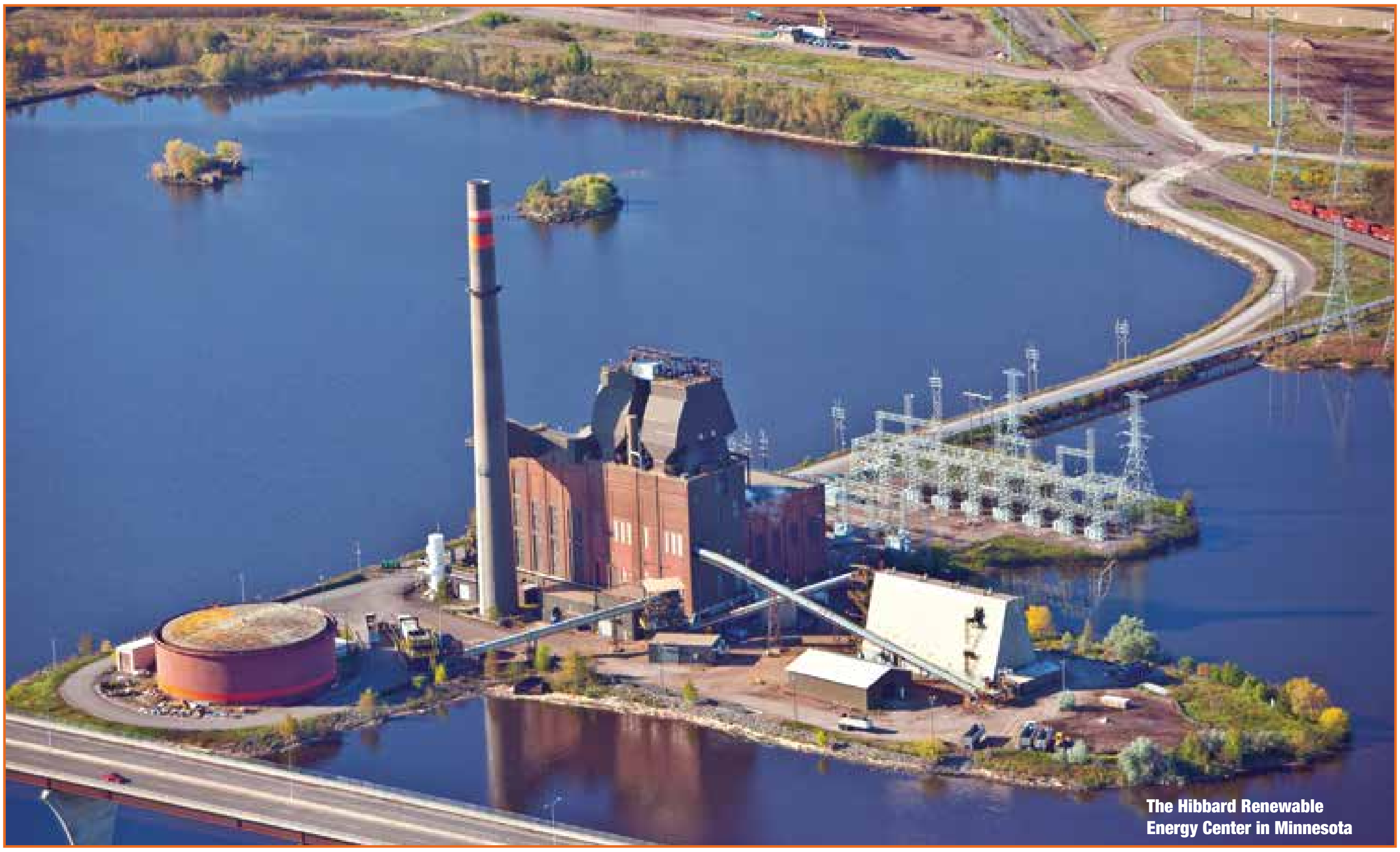

A US-based biomass boiler combustion system specialist reveals how it successfully converted a fossil fuel power station to burn biomass

Replacing coal with biomass

Minnesota Power operates the Hibbard Renewable Energy Center in Duluth, Minnesota, US. At Hibbard, superheated steam for power generation is supplied by two identical boilers. The units, originally supplied in the 1950s to burn pulverised coal, were converted in 1985 to each generate 136,100kg/hr of superheated steam by firing a mixture of wood and stoker coal (in a 60:40 heat input split) on a travelling grate.

During the 1985 conversion, overfire air (OFA) systems (typical of that period), comprising numerous small circular ports arranged in multiple levels on the rear and front wall, were installed (see Figure1). The boilers currently fire Powder River Basin (PRB) stoker coal and biomass fuel which consists of a mix of purchased wood wastes, railroad cross-ties, and short fibre residue.

