DESIGN AND OPERATION OF A WOODWASTE COGENERATION PLANT

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ABSTRACT

In response to current market demands, the efficient combustion of woodwaste and other biomass fuels is required. An internally circulating fluid bed boiler has been developed to burn woodwaste and sludge as part of a paper mill's cogeneration facility. This plant produces 103,400 kg/hr of high-pressure steam that is fed to a 14MWe back-pressure turbine generator set. This paper reviews the design features of the plant as well as providing initial operational experience with the equipment. The results of the performance testing of the boiler will also be reviewed.

INTRODUCTION

As a result of development work performed by ABB Power Generation, an "Internally Circulating Fluid Bed" was designed to burn wood-waste of variable moisture content. This is a special design of a bubbling fluid bed that incorporates features that cause the fuel and bed material to recycle within the fluid bed. The existing stoker boilers used to burn woodwaste become limited in performance as the moisture and sludge content of the fuel rises. They may also suffer from poor combustion efficiency and high carryover due to fines in the fuel. The bubbling fluid bed design can overcome these shortcomings. As part of this development, a fluid bed was designed, built and tested which can burn various woodwaste fuels including fines and up to 100% de-inking sludge. This patented technology incorporates several key features to aid in the combustion of these difficult fuels. The result of previous testing has been reported earlier and is contained in the references.

This paper will report on the continuing development and initial operation of the first large-scale bubbling fluid bed boiler based on this patented technology. The boiler is part of a turnkey cogeneration plant located within a paper mill. The fuel is a mixture of woodwaste from a number of different sources with a normal composition of 95% woodwaste and 5% sludge. The source of the woodwaste is:

Log Yard Debris – 2%
Lily Pads and Short Ends – 3%
Bark – 35%
Sawdust – 20%
Chip Screens / Fines – 8%
Planer Mill Shavings and Fines – 32%

Being in a northern climate the fuel moisture level varies from 35% up to 65% depending on the source of the woodwaste. At times the fuel has been frozen and containing snow. The sludge is from the primary clarifiers. The boiler is also designed to fire full load with natural gas as a back up fuel.

PLANT STEAM SYSTEM

The bubbling fluid bed boiler is part of a cogeneration plant that supplies 14 MWe to the mill and process steam to the paper machine. The scope of the turnkey plant included the bubbling fluid bed boiler and the associated equipment, the wood supply system from the yard to the boiler, the ash removal and gas cleanup systems from the boiler. The scope also included the building and the associated services. The steam turbine scope included the turbine, generator and high-pressure piping and all plant interfaces. The boiler is designed to generate 103,400 kg/hr of steam at a pressure of 6.53 MPa(g) and 482ºC.

The plant steam system is shown in **Figure 1**. The boiler is fed by two of three 50% capacity feed pumps. The steam output from the boiler is directed to a backpressure turbine located in an adjacent bay. The turbine is an axial multistage machine with a single casing. The turbine and the generator were shop installed on a common grid. The boiler supplies the process steam to the paper machine at 0.45 MPa(g). The paper machine requires approximately 68,000 kg/hr. The remaining steam is condensed in an air-cooled dump condenser mounted on the roof of the building and sent to the condensate tank. Small amounts of process steam are also extracted off of the turbine at 1.13 MPa(g). The steam plant is subject to numerous paper machine startups and shutdowns, which can reduce the steam demand by 68,000 kg/hr within 10-15 minutes. To accomplish this, the dump condenser is designed to accept the steam when the demand drops suddenly. The dump condenser can be used to maintain the steam load to the turbine to generate the full rating of the turbine. For cases of major upset, during which the pressure cannot be relieved fast enough, a steam shedding valve located at the paper machine is used to vent steam.

