TECHNICAL PUBLICATION

Biomass Combustion Technologies

A Comparison of a Biomass 50MW Modern Stoker Fired System
and a Bubbling Fluidized Bed System

by

John Bowman
Sr. Principal Applications Engineer
Babcock Power Environmental Inc.

Michael Davidson
Manager of Proposal Engineering
Riley Power Inc.

Jeffrey Penterson
Proposal Manager
Riley Power Inc.

Kevin Toupin
Director of Boiler Equipment
Riley Power Inc.

Presented at

POWER-GEN International
December 8-10, 2009
Las Vegas, NV

Riley Power Inc.
5 Neponset Street
Worcester, Massachusetts 01606
www.babcockpower.com

T-218

BIOMASS COMBUSTION TECHNOLOGIES

A Comparison of a Biomass 50MW Modern Stoker Fired System and a Bubbling Fluidized Bed System

by:

John Bowman
Sr. Principal Applications Engineer
Babcock Power Environmental Inc.

Michael Davidson
Manager of Proposal Engineering
Riley Power Inc.

Jeffrey Penterson
Proposal Manager
Riley Power Inc.

Kevin Toupin
Director of Boiler Equipment
Riley Power Inc.

Presented at:

POWER-GEN International
December 8-10, 2009
Las Vegas, NV

ABSTRACT

In today's dynamic marketplace, there is a growing demand for renewable technologies such as biomass power plants. Two basic technologies can effectively address firing of biomass fuels —Modernized Stoker Systems and Fluidized Beds. There is a need to evaluate the technical merits of each and to determine which is best suited for a given power generation application. This paper focuses on these two major biomass technologies in use today, compares the application of each for net 50 MW electricity power plant, and evaluates each in terms of possible plant heat rates, boiler efficiencies, fuel flexibility, emissions, and plant power consumption requirements when firing biomass fuels.

To properly evaluate these technologies, one must understand project requirements and complete a review of the technologies and their abilities to address specific technical and financial requirements. Data, including design parameters and typical process flow diagrams, for the two technologies will be presented in this paper to address these issues and to improve one's knowledge of these technologies.

INTRODUCTION

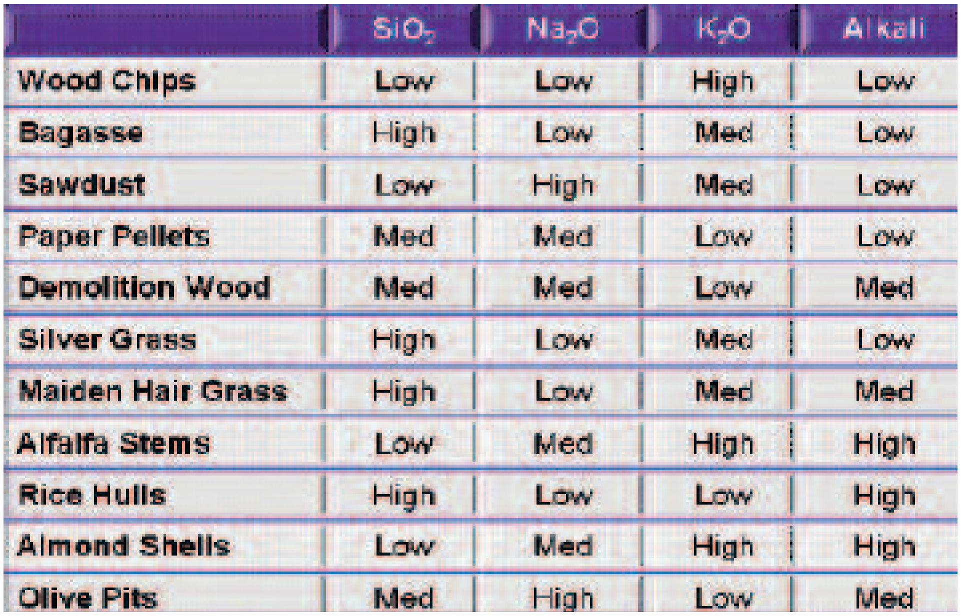
There has been much debate about which technology — stoker or bubbling fluid bed (BFB) — is best suited for firing biomass fuels in the 50MW net plant size. Both technologies have positive merits and can burn this fuel effectively.

