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Operating Experience and Latest Developments of Alstom Power's 300 MWe Class CFB Boilers

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OPERATING EXPERIENCE AND LATEST DEVELOPMENTS OF ALSTOM POWER'S 300 MWe CLASS CFB BOILERS.

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ABSTRACT

Fuel flexibility combined with low emissions, particularly with high sulphur fuels, are the key drivers for installing a Circulating Fluidised Bed (CFB) Boiler. Taking into account the global drive for more efficient and clean combustion, and the development of CFB combustion and emission reduction technologies accordingly, worldwide applications for CFB Boilers are increasing.

Accordingly, Alstom Power continues the evolutionary development of its CFB Boiler portfolio, based on the experience gained with operating units. This paper focuses on Alstom Power's 300 MWe Class CFB Boiler products.

East Kentucky Power Cooperative's (EKPC) Spurlock unit 4 is one of the large Alstom's 300 MWe CFB boilers in operation since 2009. This unit is a duplicate of EKPC's Gilbert #3 CFB boiler unit, which was also supplied by Alstom. The lessons learned from the Gilbert #3 unit were applied to the Spurlock #4 unit, which has resulted in high availability and smooth operation to date. The performance and operation of the Flash Dryer Absorber system and SNCR for NOx removal, which are an integral part of the CFB unit where stringent emission control is a requirement, are also discussed.

Low NO_x emissions were achieved by the low temperature combustion and by the use of the selective non-catalytic reduction (SNCR) system developed and tested by Alstom at the EKPC Spurlock station, leading to 20% reduction of the ammonia consumption. A 98% SO2 removal rate was achieved with limestone injection into the furnace. The proprietary Flash Dryer Absorber (NID™) system developed and tested by Alstom has helped to improve overall O&M by reducing the limestone consumption by around 25%.

Finally, the paper introduces the latest 300 MWe Class CFB Boiler product, built on the well proven features of the operating units, which has been developed to further enhance fuel flexibility and clean combustion on a cost-effective basis.

INTRODUCTION

The latest 268 MWe (net) boiler, named Spurlock #4, is the fourth generating unit at East Kentucky Power Cooperative's (EKPC) Spurlock Station near Maysville, Kentucky (KY), USA. It is located alongside Gilbert #3, as well as two pulverized coal units, 300 MWe and 500 MWe, that were built over 25 years ago. It burns a variety of coals primarily supplied by Kentucky mines and reached commercial operation in 2009.

Low SO_2 emissions is achieved by sulfation of limestone sorbent in the CFB and by additional sulfation of unreacted sorbent in the NID™, a proprietary flash dryer absorber (FDA) system located downstream of the CFB. This permits low SO2 emissions (245 mg/Nm^3, 98% removal). Very low NO_x emissions (85 mg/Nm^3) are enabled by the low combustion temperatures of the CFB and by the use of proprietary selective non-catalytic reduction (SNCR). The latter employs the addition of anhydrous ammonia and extended residence times at low temperature to further reduce NO_x within the boiler.

CFB BOILER DESCRIPTION

The CFB is a natural circulation boiler consisting of a single grate furnace; three recycle cyclones and two Fluidized Bed Heat Exchanges (FBHEs) in the hot loop. Some superheater and evaporator panels are provided in the furnace to attain the total duty required in the hot loop. The finishing superheater and reheater are located in the FBHEs. A portion of the solids from the recycle loop are passed through the FBHEs in a controlled manner in order to maintain the duty and, therefore, the final reheat and superheat steam temperatures. With this approach, the plant heat rate is minimized by not using spray water to control the final reheat temperature and only a minimum amount of spray to control the final steam temperature.

A Just-In-Time (JIT™) limestone system is provided for sorbent injection into the CFB for 90+% reduction of SO_2 within the furnace. The JIT™ system utilizes two 100% capacity Raymond™ Roller Mills operating with a pressurized Primary Air system to directly transport the limestone to the furnace.

