnace. The successful results of decreased undergrate air are shown by comparing Figures 3 and 4, noting the reduced carryover quantitites and increased completion of combustion.





Figures 3 and 4 Ash Carryover Rate vs. Level of Excess Air as Measured Downstream from the Combustion Process

If a unit were designed for coal only, there would typically be a cold overfire air system delivering approximately 30% of the total air. Units firing both fuels would be designed by the wood requirements.

Ash is the non-combustible mineral matter left behind when the fuel burns completely. Table III shows typical ash analyses for wood and coal. Here the largest differences can be seen in the silica, iron, aluminum, and calcium constitutents.

	Wood	Coal
Silicon Dioxide (SiO_2)	14.3	47.5
Aluminum Oxide (Al_2O_3)	4.0	17.9
Iron Oxide (Fe_2O_3)	3.5	20.1
Calcium Oxide (CaO)	6.0	5.8
Magnesium Oxide (MgO)	6.6	1.0
Sodium Oxide (Na_2O)	18.0	0.4
Potassium Oxide (K_2O)	10.6	1.8
Titanium Oxide (TiO_2)	.0.3	0.8
Manganese Oxide (Mn_3O_4)	0.1	—
Sulfite (SO_3)	7.4	—
Chloride (CL)	18.4	—
Other Compounds	10.8	4.7
	100.0	100.0

Table III Ash Analysis—Percent by Weight

The ash content of wood is low, generally less than one percent. Bark has more ash content, often reaching seven percent. A large factor in ash determination is logging and hogged fuel handling techniques. High values of sodium and potassium may lead to superheater fouling, especially when wood and coal are fired simultaneously.

Traveling grate spreader stokers are generally used for units with capacities greater than 150,000 pounds per hour. Grate heat releases of 1,000,000 Btu per hour per square foot are utilized for wood firing compared to 750,000 Btu per hour per square foot for coal firing. Traveling grates, despite their high cost compared to stationary or water-cooled grates, allow a combination firing of coal and wood, continuous ash discharge and rapid load change response characteristics.

FURNACE DESIGN

Furnace design varies with the capacity of the unit and fuels to be fired. Generally small units (100,000 lbs. of steam per hour or less) are constructed of the tube and tile arrangement, although welded wall construction is becoming more popular even at these low capacities. The welded wall construction insures a tight furnace, minimizing infiltration of air in balanced draft units and leakage of flue gas from pressurized units.

The sizing of water-cooled furnaces for wood burning is affected by the moisture content of the wood fuel and the characteristics of the auxiliary fuel. The grate heat release will ultimately determine the depth and width of the furnace while the height will be dependent on the moisture content of the fuel and the properties of the auxiliary fuels which are to be fired. High moisture content wood fuels require a greater furnace height to allow sufficient residence time for combustion of material in the furnace. Generally, residence times of 2 to 3 seconds, based on superficial velocities, are used in sizing the furnace. High turbulence overfire air systems make an exact determination of residence time nearly impossible. With grate heat releases determining the plan area and width and depth dimension, the minimum height of the furnace will be determined by ERS and volume requirements.

Releases for wood firing are slightly higher than comparable values for coal firing on a square foot and a cubic foot basis. The range of heat release for wood firing would be 25 to 30 thousand Btu/hr per cubic foot for wood and 20 to 25 thousand Btu/hr per square foot for coal. On a square foot of effective radiant surface basis, heat releases of 70 to 90 thousand Btu/hr per square foot are used for wood firing compared to 60 to 80 thousand Btu/hr per square foot of effective radiant surface for coal.

The design of the furnace must also take into consideration the characteristics of the auxiliary fuel. The turn down requirements and the differences in slagging and/or fouling characteristics of the fuel must be considered and a compatible furnace design developed. The furnace should be designed with sufficient cooling surface for auxiliary fuel firing by itself or in combination with wood fuel.