Bubbling Fluidized Bed (BFB) Boilers are applicable for a range of specific biomass fuels including agricultural wastes, wood waste and paper mill sludge. Well-designed systems have low unburned carbon, carbon monoxide and NO_x emissions. The bubbling bed of sand provides a heat sink, which allows the boiler to handle various types of fuels and somewhat variable moisture contents.

Stoker fired boilers fire a wide range of biomass fuels including agricultural wastes, wood waste and municipal solid waste derived fuels. Biomass combustion technology has evolved from incineration of a nuisance waste fuel to combustion of a valuable fuel. With the biomass fuel evolution, the combustion systems have been continually upgraded for improved efficiency. Environmental regulations have required further changes to the stoker designs making them more efficient and better able to meet environmental requirements.

For this comparison, the unit size will be 50 MWe and the fuel wood based biomass (wood chips, wood pellets, tree bark, sawdust, clean wood demolition wastes) and the potential energy crops like maiden grass, alfalfa and eucalyptus.

The fouling and slagging tendency of different fuels are presented Figures 1 and 2 below. In general, as the alkali content increases, the fouling potential increases. Fouling can manifest in the furnace as well as convective surfaces.



	SiO_2	Na_2O	K_2O	Alkali
Wood Chips	Low	Low	High	Low
Bagasse	High	Low	Med	Low
Sawdust	Low	High	Med	Low
Paper Pellets	Med	Med	Low	Low
Demolition Wood	Med	Med	Low	Med
Silver Grass	High	Low	Med	Low
Maiden Hair Grass	High	Low	Med	Med
Alfalfa Stems	Low	Med	High	High
Rice Hulls	High	Low	Low	High
Almond Shells	Low	Med	High	High
Olive Pits	Med	High	Low	Med

Figure 1. Biofuel Ash Constituents

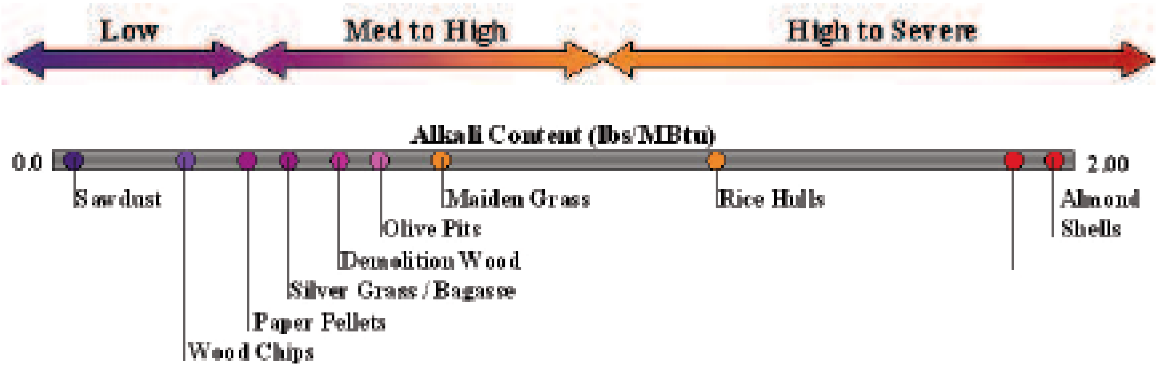


Figure 2. Different Biofuel Fouling and Slagging Tendencies

REVIEW OF TECHNOLIOGY

Stokers

One hears from the fluid bed proponents that stoker boilers are "old" technology and that BFB is the "new" technology. Old technology is not necessarily negative if it also means proven, reliable and cost effective. BFB proponents infer that stoker technology has not changed over the past 75 years. This is simply not true. Stoker technology is both a mature technology in that it has been around for more than 100 years but also a continually evolving technology. Older units have had small inefficient overfire air systems, which can result in lower efficiency, low steaming rates, poor carbon burnout, and high CO, NO_x and particulate emissions. Today's advanced stokers are reliable and efficient and are used to fire a variety of fuels, including coal, wood waste, municipal solid waste, and agricultural materials. Improvements have been made regarding firing systems, fuel distribution systems, furnace design, efficiency and reliability.

Stokers can burn many types of fuels individually or in combination. Some operate similar to a gasifier with a deep bed of fuel on the grate. The bed can be burned in a low oxygen environment with undergrate air. Overfire air completes the combustion higher in the furnace. The advantage is a reserve of fuel in the boiler, ready to pick up an increase in steam demand. A rapid decrease in steam demand is attained by reducing undergrate air and fuel under controlled conditions.

