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Capacity Restoration, Reliability Improvement, NO_x Reduction and SO_2 Reduction of Existing Circulating Fluidized-Bed (CFB) Boiler

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Abstract – There are many circulating fluidized-bed (CFB) steam generators currently in operation around the world for both industrial and utility applications. CFB steam generators feature a popular combustion technology that can utilize a wide range of fuels, produce low levels of nitrogen oxides (NO_x) compared to other combustion technologies, and capture most or all the required sulfur utilizing only limestone or other locally available low-cost sorbent added directly into the furnace. Although the CFB steam generator design and technology enhancements that have evolved over time have primarily focused on improved reliability and lower maintenance costs, there remains a significant number of CFB steam generator installations that still utilize inferior designs and operate with low reliability or significant maintenance costs. Many of the enhanced features being utilized on new CFB steam generators can be retrofitted onto existing CFB steam generators. The Babcock & Wilcox Company (B&W) successfully completed such a retrofit of an existing CFB steam generator at the IRPC Petrochemical Complex located in Rayong, Thailand. This paper will discuss the issues the unit was experiencing prior to the retrofit project and the enhancements that were added to improve the performance and reliability, as well as to reduce the maintenance costs, of the CFB steam generator.

INTRODUCTION

The existing CFB steam generation system at IRPC's Petrochemical Complex located in Rayong, Thailand, was constructed and commissioned by AE&E (now Andritz) in the mid-1990s. It is comprised of a natural circulation water-cooled furnace, primary/secondary/tertiary superheaters, and economizer. A sectional side view of the original unit is shown in Figure 1.

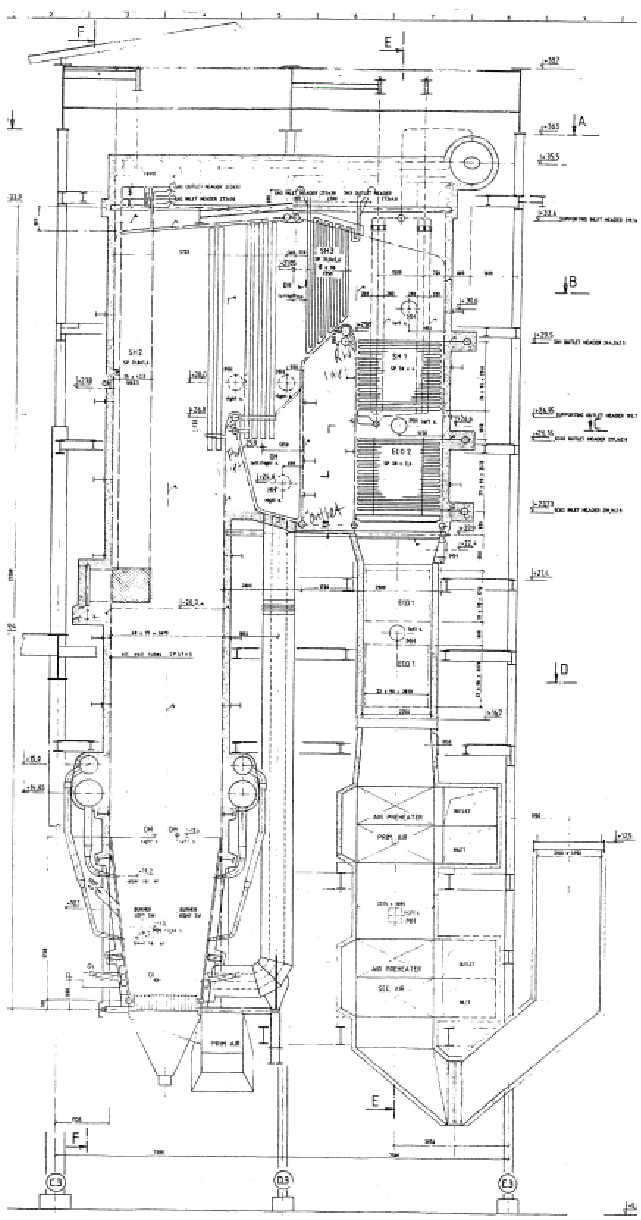

Figure 1. Sectional Side View of Existing IRPC CFB Boiler

The CFB steam generator has a Maximum Continuous Rating (MCR) main steam flow of 130 T/hr at 525 °C and 115 bar, with a normal feed-water temperature to the boiler of 195 °C while firing bituminous coal.

HISTORICAL OPERATIONAL AND MAINTENANCE ISSUES

Immediately after final commissioning and commercial operations were turned over to IRPC, the unit began experiencing operational and maintenance issues. The primary operational issue was the inability to control furnace temperature. The high furnace temperatures resulted in the unit typically being run at no higher than 70% MCR load. Except for one performance test, the unit was never able to reach 100% MCR operating conditions.

Maintenance issues also began to arise soon after commissioning. A high amount of erosion occurred on the furnace walls at the tube-refractory interface zone. Erosion was found in the external recirculation loops (L-valves), and significant back sifting was experienced through the primary air distribution system (bubble cap arrangement and design) in the lower furnace. There were also several other nuisance operation and maintenance items that had to be addressed to improve the reliability of the unit.

Upon review of the unit it was determined that the operational limitations and maintenance issues being experienced could be alleviated by the retrofit of design enhancements currently being used by Babcock & Wilcox (B&W) on its latest internal recirculation (IR)-CFB steam generators. Figure 2 highlights the primary modifications that B&W performed on the IRPC CFB boiler.