Flue gases leaving the furnace pass over two long flow superheater sections before entering a long flow generating bank (GB). Downstream of the GB, the gas stream flows into an ash collection hopper, followed by a secondary tubular air heater (TAH) section, economiser, primary TAH section, and mechanical dust collector (MDC), before entering the induced draft (ID) fan and the electrostatic precipitator (EP).

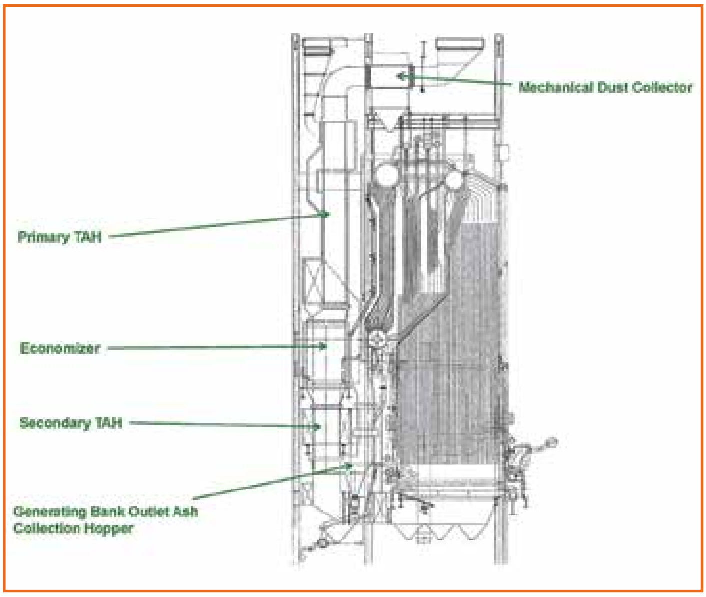

Figure 1: A sectional side view of the boilers following the 1985 conversion

Historically, the boilers had not been able to reliably achieve the designed biomass firing rates; increased biomass firing (and reducing coal firing) led to excessive carryover of unburned char and fly ash, high flue gas exit temperatures and limited ID fan operating margin. Looking to increase the biomass firing rates and eventually eliminate coal firing without increasing air emissions, Minnesota Power contracted Jansen Combustion and Boiler Technologies to meet its goals through a phased programme of evaluation, engineering and equipment supply.

The first step in meeting the project objectives was to gather reliable information on the boiler operations. Jansen engineers made first-hand observations and collected data from the boilers while being operated at high steaming rates with -57% of the heat input being supplied by biomass and the rest by coal. The approach and methodology for this work is described in Reference 1. The following operational deficiencies were identified from this evaluation:

- Non-uniform fuel delivery and an ineffective OFA penetration and mixing caused high char and ash carryover
- High flue gas velocities in the GB outlet ash hopper resulted in poor ash collection and increased the ash loadings to downstream equipment
- High flue gas velocities and low heat transfer surface area of the economiser and TAHs contributed to increased erosion, high flue gas exit temperatures (~260°C), and low boiler thermal efficiency
- The high gas exit temperature also increased the flue gas volumetric flow, which limited the ID fan capacity.

To overcome these limitations, the following upgrades were recommended to sustain increased biomass firing rates, while achieving lower ash loadings in the back passes without exceeding the capacities of the MDC, the ID fan and the EP:

- A combustion system upgrade that improves the burnout of in-flight char and volatile gases. This included upgrading the OFA system and replacing the existing fuel distributors with modern, more effective fuel distributors
- A redesigned GB outlet ash hopper for improved ash collection to lower fly ash loading in the boilers' back passes. The ash hopper was designed with improved access to the hopper internals to clear out ash deposits
- An upgrade of the existing economiser with a significantly larger one to improve heat capture, increase boiler thermal efficiency and lower flue gas flow rates
- The replacement of the existing TAH with a larger unit to improve heat capture and to reduce erosion rates.

All of these recommended upgrades have now been implemented on the boilers except an upgrade of the fuel distributors.

Combustion system modelling and design

Computational Fluid Dynamics (CFD) modelling was implemented to quantify flue gas flow patterns, oxygen (O_2) and carbon monoxide (CO) levels, turbulence and temperatures for different OFA delivery strategies; and fuel delivery patterns to illustrate the advantage of an upgraded combustion system over the existing configuration.

Jansen has used CFD modelling to evaluate over 150 industrial boilers burning a variety of solid and liquid fuels. These models have been used to identify combustion improvements and other operating problems while firing biomass, coal, sludges, refuse-derived fuels and spent chemical liquors.