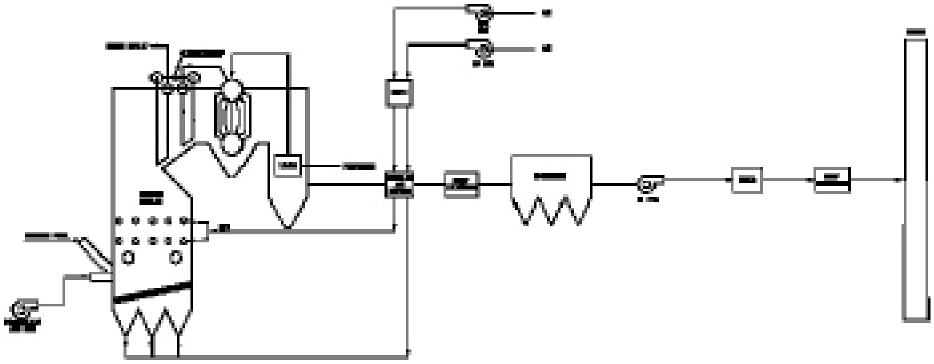


Figure 3. Stoker Process Flow Diagram

Fuel is burned in today's stokers on mechanical traveling, reciprocating or water/air cooled vibrating grates. Fuel is introduced on the grate through multiple fuel delivery chutes on one side of the boiler using a mechanical or pneumatic system. The pneumatic fuel distributor design allows for side and depth distribution adjustments. This is achieved by controlling the air pressure, air vanes, and fuel trajectory plate angle. The operator has improved control systems capable of biasing individual feeder fuel flows to balance the fuel distribution on the grate. 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. This is achieved by improved control room excess oxygen measurement across the boiler width by the use of multiple oxygen sensors located at the economizer outlet.

Combustion air is supplied through both undergrate and overfire (OFA) air systems. Improved undergrate combustion air distribution is achieved by compartmentalizing the grate air plenum. This allows for control of the airflow to the grate sections for balancing or biasing airflow to the grate. Grate surface oscillation/vibration improves fuel and air mixing, reduces fuel piling and improves fuel distribution. Cooled surfaces allow the capability to vary airflow as required without overheating of the grate cast surface (i.e. the surfaces do not require air flow for cooling) and for co-firing fuels burning in suspension such as pulverized coal.

New furnace configurations have been developed to improve combustion efficiency (reduced CO and LOI) while maintaining the ability to fire a range of wood waste fuels. New furnace designs include flat wall, single arch and double arch designs all with multi level OFA systems. Design changes have been made to increase the turbulence and mixing of the OFA and fuel in the combustion process by improved nozzle penetration and optimized nozzle locations. Today's stoker OFA system is designed for 50% of the total combustion airflow. These systems have multiple OFA levels with individual level control dampers.

Stokers can fire many types of fuels with large particle variations and moisture contents ranging from 15% up to 58%. The grate firing systems are not prone to fuel bed agglomeration. There is little wear to stoker bed components due to the nature of the design.

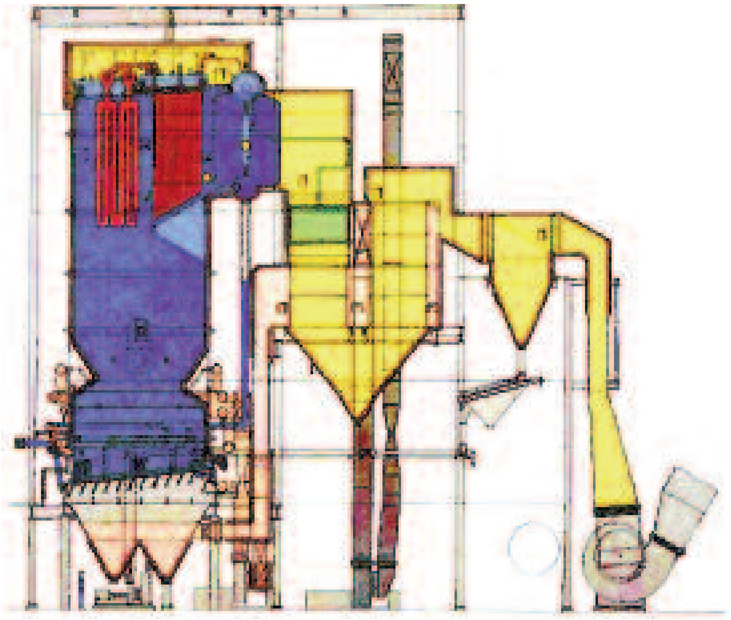


Figure 4. Riley Power Biomass Stoker Boiler

Bubbling Fluid Bed (BFB)

