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MODERN WOOD FIRED BOILER DESIGNS– HISTORY AND TECHNOLOGY CHANGES

by

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ABSTRACT

Boiler and combustion system designs for firing waste wood have evolved as a direct function of the perception of wood as fuel.

The objective of wood firing technology has evolved from incineration of nuisance wood waste to efficient combustion of a valuable and desirable fuel. With this evolution, the combustion and boiler systems have been upgraded to improve reliability, boiler efficiency, and combustion efficiency. In addition, steam temperatures and pressures have gradually increased to meet higher turbine cycle requirements resulting in new superheater designs. Recently environmental emissions regulations have added further changes to the unit designs.

This paper discusses the history and evolution of wood firing including a review of the boiler and combustion system design changes/improvements and modifications required to meet environmental emission limits.

HISTORY AND TECHNOLOGY CHANGES

The history of burning wood waste can be separated into four developmental stages. The objective of each stage is based on the "perception" of wood as a fuel.

	Perception	Design Objective
STAGE 1	**Undesirable Waste Product**	**Incineration**
STAGE 2	**Free Steam**	**Heat Recovery and Incineration**
STAGE 3	**Wood Waste as a Marketable Fuel**	**Improved boiler and Combustion Efficiency**
STAGE 4	**Valuable Fuel and Reduced Emissions**	**Emissions Reductions and Further Heat Rate Improvements**

STAGE 1–Incineration

In the beginning waste wood[1] was considered a nuisance product requiring disposal. Burning was usually the disposal method of choice and combustion designs were based on incineration at minimum capital cost. One method commonly used for incineration was pile burning in an exterior metal enclosure called a "Tepee Incinerator". Provisions for heat recovery and emissions considerations were not considered. Refer to Figure 1, STAGE 1 - "Tepee Incinerator," for a typical side view arrangement of this system.

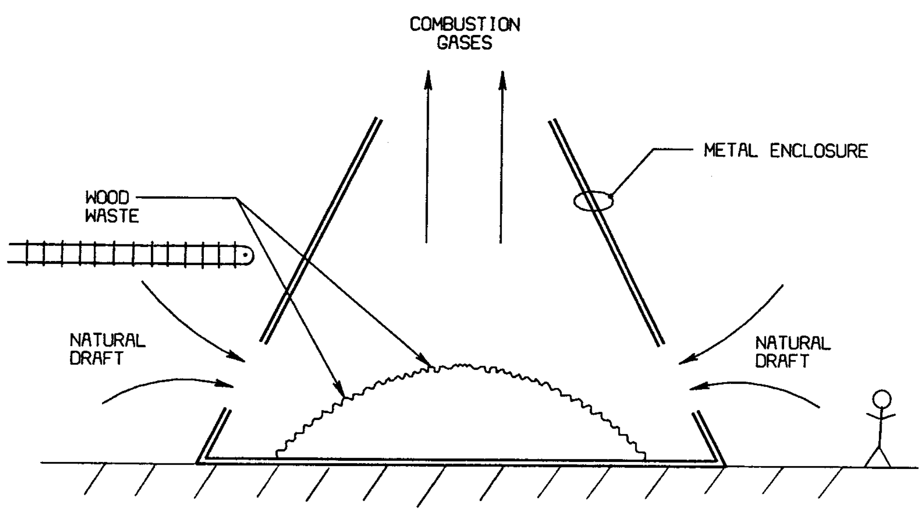

Figure 1 Stage 1–"Tepee" Incinerator

[1] Waste wood is defined as the by products of the lumbering and paper industry. The byproducts would include bark, tree trimmings, sawdust and poor quality wood.

STAGE 2–Free Steam

In this era, the principal objective for wood incineration remained disposal. A second objective became the generation of "free" steam for process and/or heating. Heat recovery equipment was now being installed with the incinerator system. Also, advancements in combustion were being introduced with the development of the "Dutch Oven". The "Dutch Oven" demonstrated initial combustion system improvements consisting of the following:

- refractory combustion chamber
- initial stages of overfire air to aid combustion occurring above the fuel pile.

Refer to Figure 2, STAGE 2, Free Steam - "Dutch Oven", for a side view arrangement of this boiler system. These systems were reliable but produced low combustion efficiency (high carbon monoxide (CO) and high ash loss on ignition[2] and low boiler efficiency. (high stack temperature and high excess air requirements). The ash removal systems were manual. These units normally generated steam flows of 10,000 - 40,000 lbs/hr of low pressure steam at saturated or slightly superheated temperatures.

