# TECHNICAL PUBLICATION

## Efficient and Low Emission Stoker Fired Biomass Boiler Technology in Today's Marketplace

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# EFFICIENT AND LOW EMISSION STOKER FIRED BIOMASS BOILER TECHNOLOGY IN TODAY'S MARKETPLACE

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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 no net $CO_2$ releases to the environment. Biomass boilers equipped with new 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 the new units to the existing operating biomass boilers. On the combustion side, new Over-fire air and Stoker technology are used to increase combustion efficiency. Emissions are controlled using a system called the "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, with $NO_x$ reductions of >70% and CO reductions >50% achieved. 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 the 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 no net $CO_2$ releases into the environment. Biomass boilers equipped with new 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 new combustion advancements and present quantitative comparisons of the new units available today vs. the 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 hereby unheard of for biomass boilers. Emissions are controlled using a system called the "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 >80%. The 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 the RSCR, which was 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/Oscillating Stoker. Biomass combustion technology has evolved from incineration of a nuisance waste fuel to combustion of a valuable fuel. With this biomass fuel evolution, the combustion systems have been continually upgraded for improved efficiency. Currently, environmental regulations have added further changes to the stoker designs as discussed in this paper. The resulting objectives of a modern biomass stoker combustion system include: maintaining an <u>efficient</u>, <u>stable</u> combustion process while supplying the desired boiler <u>heat input</u> with <u>low emissions</u>.

* **Efficient Combustion**
  Produce efficient combustion with low carbon monoxide (CO) and low unburned carbon (UBC)

* **Stable Combustion**
  Produce stable and consistent combustion to maintain consistent design parameters and boiler performance

* **Heat Input**
  Generate the heat input 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 ($NO_x$)

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

## 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 roll 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 of modern stoker combustion systems consist of both combustion and boiler components. The following lists recent system improvements:

- 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 to reduce flue gas laning along the walls and increase mixing of fuel & air
- Improved mixing of fuel & air by the use of grate oscillation/vibration
- Reduced air infiltration by new seal designs (air bypassing the combustion system)

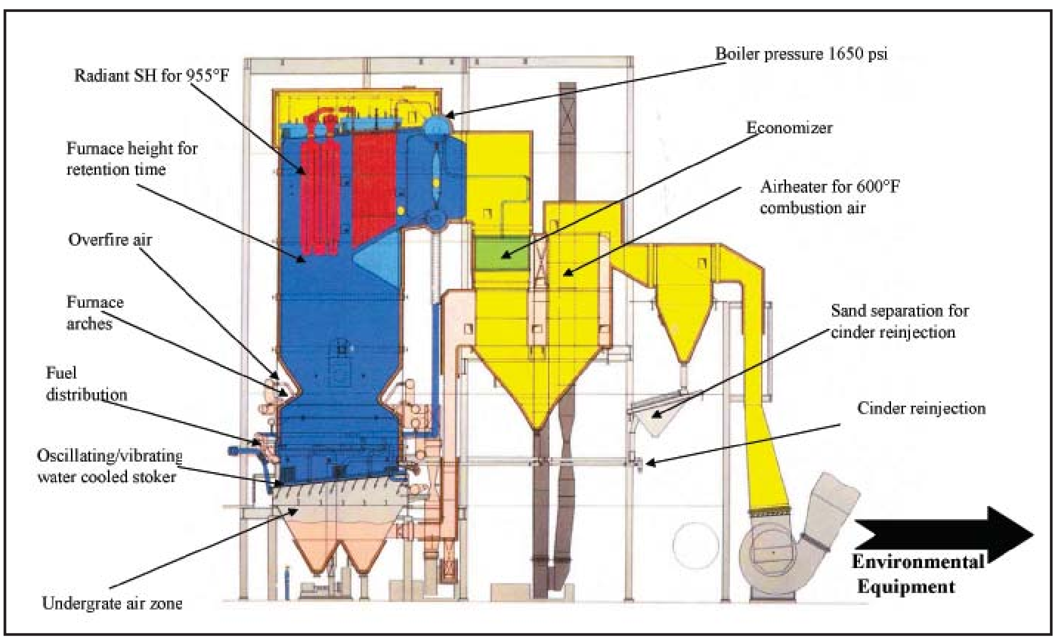


*Figure 1. Typical Modern Biomass Stoker Boiler System.*

## General Performance Comparison

The following is a general performance summary and comparison of biomass past stoker designs verses modern stoker designs:

Table 1

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

| | Older Stoker Design (welded wall) | Modernized Stoker Design | |
|---|---|---|---|
| Steam Flow lbs/hr x $10^3$ | 100 - 500 | 100 - 500 | |
| Steam Press. Psi | 600 - 900 | 1,250 - 1,650 | |
| Steam Temp. °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-ft$^2$ | 1,000,000 - 1,200,000 | 850,000 (maximum) | |
| Boiler efficiency % (2) | 68.40 | 71.25 | |
| **Emissions:** | | | |
| CO lbs/$10^6$ Btu @ 3.0% $O_2$ (ppm) | 0.35 - 0.60<br>(430 - 735) | 0.10 - 0.30<br>(122 - 370) | ***Base*** |
| CO **w/RSCR** lbs/$10^6$ Btu @ 3.0% $O_2$ (ppm) | --<br>-- | 0.05 - 0.15<br>(61 - 185) | ***(-50%)*** |
| $NO_x$ lbs/$10^6$ Btu @ 3.0% $O_2$ (ppm) | 0.15 - 0.20<br>(112 -145) | 0.15 - 0.25<br>(112 -188) | ***Base*** |
| $NO_x$ **w/SNCR** lbs/$10^6$ Btu @3.0% $O_2$ (ppm) | -<br>- | 0.10 - 0.17<br>(75 - 130) | ***(-30 to 40%)*** |
| $NO_x$ **w/RSCR** lbs/$10^6$ Btu @ 3.0% $O_2$ (ppm) | --<br>--- | 0.06 - 0.075<br>(45-56) | ***(-60 to 75%)*** |

(1) Based on flue gas velocities, fuel particle retention will be longer based on 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 may vary based on individual manufacturers designs and performance results.

The benefits of the Modernized stoker system are exhibited in the combustion system 1) stability, 2) lower CO emissions, and 3) lower unburned carbon; all of which 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).

## Design Details

The following lists the major equipment design upgrades associated with stoker combustion improvements:

1. Fuel Feed & 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.

### 2. Stoker Designs

*Objective:* 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 traveling 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 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 600ºF. 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 using water cooled grate surface. Water cooled surfaces allow the capability to vary air flow as required without overheating of the grate cast surface (i.e.: the surfaces do not require air flow for cooling) and also reduces maintenance costs.

— Design the grate surface area for a maximum 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 2, 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:

- 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.

