TECHNICAL PUBLICATION

Efficient, Low Emissions and Fuel Flexible
"Today's Stoker-Fired Biomass Systems Technology"

by

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Presented at

International Biomass Conference
April 28-30, 2009
Portland, Oregon

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ABSTRACT

There is a need for today's power plants to meet the growing demand for electricity while achieving efficient combustion, low emissions, and fuel flexibility. Biomass boilers equipped with new boiler and combustion techniques to enhance efficiency resulting in lower heat rates, as well as new, proven emissions control devices to significantly reduce NO_x and CO emissions, have been developed to meet this need. This paper will discuss new combustion and emissions control technology advancements and present quantitative comparisons of new units to the existing operating biomass boilers. (To increase combustion efficiency, new over-fire air and stoker technologies are employed). Emissions are controlled using a system called an "RSCR™," which is a selective catalytic device applied to the "cold" gas (after the boiler and particulate removal equipment) prior to its discharge to the stack. The RSCR System is capable of NO_x reductions of >70% and CO reductions of >50%. The paper will describe the overall performance of a typical biomass boiler plant using these new technologies. The paper will also provide actual operating data on an RSCR which was retrofitted to an existing biomass fired unit.

INTRODUCTION

There is a need for today's power plants to meet the growing demand for electricity while at the same time achieving efficient combustion, low emissions, and fuel flexibility. Biomass boilers equipped with new boiler and combustion techniques enhance efficiency, which results in lower heat rates. Combined with new, proven emissions control devices to significantly reduce NO_x and CO emissions, the challenge of meeting higher energy demands will be met.

In the first section, this paper will discuss biomass and supplemental co-firing fuels, new boiler/combustion system advancements, as well as quantitative comparisons of the new units available today to existing biomass boilers in operation. Advancements, such as a new Over-Fire Air (OFA) design and state-of-the-art stoker technology with grate oscillation/vibration, are used to increase combustion efficiency. The furnace is designed to reduce flue gas laning along the walls and increase the mixing of fuel and air. Without impacting performance these improvements afford better fuel utilization, lower unburned carbon, lower CO emissions and the ability to handle a wide range of fuel moisture content.

The second section of the paper deals with a new system for the reduction of NO_x emissions to levels previously unheard of for biomass boilers. Emissions are controlled using a system called an "RSCR™", which is a selective catalytic device applied to the "cold" gas (after the boiler and particulate removal equipment) prior to its discharge to the stack, achieving NO_x reductions of >70%.

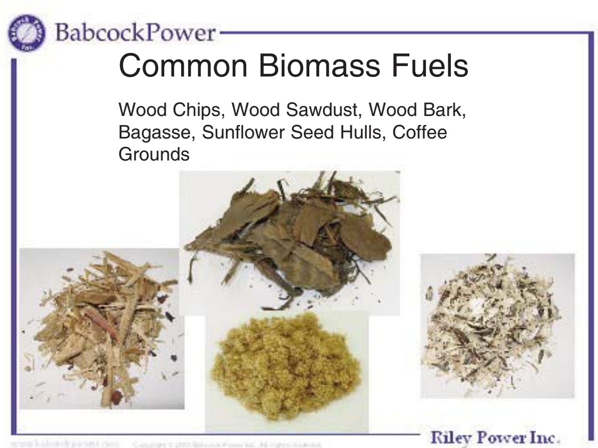
This paper will describe the design and overall performance of a typical biomass boiler plant using these new technologies. The paper will also provide actual operating data on an RSCR, which has been retrofitted to existing biomass-fired units.

BIOMASS STOKER COMBUSTION

Historically, industrial biomass combustion systems utilized three types of stokers: Water Cooled Stationary Stoker (commonly referred to as Pin-Hole Grates), Traveling Grate Spreader Stoker (TGSS), and Water Cooled Vibrating or Oscillating Grate Stoker. Biomass combustion technology has evolved from incineration of nuisance waste fuels to the combustion of valuable fuels. With this fuel evolution the combustion systems have been continually upgraded for improved efficiency. Currently, environmental regulations have added further changes to stoker designs which are also discussed in this paper. The resulting objectives of a modern biomass stoker combustion system include: maintaining an efficient and stable combustion process while supplying the desired boiler heat input, low emissions, and the capability of firing a variety of fuels (fuel flexibility).