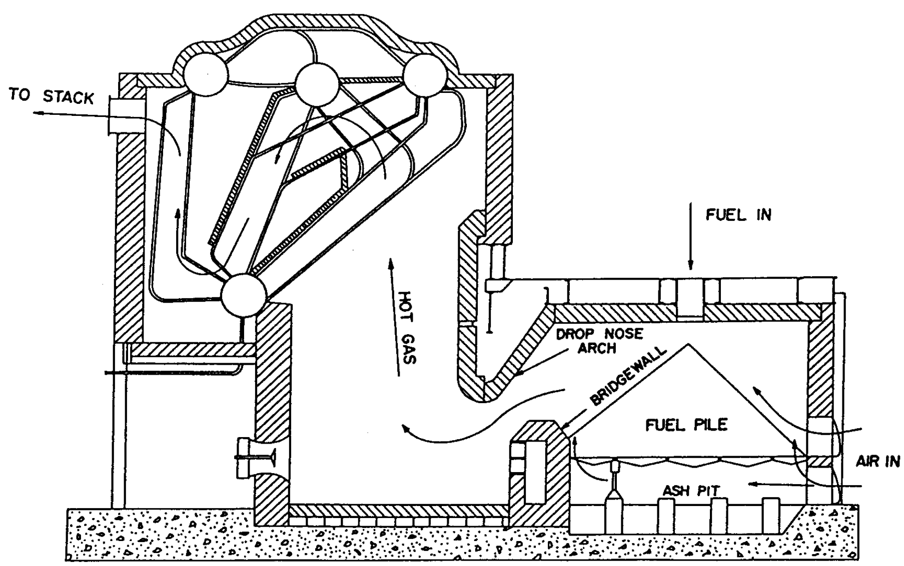

Figure 2 Stage 2–Free Steam - "Dutch Oven"

STAGE 3–Wood Waste as a Fuel

During this period the perception of wood wastes had changed from a nuisance disposal item to a marketable fuel. The combustion systems and heat recovery designs evolved with the objective of improving efficiency. Innovative methods of combustion as well as new boiler designs were the result. Improvements in combustion and heat recovery included:

- Suspension burning with the development of spreader stokers with pneumatic fuel distributors and further development of overfire air systems.

[2] Ash loss on ignition (LOI) is the weight percent of unburned combustibles in the ash sample.

- Stokers with automatic ash discharge which included dumping grates, steam cleaned stationary water cooled grates, water cooled vibrating grates, and traveling grates.
- Cinder reinjection systems to reduce unburned combustibles in the ash.
- Addition of economizers to increase boiler efficiency.
- Addition of air heaters to improve the combustion process by aiding the evaporation of moisture in the wood waste and to increase the boiler efficiency by reducing the flue gas stack temperature.
- Further development of overfire air systems with multiple levels and configurations with the objective of improving the combustion occurring in suspension.
- The use of water cooled furnaces to reduce refractory maintenance and slagging on the walls.
- Methods to reduce tube erosion which included the addition of tube shields and the reduction of passes in the generating banks.
- Addition of superheaters for improved heat rate.
- Increase steaming pressures to improve the heat rate.

The initial boilers designed during this era were short which reduced retention time (approx. 1.25 seconds) of the fuel in the furnace. For an arrangement view of this boiler system, refer to Figure 3, STAGE 3, Wood Waste as a Fuel - Initial Design.

As the boiler designs progressed, the height of the furnace was extended for the purpose of increasing the furnace retention time (approx. 2.25 seconds). Increasing the furnace retention time reduced both CO emissions and unburned combustibles in the ash. For an arrangement view of this boiler system, refer to Figure 4, STAGE 3, Wood Waste as a Fuel - Improved Design. These units generated steam flows from 30,000 - 400,000 lbs/hr generally at pressures of 600 - 900 psi and steam temperatures of 750 - 825°F.