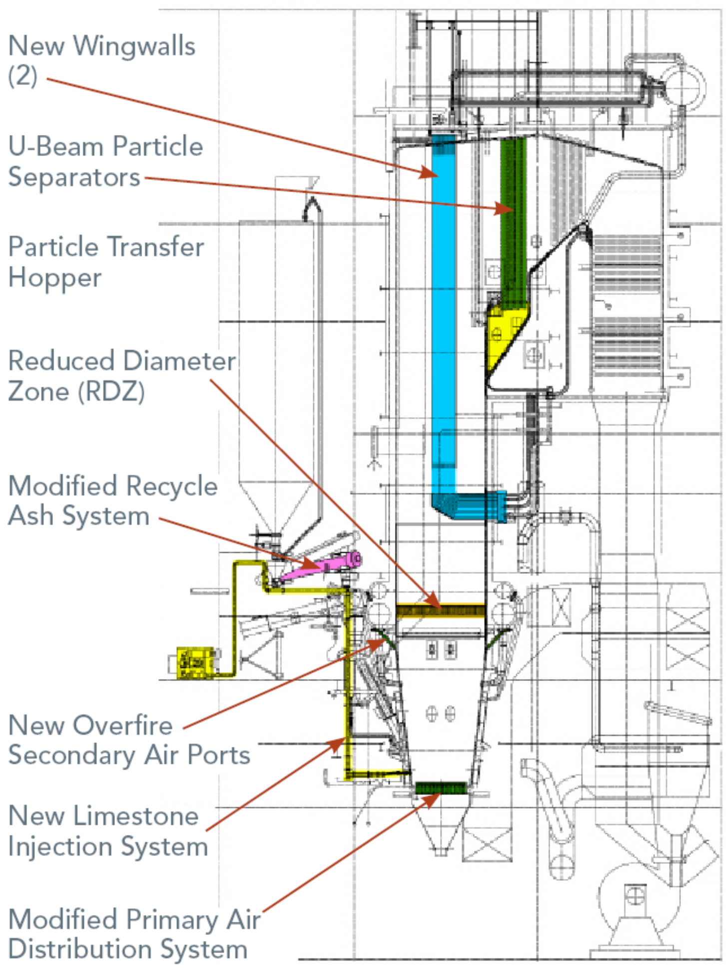

Figure 2. Primary Boiler Modifications

ENGINEERING REVIEW

B&W's detailed engineering review revealed that the 100% MCR operating condition of the CFB boiler could be achieved by considering the following key functional conditions and fundamentals of the CFB design.

- The capability to control the furnace temperature within a proper range. This requires:
  - Recycling sufficient solids to the furnace for both steady loads and transient conditions. The solids are recycled from the following areas in the unit: bottom ash, primary collectors (U-beams), and secondary collector (air heater [AH] hopper and Electrostatic Precipitator (ESP) hoppers).
  - Producing and maintaining sufficient solids inventory in the furnace to allow the necessary heat transfer for temperature control, in conjunction with good distribution of the recycle solids to the furnace.
  - Proper fuel distribution into the primary zone at the bottom of the furnace.
- Proper fuel/air mixing in both the primary and secondary (overfire air [OFA]) zones.
- The capability to adjust primary air/secondary air splits.
- The capability to inject sufficient limestone with good distribution to the furnace.
- Controls capability to maintain the necessary conditions with the ability to respond to changes in fuel, load, demand, ambient conditions and other conditions.

FURNACE TEMPERATURE CONTROL

Furnace Temperature

It is important to control the furnace operating temperature on a CFB steam generator so that emissions are kept at required levels, sulfur is captured effectively, and the entire steam generation process occurs as intended. The furnace operating temperature depends on achieving a balance between the amount of furnace inventory that is developed, the heat transfer that occurs between the solids in the furnace and the furnace heating surface, and the heat that is released during combustion of the fuel. If a proper furnace inventory is not developed or the furnace does not contain enough heat transfer surface, then the furnace will run at elevated temperatures and cause operational and maintenance issues.

Furnace Inventory

Furnace inventory is one of the most important parameters to monitor on a CFB steam generator.

Developing a sufficient furnace inventory:

- helps achieve the expected operating temperature profile throughout the entire unit,
- promotes proper and expected heat transfer to all components located in the furnace, and

- promotes effective and efficient in-furnace sulfur capture.

The furnace inventory in a CFB boiler is typically divided into two parts:

1. Lower Furnace/Dense Bed: the lower portion of the furnace where fresh inert material, coal, recycled material, and sorbent is injected. This zone of the furnace serves these important functions within the CFB boiler, including:
    - drying and fragmentation of fuel,
    - attrition/segregation/elutriation,
    - turbulence and mixing,
    - active char combustion,
    - volatile combustion,
    - calcination of limestone, and
    - sulfation of lime.

2. Upper Furnace/Shaft Inventory: the inventory that is circulating in the furnace between the top of the dense bed and the furnace exit. This area of the furnace also serves these important functions within the CFB boiler:
    - char combustion,
    - intensive overfire air mixing,
    - Carbon monoxide (CO) and volatile combustion,
    - sulfation of lime, and
    - solids recirculation.

The furnace inventory on a CFB steam generator is comprised of ash, sorbent, and supplementary inert material. Fuels that have a low ash and sulfur content are typically not able to introduce enough solids into the CFB steam generation system to produce an adequate furnace inventory for temperature control. When this condition exists, supplementary inert material is fed into the furnace along with the fuel and sorbent to create the required furnace inventory. Fuels that have a high ash and sulfur content typically introduce enough solids into the CFB steam generation system so supplementary inert material is not required.

Furnace Inventory Control

The furnace inventory on the IRPC CFB steam generator is controlled using a two-stage particle capture and recycle system. The first and primary stage of particle capture and recycle is accomplished by U-beams located both in the furnace and after the furnace exit. The second stage of particle capture and recycle is by a combination of an air heater outlet hopper and the first field of an electrostatic precipitator (ESP).

Primary Solids Recycle: U-Beam Impact Separators

U-beam impact separators are channel-shaped metallic beams that are designed to capture and recycle as much as 97% of the solids recirculated throughout the CFB steam generation system. They are made of materials that can withstand the normal operating temperatures of a CFB furnace and have low erosion rates. The advantage of using this system of solids capture as the primary stage is that it eliminates the need to use refractory-lined cyclones for solids separation. Eliminating the cyclones on a CFB steam generator also eliminates the cyclone inlet duct, cyclone outlet duct, the loop seal and the high temperature expansion joints located around the cyclone as well as all associated cyclone maintenance.

The U-beams on the IRPC unit are a single-piece design, uncooled, and hung from the roof of the unit. The configuration consists of two rows of internal U-beams located in the furnace and four rows of external U-beams located downstream of the furnace exit. The U-beams are oriented on a vertical axis such that the furnace exit flue gas stream flows in a horizontal pattern perpendicular to each U-beam. As the flue gas and solids mixture enters the U-beams, the flue gas can reverse and continue around the U-beams, but the solids entrained in the flue gas cannot. The solids enter the U-beams and flow downward to be recycled back to the unit. Figure 3 illustrates how the flue gas and solids mixture flows through the U-beams.