* *Efficient and Stable Combustion Process*
  Produce an efficient and stable combustion process to maintain consistent boiler design parameters and boiler performance
* *Heat Input*
  Generate the heat input necessary to produce the desired boiler steam flow, pressure and temperature
* *Low Emissions*
  Produce low carbon monoxide (CO), low unburned carbon (UBC) and low nitrogen oxides (NO_x)
* *Fuel Flexibility*
  Capable of firing a variety of fuels
  Co-firing and/or alternate fuel firing capability allows the plant to:
    - ♦ Stay on-line if the main fuel is disrupted
    - ♦ Be more economically viable based on fuel costs

BIOMASS FUELS



Traditional Biomass Fuels

When optimizing the combustion system, it is important to understand that both the combustion systems and boiler systems are "not" stand-alone entities, but are interlinked. To optimize the overall plant design, both the combustion and boiler systems need to be designed together as a system.

Three T's of Combustion

The age-old "Three-T's" of combustion, Time/Temperature/Turbulence, apply to the design of an efficient biomass stoker combustion system. Some of the combustion design parameters that play an important role in meeting the requirements of the "Three-T's" on stoker units are fuel characteristics, fuel distribution, air distribution, fuel/air mixing, reduced air infiltration and furnace retention time.

Improved Modernized Stoker Designs

Improvements to modern stoker combustion systems consist of changes to both combustion and boiler components. Recent system improvements include:

* Improved fuel feed control and distribution across the grate
* Improved combustion air distribution
* Advanced overfire air systems
* Reduced excess air requirements
* Lowered grate heat release rates (larger grate surfaces)
* Increased furnace retention time
* Improved furnace arrangements with lower arches to reduce flue gas laning along the walls and increase mixing of fuel and air
* Improved mixing of fuel and air by the use of grate oscillation/vibration
* Reduced air infiltration by new seal designs (air bypassing the combustion system)

Refer to the boiler arrangement shown in Figure 1, Typical Modern Biomass Stoker Boiler System.

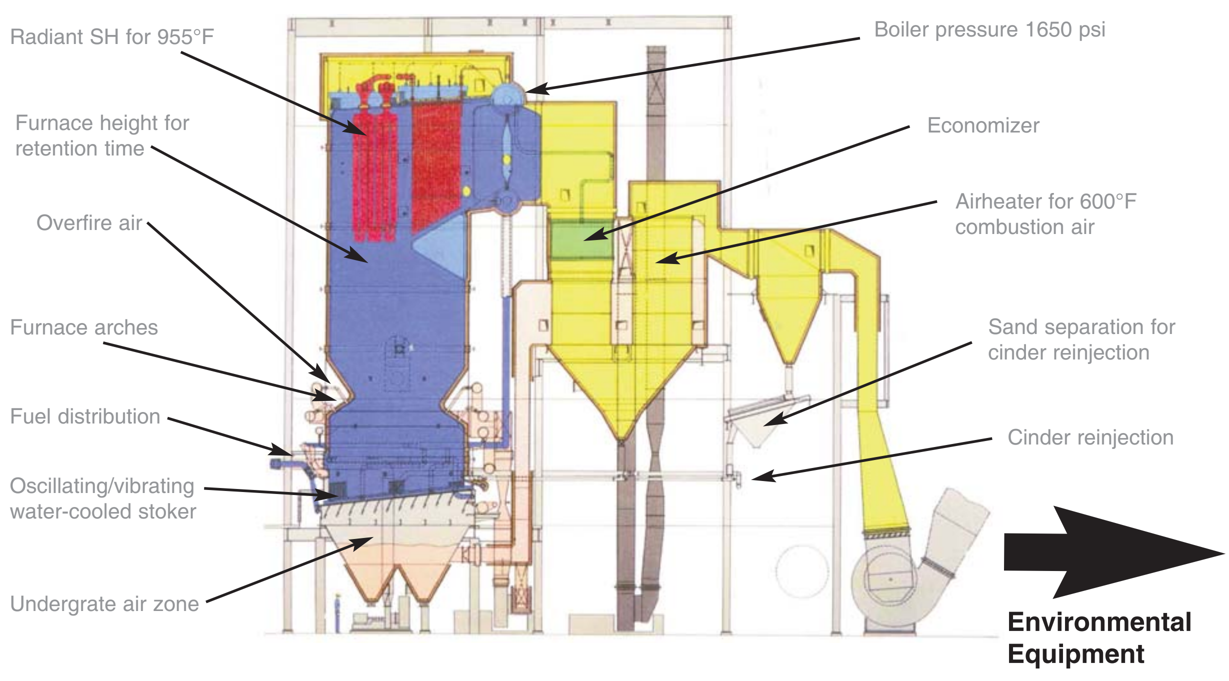


Figure 1: Typical Modern Biomass Stoker Boiler System

General Performance Comparison

General performance summary and comparison of past biomass stoker versus modern stoker designs:

Table 1

GENERAL PERFORMANCE SUMMARY (45-55% Moisture Wood)

	Older Stoker Design	Modernized Stoker Design	
Steam Flow lbs/hr x 103	100 - 500	100 - 500	
Steam Pressure psi	600 - 900	1,250 - 1,650	
Steam Temperature °F	650 - 850	955 - 1,000	
Unburned Combustibles Boiler Efficiency Loss (%)	2.0 - 4.0	1.0 - 1.5	
Furnace Retention sec. (1)	1.5 - 2.0	3.0	
Grate Heat Release Btu/hr-ft2	1,000,000 - 1,200,000	850,000 (maximum)	
Boiler efficiency % (2)	68.40	71.25	
Emissions:			
CO lbs/106 Btu @ 3.0% O_2 (ppm)	0.35 - 0.60 (430 - 735)	0.10 - 0.30 (122 - 370)	***Base***
CO **<u>w/ RSCR</u>** lbs/106 Btu @ 3.0% O_2 (ppm)	— —	0.05-0.15 (61 - 185)	***(-50%)***
NO_x lbs/106 Btu @ 3.0% O_2 (ppm)	0.15 - 0.20 (112 -145)	0.15 - 0.25 (112 - 188)	***Base***
NO_x **<u>w/ SNCR</u>** lbs/106 Btu @3.0%O_2 (ppm)	— —	0.10 - 0.17 (75 - 130)	***(-30 to 40%)***
NO_x **<u>w/ RSCR</u>** lbs/106 Btu @ 3.0% O_2 (ppm)	— —	0.06 - 0.075 (45 - 56)	***(-60 to 80%)***

(1) Based on flue gas velocities, fuel particle retention will be longer due to size, weight, moisture content, etc.

(2) Boiler efficiency based on 50% moisture wood (efficiency improvement results from lower UBC, lower stack temperature, lower excess air)

Note: The above summary lists general or typical performance results. The performance will vary based on individual manufacturer's designs and performance.

The benefits of the modernized stoker system are exhibited in the combustion system:

* Stability
* Lower CO emissions
* Lower unburned carbon
* Capable of firing various fuel

All of these parameters can be directly measured and the improvements evaluated. However, these improvements, as associated with all combustion processes, optimize the combustion process but do not reduce the NO_x emissions. In-fact, NO_x tends to increase with combustion optimization. Methods for reducing NO_x emissions consist of: lowering excess air (approx. 5% reduction), adding flue gas recirculation (approx. 10% reduction), adding a SNCR (approx. 40% reduction), and/or adding a back end RSCR (approx. 70% reduction as discussed later in this paper).

FUEL FLEXIBILITY

Fuel flexibility is becoming more important as biomass fired power plants become more prevalent. The primary advantages of fuel flexibility include:

1. Allows the plant to be more economically viable by the having the ability/option to fire less costly fuels

2. Supplies back-up fuel sources for the main fuel

An example of fuel flexibility is a plant located in the North East. Originally designed for whole tree wood chips, this plant had economic issues due to high wood chip fuel costs. Consequently alternate fuels were investigated. The first alternate fuel tested was Construction & Demolition (C&D) wood. Due to boiler fouling, emissions, ash disposal and permit issues C&D fuel was not selected. Further fuel evaluations included Landfill Gas (a landfill is located approximately one mile from the boiler) and clean Paper Waste (cubed). Both fuels proved technically and economically viable and are currently co-fired along with the original wood chip fuel.

The combustion methods include:

* Landfill Gas (after it is cleaned, filtered and moisture removed) is injected into the auxiliary/start-up burners at approximately 20% of total heat input
* Paper cubes are uniformly mixed with the wood chips and distributed on the grate combustion system at approximately 10 - 20% of total heat input

Refer to Figure 2, Biomass Stoker Boiler System with Co-firing Fuel Capability.

Note: Uniform fuel mixing and distribution is essential when co-firing fuels. Improper mixing can lead to combustion, emission and boiler performance problems such as steam temperature unbalances, high CO emissions, etc.