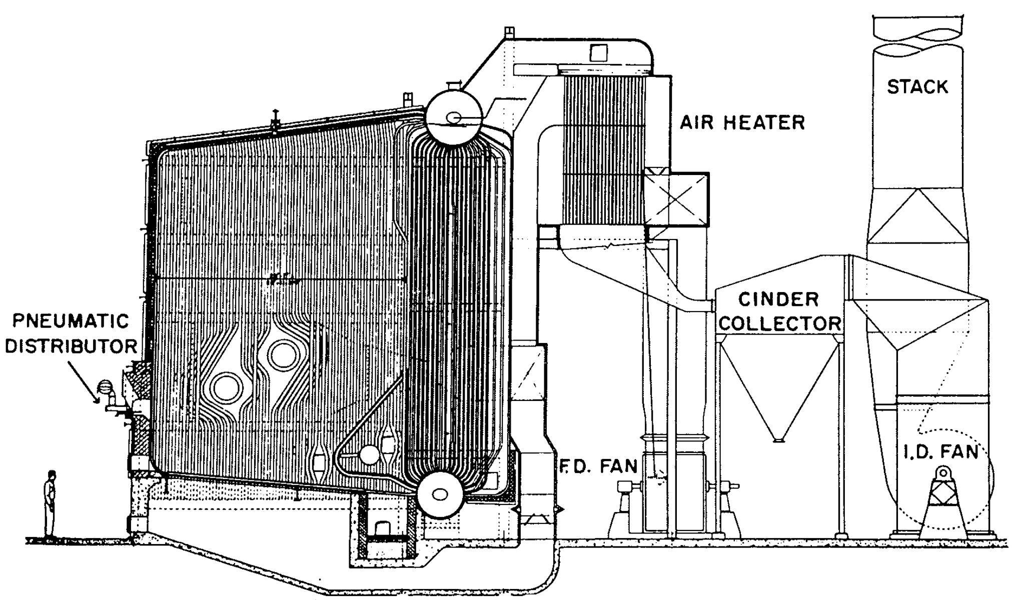

Figure 3 Stage 3–Wood Waste as a Fuel - Initial Design

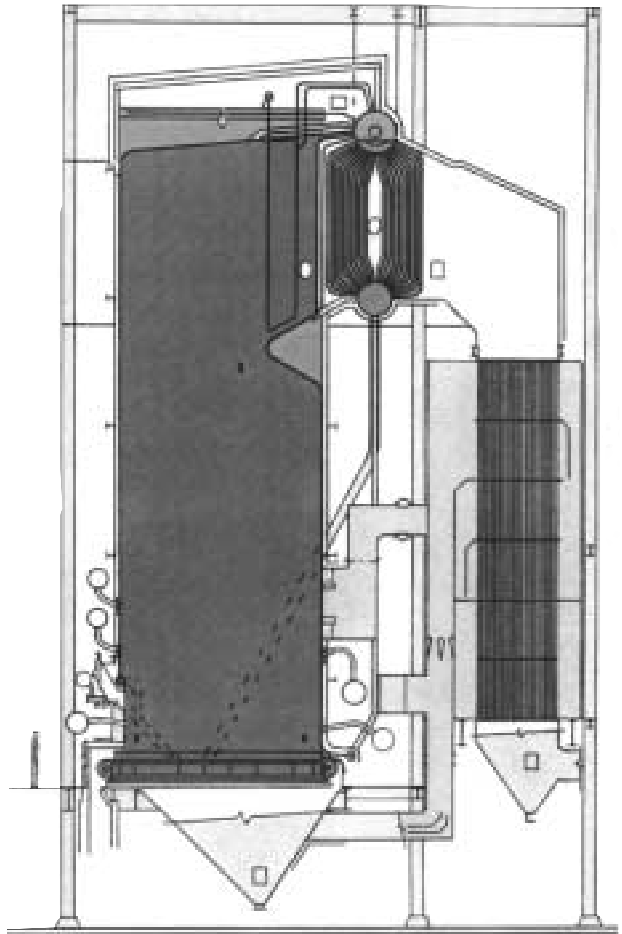

Figure 4 Stage 3–Wood Waste as a Fuel - Improved Design

STAGE 4   Emissions Reductions and Further Heat Rate Improvements

With the increase in market price for wood waste and more stringent emission requirements, upgraded stokers and new combustion designs were developed.

Dramatic design changes occurred during this stage of development. Three separate designs emerged with the objective of improving the combustion process (reduced CO emissions and reduced unburned carbon on the ash). The three designs are:

- Modernized Stoker Design.
- Bubbling Fluidized Bed Design.
- Circulating Fluidized Bed Design.

The following reviews each of these designs.