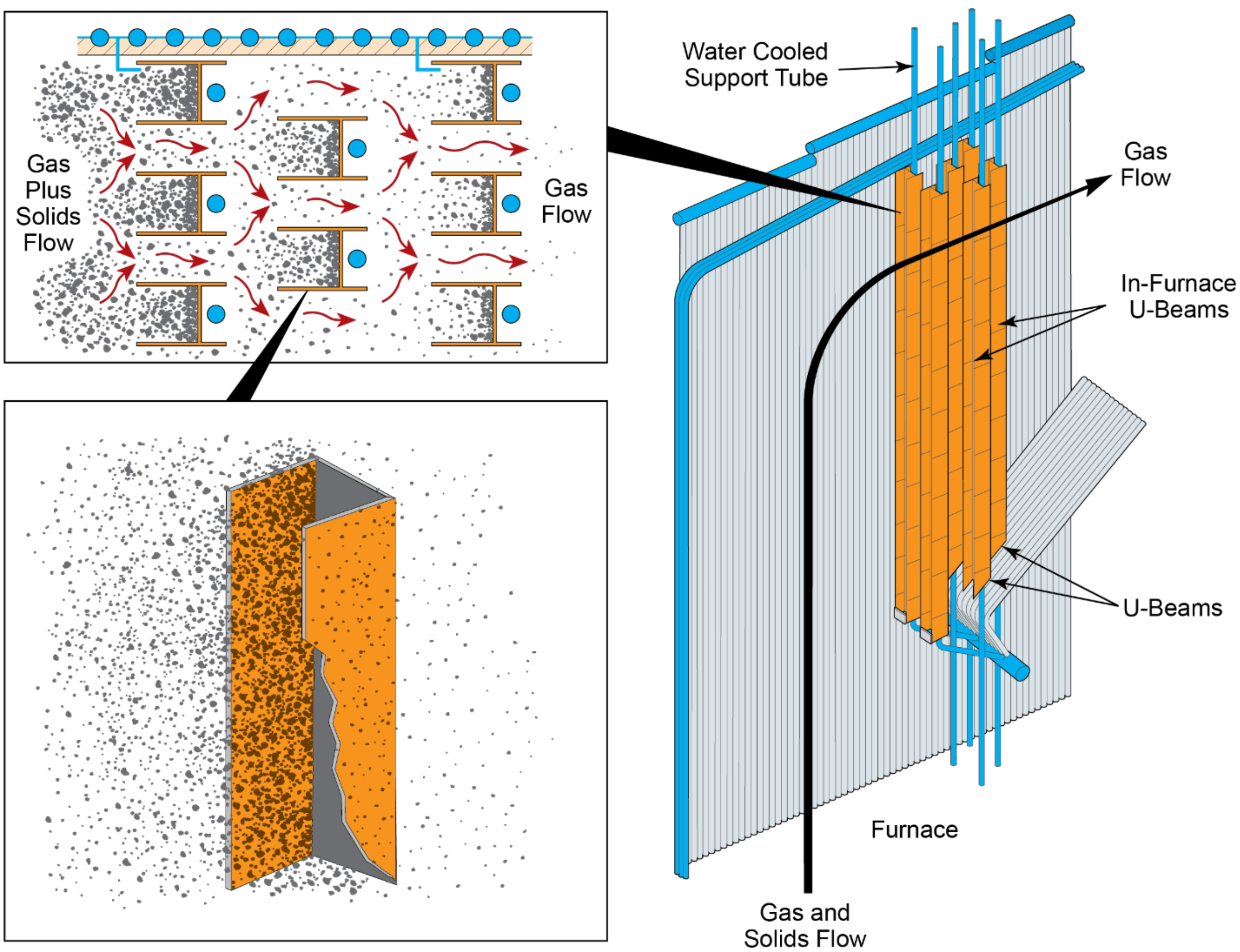

Figure 3. Views Showing Flue Gas and Solids Flow Through U-Beams

Prior to the retrofit, the solids exited the bottom of the original external U-beams and entered a particle storage hopper. The particles in the storage hopper were then recycled back to the furnace using external loops (L-valves). The vertical leg of the L-valve also provided a flue gas seal between the high pressure of the lower furnace and the low pressure within the U-beam cavity. Figure 4 shows the arrangement of the external U-beams and the particle storage hopper prior to the retrofit.

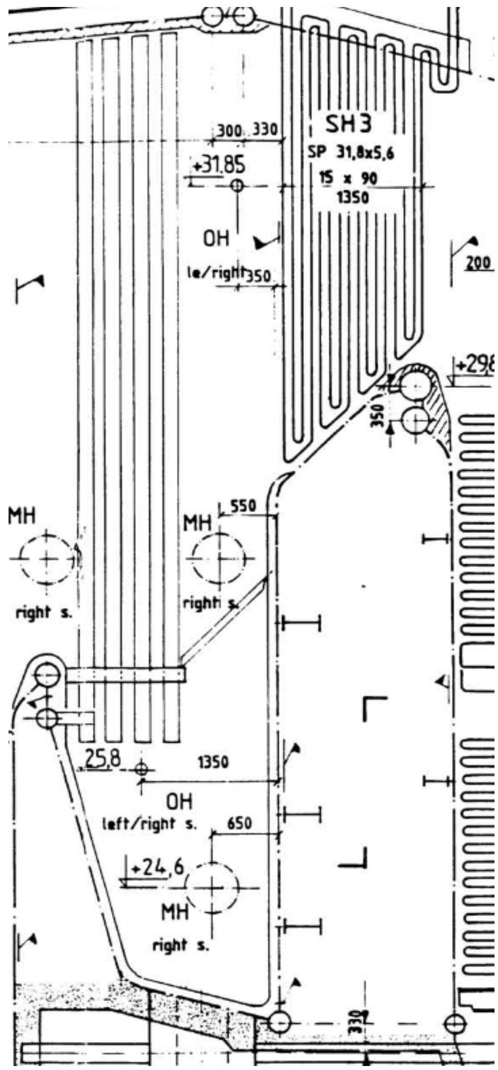

Figure 4. External U-Beams and Particle Storage Hopper Before Retrofit

The L-valves were very inconsistent in their ability to return the captured solids back to the furnace. This resulted in a lower than expected furnace inventory and an unacceptably high furnace operating temperature. High furnace operating temperatures can significantly impact the amount of sulfur capture that can be achieved in the furnace. As the temperature increases the amount of sorbent that must be injected also increases. For example, a 56 °C rise in furnace operating temperature could lead to a 20% increase in the amount of sorbent that must be injected into the furnace to achieve the same level of sulfur capture prior to the temperature rise. The increase in free lime to account for this temperature rise, in addition to the temperature rise itself, can also increase the NO_X emissions from the unit.

Primary Solids Recycle: Modifications

As part of the retrofit, the L-valves were completely removed, and the particle storage hopper was 5eplaced with a particle transfer hopper below the external U-beams. Figure 5 shows the arrangement of the U-beam area and particle transfer hopper after the retrofit.