Wood fired designs not too long ago utilized up to 50% excess air to insure complete combustion. Present day practice calls for excess air levels of 30%, but the percent of overfire air has gone in the reverse direction, increasing from 30 to 50 percent. Furnace exit gas temperatures shown in Figure 5 are 100 to 150 degrees higher on coal firing compared to wood fuels. This is partly due to the higher moisture content of wood and partly due to the lower emissivities of the wood-fired flame.

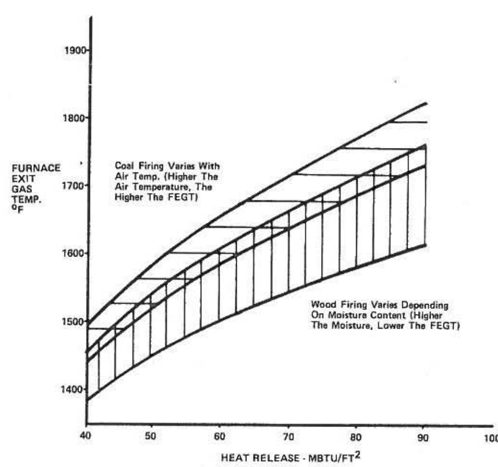


Figure 5 Furnace Exit Gas Temperatures

HEAT RECOVERY SURFACE DESIGN

For wood-fired boilers, the boiler bank and superheater should be designed to minimize erosion caused by sand and dirt in the flue gases. In single-pass boilers like the one shown in Figure 6, maximum flue gas velocities should not exceed 50 ft/sec. In multiple-pass or baffled boiler banks similar to Figure 7, velocities should be a maximum of between 30 and 40 ft/sec to prevent damage from erosion and cutting. Tube spacing will be determined by fouling characteristics of the wood or auxiliary fuel.