4.1   Modernized Stoker Design

The combustion system utilizing stokers and boiler designs were upgraded and improved with the following changes:

- Further advanced overfire air systems.

- Improved fuel distribution across the grate.
- Improved combustion air distribution with the development of the compartmentalized windbox and stoker modifications.
- Reduced excess air requirements from 40% to 30%
- Reduced grate heat release rates from a maximum design of 1,000,000 to 850,000 Btu/hr-ft^2.
- Increased furnace retention time to approximately 3.0 seconds.
- Increased steaming conditions to 1500 psi and 955°F
- New furnace configurations with furnace arches to reduce flue gas laning along the walls and increase mixing of fuel and air.
- The addition of Selective Noncatalytic Reduction (SNCR) systems to reduce NO_x up to a maximum reduction of 50%.

Refer to Figure 5, Stage 4 - Emissions Reduction and Further Heat Rate Improvements, Modernized Stoker Design, for an arrangement of this boiler system. These units generate steam flows from 100,000 to 500,000 lbs/hr at pressures up to 1500 psi and superheat temperatures up to 955°F.

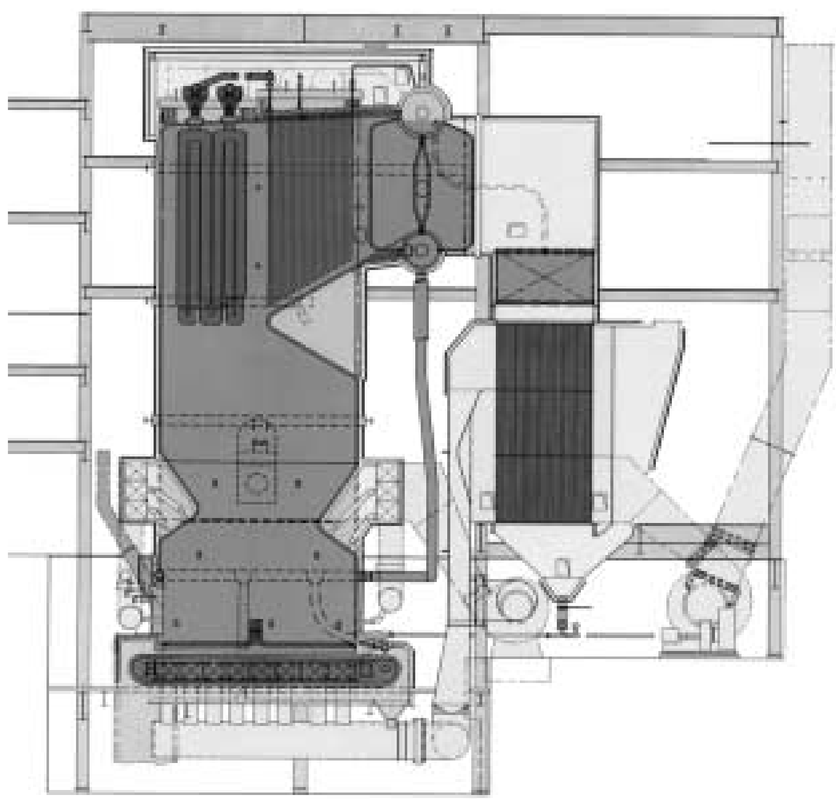

Figure 5 Stage 4–Emissions Reductions and Further Heat Rate Requirements Modernized Stoker Design

4.2 and 4.3–Bubbling Fluidized Bed Design and Circulating Fluidized Bed Design

Fluidized bed combustion is a process which has fuel suspended in a turbulent mixture of upward flowing air and inert material (usually sand). The basis for the fluidized combustion system designs are:

- Improved mixing and interaction of fuel and combustion air.
- Longer fuel retention time in the combustion zone.
- Uniform combustion temperatures.
- Lower combustion temperatures which reduces NO_X generation.

The Bubbling Fluidized Bed operates with low combustion bed velocities (3 - 8 ft/sec) which in-turn reduces the flue gas entrainment of fuel and ash particles. The Bubbling Fluidized Bed systems are less complicated as compared to the Circulating Bed design and are generally used when firing consistent fuels with minimum load variations.