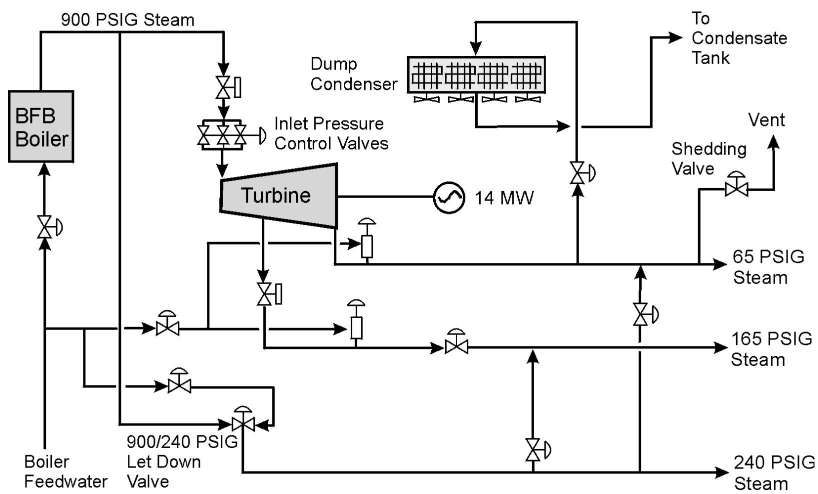

Figure 1. Plant Steam System.

WOOD HANDLING SYSTEM

The wood handling plant was designed to supply woodwaste and sludge to the boiler in a uniform manner. The overall schematic for the wood handling system is shown in **Figure 2**. The wood waste is delivered from the sawmills to the cogeneration plant in self-unloading truck trailers. These trailers unload directly to the woodwaste fuel storage pile. The woodwaste is either reclaimed off the pile using mobile equipment or dumped directly into the main reclamation pit. The day storage pile is built by conveying the woodwaste up into a transfer building containing a disc screen and magnets and then on to the conical day pile. The oversize material is hogged and placed on the day pile. A reclaim screw conveyor located under the base of the day pile reclaims the material and discharges onto a belt conveyor located in a tunnel under the day pile. This belt conveyor carries the fuel up to a second transfer building onto a magnet and disc screen where material larger than 65mm is rejected. The accepted material is carried up into the boiler house by another belt conveyor.

The sludge feed to the boiler is not introduced directly onto the woodwaste fuel pile. To ensure a uniform sludge feed rate to the boiler, it is a design requirement that the sludge be mixed with bark prior to being fed to the system. The mixture is 4:1 woodwaste to sludge. This will ensure that no unwanted slugs of high moisture fuel will be introduced to the system but more importantly, the sludge will not freeze and become unmanageable during the winter months. The sludge is added just after the day pile with a separate two-speed screw discharging onto the belt conveyor.

At the boiler house the belt conveyor discharges onto a drag chain distribution conveyor. There are three fuel surge bins located at the front of the boiler. The bins are filled sequentially by the distribution conveyor. The bins are designed to hold 30 minutes of fuel supply to the boiler. The first two bins are filled completely. The level in the third bin is used to control the variable speed woodwaste reclaim screw. The operators maintain the fuel level in the third bin between high and low level switches by altering the speed as required. From the surge bins, the fuel is fed into the boiler by 3 – 50% capacity fuel trains consisting of the surge bins, a non-consolidating 'moving-hole' feeder, a fuel chute and a fuel feed auger. The use of the fuel feed auger is different than commonly used on either stoker or other fluid bed boilers. This arrangement provides a reliable feed to the boiler.