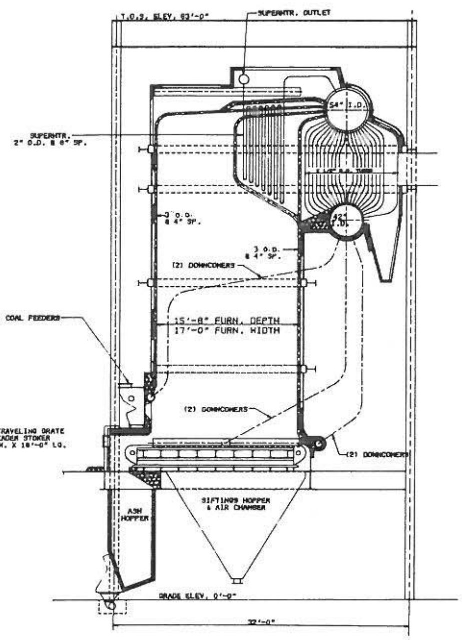


Figure 6 Typical Single-Pass Boiler

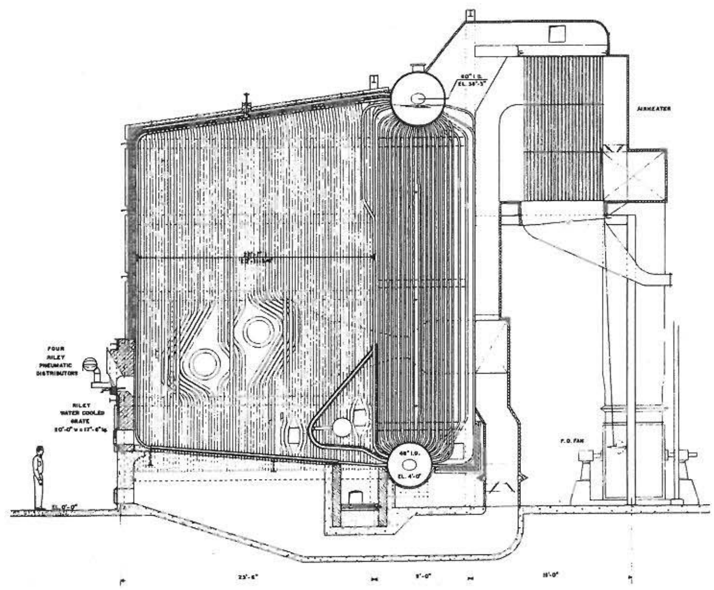


Figure 7 Typical Multiple-Pass Boiler

The design of the superheater must take into consideration the moisture content of the wood fuel as well as the auxiliary fuel which may be used alone or in combination with wood. In the case of wood versus coal firing, less superheater surface is required to achieve a given superheat steam temperature for wood. This is due to the higher volume of flue gas which occurs with wood firing. Even though the furnace exit gas temperature levels may be lower, the mass flow increase more than makes up for this deficiency. As a general rule of thumb, units designed to fire both coal and wood have superheaters that are designed with a control range of wood and full steam temperature only at full load on coal.

Heat recovery equipment such as airheaters and economizers are used with units designed for wood firing. On relatively small units, only an airheater is utilized. Larger units require both an economizer and an airheater. Again the flue gas velocities are maintained below 50 ft/sec to prevent problems from erosion. Tubular airheaters are installed in the majority of cases. Regenerative airheaters may be used for coal firing but char from wood fired plants is easily trapped in regenerative airheaters which may result in fires. Either staggered or inline tube arrangements can be used for the tubular airheater. The difference is primarily one of draft loss on the air side. The staggered arrangement allows a smaller sized airheater physically, but has a higher draft loss.

AIR POLLUTION CONSIDERATION

Figure 8 shows a comparison of typical sizes of fly ash for wood and coal. Wood fly ash is one order of magnitude larger than coal (burned on a stoker). The amount of particulate matter leaving a wood-fired unit ranges from 0.5 to 8.0 grains per dry standard cubic foot. The actual dust loading depends on the type of fuel, ash content, firing method, grate heat release, furnace configurations and reinjection quantities.

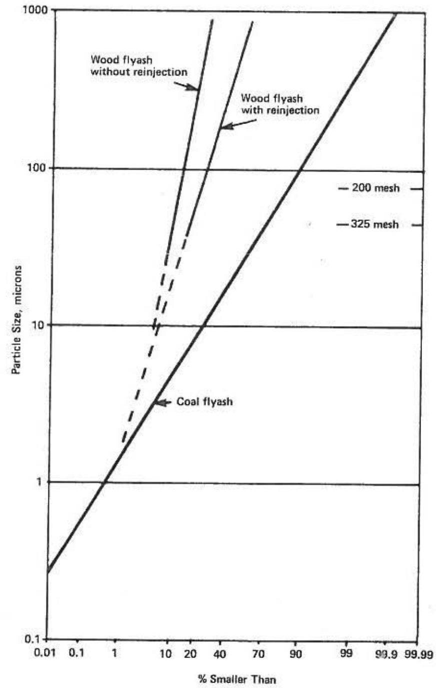


Figure 8 Size Distribution of Wood and Coal Fly Ash

In wood-fired power plants the air pollutant of primary concern is particulate matter. Particulate from a wood burning operation consists primarily of ash and unburned carbon, the latter normally comprising one-half to two-thirds of the total particulate leaving the boiler. To meet EPA Standards governing particulate emission, mechanical collectors, which usually cannot satisfy emission requirements by themselves, are used in series with scrubbers, electrostatic precipatators or fabric filters (See Figure 9). Two-stage mechanical collectors with variable vanes coupled in series may be capable of meeting the current EPA Standard of 0.1 pounds per million Btu, but it is impossible to design a mechanical collector with a collection efficiency high enough to meet the proposed standard of 0.03 pounds per million Btu. A mechanical collector and an electrostatic precipatator in series, with collection efficiency of 80 and 97 percent respectively, gives a combined collection efficiency of over 99 percent.