The Circulating Fluidized Bed is designed for higher combustion bed velocities (10 - 30 ft.sec) that entrain fuel and ash particles which in-turn requires recirculation of the entrained materials (ash and unburned fuel) back to the bed. The recirculation of ash and unburned fuel back to the fluidized bed is used to complete the combustion of unburned fuel and to control the fluidized bed temperature. Circulating Fluidized Bed systems are generally more complicated as compared to the Bubbling Bed design but have greater flexibility for load control and fuel variations.

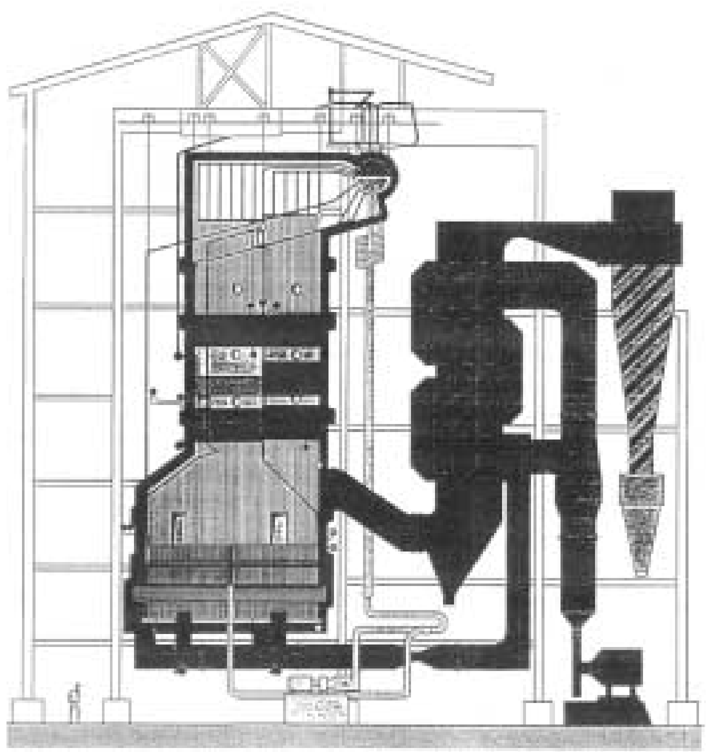

Figure 6 Stage 4–Emissions Reductions and Further Heat Rate Requirements Bubbling Fluidized Bed Design

Both fluidized boiler designs also incorporate the latest upgrades and improvements in the overfire air system designs and increased steaming conditions up to 1500 psi/955 °F.

Refer to Figures 6 and 7, Stage 4 - Emissions Reduction and Further Heat Rate Improvements, Bubbling Fluidized Bed Design and Circulating Fluidized Bed Design, respectively, for an arrangement of these systems.