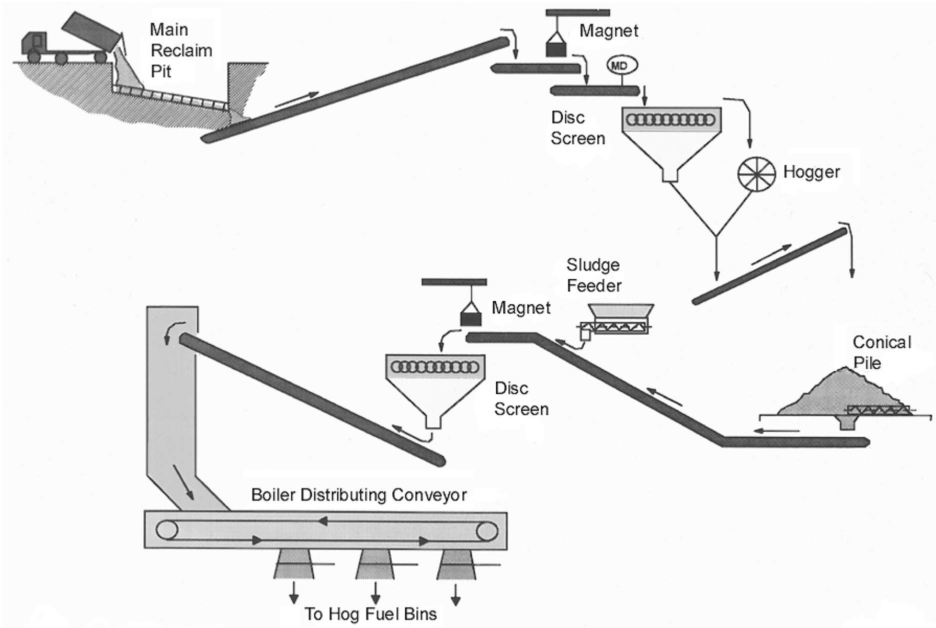

Figure 2. Hog Fuel Handling System.

During the start-up phase, it became apparent that the fuel quality played a significant role in the smooth operation of the boiler. The fluid bed boiler responds very quickly to changes in the fuel fed to the boiler. Although there is a large thermal sink in the boiler with the fluid bed, there is very little inventory of fuel in the bed. When the fuel is introduced into the bed, it is immediately brought up to bed temperature. It is quickly dried and the volatile matter in the wood is driven off and burned. When there is a change to the heat input rate to the furnace, either a change in fuel feed rate or a change in fuel quality, there is an immediate effect on the furnace. This means that the boiler can respond very quickly to changing steam requirements. However, if the fuel supply is not consistent, there can be upsets in the combustion process. This is true for both changes in fuel quantity and fuel quality. When wet fuel (greater 60%) is being burned in the boiler, the fuel should be well mixed. With this type a process, self-sustained combustion can be maintained with very poor fuel without the use of auxiliary fuel.

The feed system to the boiler was subject to a considerable amount of adjustment in the start up period. The main focus was the distribution conveyor along with the fuel feed bins and feeders. As noted above, a constant feed rate of fuel to the boiler is very important. This plant was designed for 50% moisture fuel. However during the course of operation, fuel up to 62% moisture was fed to the boiler. At times the fuel was frozen and layered with snow. This high moisture content induced a much larger weight on the feeders than anticipated during the design phase. The fuel feed bins are quite tall and contributed to this greater load on the feeder. As a result the feeder bearings and related parts had to be strengthened. At no time, however, were problems experienced with fuel hang up in the bins or bridging of the chutes.

COGENERATION PLANT DESIGN PHILOSOPHY

The overall boiler and turbine plant design philosophy was established to provide a cost-effective design and provide for a short construction period. The schedule from order to start-up was 18 months.

The bubbling fluid bed steam generator is a single drum bottom supported boiler. The design permits a compact layout and less structural steel than a typical top-supported boiler. As the building does not support the boiler, it is a lighter structure. The shell of the building can be designed and built independently of the boiler. The boiler house is approximately 26m by 26m by 26m above grade. The combination of the bottom supported boiler and the independent building supported the short overall schedule.

The boiler itself is a natural circulation unit with membrane wall construction. The fluid bed pressure part components are integral with the boiler circulation system. The fluid bed plenum is formed from boiler furnace tubes and provides for support of the furnace floor. This design provides a robust air plenum under the fluid bed that will tolerate variations in pressure and temperatures experienced during operation without adverse effects. This is major advantage over plenums fabricated from plate work as these older designs suffer from leakage due to the high pressure.