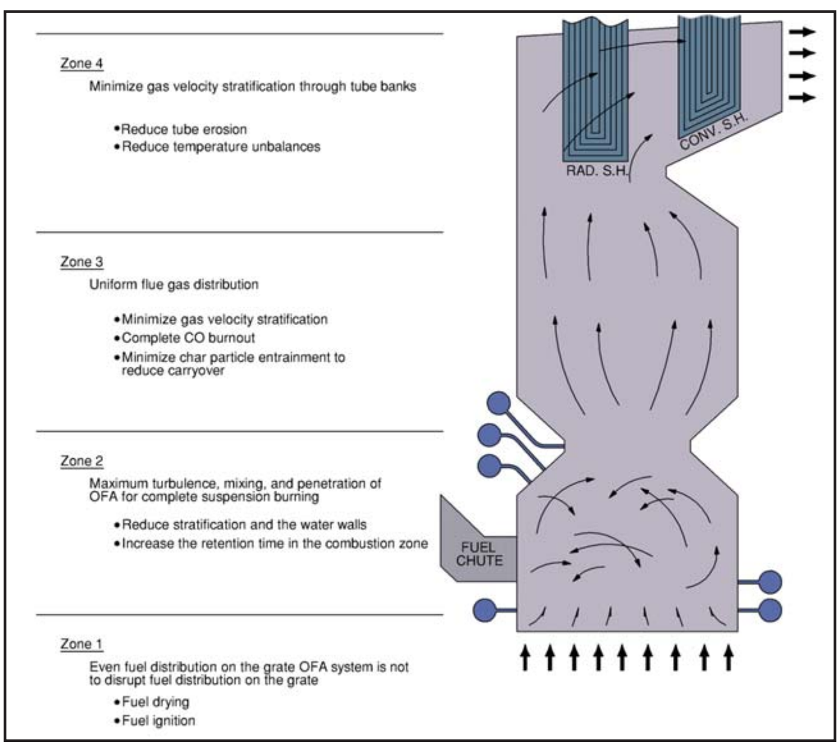


*Figure 2. Furnace Design Objectives.*

**4. Over-fire Air Designs**

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

*Enhancements:*

— Design changes to 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 water walls.

— 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.

**5. Cinder Reinjection Designs**

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

*Enhancements:*

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

## RSCR™ Technology for Efficient $NO_x$ Reduction on Biomass Boilers

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.

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 which 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.

### System Components

The major components of an RSCR system are:

* Ductwork for diverting the flue gas flow to the RSCR and back to the stack
* Modularized canisters that house the thermal media, catalyst, retention chamber, burner system, etc.
* A high efficiency thermal media system
* Catalyst for $NO_x$ and optional CO removal
* A burner system including combustion air fan
* Ammonia injection, delivery and storage system
* Hydraulic power system for damper operation
* Water wash system
* Flue gas booster fan
* Damper system
* Controls and instrumentation

## System Operation

An RSCR system is a combination of two established and proven technologies: Regenerative Thermal Oxidizer (RTO) and SCR. By utilizing the direct contact regenerative heater technology (usually associated with an RTO), in which cycling beds of ceramic media are used to transfer heat, the low temperature issue is resolved. $NO_x$ reduction takes place in SCR catalyst modules positioned above the heat transfer bed, where the flue gas has been heated to around 600ºF and the proper amount of ammonia has been added upstream of the canisters. Either anhydrous or aqueous ammonia can be used.

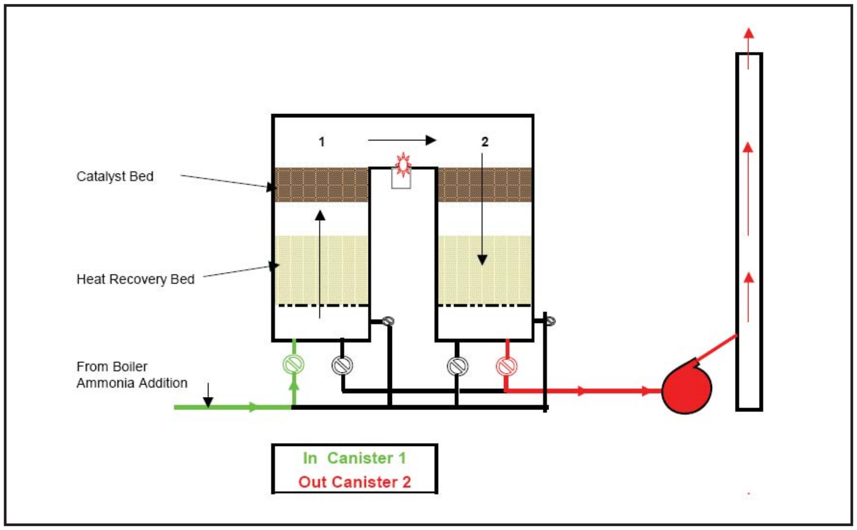


*Figure 3. Operation of a simple 2-Canister RSCR design.*

Simplified, a typical operation sends cleaned flue gas from the particulate control device (ESP or baghouse) containing $NO_x$ to the inlet of the system and mixes with ammonia. The temperature of the flue gas is not critical and can be saturated or higher. The gas passes up through the preheated heat transfer media bed and it is heated to around 600ºF.