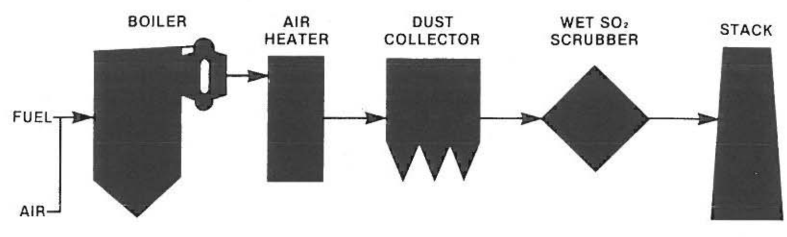


Figure 9 Dust Collector for Particulate Followed by Wet Scrubber for SO_2 Removal

An alternative to electrostatic precipatators is the use of fabric filters in a baghouse. Collection efficiencies of baghouses of over 99% can be achieved assuming the humidity and temperature of the flue gas does not impose limitations. Baghouses generally require more collection area and cleaning. These can be susceptible to fires if fuel oil is burned independently or in conjunction with wood

High energy wet scrubber designs involving high draft losses to create turbulence in a venturi throat or similar restriction can be applied to wood-fired boilers in place of electrostatic precipatators or baghouses. Wet scrubbers are effective for removing many of the small particulates that are not captured by cyclones and they also have the ability to follow load changes without sacrificing collection efficiency. Scrubbers require substantial water treatment facilities, however, and can be quite expensive when sulfur bearing fuels are burned in conjunction with wood. The installation of wet scrubbers can produce heavy saturated plumes which may settle out on the plant and the environment.