The design of the boiler is modularized. This means that the boiler is divided up into large sections that were manufactured in the shop and shipped to the site in order to minimize field assembly. This also resulted in a reduction of the overall schedule including procurement, manufacturing, delivery and construction. Similarly the turbine was supplied pre-assembled on a skid to reduce installation time.

The boiler water wall panels were shipped as 18m modules with the upper and lower headers attached. As well, most of the pressure part attachment plates and bars were also installed in the shop. Examples of these are; refractory retaining studs, scallop bars for seal boxes and buckstays attachments. The underbed air plenum / floor was shipped in three sections. Each segment came complete with the pressure parts, floor support steel and fluidizing nozzles.

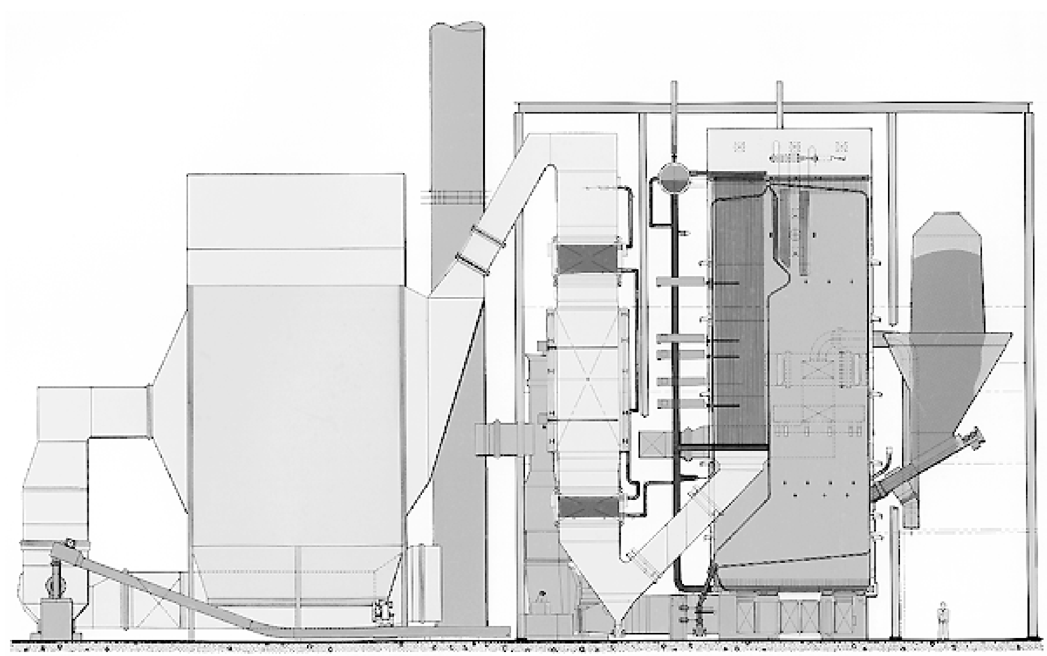

Figure 3. Boiler Side Elevation.

BOILER DESIGN

The general arrangement of the boiler is shown in **Figure 3**. The fluid bed is located on the floor of the furnace. Air to fluidize the bed of sand is introduced below the bed through the plenum and the fluidization nozzles. Air is also introduced above the bed at the overfire air level. This provides the total air to complete the burning of the volatile matter and fines. Located above the overfire air level is the main auxiliary fuel burner elevation. The flue gases then pass over a two-stage superheater. The second, high temperature stage is a pendant superheater located in the upper furnace. The primary superheater is a horizontal, convective superheater stage located in the backpass of the boiler. Below the primary superheater is the evaporator surface. The evaporator surface complements the waterwalls in providing surface for steam generation. It is arranged in a serpentine manner with 15º slope to ensure proper circulation. The flue gases then pass out of the boiler through ductwork to a two-stage economizer with an air heater located between the stages. The flue gases then pass through the precipitator, induced draft fan and then through the stack.