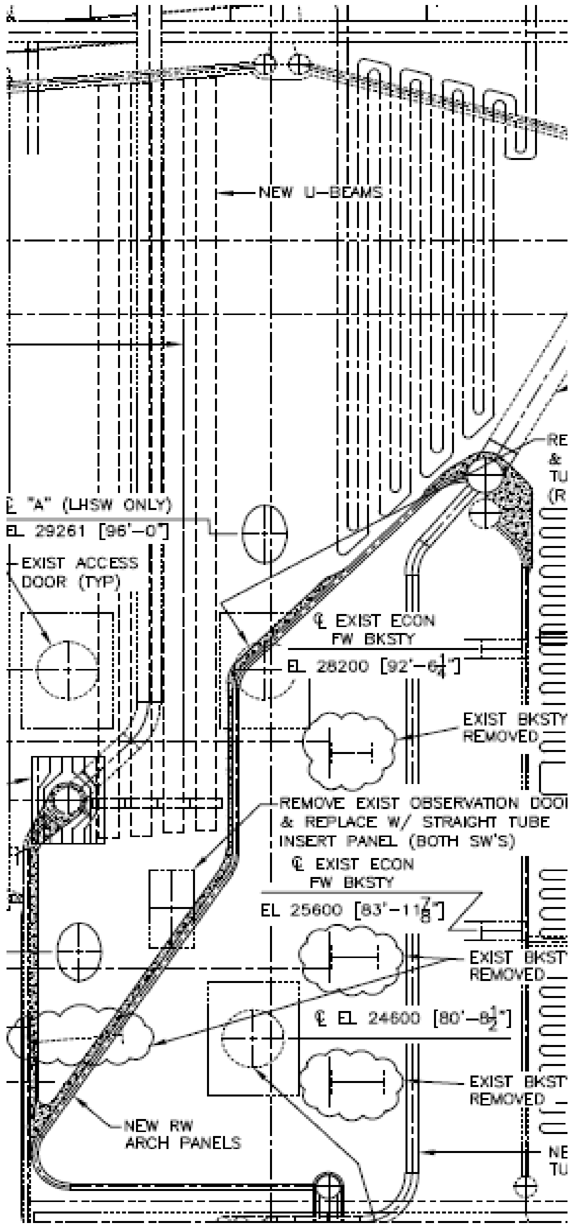

Figure 5. External U-Beams and Particle Transfer Hopper After Retrofit

The particle transfer hopper recycles 100% of the solids captured by the U-beams back to the furnace through ports located on the upper furnace rear wall. The particle transfer hopper is a self-controlling design, thus does not have either a significant storage volume or a control mechanism to increase or decrease the flow of solids back into the furnace. B&W has found that returning all the solids collected by the external U-beams to the top of the furnace is the preferred design since it effectively recycles all the captured material back to the furnace without the significant maintenance and control issues associated with an external recirculation loop.

Secondary Solids Recycle: Air Heater Hopper and ESP Hoppers

The original secondary solids recycle system collected material from the air heater (AH) hopper, the first field ESP hoppers, and selective material collected from the second and third ESP field hopper. The recycle material was transported via a pneumatic pressure system to a recycle ash silo. Screened bed-drain solids from the bed drain system were also originally transported to the recycle ash silo. A single variable speed screw conveyor moved the recycle material from the recycle ash silo towards the front of the CFB furnace, with the top of discharge section of the recycle ash screw conveyor also receiving fresh inert material discharged from a separate fixed-speed sand screw conveyor. A single rotary seal was used to feed the combined recycle ash and inert bed stream. A three-way splitter, positioned below the rotary seal, directed the combined recycle ash and inert material streams into three flow paths for distribution into the furnace.

The original pneumatic system had critical points for operation and was upgraded to a vacuum system prior to the retrofit. Although the revised arrangement separated the AH hopper, it still relied on the original variable speed screw conveyor at the base of the AH hopper. A second vacuum transport system was utilized to transport material from the ESP hoppers to the recycle ash silo.

Secondary Solids Recycle: Modifications

The retrofit modifications to the secondary solids capture and recycle system consisted of converting the recycle ash vacuum transport system into a vacuum/pressure system and included the replacement of the original AH hopper discharge screw conveyor with mini-hoppers. The solids that are collected in the AH hoppers and the ESP hoppers are pulled using the vacuum side of the system to filter collectors. The pneumatic transport part of the system then transports the solids from air locks, located at the base of the filter collectors, to either a waste silo or the recycle ash silo. The material in the waste silo is disposed of and the material in the recycle ash silo is transported back to the furnace as needed (for furnace temperature control).

In addition, B&W determined that the original three-way splitter recycle ash feed system was ineffective at distributing material. Also, the three injection points were interfering with the new coal chute and limestone feed equipment/modifications being retrofitted to the unit. As a result, the number of recycle ash feed chutes was reduced to one and a new variable speed rotary valve and constant-speed screw conveyor system was added between the bottom of the silo and new chute. The rotary valve serves as a pressure seal and metering device and the recycle ash screw serves as a transport device. The material leaving the recycle ash screw drops into the furnace through the chute using gravity. The single injection point of recycled solids was found to be effective at controlling furnace operating temperature across the load range and only induced a 19 °C imbalance in dense bed operating temperature at the injection location which did not cause in any negative impacts to unit performance. Figure 6 shows the complete schematic of the retrofit secondary solids recycle system.

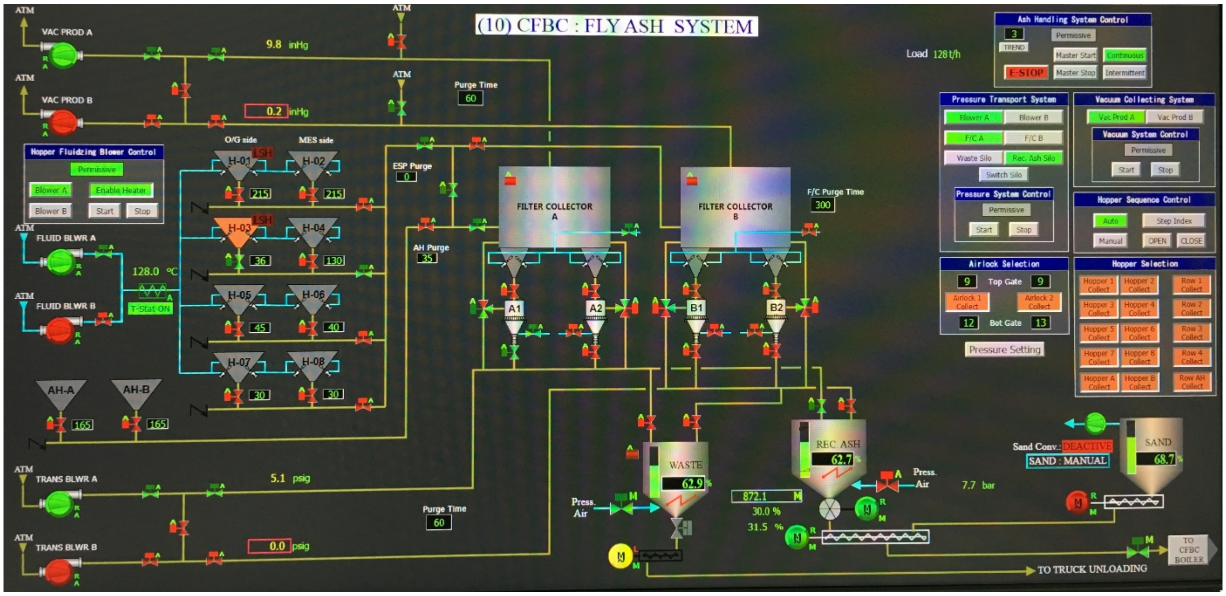

Figure 6. Secondary Solids Capture and Recycle System Schematic

The advantage to using a two-stage solids capture and recycle system is that the flow rate of secondary solids recycling can be adjusted to control the furnace operating temperature and furnace inventory. This feature allows load changes or operational upsets to be handled without large upsets to the steam generation process. During load increases the secondary recycle rate can be increased prior to fuel flow being increased to allow the bed temperature to remain nearly constant through the ramp. Reducing the amount of secondary recycle rate during load reductions also has the same effect.

