

TO BURN WOOD *continued*

the stack as flyash. Extraneous matter, like earth, stones, sand, forms clinkers on the grates.

Combustion air enters the furnace, up through the grates, through openings in the furnace doors to pass over the fire, through the feed-hole openings in uncontrolled form, horizontally through special tuyeres in side and center partition walls above the grates. Air may also be admitted through tuyeres in the bridge wall and through nozzles in the arch nose.

All oxygen passing up through the first two inches of burning fuel bed combines with the carbon to form CO₂. Above this level, CO₂ reduces to CO on contacting further hot carbon. Combustible gas leaving the fuel bed contains CO and hydrogen, a combination known as producer gas, which has a heating value of about 200 Btu per cu ft.

Increasing air-flow rate through the grate raises the gas-production rate without affecting completeness of combustion. Producer gas burns at the surface of the cone-shaped fuel pile. To complete this burning, about 85% of the combustion air must be supplied over the fire, the remainder through the grate.

Air for burning the gas must be applied near the fuel-pile surface with a velocity great enough to insure contact and turbulence. This insures maintaining a high temperature and causes a high rate of heat transfer to freshly fired fuel to force rapid distillation of moisture and volatile.

$$\text{Theoretical combustion air} \\ = 11.61C + 34.8\left(\frac{H}{8} - \frac{O}{8}\right)$$

where C, H and O are weights of these components per lb fuel as shown by the ultimate analysis.

Actual air needed for combustion varies from the theoretical over a wide range depending on furnace layout, load, fuel type, firing method, as it does for any fuel. Excess air must be determined experimentally for each installation. In general, hogged fuel needs about 33% more air than No. 6 fuel oil. To recapitulate well-known relationships: (1) CO₂ in flue gas is an index of combustion efficiency. (2) Exit-gas temperature is an index of boiler efficiency. (3) Combustible in the ash is an index of grate efficiency. Within limits each of these indexes influences the other.

Burning Behavior. Small particles, like sander dust, ignite and burn instantaneously. Pieces the size of sawdust take a few seconds to burn completely. Large pieces up to 2x2x6 in. may take hours to burn up. With these large pieces, the surface loses volatile matter and moisture first, and time elapses before the inner fibers give up

I: Typical Analyses of Waste-Wood Fuels Percentages by Weight

Fuel	Calif. redwood	Western hemlock	Douglas fir	Pine sawdust
Moisture:				
As received, %	50.4	57.9	35.9	—
Air dried, %	7.3	7.3	6.5	6.3
Proximate analysis (dry):				
Volatile, %	82.5	74.2	82.0	79.4
Fixed carbon, %	17.3	23.6	17.2	20.1
Ash, %	0.2	2.2	0.8	0.5
Ultimate analysis (dry):				
H, %	5.9	5.8	6.3	6.3
C, %	53.5	50.4	52.3	51.8
N, %	0.1	0.1	0.1	0.1
O, %	40.3	41.4	40.5	41.3
S, %	0.0	0.1	0.0	0.0
Ash, %	0.2	2.2	0.8	0.5
Higher heating value (dry):				
Btu per lb	9920	8520	9050	9130

IV: Firing Data of West Coast Waste Wood

Heating value, dry	9000 Btu per lb	Feedwater temperature	150 psig	Stack temperature	350
Steam pressure	150 psig	Stack temperature	350		
Fuel moisture, %	10	20	30	40	50
Heating value, as fired, Btu per lb	8100	7200	6100	5400	4900
Fuel moisture loss, Btu per lb	131	263	394	525	657
Volatile distillation loss, Btu per lb	144	128	112	96	80
Net heating value, Btu per lb	7825	6809	5794	4779	3743
Lb steam generated per lb fuel fired:					
At 40% over-all efficiency	3.00	2.60	2.22	1.83	1.43
At 50% over-all efficiency	3.70	3.25	2.73	2.28	1.81
At 60% over-all efficiency	4.30	3.90	3.33	2.74	2.16

these components. This delay results from the low heat conductivity of wood. Loss of moisture and volatiles causes the outer wood layers to shrink and crack. This permits the inner layers to give up their gaseous components.

Waste wood burns slowly because of the high moisture content. It can be burned as fast as water and volatile matter distill off. This matter in turn depends on the rapidity of heat supply. Fresh fuel receives heat by radiation from the burning fuel, walls and arch, and by conduction through the wood and furnace gases. For rapid combustion, fuel should be finely shredded.

Combustion temperature depends a great deal on moisture content. Maximum temperatures obtainable with 20% excess air at 70 F range as follows:

33% moisture	3000
50% moisture	2580
60% moisture	2250
67% moisture	1950
71% moisture	1700
75% moisture	1450
Maximum temperatures obtainable with an air preheater, passing 85% the combustion air entering the boiler at 70 F and leaving at 600 F, with remainder leaking into the furnace at 70 F, range as follows:	
33% moisture	3720
50% moisture	3280
60% moisture	2800
67% moisture	2480
71% moisture	2180
75% moisture	1900
With moistures in excess of 80% improved operation and efficiency	1680

Example Calculation of Available Heat in Wood Fuel

1. Moisture, 1 lb wood, dry basis	9000 Btu
2. Moisture, as delivered	50%
3. Moisture, 1 lb wood as delivered	4500 Btu
4. Heat loss to evaporate moisture from 1 lb of 50% steam	—
5. Heat loss to superheating steam	573.2 Btu
6. Heat loss to preheating steam	—
7. Heat loss to 212 in 550 F	41.1 Btu
8. Heat loss to evaporate 79.55% moisture, dry basis	—
9. Heat loss to 79.55% steam	79.6 Btu
10. Heat loss and volatile loss	736 Btu
11. Heat loss value, as delivered, (3)-(7)	3764 Btu

Installation of an air heater. The heater raises combustion temperature about 240 F for the given conditions. The gas entering the heater must have a temperature at least 100 F higher than the leaving air to keep the heater at an economical size.