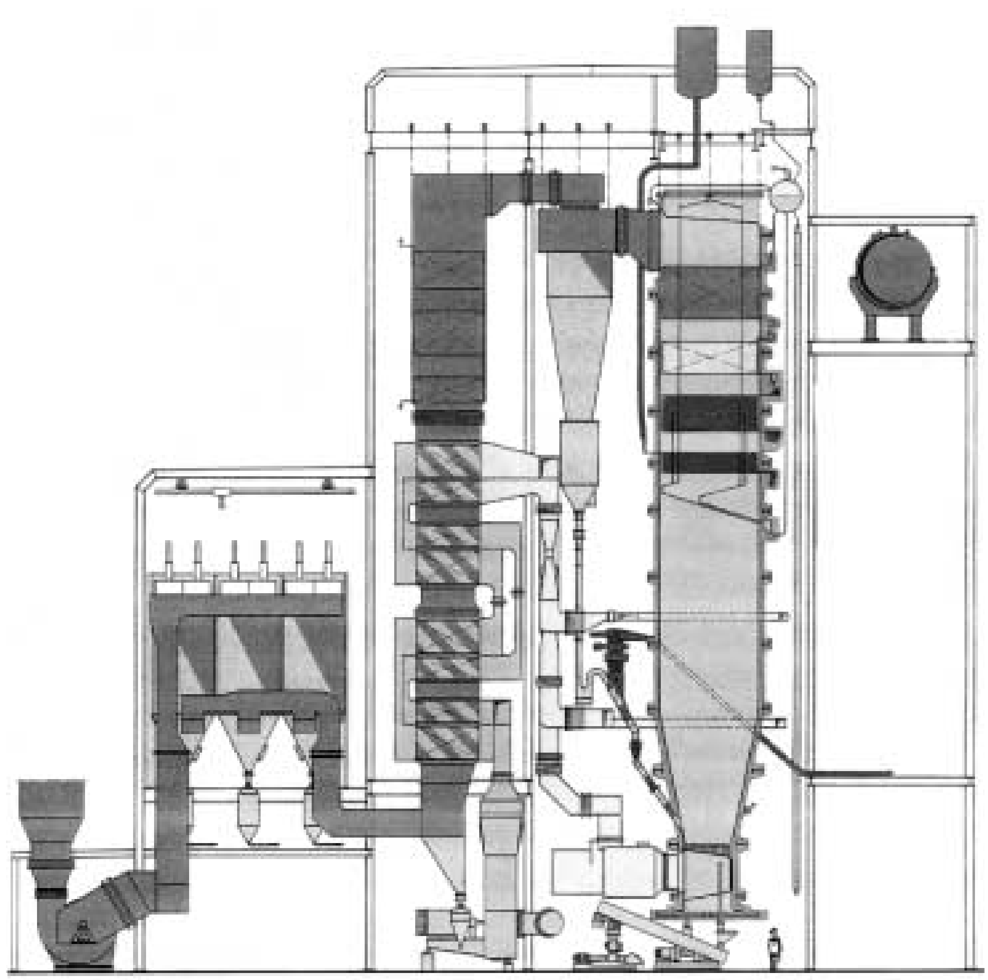

Figure 7 Stage 4–Emissions Reduction and Further Heat Rate Requirements Circulating Fluidized Bed Design

The following table lists and compares the General Performance Summary for the Historical Stages 2, 3 and 4.

HISTORICAL GENERAL PERFORMANCE SUMMARY (45-55% Moisture Wood)

	Stoker Dutch-Oven	Stoker Tube and Tile Short Furnace	Stoker Welded Wall Tall Furnace	Modernized Stoker Design	Bubbling Fluidized Bed Design	Circulating Fluidized Bed Design
Steam Flow, lbs/hr x 10^3	10 - 40	50 - 200	100 - 500	100 - 500	50 - 200	150 - 500
Steam Press. psi	200 - 300	250 - 600	450 - 825	1250 - 1500	450 - 1500	900 - 1500
Steam Temp.°F	Sat.	Sat. - 725	725 - 900	825 - 955	825 - 955	825 - 955
Emissions						
_ CO lbs/10^6 Btu	* 0.8 - 3.2	0.4 - 1.6	0.35 - 0.60	0.1 - 0.35	0.05 - 0.15	0.05 - 0.15
(ppm)	(1000 - 4000)	(500 - 2000)	(430 - 735)	(120 - 430)	60 - 180	60 - 180
_ NO_x lbs/10^6 Btu	-	-	0.15 - 0.20	0.15 - 0.25	0.15 - 0.17	0.15 - 0.17
(ppm)	-	-	(112 - 149)	(112 - 188)	(112 - 128)	(112 - 128)
w/SNCR lbs/10^6 Btu	-	-	-	0.1 - 0.17	-	-
w/SNCR ppm	-	-	-	(75 - 130)	-	-
Unburned Combustibles						
Boiler Eff. Loss (%)	* 5	4.0 - 6.0	2.0 - 4.0	1.0 - 1.5	0.5	0.5
Furn. Retention sec.**	-	1.5	2.2	3.0	4.5 - 5.5 per cycle	3.0 - 4.5
Grate Heat Release Btu/hr-ft^2	-	1,000,000	1,000,000	850,000	NA	NA

*Based on pile burning experience, no actual data on the subject design.

**Based on flue gas velocities. Fuel particle retention will be longer based on size, weight, moisture content, etc.

Note: The above summary lists general or typical performance results. The performance may vary based on individual manufacturers' designs and performance results.

The following section reviews, in more detail, the major design upgrades for the following equipment:

- Stoker Designs
- Furnace Designs
- Fuel Distributor Designs
- Overfire Designs
- Cinder Reinjection Designs
- Superheater Designs

1. Stoker Designs

Objective: To supply a surface to combust the larger fuel particles and to remove the ash and inorganic materials after combustion. Currently the most common stokers are the travelling grate spreader stokers, stationary water cooled grates with steam cleaning, and water cooled vibrating grates.