Jansen's approach was to install eight 'dual range' OFA nozzles on the furnace sidewalls in an interlaced pattern that supply 35-50% of the total combustion air. The nozzles' dual range design achieves optimal flow and jet penetration over a range of flow demands. In addition, the nozzles' low pressure drop design allows OFA feed pressures of less than 38cm wg (water gauge). In this case, the low feed pressure requirement allowed the system to be implemented without an upgrade of the existing OFA booster fan.

The original OFA system with numerous smaller ports provided insufficient jet momentum for the OFA to penetrate very far into the furnace. In comparison, the upgraded system provided significantly deeper jet penetration and generated intense mixing and turbulence.

As shown in Figure 4, improved air and fuel delivery improved the burnout of the in-flight fuel particles. The plots show particle traces of the in-flight fuel particles and are coloured by the particles' stage in the combustion process. The green particle traces represent drying, yellow represents volatiles burning, red represents char burning, and teal represents residual fly ash. The upgraded combustion system arrangement predicted a significant reduction in carryover of in-flight char particles and volatile gases. Improved burnout of volatiles and in-flight fuel particles in the lower furnace led to hotter lower furnace temperatures and cooler furnace exit temperatures. A hotter lower furnace aids the fuel drying process and helps prevent fuel piling on the grate.

The evaluation and CFD modelling effort concluded that the unit's furnace volume and grate surface were adequately sized to achieve 100% biomass firing and helped define the upgrade design of the OFA and fuel delivery systems.

Figure 2: The new OFA nozzle arrangement on the boiler sidewall

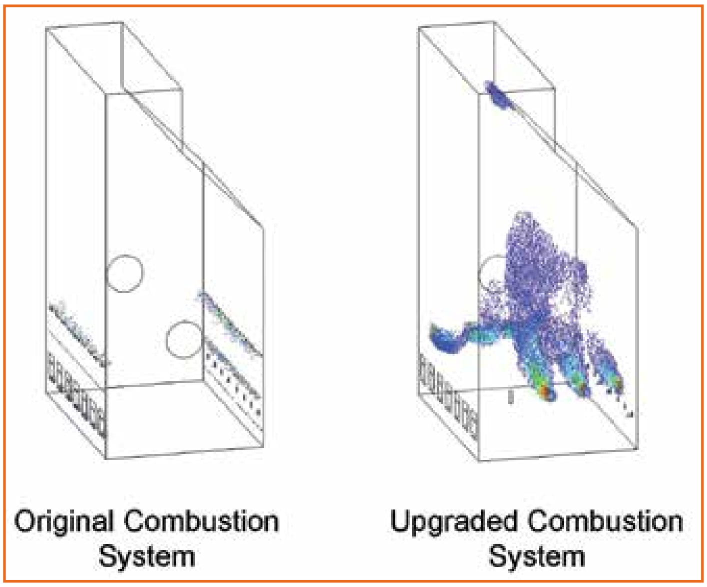

Figure 3: Modelling plots of the jet penetration profiles of the original and upgraded combustion systems, where regions of the furnace with velocities higher than 18m/s are shown

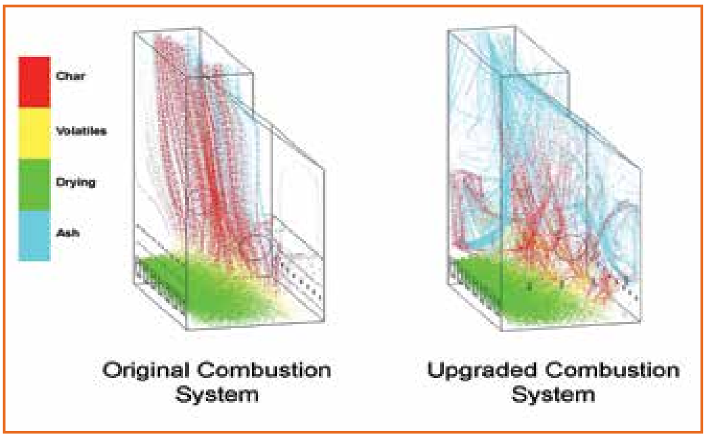

Figure 4: Improvement in the burnout in the in-flight fuel particles by improved air and fuel delivery