Fluidized bed boiler technology dates back to 1925 with atmospheric circulating fluid bed developed in the mid 1970's and the pressurized circulating fluid bed in the late 1980's. A "fluidized bed" boiler is a system where the combustion chamber contains a fluidized bed of sand, ash and fuel. In some cases, ash or other products are substituted for sand. Air and flue gas are used as the fluidizing mediums. The design of the boiler is based on optimized fluidization velocity for the bed. With this, bed material and fuel are not lost without allowing proper time for combustion. Combustion chamber height is set by residence time for combustion. The fuel particles move about freely in the bed and burn at a temperature slightly higher than the bed average. The hot gases from fuel combustion are then directed over heat transfer surface to recover the energy. In accordance with National Fire Protection Association requirements, before the bed can burn solid fuel, the bed temperature is brought to a level so it can ignite the fuel. This is achieved through the use of an auxiliary burner system.

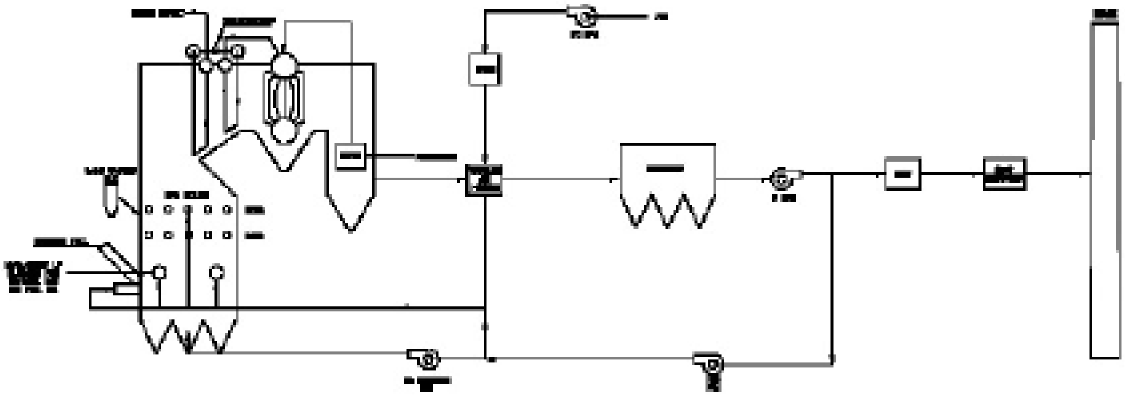


Figure 5. Bubbling Fluid Bed Process Flow Diagram

The fluid bed combustion process operates optimally at a temperature of approximately 1,500 °F. However, the bed temperature must be maintained over a relatively narrow temperature range between 1400 and 1600 °F to optimize emissions control. The bed temperature is controlled by under bed air and flue gas recirculation. The bed velocities are in the range of 3 to 8 ft/sec and are maintained with high-pressure fans providing under bed fluidizing air (50 to 60 inches water). The lower furnace combustion process is characterized by operating in sub-stoichiometric conditions. This has the effect of "gasifying" the fuel. The "gasified" fuel is then fully combusted with overfire air introduced above the bed.

However, as fuel moisture changes, the injection points for and amount of air required to maintain and optimize combustion changes. High moisture fuel will require more under bed air and low moisture fuel requires less under bed air and the addition of flue gas to control temperatures. This is needed because high bed temperatures can lead to bed agglomeration and sintering.

The major ash-related problem encountered in fluidized beds is bed agglomeration — the fusion of bed materials together causing operational problems including clinkering and loss of fluidization. In the worst case, bed agglomeration may result in total defluidization of the bed and unscheduled downtime. Because of the special ash-forming constituents of biomass fuels, several of these fuels have been shown to be especially problematic (as illustrated in Figures 1 and 2). For typical wood fuels, coating-induced agglomeration was identified to be the dominating bed agglomeration mechanism. For high-alkali-containing biomass fuels, potassium will attack the quartz bed material and form a layer of low-melting potassium silicate on the sand.

With sand or ash in the bed, there is the potential for significant combustion chamber erosion. As gas velocities increase, the potential for erosion increases exponentially. The higher the gas velocities, the more potential for erosion. The erosion potential exists for waterwalls and over the long term, backpass convective surfaces. The refractory lining found in most fluidized bed furnaces is prone to erosion and spalling.