Enhancements:

- Improved combustion air distribution by compartmentalizing the grate air plenum. This allows for control of the air flow to the grate sections for balancing or biasing the air flow to the grate.
- Improved designs for increased grate clip pressure drop (increased back pressure) which improves the air distribution through the grate and reduces the influence of the fuel/ash bed thickness on air distribution.
- Improved grate clip metallurgy allowing for combustion air temperatures up to 600°F. Higher combustion air temperatures improve the drying of high moisture woods.
- Improved stoker seal designs to reduce leakage around the periphery of the stoker.

2. Furnace Designs

Objective: To combust the fuel and recover radiant heat generated by the combustion process. Refer to Figure 8, Furnace Design Objectives, which outlines the separate furnace zones and design objectives.

Enhancements:

New furnace configurations have been developed to improve combustion efficiency (reduce CO and LOI) while firing a range of wood waste fuels. The objectives of the new furnace configurations are to:

- Establish a defined combustion zone.
- Reduce stratification along the side walls.

Zone 4	**Minimize gas velocity stratification through tube banks** • Reduce tube erosion • Reduce temperature unbalances
Zone 3	**Uniform flue gas distribution** • Minimize gas velocity stratification • Complete CO burnout • Minimize char particle entrainment to reduce carryover
Zone 2	**Maximum turbulence, mixing, and penetration of OFA for complete suspension burning** • Reduce stratification and the water walls • Increase the retention time in the combustion zone
Zone 1	**Even fuel distribution on the grate OFA system is not to disrupt fuel distribution on the grate** • Fuel drying • Fuel ignition

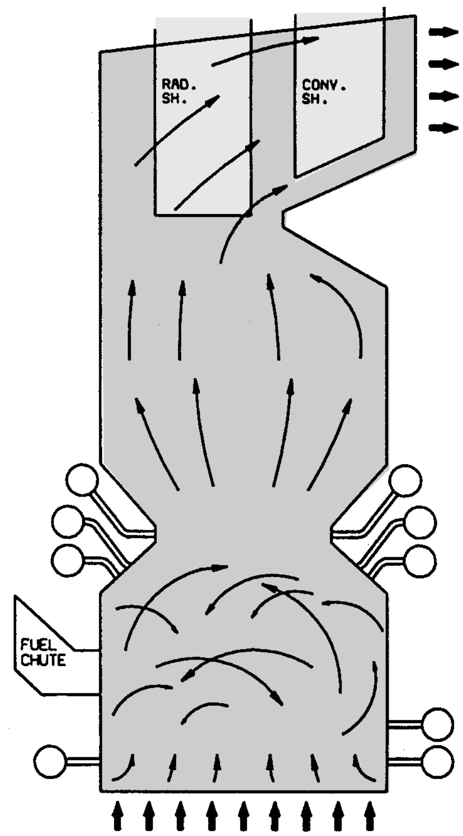

Figure 8 Furnace Design Objectives

- Increase mixing and turbulence in the combustion zone.
- Increase residence time in the combustion zone and main furnace.
- Minimize char (unburned combustibles) entrainment and char carry-over.

New furnace designs include flat wall, single arch and double arch designs all with multi level OFA systems.

3. Fuel Distribution Designs

Objective: To uniformly spread the fuel over the grate surface.

- Pneumatic fuel distributors utilizing high pressure, pulsating air.
- No moving mechanical parts exposed to furnace radiation
- Improved suspension burning of the small fuel particles.

Enhancements:

- Improved means of adjusting depth and side to side distribution by the use of air pressure, air vanes and trajectory plate angles.

4. Overfire Air Designs

Objective: To complete the combustion occurring in suspension and reduce the unburned carbon furnace carry-over.

Enhancements:

- Design changes to increase the turbulence and mixing of the OFA in the combustion process by improved nozzle penetration and optimized nozzle location.
- Reduce flue gas stratification along the water walls.

5. Cinder Reinjection Designs

Objective: The objective of this system is to reinject the char (unburned combustibles) from the convection pass hoppers and/or dust collector back to the combustion zone for reburning.

Enhancements:

- Improved sand separator design with the development of rotary sand separators to increase reliability.
- Improved designs to maintain uniform fuel distribution across the stoker.

6. Superheater Designs

Objective: The objective of the superheater is to increase the steam temperature above saturation.

Enhancements:

- Addition of radiant superheater surfaces.
- Increased transverse tube spacing for reduced fouling.
- Improved metallurgy.