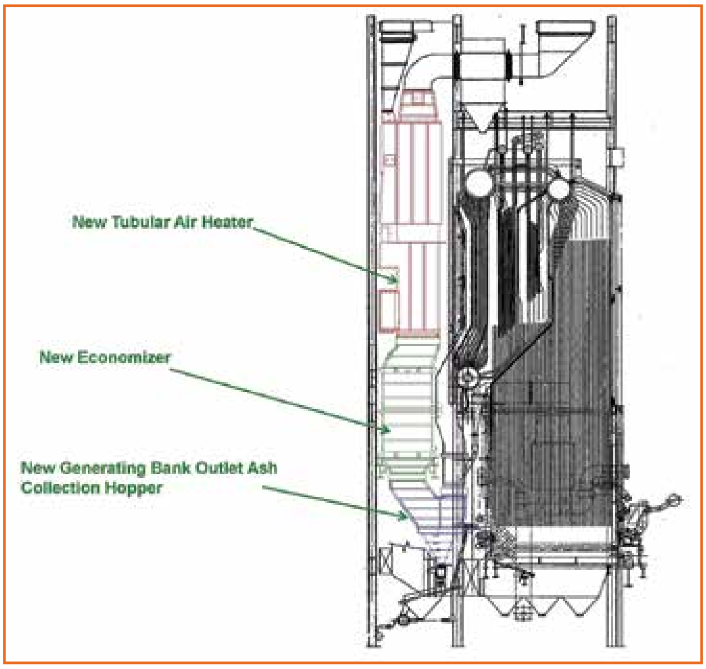

Figure 5: The modified GB outlet ash collection hopper that was installed on the boilers to reduce the flue gas velocities through the 180° turn and improve the drop out of fly ash into the hopper

Upgrades to lower erosion and improve heat capture

The original economiser was replaced with a larger one with a surface area more than 2.3 times larger than the original. The secondary TAH was removed to make room for the upgraded GB outlet ash collection hopper and the new economiser.

The primary TAH was upgraded with larger tubes that increased the gas inlet cross-sectional flow area by over 50%. This area increase was designed to significantly lower flue gas velocities and control erosion. In addition, the TAH tube arrangement and length was optimised such that the new TAH surface area was more than 50% higher than the original primary and secondary TAH.

Post-upgrade operation

Jansen provided support to Minnesota Power for the commissioning of the upgraded equipment on the two boilers which included training and hands-on start-up assistance. Boiler operating data following the commissioning was evaluated to estimate the improvements in boiler operation due to the various upgrades. This evaluation demonstrated the following benefits from the boiler upgrades:

- The biomass fuel heat input was successfully increased to account for 78% of the total fuel heat input. If the recommended fuel distributor upgrades are made, the boilers are expected to be able to achieve operation on 100% biomass
- Even with increased biomass firing, adequate capacity margins on the FD and ID fans were achieved
- The flue gas exit temperature was reduced by -65°C
- Lowering the flue gas exit temperature reduced the flue gas volumetric flow at the ID fan by 21%
- Lower flue gas exit temperatures, and reduction in unburned fuel losses, increased the boiler thermal efficiency by 6 percentage points
- These improvements have resulted in a 10% increase in steam generation for the same fuel heat input.

Conclusions

The replacement of fossil fuel with biomass fuel firing requires a comprehensive evaluation of boiler operating parameters that starts from the fuel delivery into the furnace and continues through to the flue gas exit from the stack.

It is necessary to evaluate the OFA system performance to determine whether the system has adequate flow capacity and jet penetration to generate an intense mixing zone above the grate to burn out the in-flight char and volatiles that result from firing biomass. Experience has shown that an OFA system upgrade is often required to support increased biomass fuel firing.

Typically, increases in biomass fuel firing leads to increased fly ash loadings as compared to stoker coal firing. Therefore, an evaluation of the back end fly ash collection systems is required. Maximising the collection of fly ash at the GB outlet will lower erosion rates and put less ash load on the MDC.

Replacing coal with biomass results in increased flue gas flow rates for the same steaming rate. An increase in the flue gas cross-sectional flow area (similar to the TAH upgrade at Hibbard) may be required to control erosion while increasing biomass fuel firing.

Adequacy of the heat transfer surface areas should also be evaluated to identify opportunities for increased heat recovery (similar to the economiser upgrade at Hibbard).

Evaluations of the combustion air and ID fans, and pollution control devices should be included to ensure that these auxiliaries have sufficient capability to support the higher air and flue gas flow rates associated with increased biomass firing.

Optimising the fuel delivery patterns on the grate is one of the critical factors in ensuring uniform grate combustion conditions. Upgrades to the fuel distributors, changes to the fuel delivery elevation, or possible adjustments to fuel size distribution are some of the upgrades/modifications that can be implemented to improve grate fuel delivery patterns.

At the Hibbard plant, successful boiler upgrade projects to increase biomass firing were accomplished by first implementing a thorough review of the boilers' operation and their auxiliaries. Upgrades and modifications targeted to overcome existing limitations were integrated successfully with the existing equipment. To make this possible, close interaction between Minnesota Power, Jansen and equipment vendors was required during every stage of the project, including design concept development, engineering and supply of deliverables, boiler outage planning, and subsequent start-up support.

Reference:

1. Verloop, Arie, Biomass Combustion Troubleshooting, Bioenergy Insight, June 2012, Issue 3, Volume 3, p. 56-58.

For more information:

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