A catalyst module is placed downstream of the heat transfer media bed. The ammonia in the flue gas reacts with $NO_x$ to form nitrogen and water. As the gas leaves the catalyst in the first canister, a burner located in the retention chamber (the space connecting the first and second canister), adds heat. The burner is required to make-up for heat losses through the walls of the canisters and inefficiency in the heat transfer media. It raises the temperature in the retention chamber by about 10-15ºF. The gas flows into the second canister, through the catalyst, and passes through the second media bed. The media in the second canister absorbs heat from the hot flue gas as it cools from 610ºF to about 10-15ºF warmer than it first entered the system. A portion of the $NO_x$ reduction takes place as the gas passes through the second canister.

Once this cycle is completed, the flow reverses, so that the second canister (which was heated) becomes the inlet canister and the first canister becomes the outlet canister. Careful operation of the dampers routes the flue gas through the particular canister and is controlled by a central PLC.

## Design Basis

The system design depends upon the inlet flue gas flow, $NO_X$ concentration, temperature and constituents in the flue gas, especially normal fuel analysis plus compounds of chlorine and sulfur, along with trace ash components. Particulate loading in the inlet flue gas is an important parameter in the design of the RSCR system. Properly functioning particle removal technology is mandatory upstream of the RSCR.

The possibility of reaching the acid dew point, which could be corrosive and could lead to ammonium bisulfate formation, means that the $SO_3$ content in the exhaust gas must be specified. When present in large quantities, the system design may require provisions to account for their removal.

## System Description

In order to better understand an RSCR system, it is worthwhile to describe the major system components in detail. The main function of ductwork is to route the flue gas from discharge from the particulate control device or ID fan to the RSCR and return it to the stack after treatment. The ductwork is typically made of carbon steel material. The ductwork must take into consideration two important design features: it must allow sufficient distance for ammonia to mix and it must be adequately sized to minimize pressure drop.

Figures 4 and 5 show results of CFD modeling illustrating velocity and temperature profiles for a 3-Canister RSCR system for a typical 15 MW wood-fired boiler.