Fuel Feed Distribution

Uniform fuel distribution into the primary area of the lower furnace from the four feed chutes promotes good combustion. The original arrangement at the lower end of each fuel chute did not allow for good distribution into the primary zone and may have promoted material buildup at the chute discharge. This was due to insufficient motive air to help push the fuel out and away from the fuel feed chutes along with the ineffectiveness of the annular motive air/fuel feed chute arrangement. In addition, the use of heated primary air (PA) for the motive air may have contributed to the partial, local combustion of the fuel as it immediately exited the chutes, instead of combustion taking place well into the primary zone, which contributed to sintering and buildup at the fuel chute exit.

Fuel Feed Distribution: Modifications

The retrofit included the replacement of the original coal chutes with refractory-lined feed chutes, fitted with motive air lines that penetrate to the face of the refractory lining and introduce motive air directly into the flowing fuel through the center of the wall opening into the furnace. Motive air introduced in this manner will directly push the flowing fuel beyond the wall opening. In addition, the motive air source was changed from heated PA to cool PA from the PA fan discharge. The cooler motive air will reduce the potential for localized combustion occurring near the fuel chute and provide better fuel distribution capability into the furnace primary zone. The motive air supply pipes are equipped with orifice plates and butterfly valves to control the amount of air flow to each coal chute. Figure 7 shows the arrangement of the coal chutes and motive air piping after the retrofit.

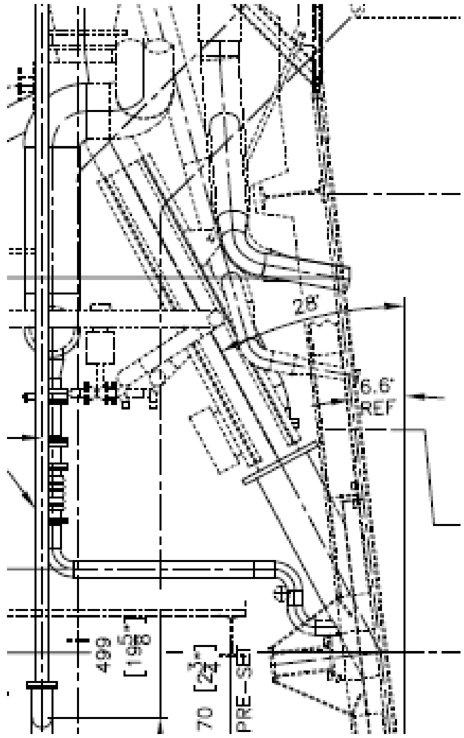

Figure 7. Coal Chutes and Motive Air Piping After Retrofit

FURNACE HEAT ABSORPTION AND EROSION PROTECTION

Furnace Design

The heat transfer surface in a CFB steam generation system is arranged to produce a desired amount of steam at a predetermined temperature and pressure and control the flue gas temperature profile throughout the unit. The amount of heat transfer surface placed in the furnace is important to achieving the desired furnace operating temperature to maximize sulfur capture and reduce NO_X emissions.

The IRPC unit was originally arranged with a completely water-cooled furnace, eight water-cooled wing walls located on the front wall, and no division walls. The lower furnace walls were covered with refractory held in place by pin studs attached to the furnace wall tubes. The original furnace arrangement was found to have the following serious deficiencies leading to operational and maintenance issues:

1. The transition between the refractory-coated portion of the wall and the bare portion of the wall experienced significant levels of erosion in this area and caused excessive maintenance and reliability issues.

2. The originally installed heat transfer surface in the furnace was insufficient when combined with the lower-than-expected furnace inventory. This caused the furnace to operate at temperatures above 925 °C resulting in undesired levels of SO2 emissions.

3. The lower furnace plan area was also found to be insufficient. The unit was designed to have a flue gas velocity of 6.1 m/sec. Velocities at this level within a CFB furnace can contribute to

undesirable levels of erosion on furnace surfaces. The high flue gas velocities resulted in IRPC unit operators limiting the use of fresh inert material to make up the deficiency in furnace inventory because it further increased the erosion rates on all the furnace surfaces. Limiting fresh inert material feed into the furnace resulted in the unit running at a de-rated load.

Furnace Modifications

The retrofit project included two large modifications to the furnace to improve the performance of and reduce the maintenance on the unit while designing within the limitation of the fixed furnace size.

The first modification was the addition of two water-cooled wing walls on the rear wall of the furnace. While the solids inventory control was expected to improve due to the removal of the external loops, it was still expected that the furnace inventory would be insufficient due to the low-ash and low-sulfur design fuel. The additional water-cooled wing walls were intended to lower the furnace operating temperature without relying on the addition of fresh inert material to raise furnace inventory. Removing or reducing the reliance on adding inert material helped reduce the risk of excessive furnace erosion at high-load operation due to the high flue gas velocities.

The second modification was the addition of a reduced diameter zone (RDZ) at the interface between the refractory coated and bare tube surfaces in the lower furnace. The B&W patented RDZ is formed by swaging the furnace tubes to a smaller diameter and then back up to the original diameter over a specified length at the transition. A specially designed tile is then added to the lower swage. The design allows the eddies formed by solids flowing down the walls to hit the erosion-resistant tiles instead of bare tube surface that is susceptible to wear. Figure 8 illustrates the reduced diameter zone installed in the IRPC unit.