As noted above, BFB's typically require a controlled operational bed temperature range of between 1400 °F and 1600 °F with a target of 1500 °F. The unit is normally designed to operate with the higher moisture content fuel w/o flue gas recirculation. When the moisture in the fuel decreases (for example from 50% in winter to 30% in summer) the in-bed heat release rate is decreased by the reduction of under bed air and the addition of a flue gas recirculation system. Typically in the winter the bed velocity is approximately 8 ft/sec in the winter and is reduced to 4 ft/sec in the summer.

Fuel is introduced into the BFB through fuel chutes on one or more of the walls. The unburned combustible loss leaving the boiler is fuel dependant.

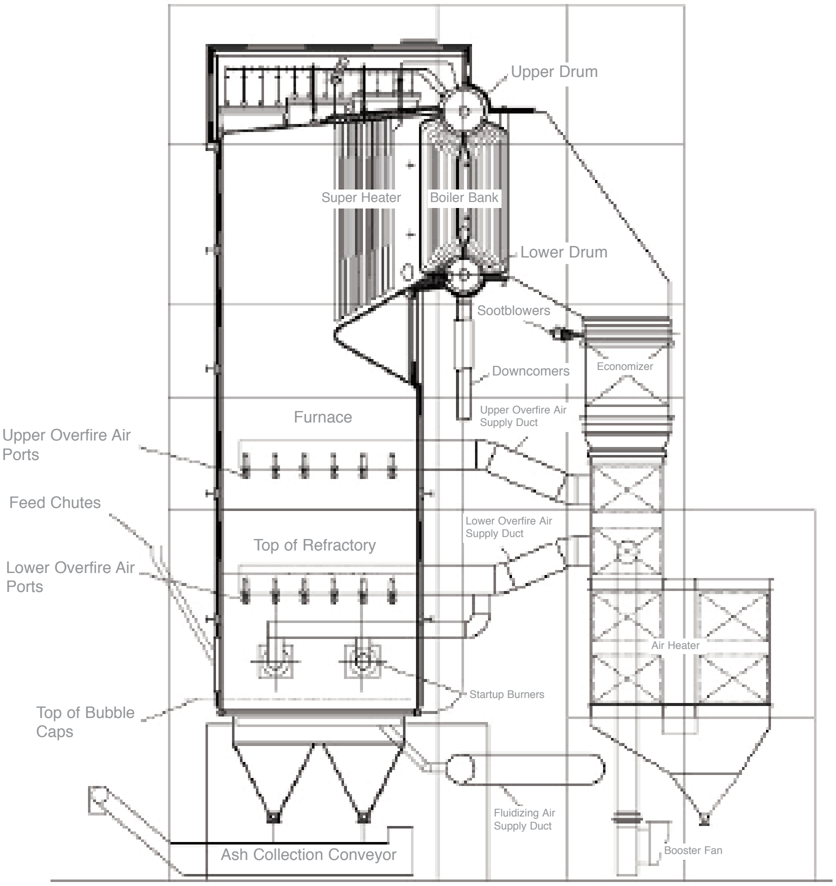


Figure 6. Bottom Supported Bubbling Fluid Bed Boiler

Emissions

Biomass fuels normally contain little sulfur with varying amounts of nitrogen as compared to coal. Uncontrolled SO_x emissions from biomass combustion are negligible compared to uncontrolled SO_x emissions from coal combustion. Uncontrolled NO_x emissions can be comparable -- and are dependent on the conversion process and nitrogen content of the biomass. NO_x emissions comprise fuel-bound NO_x and thermal NO_x. Generally, wood contains less nitrogen (i.e., protein) than perennial herbaceous crops or crop residues.

Remaining below Prevention of Significant Deterioration (PSD) emission thresholds for NO_x, CO and SO_2 (250 TPY for attainment areas and, at most, 100 TPY in non-attainment areas) drives the emission limits for many biomass power projects. For the 50 MW plant comparison in an attainment area, typical of many of the projects under development, the NO_x, CO and SO_2 emissions must be less than or equal to 0.08 lb/MMBtu (8,760 hrs.).