The feedwater is fed to the boiler drum through the economizer sections located behind the boiler. The water flows through downcomers to the furnace lower waterwall headers. These downcomers and headers also serve to provide the support structure for the drum and furnace. Water is also fed in parallel from the economizer to the evaporator section located in the back pass.

The Internally Circulating Fluid Bed (ICFB) process has been used in many applications by different manufacturers It is suited to the combustion of high moisture and ash content biomass fuels. These fuels are rich in volatile matter and gasify readily, however they present significant challenges due to their highly variable form and composition. Although the woodwaste is sized by hogging, it can bridge during handling and is difficult to meter consistently. Fines such as sawdust and planer shavings are typically present. This could lead to physical entrainment within the furnace, resulting in unacceptable carbon losses. Sludge contains fine material, which if introduced to the furnace incorrectly can lead to further carryover and freeboard burning. Finally, wood waste often contains rocks or debris collected in the yard which are not always removed by screening operations and magnets. These materials tend to settle and collect within the fluid bed unless a means of purging the bed is provided.

The fluid bed region does not contain in-bed pressure parts. With the range of fuels specified for this boiler, modifying the amount of air to the bed can control the bed temperature. This is important as eliminates a major source of erosion in fluid bed boilers. It also eliminates the maintenance of pressure part supports and associated equipment. The only pressure parts within the fluid bed area are the waterwalls that are protected by refractory.

The fluid bed design incorporated into the boiler is comprised of three key elements where significant advances have been made to the previous technology. The first element is the fuel feeding system. The second element is within the ICFB implementation and the third element is the bed cleaning system.

The first element in the design is the improved fuel admission to the bed to ensure that the maximum amount of fuel comes into direct contact with the bed. The fuel is not broadcast over the bed as in a stoker unit but is directed into the bed by fuel feed augers. This also serves to reduce the entrainment of fines, thereby reducing carryover.

The next element incorporates improved bed mixing in order to avoid hot spots that promote clinker formation. This advanced bubbling fluidized bed concept specifically addresses this improvement in a "dual" velocity bubbling bed configured to cause an internal recirculation of hot bed material onto the incoming fuel stream. This serves two purposes. First, the incoming fuel is covered with hot bed material that promotes rapid drying and devolitalization within the bed. Second, the bed is well mixed, minimizing temperature stratification. See **Figure 4**.

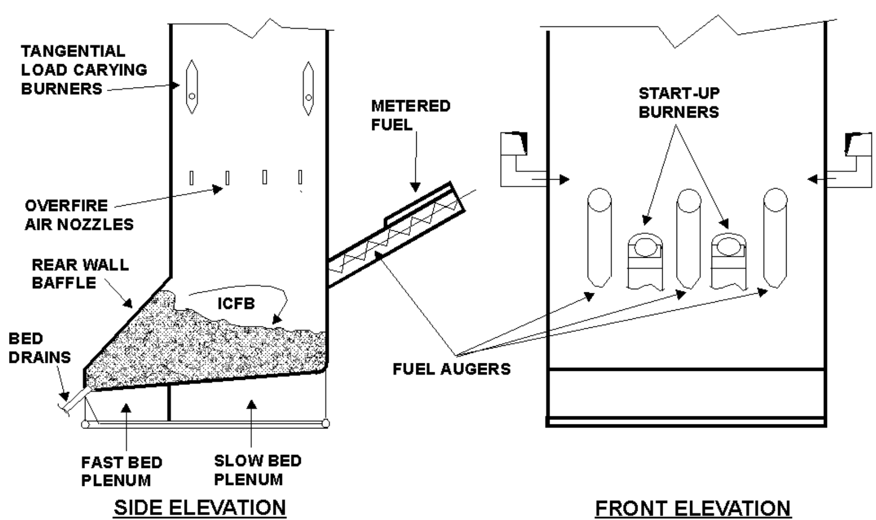

Figure 4. Boiler Combustion System.