A Selective Non Catalytic Reduction (SNCR) system is provided that optimally discharges ammonia reagent into the inlet and outlet of the cyclone in order to control the NO_x emission to the permitted levels.

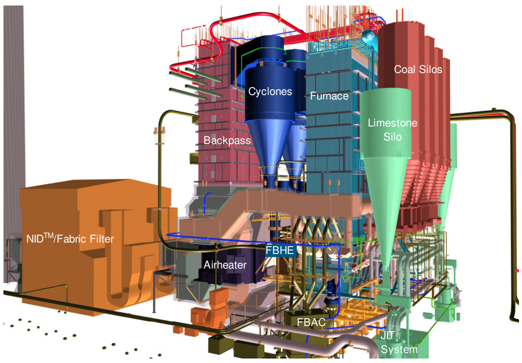

Figure 1: Model of the Gilbert 3 and Spurlock #4 Boiler Island

The flue gas leaving the cyclones is passed through a convection backpass consisting of the primary reheater and superheater and economizer surface. Final heat recovery is done by Alstom's tri-sector Air Preheater. The flue gas leaving the

Air Preheater is directed to a NID™ and baghouse for final SO_2 and particulate control.

The solids inventory is controlled by removing bottom ash via two Fluidized Bed Ash Coolers (FBACs) consisting of water cooled surface.

FUEL FLEXIBILITY

Coal Firing: Being situated on the Ohio River and adjacent to CSX rail lines, EKPC is able to choose fuels from a number of sources. The use of a CFB boiler enhances fuel flexibility by being able to fire a wide range of fuels. Table 1 shows the range of fuels used in the design of the Gilbert #3 and Spurlock #4 units.

The use of a CFB boiler also allows EKPC to burn this wide fuel range while maintaining low emissions rates as called for in the permits. The coals are High Volatile Bituminous coals as per ASTM classification which can produce up to 12000 mg/Nm3 uncontrolled SO_2. The permitted emissions for the Spurlock #4 Unit are well below the New Source Performance Standards (Table 2)

Table 1: Coal Fuels Ultimate Analysis

Fuel analysis (%) on weight basis	Design fuel	Pine Branch	Pittsburgh 8	Range for all Fuel Fired
Carbon	53.48	61.67	70.84	47.79 – 71.48
Hydrogen	4.40	2.40	3.87	2.40 – 4.56
Oxygen	7.21	5.03	3.95	3.79 – 10.11
Nitrogen	0.90	1.33	1.41	0.72 – 1.41
Sulfur	4.50	1.50	4.00	1.21 – 5.56
Ash	20.00	20.00	8.00	6.30 – 30.00
Moisture	9.51	8.07	7.85	7.24 – 17.46
Higher Heating Value Btu/lb (Kcal/kg)	10,400 (5800)	10,215 (5600)	12,502 (7000)	9,154 – 12,710 (5100 – 7000)

Table 2: Comparative Emissions Levels

Spurlock #4 Emissions Lb/mmBtu (mg/Nm^3, 6% o_2 dry gas)	**Spurlock #4 Permitted Emissions**	**New Source Performance Standards**
NO_x	0.07 (85)	0.60 (740)
SO_2	0.2 (245)or 98+% reduction	1.2 (1500)
Particulate PM_{10}	0.015 (20)	0.03 (35)

Biomass and Opportunity Fuel firing: In addition to the coals specified, the unit is also designed to burn biomass and approximately five million tires per year. Having the widest possible fuel choices allows EKPC to continuously supply power to their customers at the lowest possible rates. EKPC CFB units to date have co-fired biomass up to 45 MW_{th} and Tire Derived Fuel (TDF) up to 135 MW_{th} (20% of firing capacity). Table 3 shows the analysis of these alternative fuels.