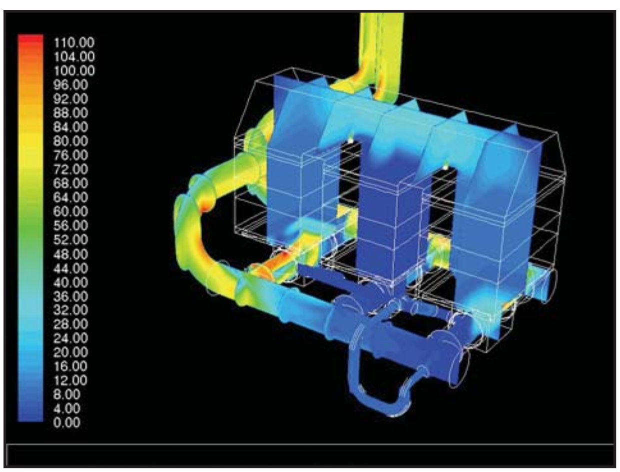


*Figure 4. CFD modeling showing velocity profile in a 3-Canister RSCR system.*

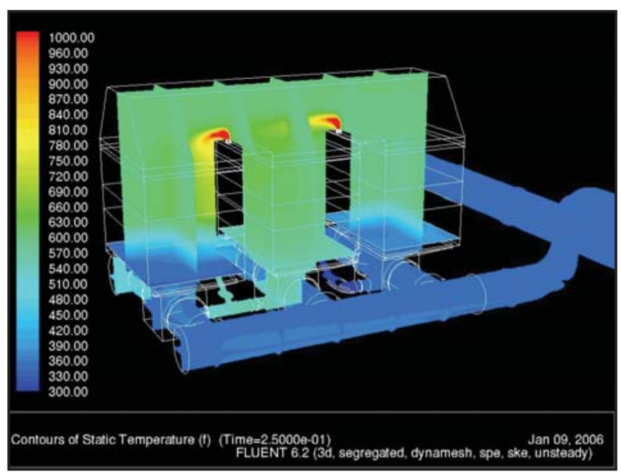


*Figure 5. CFD modeling showing temperature profile in a 3-Can RSCR Unit.*

The selection of thermal media is a critical feature of RSCR design. Factors that need to be taken into consideration during the design process are: gas-side pressure drop, thermal efficiency and cost. A large bed face area reduces the pressure drop and operating cost but increases capital cost. Figure 6 shows a photo of a typical thermal media used in this type of application with a cross section area of 6" by 6" and a height of 12".

The $NO_x$ reduction catalyst, supplied by Cormetech, Inc., is installed downstream of the thermal media where the flue gas temperature is sufficient for the catalyst to operate. The factors taken into consideration are: sufficient catalyst volume for $NO_x$ reduction and minimizing ammonia slip and pressure drop. The presence of alkaline metals like sodium or potassium or poisons like arsenic can deactivate the catalyst. Proper selection of catalyst pitch is necessary to mitigate the possibility of pluggage. The useful catalyst life, $NO_x$ reduction and ammonia slip are guaranteed.

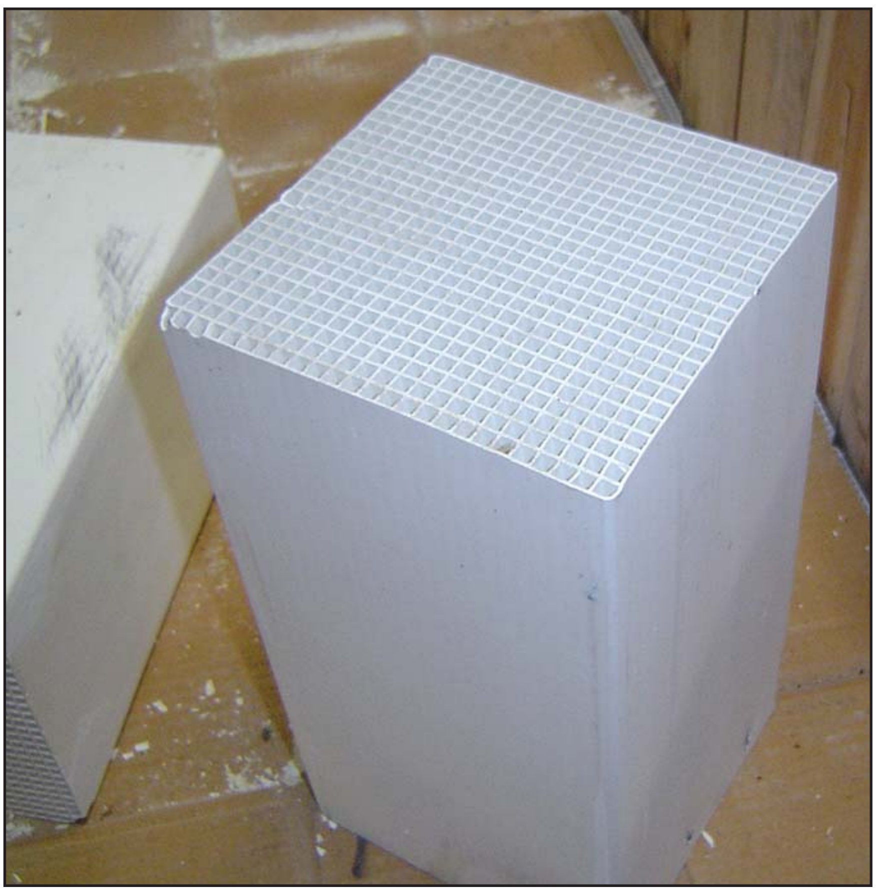

*Figure 6. A block of monolith ceramic thermal media.*

A burner is required to compensate for inefficiencies in heat recovery and to make up for heat loss through the walls of the RSCR. The burners are located in the headspace of the RSCR in the retention chamber. The number of burners required is one less than the total numbers of canisters. Therefore, two burners are required for a 3-Canister system. View ports are provided in the retention chamber for visual inspection of the burners (see Fig. 7).