Dividing the air plenum into two zones creates the internal circulation. This is accomplished by the installation of a partition plate within the underbed air plenum. The section of the bed nearest the fuel admission zone is termed the slow bed. The other section is the fast bed. Admitting a greater flow of air to the fast bed than the slow bed creates the circulation action. The fast bed will expand to a greater degree, and maintain a higher void fraction. The rear wall arch of the boiler redirects this expanding volume of gas and sand towards the slow bed. The slow bed is designed to operate at a level with a low fluidization velocity. This velocity is enough to maintain optimum fluidization but not induce fuel carryover. The low bed is well mixed vertically. The recirculation action, along with the sloping floor and directional nozzles draw the fuel into the fast bed and create good mixing. Cold flow modeling studies have shown that the lateral mixing is at least 5 times greater than a mono-velocity bed. This was confirmed during startup, as the temperature stratification in different areas of the bed was minimal.

The initial operation has confirmed the full-scale operation of the ICFB features. During this period the fuel varied from relatively dry fresh woodwaste to very wet rock laden reclaim material. During this period of time it was noticed that the boiler was excellent at consuming the bark. The boiler also did very well at burning the very wet woodwaste. If the fuel was consistent, the boiler could burn this fuel without support energy. On occasion, when the fuel varied too much, with high moisture and/or high contaminants, a lower heating value fuel resulted. Under these conditions, the bed temperatures could drop. During these periods of time the overbed burners were used to maintain bed temperature.

The fluid bed air supply system is equipped with an in-duct start-up burner in the underbed air duct. This is used during start-up to heat the air to the bed to decrease start-up times. Although effective during initial start-up, the duct burner is not used to any large extent after this period of time.

The combustion in the bed is controlled by the admission of air. By limiting the air quantities, the bed temperature can be controlled within the desirable range of 760-870ºC. In periods of very dry fuel, the air quantity required is too low for proper fluidization of the bed. To widen the operating range of the boiler, the plant is equipped with a gas recirculation duct to introduce cooled flue gas from after the precipitator into the inlet of the underbed air fan. This serves to provide the correct amount of fluidization to the bed but limit the oxygen available for combustion. As the fuel quality improves (becomes drier), the quantity of air required to maintain the bed temperature in the desired range decreases to a point that there is not sufficient volume for proper fluidization. The gas recirculation is used to supplement this volume under these conditions. Thus the design has extended fuel capability to handle drier fuels, without the use of in-bed pressure parts. The fuel range is about 40 to 62% moisture. This feature was also tested during the early trials. The air and flue gas schematic is shown in **Figure 5**.