Table 3: Alternative Fuels Ultimate Analysis

Fuel analysis (%) on weight basis	Switchgrass	TDF	Wood chips
Carbon	46.38	78.35	24.5
Hydrogen	5.56	6.62	3.00
Oxygen	40.20	1.22	22.00
Nitrogen	0.24	0.22	-
Sulfur	0.05	1.15	-
Ash	2.53	11.74	0.5
Moisture	5.04	0.7	50.0
Chlorine	0.049	-	-
Higher Heating Value Btu/lb (Kcal/kg)	7,764 (2300)	14,950 (4350)	4,730 (2600)

Biomass and opportunity fuels are fired into the unit as and when they are available. No impact on operation, performance and emissions were observed at these rates of firing.

These fuels were fired without additional equipment. The raw limestone storage and conveying system to the JIT™ system was used to add the biomass. When feeding the biomass, the conveyor system leaving the limestone storage discharges the biomass onto the conveyor belt carrying prepared coal to the common tripper. The biomass is introduced at a predetermined ratio via the limestone system while the prepared coal is loaded onto the coal bunkers. So, the biomass is blended with the coal and introduced to the CFB furnace via the normal feed system. If the raw limestone make-up is required the control system switch to the usual mode so as to feed separately the raw limestone bins.

EMISSIONS CONTROL

With a CFB boiler, combustion takes usually place in the range 850 – 900°C, which results in a lower NO_x emission compared to the higher combustion temperature associated with PC boilers. SO_2 emission can also be reduced by injecting limestone into the furnace. The limestone is calcined in the boiler to become lime that subsequently reacts with SO_2 released in the combustion process to form gypsum, a very stable inert compound. This is then removed from the CFB unit either with the bottom or the fly ash.

To control emissions further, the Gilbert #3 and Spurlock #4 boilers include additional methods of SNCR technology for NO_x control and the recently developed Alstom NID™ system for advanced SO_2 emissions control.

In the SNCR process ammonia gas is injected into the flue gas stream where it thermally reduces the NO_x in the flue gas to form nitrogen (N_2) and water vapor. The anhydrous ammonia is injected in the CFB's gas ducting via a novel proprietary grid, providing excellent mixing and dispersion of the reagent.

The NID™ system uses the fly ash produced in the boiler that contains unused lime as the reagent. The fly ash collected in the baghouse is hydrated slightly and then re-entrained in the flue gas stream. The hydrated lime then reacts with any SO_2 present in the flue gas. In order to maintain the permitted SO_2 emission, the overall removal rate for the Spurlock #4 CFB with the NID™ system is greater in operation than 95% over the complete range of fuels.

NO_x REDUCTION FROM GILBERT #3 TO SPURLOCK #4

The operation of Gilbert #3 unit has highlighted a difference of bed temperature between the right side and the left side of the furnace. The deviation in the bed temperature led to a hotter area resulting in higher NO_x formation in comparison with the opposite side. On Spurlock #4 unit additional evaporative panel was added to the left side for keeping a bed temperature uniformly low.

After over a year in commercial operation, EKPC has reported that the addition of the evaporative panel has in effect lowered the bed temperatures on the left side of the unit by an average of 10℃ and has met its intended performance of reducing the formation of NO_x.

The second effort was focused on the SNCR's efficiency by improving the quality of ammonia injection into the flue gas.

Alstom's original SNCR employed three to four wall lances in the cyclone outlet and inlet duct (Figure 2). Through testing it was determined that the standard CFB industry approach of injecting ammonia reagent to the gas stream was ineffective because of the following reasons:

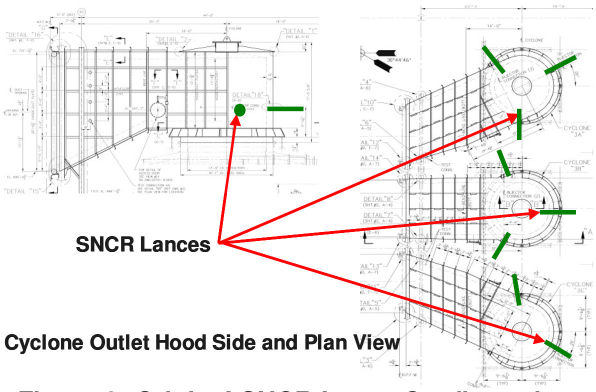

Figure 2: Original SNCR Lance Configuration

1-The gas distribution was uneven over the duct section
2-The NO_x concentration was uneven over the duct section
3-The lances were not as effective in distributing the ammonia as required to address the non-uniformity as indicated in 1 and 2 above.