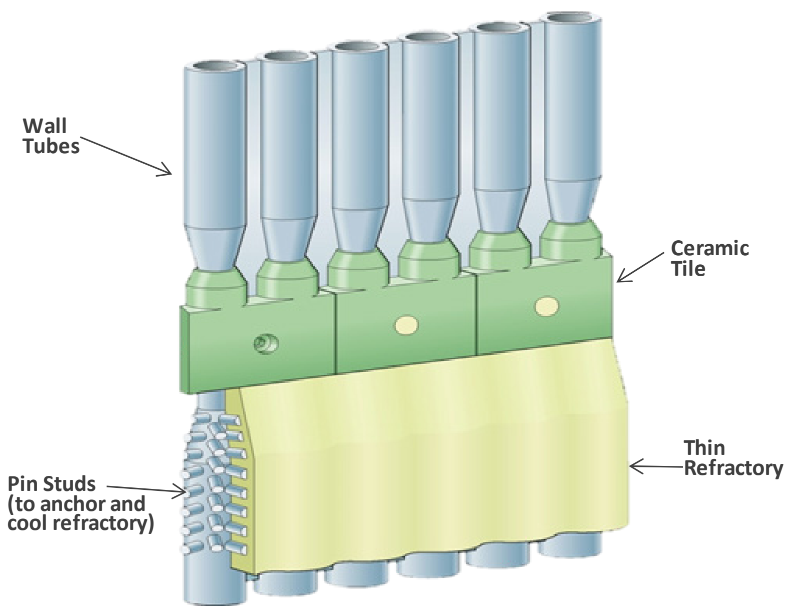

Figure 8. Reduced Diameter Zone at the Refractory Transition in Lower Furnace

The RDZ is a very effective method of significantly reducing the erosion at the refractory-to-bare-tube transition and is easily maintained. Installation of the tiles is accomplished using threaded studs and a small amount of mortar to hold the tiles in place during operation. Figure 9 shows the installation of RDZ tiles on a new CFB steam generator and Figure 10 is an example of an RDZ after several years of operation.

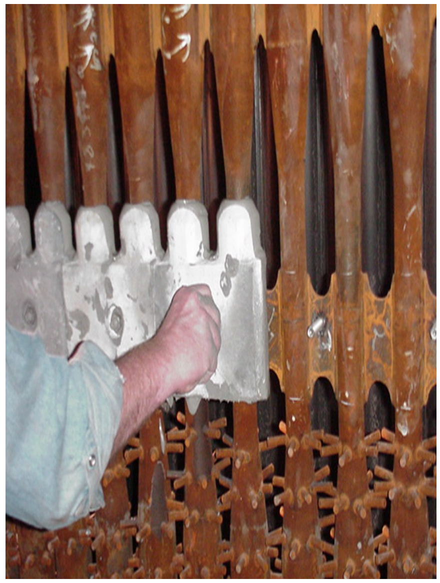

Figure 9. Initial Installation of RDZ on New CFB Steam Generator

Figure 10. Lower Furnace Refractory and RDZ Zone After Several Years of Operation (note that the shine on the tubes was for UT measurement during the outage; it was not from erosion)

Circulation Analysis

B&W has developed an extensive set of design requirements for natural circulation steam generators to meet the demanding conditions required for today's typical steam generator operation. Analyzing for flow excursions (Figure 11) during load changes and transient operation is used to optimize the supply and riser connections to the steam generating surface. An optimized circulation system design provides a reliable steam generation system, which eliminates most of the operational issues that result from an improperly designed unit.

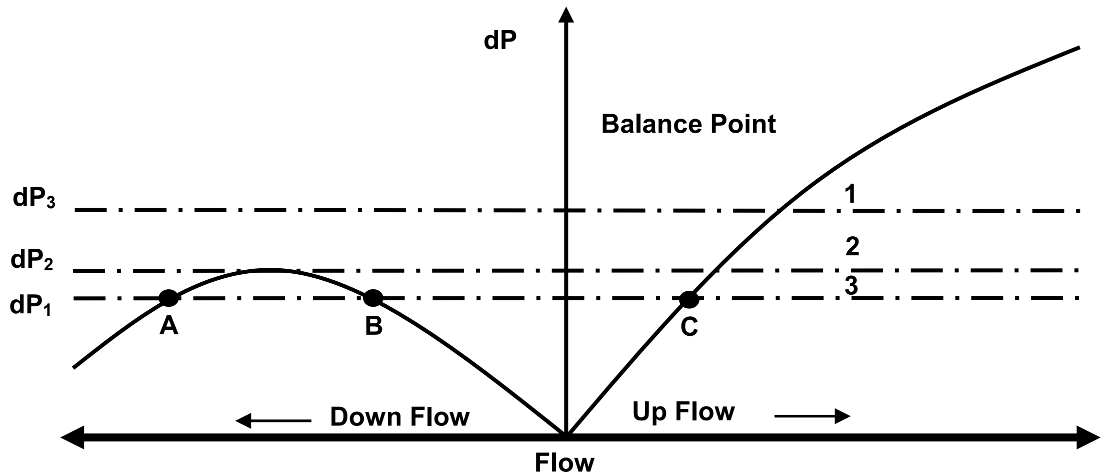

Figure 11. Pressure Drop Characteristics of a Boiler Tube

Design considerations also include the exit quality from each outlet header, velocity within the tubes and circulation connections, sensitivity of the evaporator tubes to heat variation and load change, static and dynamic flow stability of the evaporator system, departure from nucleate boiling (DNB) and drum steam separation performance. See Figure 12 for DNB considerations.

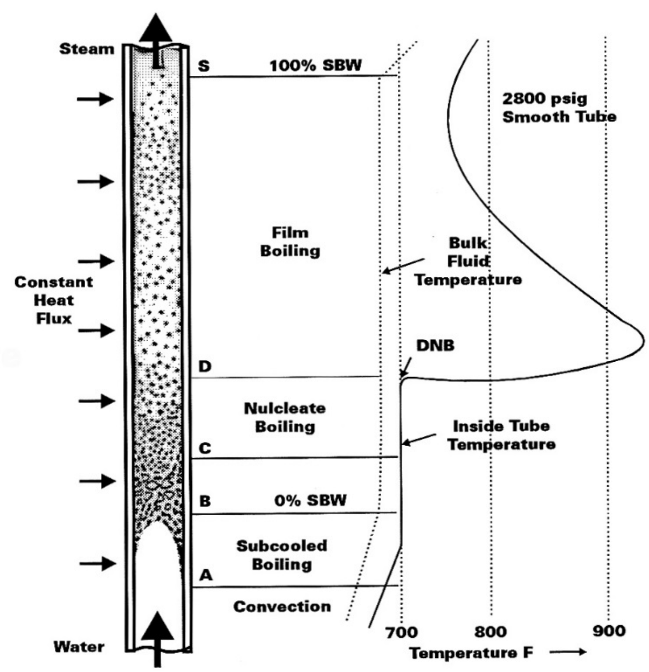

Figure 12. Characteristics of Departure from Nucleate Boiling

Following sound engineering practice, in consideration of the modifications to the furnace during the retrofit, a detailed circulation analysis was performed on the unit to ensure the existing furnace water walls, existing wing walls, and new wing walls would perform within B&W circulation design standards. The circulation analysis was also used to determine the appropriate number of risers and supplies that needed to be added as part of the retrofit.

PRIMARY AND SECONDARY AIR DISTRIBUTION

Air Distribution Grid

The air distribution grid on a CFB steam generator is designed to provide uniform distribution of primary combustion air across the entire bottom of the CFB furnace while simultaneously preventing the back-sifting of bed material into the wind box or air distribution headers. If air is not uniformly distributed across the bottom of the furnace, operational problems such as undesirable emissions or poor fluidization of the bed may occur. If back-sifting occurs it can plug the wind box or air distribution headers or lead to severe erosion of the air distribution nozzles, both of which lead to increased maintenance costs and additional downtime during outages.

