Operating Experience with High Efficiency Emissions Reduction System for Biomass Boilers

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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 a new, patented emissions control technology advancements using a system called the "RSCR®", which is a selective catalytic device applied to the relatively 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 this new technology. The paper will also provide actual operating data on the RSCR, which has been retrofitted to three 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.

Advancements to stoker boilers including a new over-fire air (OFA) design and state-of-the-art stoker technology with grate oscillation/vibration are used to increase combustion efficiency. In addition, 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 stoker combustors offer a significantly better heat rate than fluidized or bubbling bed combustors because of the reduced parasitic load in the stoker boiler.

A new system for the reduction of NO_x emissions to levels hereby unheard of for biomass boilers has been developed and commercialized. Emissions are controlled using a system called the “RSCR”, which is a regenerative selective catalytic device achieving NO_x reductions of >80%, applied to the relatively cold gas (after the boiler and particulate removal equipment) prior to its discharge to the stack. This paper will provide actual operating data on the RSCR, which has been retrofitted to three existing biomass-fired units. The technology is covered by US patent #7,294,321.

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. The resulting objectives of a modern biomass stoker combustion system include maintaining an efficient, stable combustion process while supplying the desired boiler heat input with low emissions.

- Efficient Combustion
  Produce 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 Uncontrolled Emissions
  Produce low CO, low UBC and low nitrogen oxides (NOx).

RSCR® Technology for Efficient NOx Reduction on Biomass Boilers

The conventional technology for attaining NO_x reductions >50% from a combustion process is Selective Catalytic Reduction (SCR). Hundreds of coal and gas fired 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 600-800°F.

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 biomass boiler where gas temperatures are cool, typically 300 to 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 typically 10-15% of that consumed by 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, burners
- 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 600°F and the proper amount of ammonia has been added upstream of the canisters. Either anhydrous or aqueous ammonia can be used.

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 600°F.

Catalyst modules are 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°F. 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 610°F to about 10°F 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.

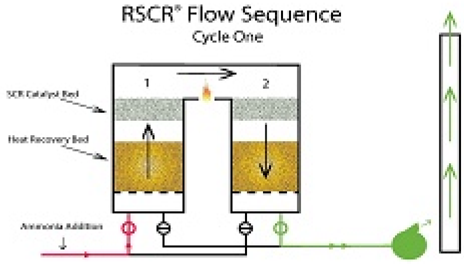

Figure 1: Operation of a two-canister RSCR design.

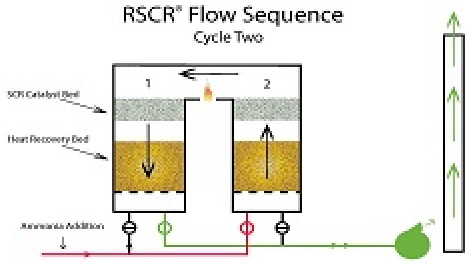

Figure 2: RSCR flow sequence – cycle two

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

Figure 3: A block of monolith ceramic thermal media

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.

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 3 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 metals such as arsenic can irreversibly 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. A layer of precious metal CO oxidation catalyst can be provided on top of the SCR catalyst to achieve >50% CO reduction simultaneously with NO_x reduction.

A burner is required to compensate for the small 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, one burner is required for a two-canister system. View ports are provided in the retention chamber for visual inspection of the burners (see Fig. 4).

Figure 4: Photo of RSCR system burners in operation

A small fan is required to supply combustion air for the burners. 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, low sulfur fuel oil, or biodiesel, 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 120°F.

The ammonia delivery system consists of ammonia pumps, storage tank, interconnecting piping and a control system (See Figure 5). The size of the tank depends upon injection rates, hours of operation and typical delivery truck volume. The small, redundant ammonia pumps use 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.

Figure 5: Ammonia skid/storage tank -50 MW RSCR.

The key to the operation of the RSCR is the ability to cycle the valves every two to three 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 bypass 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. 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. The panel also includes communication modules, diagnostics screens for all instrumentation/controls/field devices, a modem and other instrumentation.

Installed Base

The RSCR system has been installed on four wood-fired boilers in the US – two 15 MW units in New Hampshire, a 50 MW unit in Maine, and a 50MW unit in Vermont. Both 15 MW plants and the 50 MW plant in VT use 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 first installations was to qualify for Connecticut Renewable Energy Credits (REC), while the VT plant could qualify for RECs in Massachusetts. The CT state requirement for qualifying for RECs is achieving NO_x level of 0.075 lb/MBtu or less, while the MA requirement is 0.065 lb/MBtu or less, both measured on a quarterly average.

The inlet NO_x levels at the sites are typically in the range of 0.25 to 0.28 lb/MBtu. While designed to reduce NO_x levels by 70 to 75%, the systems have been able to reduce NO_x levels significantly below 0.075 lb/MBtu. 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 RSCR be out of service for any reason.

Figure 6: A three-canister system under construction.

The RSCR system for the first 15 MW unit has been in continuous operation since the October 2004 and the 50 MW system has been in continuous operation since the beginning of the first quarter of 2005. The Bridgewater Power RSCR system, on a 15 MW boiler, started up in October 2007. The owners of the three plants have been able to qualify for Connecticut RECs every quarter since start up because of the RSCR operation, demonstrating the reliability and performance of the technology. The fourth unit at McNeil Station in Burlington Vermont, started up on October 1, 2008 and has met the required quarterly average.

See figure 6 for the first 15 MW unit under construction showing the catalyst in two canisters and thermal media in one canister. Figure 7 shows the completed system for a 50 MW boiler in which a single unit with 6 canisters was used to meet the emission reduction requirements.

Figure 7: An RSCR system with six canisters on a 50 MW unit.

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 95 %. Competing technologies that utilize regenerative 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 a proven, reliable, and economical means to reduce very low NO_x emissions from biomass plants and other applications in which a tail-end SCR is required. Systems have been operating for over four years with consistent high performance NOx reduction results.

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