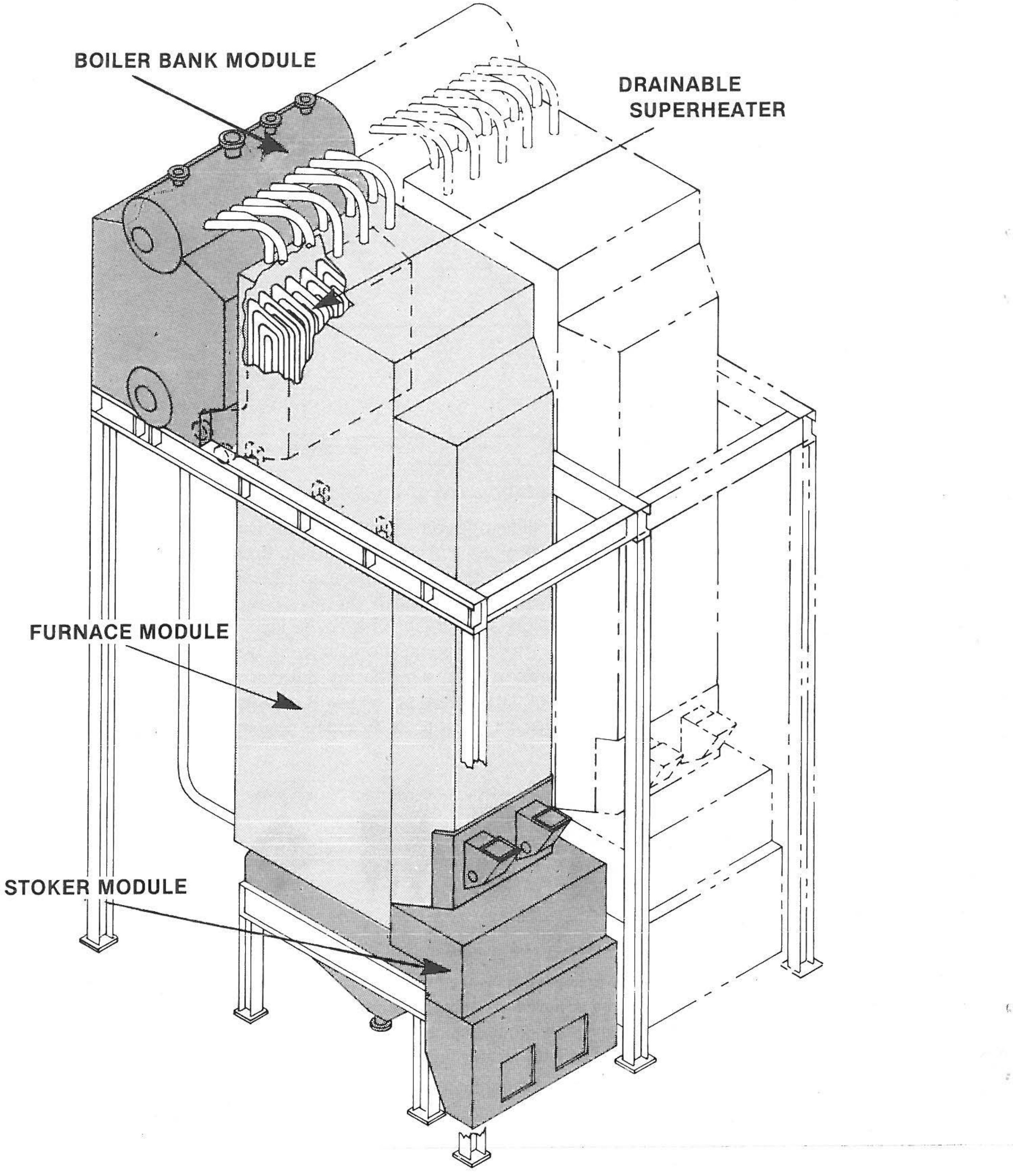


Figure 10 Shop Assembled Modular Boiler Spreader Stoker Firing

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Oxides of nitrogen (NO_X) are not generated in significant quantities from the combustion of wood fuel due to its characteristically low flame temperature. Depending on moisture content and air temperatures, these values vary between 2400° and 2700°F. Since NO_X is generated from atmospheric nitrogen in substantial quantitites only at temperatures above 2800°F, only small amounts of NO_X will be produced. NO_X generated from fuel nitrogen is in quantities considered to be insignificant. Tests conducted at Oregon State University for the U. S. Department of Energy[1] showed a mean value of NO_X emission from boilers fired with wood and bark residue of approximately 0.150 pounds per million Btu. This is well below the emission levels of NO_X which will be produced by a coal-fired unit, either pulverized (0.5-0.7 lbs/10^6 Btu) or stoker fired (0.3-0.4 lbs/10^6 Btu). Nitrogen levels in the fuel samples of the tests run at Oregon State University ranged from 0.04 to 0.77 percent by weight.

Due to the low sulfur content of wood and wood refuse fuels, sulfur dioxide formation as a product of the combustion of wood is negligible. Removal of sulfur oxides from the flue gas stream is required only for boilers burning large amounts of high sulfur coal or oil together with the wood fuel. Sulfur contents of wood fuel range from 0 to 0.1 percent, the higher value being in bark fuel.

Boiler designs for wood firing range from very small packaged boilers to large field erected units. A unique concept which lies half way between these two types is shown in Figure 10. This is a shop assembled modular boiler which is shipped in separate modular pieces. The modules include the stoker, the furnace, the superheater, and the boiler bank. Economizers and airheaters can also be shipped in modular pieces to complete the complement of steam generating unit equipment. The modular concept lends itself well to wood firing as furnace height can be increased while still maintaining good control of furnace heat releases and design criteria.

CONCLUSION

Like coal, wood is plentiful across just about all of the United States. Unlike coal, it is uneconomical to ship long distances due to its high moisture content. It is important for plant designers and energy systems engineers to survey the availability of wood resources in the vicinity of their plant before deciding whether or not wood is the proper fuel to be fired.

The design of an efficient wood-burning furnace must consider three steps in the combustion process: drying of the fuel, distillation and burning of the volatiles, and finally burning of the fixed carbon. High grate heat releases and longer residence times in the furnaces are required, compared to coal firing.

Pollution controls are simplified for wood firing. Unlike coal, NO_X and SO_2 levels are low and require little or no control unless wood is fired in combination with oil or coal. Particulate matter is of concern, however, even with low ash contents in the wood fuels.

Depending on plant siting, wood can be less expensive than the fossil fuels: coal, oil or natural gas. Wood will probably never replace the fossil fuels, but it can help to lessen the effect of rising fuel costs and fuel availability.

REFERENCE

1. Tappi/April 1980, Vol. 80, No. 4