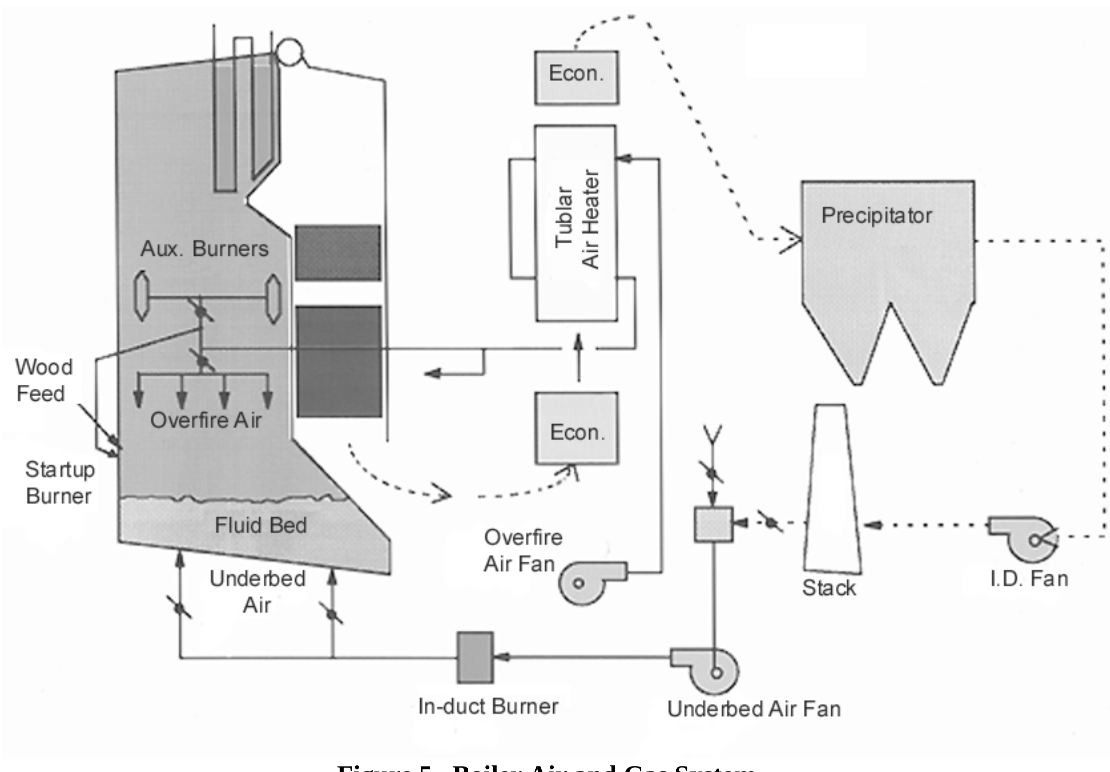

Figure 5. Boiler Air and Gas System.

The last element is improvements to the bed ash removal system. This will be discussed in the next section.

BOILER ASH REMOVAL SYSTEM

The boiler bed drain system is designed to remove tramp material from the bed via a bed cleaning system. The system takes advantage of the internally circulating fluid bed feature that moves the tramp material to the low point in the rear of the furnace. The cleaning system consists of a series of pipes located across the rear of the boiler. Connected to these pipes is a rugged, air-classification device consisting of two slide gates with a fluidized air box between them. The devices are operated as follows: Each of the drains is operated in batch mode. The upper valve is opened and the fluidizing air is admitted to the pipe. The lower slide gate is kept closed. The material from the bed will fill the drain. The fluidizing air has sufficient air velocity to return the sand directly to the bed. After a preset period of time, the upper slide gate is closed and the cooled ash is discharged into a collecting conveyor by opening the lower slide gate. See **Figure 6**.

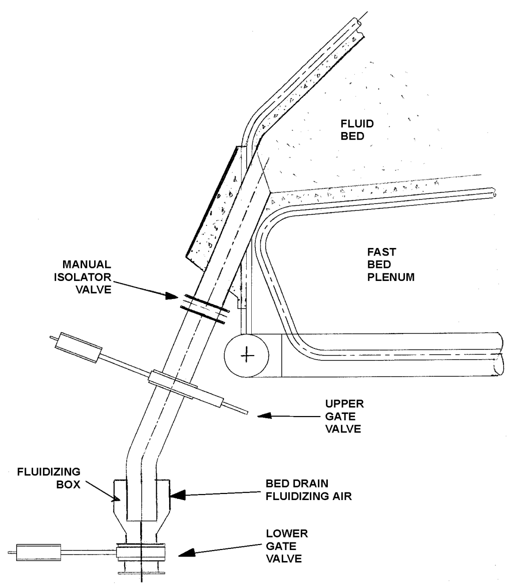

Figure 6. Boiler Bed Drain System.

In conventional systems all of the bed material is removed from multiple points underneath the bed. The complete bed material is removed, which is predominately sand. The material is cooled and then sifted and the sand is returned to the bed. The installed drain system eliminates the use of water-cooled screws and bed sifting equipment that would otherwise be required to recycle the sand back into the bed.