When evaluating new fuels, co-firing and/or alternate, the following is a general list of items that need to be investigated:

* Fuel cost
* Fuel availability and quality (amount, yearly cycles and consistency)
* Boiler fouling and slagging characteristics
* Emissions analysis
* Ash disposal analysis
* Boiler performance analysis
* Boiler corrosion analysis
* Permit(s) review
* Methods to mix and combust the fuels

Potential Co-Firing Fuels

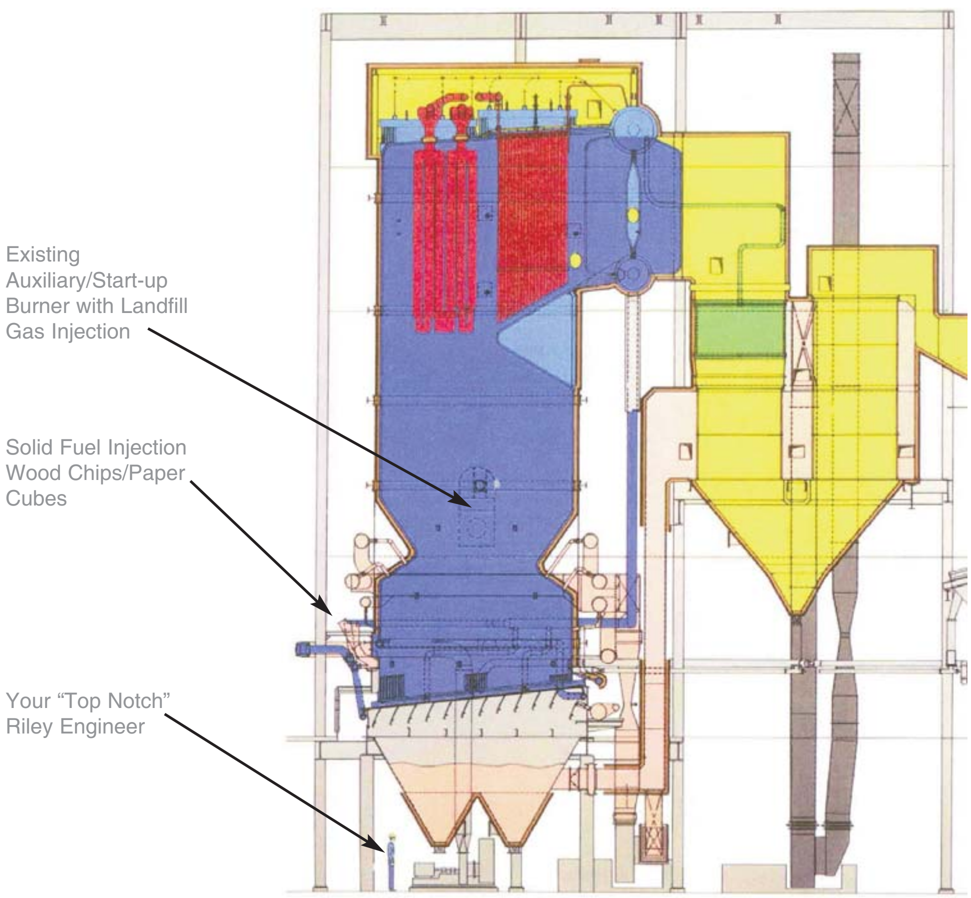


Figure 2: Biomass Stoker Boiler System with Co-firing Fuel Capability

DESIGN DETAILS

The major equipment design upgrades associated with stoker combustion improvements are:

1. Fuel Feed and Distribution
2. Stoker
3. Furnace
4. Over-fire Air
5. Cinder Reinjection Systems

1. Fuel Feed and Fuel Distribution

Objective: Uniformly distribute fuel on the grate surface to reduce fuel piling and maintain proper air/fuel ratios. This is achieved by both fuel feed and fuel distribution systems.

Enhancements:

* Improved pneumatic fuel distributor designs allowing for side and depth distribution adjustments. This is achieved by controlling the air pressure, air vanes, and fuel trajectory plate angle

* Improved control room excess oxygen measurement across the boiler width by the use of multiple oxygen sensors located at the economizer outlet. The excess oxygen profile across the unit is a direct indication of the combustion system fuel and air distribution. Analyzing the excess O^2 profile across the unit, the operator can adjust the fuel and air distribution to optimize combustion

* Improved control system capable of biasing individual feeder fuel flows to balance the fuel distribution on the grate

* Capability of distributing various fuels with varying sizes, densities and moisture contents

2. Stoker Designs

Objective: Provide a surface to combust the larger fuel particles and the ability to remove ash and inorganic materials after combustion.