The original air distribution grid on the IRPC unit was constructed using a main supply header feeding multiple small air supply headers across the width of the unit. The main supply header had multiple perforated plates intended to promote better air distribution across the width of the unit. Each small air supply header had multiple assemblies consisting of a long stem with a bubble cap attached at the end. The placement of the assemblies and headers resulted in an air distribution grid with 150 mm transverse spacing and 120 mm longitudinal spacing. The bubble cap design consisted of a single level of multiple large orifices placed around the circumference of the bubble cap. Prior to the retrofit the bubble cap orifices experienced considerable erosion and the air distribution grid design was incapable of providing good air distribution while preventing back-sifting of bed material.

To improve operation and maintenance costs of the unit the entire air distribution grid was redesigned as part of the retrofit. A computation fluid dynamic (CFD) analysis was completed as a part of the redesign to evaluate the distribution of air through the primary air headers. To minimize construction and project cost all the existing air supply headers and most of the stems were repaired and reused. The redesigned bubble caps utilized two levels of smaller holes placed around the circumference of the bubble cap. Additional bubble caps were also added to the grid by using new bifurcate assemblies attached to the existing stems to promote better air distribution across the entire lower furnace. After the retrofit the revised air distribution grid had almost twice the amount of bubble caps compared to the original design. Figure 13 shows a comparison between the original bubble cap design and the revised design.

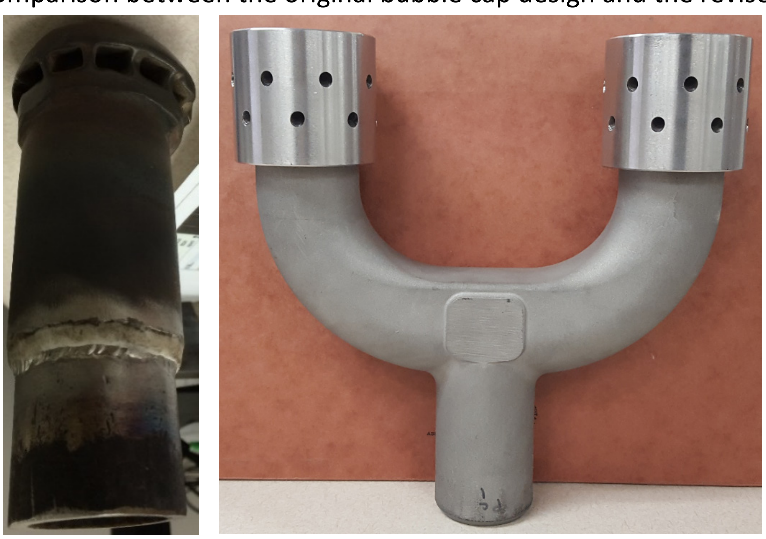

Figure 13. Original Bubble Cap Design (Left) and New Bubble Cap and Bifurcate Design (Right)

Staged Combustion

A CFB furnace also employs staged combustion conditions designed for between 40 to 60% of the total combustion air passing through the air distribution grid in the lower furnace as primary air. Most of the remaining combustion air enters the furnace through nozzles located in the lower furnace near the refractory transition elevation as secondary air. The exact primary-to-secondary air ratio is dependent on the characteristics of the fuel that is used.

The original secondary air system on the IRPC unit included one level of large air nozzles and one level of small air nozzles located on the front and rear furnace walls. All nozzles were arranged to inject straight into the furnace. The jet penetration and air distribution of the original system was evaluated and found to be inadequate to properly distribute air into the furnace above the bed. The nozzles closest to the furnace side walls were also identified as an erosion concern because they were injecting straight along the walls instead of being angled into the furnace.

During the retrofit the secondary air system nozzles were modified to increase the capability and coverage of the system. Also, the nozzles closest to the side walls were angled away from the furnace side walls for improved coverage and to reduce erosion potential of the furnace walls during high-load operation.

EMISSIONS CONTROL

Emissions Control System Overview

The emissions control system on a CFB steam generator is customized on each project to reach acceptable emissions levels. Typical CFB steam generators utilize low-cost sorbents injected into the furnace for sulfur oxides (SO_X) control, combustion air control for NO_X and carbon monoxide (CO) control, and a particulate matter (PM) collection device (fabric filter or ESP). Secondary capture systems are added if project-specific SO_X or NO_X emissions limits exceed what can be achieved with in-furnace capture or unit tuning. Additional sulfur capture can be achieved using dry sorbent injection (DSI) or a flue gas desulfurization (FGD) system. Additional NO_X reduction can be achieved with selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) systems.

The IRPC unit was originally designed with a mechanical system for limestone addition into the furnace for SO_X control, staged combustion for NO_X and CO control, and an ESP for PM control. The emissions control system of the unit was reviewed prior to the retrofit and found to be insufficient to meet the desired emissions limits of IRPC for the project.

Furnace Sorbent (Limestone) Injection

The limestone feed was originally fed through the coal feed equipment until modifications to the coal feed system resulted in the limestone feed being modified and combined with the recycle ash feed. The three-way splitter and chute system fed limestone to the furnace via gravity.

B&W determined that the mechanical/gravity-fed limestone feed system could not adequately distribute limestone throughout the furnace resulting in higher than desired SO_X emissions. Therefore, a new pneumatic limestone injection system was added and the existing mechanical feed system was removed. The pneumatic injection system was arranged to introduce limestone into the furnace through four individual injection lances located on the front wall of the furnace at an approximate elevation of 400 mm above the elevation of the bubble caps. Two separate limestone metering systems that use rotary feeders and blowers transport the crushed limestone to the furnace. The pneumatic injection system with properly spaced injection locations resulted in significantly improved sorbent distribution within the furnace, leading to lower SO_X emissions and lower sorbent usage. Figure 14 shows a schematic of the pneumatic limestone feed system.