*Figure 7. Photo of burners taken from view port of a 5 Canister RSCR system.*

A fan is required to supply combustion air for the burners. This fan is relatively small in size. During the start-up process, the burners help bring the system to the desired operating temperatures from the cold condition. The burners can be designed to use natural gas, propane or low sulfur fuel oil, depending upon specific plant requirements. The retention chamber and canisters are internally insulated to minimize skin temperature for a given ambient temperature and wind speed. Skin temperature generally does not exceed 120ºF.

The ammonia delivery system consists of ammonia pumps, storage tank, interconnecting piping and a control system (See Figure 8). The size of the tank depends upon injection rates, hours of operation and typical delivery truck volume. The ammonia pump uses a variable speed drive that can vary the quantity of ammonia in response to changes in $NO_x$ as detected by the plant CEMS monitor. These pumps are small, usually 1 HP or less, and often a redundant pump is provided to assure continuity in system operation.

*Figure 8. Ammonia skid with storage tank for a 50 MW boiler.*

The key to the operation of the RSCR is the ability to cycle the valves every one to two minutes. The valves used in the main gas flow are metal seated butterfly dampers, up to 90" diameter. The dampers must cycle from fully open or closed to the opposite condition in three seconds or less, without slamming. To accomplish this, hydraulic actuators are used. The actuators move the damper blade through 95% of its travel very quickly, and then move the last 5% more slowly, until stopped by a proximity switch. A high pressure hydraulic power unit provides the motive force for the actuators, and includes an accumulator which has sufficient volume to move all dampers to their “failsafe” positions in the event of a system upset.

A heavy-duty fan is provided to offset the pressure drop through the RSCR system, and to permit the RSCR to heat up or cool down while off line. The fan size depends upon the gas flow and pressure drop through the system and care is taken to optimize its design.

Three dampers are provided to ensure smooth operation and maintenance of the RSCR system. Two isolation dampers are provided in the ductwork connecting the RSCR system to the boiler and to the stack and one bypass damper is provided in the main ductwork connecting the boiler to the stack. During normal operation, the damper in the main ductwork is closed and the other two dampers are open to route the gas flow through the RSCR system. To bypass the RSCR system, the two isolation dampers in the RSCR inlet and outlet duct are closed and the main bypass damper is open. The dampers are also hydraulically actuated There is also a damper for supplying fresh air during start-up and allows the RSCR to operate when isolated from the process. All the dampers are fail-safe in case of power loss or system upset.

A stand-alone PLC with a touch-screen interface terminal is provided for controlling the operation and monitoring of the RSCR system (see Figure 9). The panel also includes communication modules, diagnostics screens for all instrumentation/controls/field devices, a modem and other instrumentation.

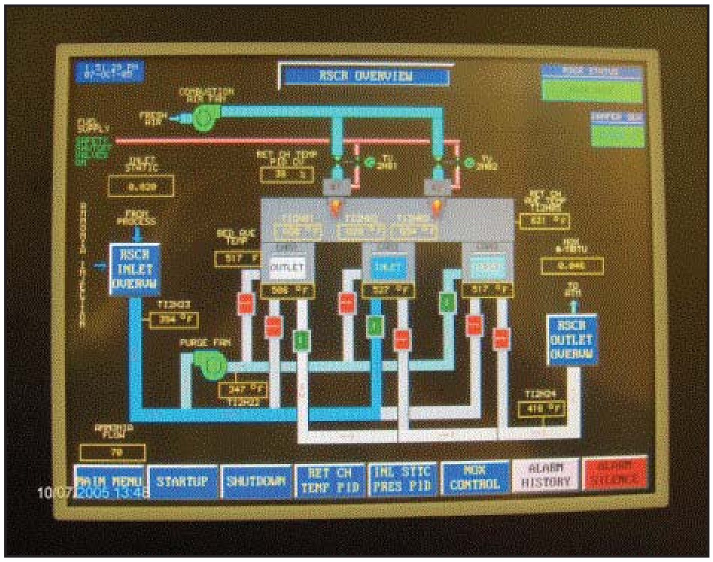


Figure 9. The PLC based control system.