This leads to the innovation of the new SNCR grid system.

The new grid system has multiple lances that spans across the duct from side-to-side (Figure 3). Each half of these lances receive reagent with a supply line that can be controlled independently. Each lance has evenly distributed nozzles to ensure even distribution of reagent from each section of the lance.

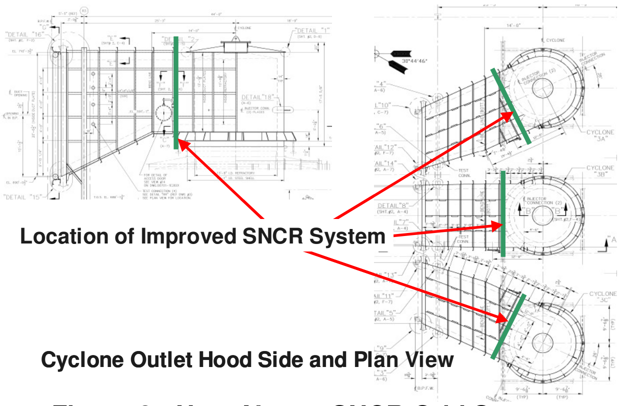

Figure 3: New Alstom SNCR Grid System

This arrangement gives the ability to distribute the reagent between cyclone and with each cyclone duct to match the NO_x concentration in the flue gas streams entering and leaving each of the cyclones thereby optimizing the SNCR system resulting in lower NO_x emission, ammonia consumption and slip.

Both EKPC and Alstom have been actively improving NO_x control with the objective of reducing both ammonia consumptions and NO_x emission. To this end, several optimization tests and modification of the SNCR were done on both Gilbert #3 and Spurlock #4 as follows:

1) 2005 – SNCR optimization with original system on Gilbert #3 unit
2) 2006 – Modification of SNCR system to change original lance system to a ammonia grid distributions system
3) 2007 – Optimization testing on Gilbert # 3 unit
4) 2008 – Addition of evaporative panel on Spurlock unit #4
5) 2009 – SNCR optimization test on Spurlock #4
6) 2009 – Emissions optimization test on Spurlock #4 unit
7) 2010 – Emissions optimization test on Spurlock #4 unit

During the optimization test all emission gas constituents (SO_2, NO_x, CO and O_2) were measured. The measurements were completed either at the outlet duct of the economizer or the outlet duct of the each of the three cyclones. On the cyclone outlet duct the gas was sampled at three points before and after the new SNCR grid system .

The cyclone outlet measurements gave a better indication of the gas composition leaving each of the three furnace sections associated with a given cyclone.

The tests showed that there was an uneven distribution of emission during the various test campaigns. The main changes were as follows:

1) Side-to-side biasing of fuel
2) Side-to-side biasing of Secondary air
3) Deeper staging of combustion air. That is, decrease in primary/secondary air ratio.

These changes, together with the use of the new SNCR distribution grid resulted in the lowering in-furnace and final NO_x, ammonia consumption by greater than 20% while maintaining ammonia slip to less than 2 ppm.

SO_2 REMOVAL RATE

The NID™ system provided on this unit was of the first generation for a large-scale unit. There were several upgrades made to eliminate problems encountered during initial operation.

However, the NID™ system has helped to improve overall O&M cost by reducing the overall limestone consumption by as much as 27%. This reduction in limestone rate has secondary benefits as follows:

- 0.8% increase in boiler efficiency
- 2.6% decrease in CO_2 emission
- 16% decrease in ash flow
- A few percent decrease in ammonia consumption.