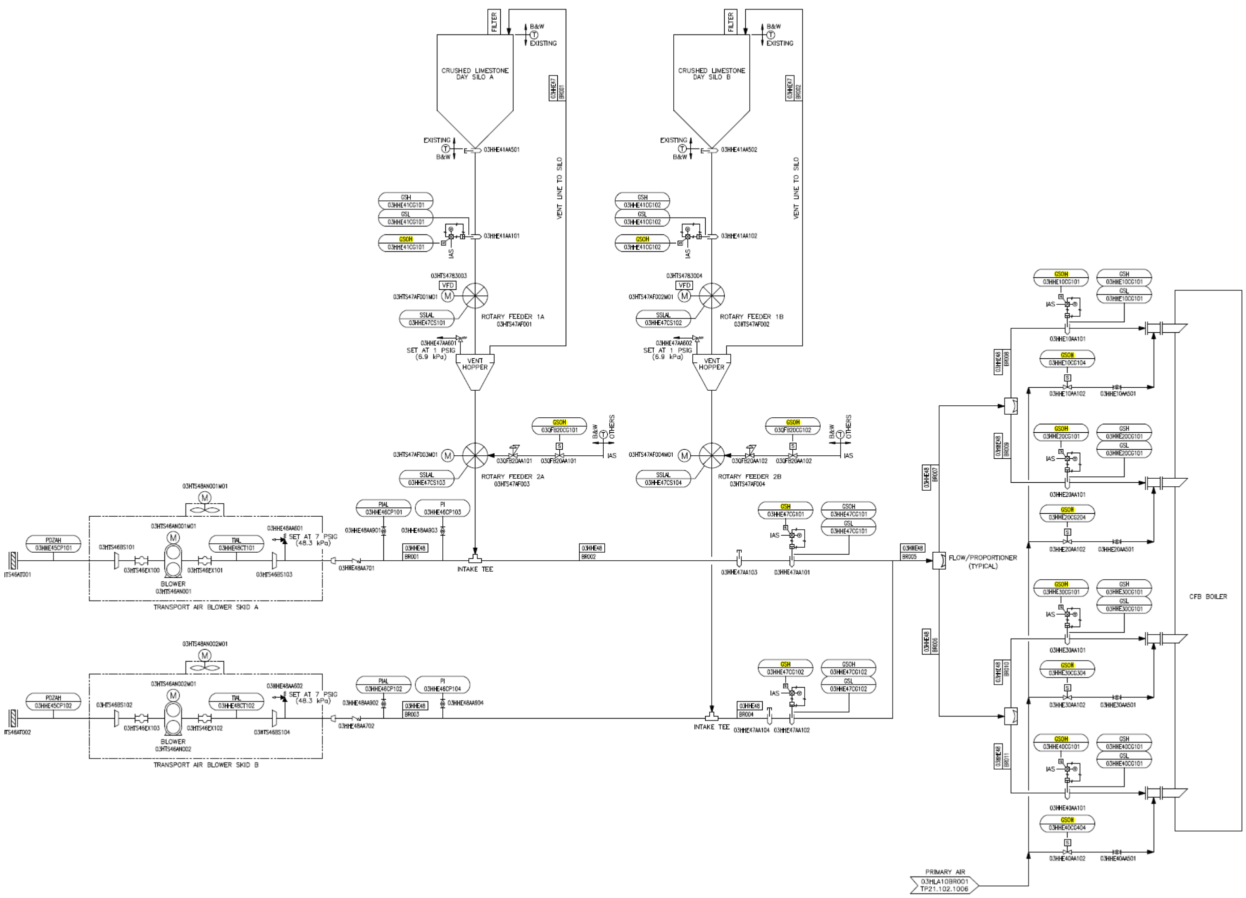

Figure 14. Pneumatic Limestone Feed System Schematic

Dry Sorbent Injection System

A DSI system designed to use sodium bicarbonate as the sorbent was also added to the unit upstream of the ESP. While the limestone injection system achieved the required SO_X emission limit for the unit, the DSI system was added to provide IRPC additional SO_X reduction capability to eliminate the need for additional SO_X capture systems elsewhere within the refinery. The DSI is only used as required to trim overall SO_X emissions at the refinery and is not used as the primary method of sulfur capture on the CFB boiler.

PERFORMANCE TEST RESULTS

Upon completion of the retrofit project multiple high-load performance tests were completed to verify that the modifications to the unit enabled it to reach the desired operating conditions and specified main steam capacity SO_X emissions levels. The results of the performance tests are summarized in Table 1.

Table 1. Summary of Performance Test Results

Design Parameter	Design Value	Trial Test	Performance Test #1	Performance Test #2
Unit Capacity:				
Steam Flow Rate	128 ± 1.28 T/hr	137.0 T/hr	131.4 T/hr	132.4 T/hr
Steam Temperature	520 °C	511 °C	515 °C	512 °C
Steam Pressure	112.5 bar(g)	107.4 bar(g)	109.6 bar(g)	110.8 bar(g)
Fuel:				
Fuel Type	High-Volatile Bituminous Coal	High-Volatile Bituminous Coal	High-Volatile Bituminous Coal	High-Volatile Bituminous Coal
Higher Heating Value	24,733 kJ/kg	25,649 kJ/kg	25,649 kJ/kg	25,649 kJ/kg
Moisture (% weight / as received)	9.00	12.94	12.94	12.94
Ash (% weight / as received)	14.20	8.33	8.33	8.33
Sulfur (% weight / as received)	0.70	0.31	0.31	0.31
Emissions:				
SO_X (7% O2 dry volume)	100 ppm*	57.5 ppm*	31.9 ppm	31.3 ppm
* Without DSI System				
Furnace:				
Primary/Secondary Air Split	50% / 50%	54% / 46%	57% / 43%	58% / 42%

The trial test was performed prior to the commissioning of the DSI system so SO_x capture was only via limestone injection. The performance tests were completed after the DSI system was commissioned and thus, SO_x capture was via limestone and sodium bicarbonate injection. The boiler combustion controls were operated in manual for the duration of the commissioning and testing periods for reasons beyond the scope of the retrofit. Therefore, fuel and combustion air flows were set to generate steam outlet pressure as close to the guarantee value as possible. Regarding main steam temperature, although the 1st and 2nd stage spray water stations were kept in automatic control, the operators elected to maintain the steam temperature set-point below the guarantee value due to turbine-related concerns.

Overall, the post retrofit test results show the modifications were successful in improving the performance of the unit. After the modifications the unit was able to successfully reach and continuously operate at full load capacity (actually, above the guarantee value). Throughout the entire operating range of the unit, the bed temperature remains controlled at target values and a proper furnace inventory is developed and maintained. Achieving the target furnace operating temperatures also has resulted in the target flue gas temperature profile throughout the entire steam generation system to be achieved.

CONCLUSIONS

This retrofit project highlights many of the design features that can contribute to operational and maintenance problems encountered on CFB steam generators. The IRPC unit showed that:

- improper furnace inventory control systems or furnace designs can cause elevated operating temperatures throughout an entire unit,
- poorly designed refractory transitions and air distribution grids, along with elevated furnace velocities can cause severe erosion and increased maintenance costs and reduce unit availability, and
- improperly designed air or sorbent injection systems can cause emissions compliance issues.

The problems on the IRPC unit were so severe that the unit was operating at approximately 20% MCR prior to the retrofit.

This project also highlights that many of the enhancements used on properly designed CFB steam generators can be retrofitted onto existing units, and thus allow operation at design conditions without issue and with improved reliability.

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