With fuel containing 50% moisture the temperature drop of 300 F causes the temperature rise of 520 F, because of the difference in specific heats of air and fuel. This difference between the two will increase as the fuel moisture increases and as the amount of heated air leaking through the feed grate increases.

Furnace Design. Two types of dutch oven designs are the conventional, and the so-called producer-gas type, see p 91. In the conventional type air for combustion enters through the grates below the feed openings in the roof, in addition to coming through the furnace-door openings. None of this air is under control either by rate of flow, direction or intensity of blast.

Distillation air enters through the grate doors and comes up through the grate under the impetus of atmospheric pressure only. It finds its way through the fuel bed mostly where the pile is thin. This prevents uniform distribution of distillation air and minimizes the gas-generating capacity of the fuel. Air flow depends on the furnace load, which in turn varies with fuel-bed thickness, size of fuel particles and relative "packing." This type installation has no positive-controlled gas generation.

Overfire air is drawn through small openings in the furnace doors, or through the grates if the doors are open. The doors are usually kept closed to prevent air falling out. This air is largely uncontrolled. At best it can only come in

contact with front and sides of the fuel pile. A large part of this air rises and scrubs the arch and upper side walls, reducing the temperature of these surfaces.

Air leaking in through the feed-hole openings reduces air coming in through the furnace-door openings. It also cools the arch, aggravating the loss of radiated heat. Air and gas enter the boiler in uncontrolled fashion markedly reducing combustion efficiency.

The conventional-type dutch oven, comparable with the hand-fired coal grate, is an inefficient burner. It is a low-cost installation, but for given steam output requires a larger boiler and stack than does the producer-gas type.

Producer-gas-type ovens have distillation air forced into the ashpit under positive pressure by a blower, controlled by steam pressure. Much of the air finds its way through the thinner edges of the fuel bed, but the flow varies in response to steam demand. This feature reduces the grate and arch area needed. Distillation air is not affected by the air leaking in through the fuel-feed opening.

Overfire air enters under forced pressure through watercooled cast-iron tuyeres in side and center walls. This air blasts against the hot fuel pile where it contacts the hot carbon for good combustion. Practically the whole surface of the fuel pile has good oxygen supply.

In this type dutch oven there is a slight positive pressure. Hence the furnace and ashpit doors must be gas tight. The main combustion space below the boiler receives well-mixed gas and air from the dutch oven in controlled quantities.

Because of reduced operating and maintenance costs, watercooled grates are recommended for both type ovens.

III: Typical Test Results, Boilers Burning Waste Wood in Producer-Gas-Type Units

Boiler A—Emergency float type, U.S. Coast Guard, cross drum, inclined straight tubes

Boiler	A	B
1. Boiler heating surface, sq ft	2535	5000
2. Total steam heat output, Btu	16,232,100	25,302,100
3. Fuel net heat input, Btu	29,051,100	37,711,100
4. Efficiency, boiler, furnace, grate, %	55.9	67.0
5. Average steam pressure, psig	179	175
6. Average feedwater temperature, F	45	210
7. Average furnace draft, in. wg	-0.10	-0.11
8. Average draft at damper, in. wg	-0.50	-0.45
9. Average fuel moisture, as fired, %	45	56

This feature practically eliminates clinker formation.

Center-wall oven partitions allow cleaning one side of the furnace at a time. For the producer-gas oven they provide space for installing more air tuyere castings. This breaks up the fuel bed into smaller units, exposing more fuel-pile surface to contact with oxygen. This more nearly approaches conditions in coal-fired furnaces with level fuel beds.

Cost Comparison. To give an idea how various fuels affect steam costs here are results of one study we made for a West Coast lumber mill:

Hogged fuel, 45% moisture, 4500 lb per unit, 9000 Btu per lb dry, \$3.10 per unit delivered into dutch oven including a charge of 10c per unit for storage and conveying.

No. 6 fuel oil, 42-gal barrels, 150,090 Btu per gallon, \$2.27 per barrel, includes 12c per barrel for storage, heating, pumping.

The resulting costs per 1000 lb of steam burning hogged fuel or oil were:

Wood in conventional oven	40c
Wood in producer-gas oven	26c
Oil in conventional furnace	52c

These figures do not include ash-disposal and soot-blowing equipment.

Table III shows some typical tests of industrial boilers burning waste wood. Table IV shows variation in boiler performance for different fuel and boiler conditions.

Most of this information was obtained from Frank Balden, president of F E Balden, Inc., Portland, Oregon. He has conducted research work in the field of waste-wood burning for many years. He also pioneered the producer-gas-type dutch oven. There are many of these plants on the West Coast.