While BFB's have lower uncontrolled NO_x and CO than a stoker (temperature control dynamics within a BFB firing a low moisture fuel tend to increase uncontrolled CO emissions) as shown in Table 1. Temperature control dynamics within a BFB firing a low moisture fuel tend to increase uncontrolled CO emissions. The current environmental limits are not met by a selective noncatalytic reduction system (SNCR) on a BFB. Therefore, environmentally, both the stoker and BFB require backend NO_x and CO controls to comply with Prevention of Significant Deterioration (PSD).

Table 1

Typical Uncontrolled Emissions from a Stoker and a BFB

	Uncontrolled NO_x lb/MMBtu	**Uncontrolled CO lb/MMBtu**
Stoker	0.18 - 0.28	0.10 - 0.30
BFB	0.15 - 0.24	0.05 - 0.15

Traditionally, BFB units have baghouses and stokers employ Electrostatic Precipitators. Because there is little to no carryover, BFB systems do not usually have carbon re-injection systems. In the latest stoker systems, since entrained burning embers can pose a risk to normal baghouses downstream of a stoker, current design wood-fired stoker boilers are combined with multi-cyclone dust collectors used as “drop-out” boxes to reduce the risk of embers impacting on the fabric bags. In addition, flame retardant finishes are applied on fabric filter bags to further address this issue.

Regenerative Selective Catalytic Reduction (RSCR)

The conventional technology for attaining high reductions of NO_x from a combustion process is Selective Catalytic Reduction (SCR). Thousands of plants worldwide have had “conventional” SCRs installed between the last heat transfer surface, typically the economizer, and the unit airheater. This location produces flue gas at 600 to 800ºF, which is the ideal temperature for the catalyst. The gas can be laden with ash particles due to its location upstream of the ESP or baghouse. A conventional SCR is not suitable in processes where the ash may contain poisons such as sodium, potassium, lead or arsenic. Additionally, a conventional SCR may not be cost effective to retrofit into smaller units because of the extensive modifications required to accommodate the unit. On these problematical applications, the solution is to locate the SCR after the particulate control equipment, where the flue gas temperature is much lower than the required 600-800ºF.

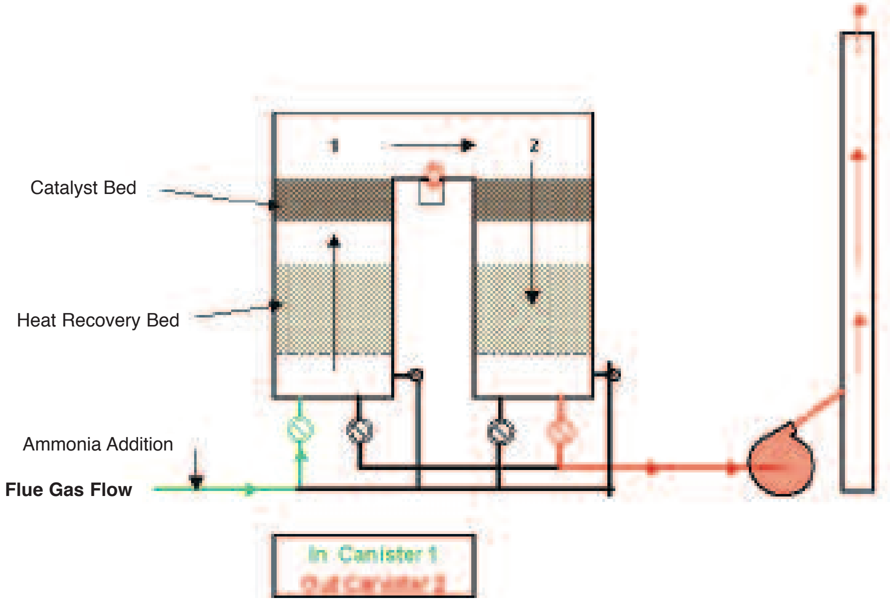


Figure 7. RSCR Flow Sequence

The primary application of an RSCR™ system is the reduction of NO_x emissions in the flue gas found at the tail end of the boiler where gas temperatures are cool, typically 300-400ºF. In an RSCR, the temperature of the flue gas is temporarily elevated for optimal catalyst performance and the heat is recovered before sending the clean flue gas to the stack. The main advantage of an RSCR system is its high thermal efficiency versus standard tail-end solutions in which a heat exchanger and duct burners are used. The RSCR thermal efficiency can be guaranteed as high as 95% in contrast to standard tail end solutions that typically achieve 70-75% efficiency. This higher thermal efficiency means that fuel consumption for the RSCR is 4-5 times lower than a standard tail end SCR. For a 50 MW boiler, these savings translate to approximately $3M in reduced annual fuel costs.