## Installed Base

The RSCR system has been installed on two boilers in the Northeast — a 15 MW and a 50 MW wood-fired boiler. The 15 MW plant uses whole tree chips as fuel; the 50 MW plant uses whole tree chips, waste wood, and construction and demolition wood as fuel for the boilers. The goal of the two installations was to qualify for Connecticut Renewable Energy Credits (REC). The state requirement for qualifying for RECs is achieving $NO_x$ level of 0.075 lb/MMBtu or less on a quarterly average.

The inlet $NO_x$ levels at the two sites were in the range of 0.25 to 0.28 lb/MMBtu. While designed to reduce $NO_x$ levels by 70 to 75%, the two systems have been able to reduce $NO_x$ levels significantly below 0.075 lb/MMBtu. Because the RECs are based on reductions averaged over the quarter and not on instantaneous values the plants are able to “catch up” their averages should the RSCRs be out of service for any reason.

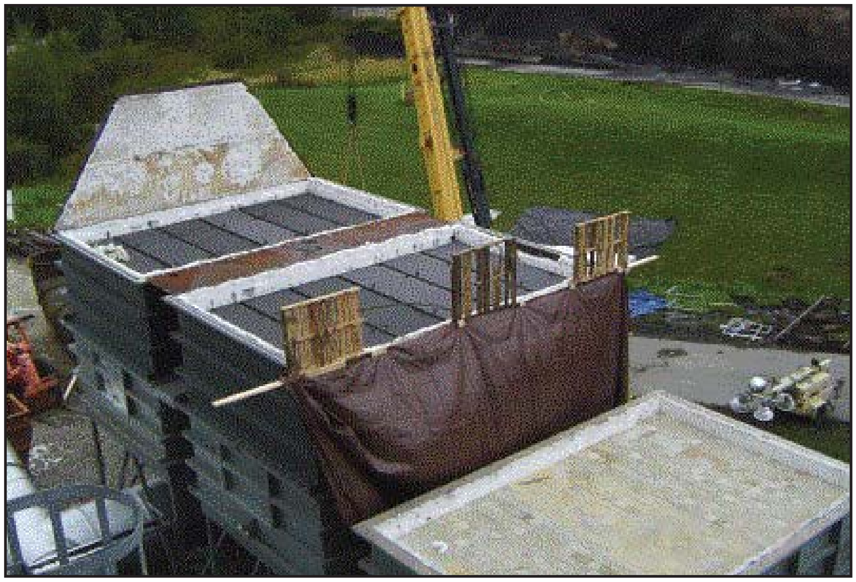

Figure 10. A 3-Canister system under construction.

The RSCR system for the 15 MW unit has been in continuous operation since the beginning of the fourth quarter of 2004 and the 50 MW system has been in continuous operation since the beginning of the first quarter of 2005. See figure 10 for the 15 MW unit under construction showing the catalyst in two canisters and thermal media in one canister. Figure 11 shows the completed system for a 50 MW boiler in which two trains of 5 canisters each were used to meet the emission reduction requirements.

Figure 11. An RSCR system showing two trains of 5 canisters each.

The feature that differentiates the RSCR from other technologies is high thermal efficiency. Normally the thermal efficiency of the RSCR in a given application is guaranteed at %. Competing technologies that utilize Lungstrom or plate type heat exchangers for heat recovery and duct burners to reach the catalyst operating temperature are typically in the range of 70-75% thermal efficiency and therefore can be expected to require five times the auxiliary fuel as the RSCR.

## CONCLUSIONS

The RSCR system has been shown to be an effective, reliable, and economical means to reduce $NO_x$ emissions from biomass plants.

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