PATH FORWARD

Based on overall experience on large scale CFBs, Alstom is developing a common product platform of standardized equipment based on various popular size units such as 100, 150, 300 MWe. The 300 MW-class CFB product has been developed and is currently offered by Alstom.

The 300 MW-class CFB is a natural circulation boiler consisting of a single grate furnace with evaporative, final reheat and superheat panels and three steam cooled recycle cyclones to attain the total duty required in the hot loop. By locating the finishing superheater and reheater in the furnace, a proper blend of radiant and convection heat duty is maintained at all loads. This ensures that a steady and high final steam and reheat steam temperature are maintained through out the control load range.

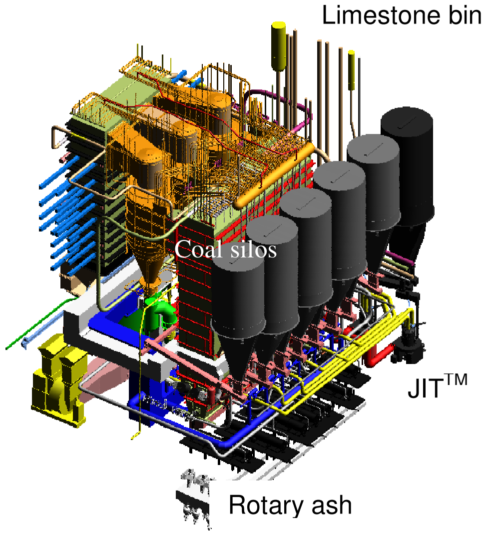

Figure 4: 300 MW-Class CFB Standard Boiler Arrangement

A reheat steam bypass system is provided around the convection surface in the backpass in order to control the final reheat temperature without the use of spray water. With this approach, the plant heat rate is minimized by not using spray water to control the final reheat temperature and only a minimum amount of spray to control the final steam temperature.

Alstom's Just-In-Time (JIT™) limestone system is provided for sorbent injection into the CFB for 90+% reduction of SO_2. The system provides sorbent to the front and back of the furnace.

Alstom's proprietary Selective Non Catalytic Reduction (SNCR) system consisting of injection grids is provided that is capable of discharging aqueous or anhydrous ammonia reagent evenly to the inlet and outlet of the cyclone in order to control the NO_x emission with high reduction levels to the permitted levels while maintaining acceptably low ammonia slip.

The flue gas leaving the cyclones is passed through a conventional convection backpass consisting of the primary reheater and superheater and economizer surface. Final heat recovery is done by a tri-sector Air Preheater. The flue gas leaving the Air Preheater is directed to a NID™ and baghouse for final SO_2 and particulate control.

The solids inventory is controlled by removing bottom ash Rotary Ash Coolers (RACs). This eliminates the issues encountered when firing fuels with large quantities of ash as rocks or agglomerates that may form in the furnace.

CONCLUSION

EKPC Spurlock #4 300MWe Power Plant is one of the cleanest burning coal fired power plants and demonstrated the flexibility of the CFB technology by burning different kinds of biomass as well as tires. The development of the SNCR distribution grid resulted in the reduction of ammonia consumption around 20% while keeping the ammonia slip below 2 ppm. The reactivation of free lime included in the fly ash by using the Flash Dryer Absorber (NID™) enabled the EKPC power plant to reduce the limestone consumption by around 25%.

The experience learned from the Gilbert #3 contract execution, commissioning and operation was applied to the Spurlock #4 unit, which has resulted in 94% availability after the first year of commercial operation.

Finally, an excellent relationship with EPKC enabled Alstom to develop and improve the integrated CFB solution with FDA and SNCR as an available clean coal technology to make coal generation a vital and environmentally responsible means of power generation in the United States.

Going forward, all design enhancements derived from this cooperation have been implemented into the current large-scale designs such as the 300 MW-class CFB standard boiler offered by Alstom.