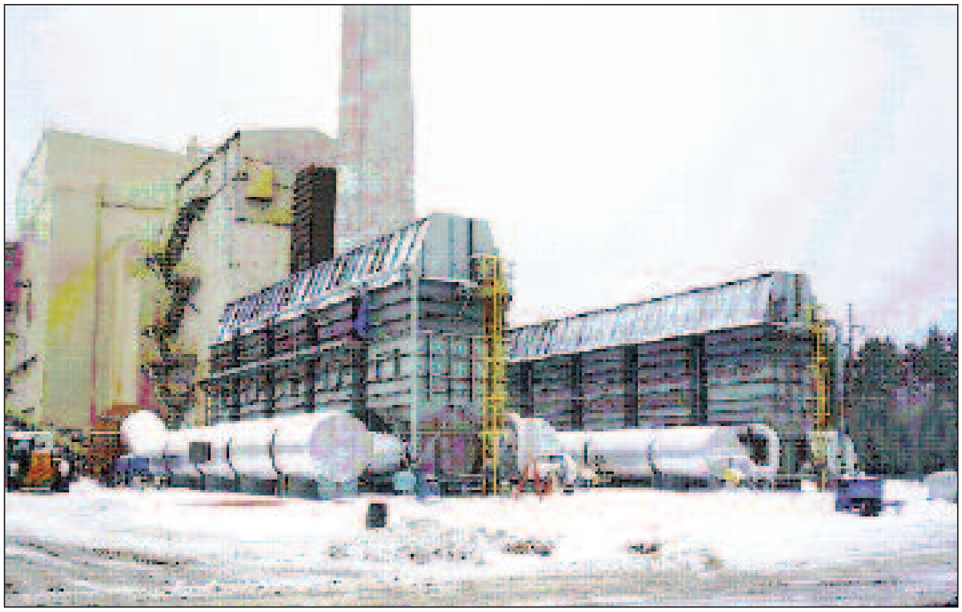


Figure 8. RSCR on Boralex Stratton 50 MW Wood Fired Boiler

Economic Comparison

Economic comparisons were developed for capital costs and operational costs for a 50MW net output wood fired unit. The results are presented below.

Heat rate

Table 2 presents the comparison between heat rates. The stoker has a nominal 1.5%* heat rate advantage over the BFB. The BFB has a 27% higher auxiliary power requirement that a comparable stoker fired unit due to the additional auxiliary power requirements of the fans as shown in Table 4.

Table 2

Heat Rate

		Stoker	BFB	
Net Plant Rating	MWn	50.0	50.0	
Total Auxiliary Power Required	MW	5.2	6.6	26.7%
Gross Plant Output	MWg	55.2	56.6	2.5%
Stm. Turbine Gen. Steam Rate	lb/kw-hr	8.7105	8.7105	
Main Steam Flow	lb/hr	480,887	493,020	2.5%
Total Boiler Output	mmbtu/hr	498.0	510.5	2.5%
Gross Heat Input (HHV basis)	mmbtu/hr	701.2	711.8	1.5%
Net Heat Rate (HHV basis)	**btu/kw-hr**	**14,023**	**14,236**	**1.5%***

** Customer/developer discussions noted that the net heat rate difference could be as high as 4%.*

Operating Costs

Operating costs for the BFB are higher that the stoker due to several issues — fuel, make-up bed material and increased maintenance. The BFB has to produce more steam to generate the same net MW output. This will require more fuel and make-up water, which will increase power consumption in the associated equipment as shown in Table 3. To insure problem free operation, a BFB requires the bed material to be changed to reduce the risk of bed agglomeration. Maintenance costs for a stoker fired boiler is lower than a BFB.

Table 3

Operating Costs

	Stoker	BFB
Fuel Cost	Base	Base + 1.5%
Sand Cost	n/a	$230,000 per year
Makeup Water Cost	Base	Base + 1.4%
Maintenance Cost	Base	Base + 5%**
Personnel Costs	Base	Base

** Customer/developer discussions noted that the net heat rate difference could be as high as 4%.*

Auxiliary Loads

The BFB has a higher auxiliary requirement principally due to the boiler fan requirements. However, because of a higher heat rate, other auxiliary systems have increased power requirements as presented in Table 4 below. Table 5 presents the fan requirements of both systems.