There has been one area where additional work has been required. Due to the unique nature of the fluid bed, the 'ash' being discharged from the bed is different from normal biomass boiler ash. The fuel being fed to the boiler is rock laden. As the rocks hit the fluid bed they shatter into fragments. These rock shards have a tendency to jam the flights. Close attention must be paid to the fit up of the conveyors to prevent the flights from jamming at the conveyor section joints. The cement in these joints was replace by welding and ground smooth.

BOILER PERFORMANCE TEST RESULTS

During the initial start-up phase, a performance test was conducted on the boiler. The purpose was to assess the boiler efficiency and measure particulate emissions. A series of tests was conducted at 70% and 100% of maximum continuous rating on both woodwaste and natural gas fuels. With both fuels, the boiler was capable of meeting the required steam flow (103,400 kg/hr) at full temperature (482ºC) and pressure (6.53MPa(g)). The table below illustrates the predicted versus the measured values for the emission tests. The predicted values are the guaranteed values corrected for the actual test conditions.

The overall boiler performance exceeded the predicted values. As can be seen in the table the emission levels were very low. The low CO readings indicate very good combustion conditions within the furnace.

In order to assess the overall boiler efficiency, the boiler flue gas leaving temperature the stack and carbon loss values were also measured during the test period. The carbon loss was predicted to be the equivalent of 1% heat loss. In actual fact the heat loss is less than 0.1%. This confirms the operation of the internally recirculating fluid bed. With the efficient mixing of the fuel within the bed the carbon is almost completely burned out.

Also due to the conservative design the boiler flue gas leaving temperature was lower than predicted which is equivalent to an efficiency improvement. The overall improvement is about 1.6% in boiler efficiency.

Table 1 – MCR Test Results.

Woodwaste/Sludge Firing	Units	Predicted	Actual Test
NOx (dry, 8% O2)	Mg/Nm3 vol.	253	203.8
CO (dry, 8% O2)	Mg/Nm3 vol.	580	82.4
Particulate (dry, 8%O2)	Mg/Nm3 vol.	84.1	11.9
Opacity	%	21.2	4.3
Unburned Carbon	kg/hr	159	12.5
Stack Temperature	º C	177	154
Efficiency	%	71.7	73.3
Natural Gas Firing			
NOx (dry, 8% O2)	Mg/Nm3 vol.	240	159.6

CONCLUSIONS

The project has provided a full-scale demonstration of a bubbling fuidized bed cogeneration system incorporating several unique features. These features target specific areas of the boiler, the fuel feed system, the fluid bed mixing and the bed cleaning system.

The initial operation has demonstrated these unique features and has shown the boiler to be able to burn the range of biomass fuels presented.

REFERENCES

Douglas, M. A. Morrison, S. A. "The Design of an Advanced BFB Steam Generator for Biomass" Presented at the 14th International ASME Conference on Fluid Bed Combustion, May 11-14th, 1997, Vancouver, Canada

Douglas, M. A., Latva-Somppi, J., Razbin, V. V., Friedrich, F. D., Tran, H. N. " Pilot Scale Fluid Bed Combustion Trials of Paper De-inking Solids (PDS)", Proc. TAPPI Engineering Conference, TAPPI Press, Vol. 1, p 301-307 (1993).

Douglas, M. A., Friedrich, F. D. " De-inking Solids Combustion at the CAN. B. F. B. Facility in Thunder Bay", Presented at the Combustion Canada '96 Conference, Ottawa, Ontario, June 5-7, 1996.

Lim, K. S., Brereton, C., Douglas, M. A. "Scale Modeling of Internally Circulating Fluidized Bed Combustors", Presented at the spring technical meeting of the Combustion Institute (Canadian Section), Victoria, B. C., May 24-26, 1995, pages 49-53.

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