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 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

* Improved fuel and air mixing reduced fuel piling and improved fuel distribution by using grate surface oscillation/vibration

* Increased grate surface casting life by the use of a water-cooled grate surface. Water-cooled surfaces allow the capability to vary air flow as required without overheating the grate cast surface (i.e. the surfaces do not require air flow for cooling) and also reduce maintenance costs

* Design of the grate surface area for a maximum heat release rate of 850,000 Btu/hr-ft2 (previous designs were at 1,000,000 and greater)

3. Furnace Designs

Objective: To combust the fuel and recover radiant heat generated by the combustion process. Refer to Figure 3, Furnace Design Objectives, which illustrates the separate furnace zones and design objectives.

Enhancements:

* Recently developed furnace configurations have improved combustion efficiency (reduce CO and LOI) while allowing the firing of a range of wood waste fuels. The new furnace configurations achieve the following:

    ♦ Establish a defined combustion zone
    ♦ Reduce stratification along the side walls
    ♦ Increase mixing and turbulence in the combustion zone
    ♦ Increase residence time in the combustion zone and main furnace
    ♦ Minimize char (unburned carbon) entrainment and char carryover

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

4. Over-fire Air Designs

Objective: Complete the combustion occurring in suspension and reduce the unburned carbon furnace carryover.

Enhancements:

* Increase the turbulence and mixing of the OFA and fuel in the combustion process by improved nozzle penetration and optimized nozzle locations
* Reduce flue gas stratification along the waterwalls
* Control capability for varying the OFA flow to optimize combustion during fuel changes and at reduced loads
* Design OFA flows for 50% total combustion air flow
* Multiple OFA levels with individual level control dampers
* Use of Computational Fluid Dynamics (CFD) modeling to optimize the OFA system design
* Capable of adjusting OFA flow to match the fuel being supplied to the boiler. For example, increasing the OFA flow rate when the fuel has more fines

5. Cinder Reinjection Designs

Objective: Reinject the char (unburned carbon) from the convection pass hoppers and/or dust collectors back to the combustion zone for reburning. This improves the boiler efficiency.

Enhancements:

* Improved sand separator designs with the development of rotary sand separators and vibrating sand separators for increased performance and reliability

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

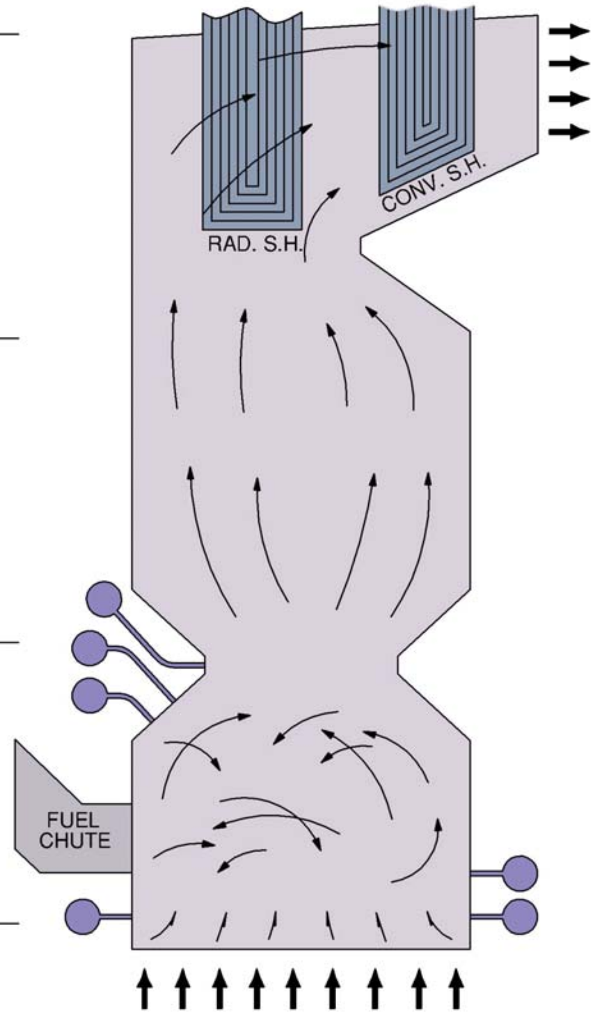


Figure 3: Furnace Design Objectives

REFERENCES

1. Advisory Ruling, Northern Power Systems, Inc., Commonwealth of Massachusetts, Office of Consumer Affairs & Business Regulations, Division of Energy Resources, May 2004