Table 4

Auxiliary Loads

		Stoker	BFB
Condensate Pump	kW	38	39
Cooling Tower Fans	kW	475	487
CW Circ Pump	kW	320	328
Feed Water Pump	kW	1100	1128
Boiler Fans	kW	2175	3519
Fuel & Ash Handling	kW	1100	1100
Total		**5208**	**6601**

Table 5

Fan Power Requirements

Fans	Stoker		BFB	
Forced Draft Fan	196 hp	146 kw	1,059 hp	790 kw
Overfire Air Fan	471 hp	352 kw	---	---
Fluidizing Air Fan	---	---	1,359 hp	1,013 kw
Distributor Air Fan	112 hp	83 kw	---	---
Induced Draft Fan	2,137 hp	1,594 kw	1,924 hp	1,435 kw
Flue Gas Recirculation Fan	---	---	377 hp	281 kw
Total	**2,916 hp**	**2,175 kw**	**4,719 hp**	**3,519 kw**

Capital Costs

For the capital cost comparison as presented in Table 6, typical scopes were considered for each technology. The stoker scope includes water cooled vibrating grate, furnace, convective surfaces, ash re-injection system, ash removal system, ID/FD/OFA fans, tubular airheater, multi-cyclone dust collectors, baghouse and RSCR backend system. The bubbling fluid bed system scope includes, fluid bed system, convective surfaces, burners for start-up, ash removal system, ID/FD/FA Booster/FGR fans, tubular airheater, baghouse and SCR backend system.

For the 50 MWe capacity boiler island, within the accuracy level of our budget estimate, the capital cost of the BFB systems are approximately 10% more than the stoker system. The basic footprint of a BFB is larger that a stoker fired boiler for the same power output. The project terminal points were consistent between the two configurations. Although the uncontrolled emissions from a BFB are slightly lower than a stoker, both systems will require backend environmental systems.

Table 6

Capital Costs

	Stoker	BFB
Boiler & Air Quality Control System	Base	Base + 10.0%***
Steam Turbine Generator	Base	Base
Balance of Plant	Base	Base

** Customer/developer discussions noted that the net heat rate difference could be as high as 4%.*

Table 7

Power Generation

		Stoker	BFB
Net Plant Rating	MW	50.0	50.0
Availability Factor	%	95%	92%****
Operating Hours	hr/year	8322	8059
Total Power Generation,	MW-hr/year	416,100	402,960
Revenue from Power Sales		**Base**	**Base - 3.2%**

SUMMARY AND CONCLUSIONS

In conclusion both the Stoker and BFB technologies are viable biomass firing systems. Each technology has their own advantages and disadvantages as summarized in the following:

	Stoker	BFB
1. Fuel flexibility		
* Normal woody fuels 15 - 58 % moisture	Good	Good
* Extreme high moisture greater than 58%	Not Good (a)	Good
* Agricultural fuels (med to high alkali)	Good	Not Good (b)
* Co-firing Alternate Fuels	Good	Limited
2. Operational Complexity	Easier to Operate	More Complex to operate
3. Horsepower Requirements	Lower	Higher
4. Plant Heat Rate	Better	--
5. Final Emissions	Same	Same
6. Availability	Better	--
7. Net Power Generation	Better	--
8. Plant Capital Cost	Lower	Higher

(a) Above 58% moisture wood auxiliary fuel is required.

(b) Limited depending upon the alkali level. Example is Poultry Derived Fuel (high alkali) cannot be fired in a BFB and is typically fired on a stoker.

The perception in the industry is that Stokers are "old / out-dated technology" which is proven not true as demonstrated above. As compared to BFBs, Modernized Stokers are more fuel flexible, easier to operate, have better heat rate, same or better emissions and lower capital and operating costs.

REFERENCES

1. P. Chattopadhyay; Fluidized Bed Boilers; 2007; Galgotia Publications Pvt. Ltd.
2. J.P DeFusco, P.A. McKenzie, M.D. Fick; 2008; Bubbling Fluidized Bed or Stoker — Which is the Right Choice for Your Renewable Energy Project
3. C. Yin, L. Rosendahl, S. Kaer; 2008; Grate Firing of Biomass for Heat and Power Generation
4. E. Brus, M. Ohman, A. Nordin, B. Skrifvars, R. Backman; 2003; Bed Material Consumption in Biomass Fired Fluidized Bed Boilers Due to Risk of Bed Agglomeration — Coating Formation and Possibilities for Regeneration