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Design and Operation of a Unique SCR System for Gas/Oil Fired Utility Boilers

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INTRODUCTION

Riley Power Inc. (RPI) and Duke Fluor Daniel (DFD) collaborated in the design and construction of a Selective Catalytic Reduction (SCR) system for Duke Energy South Bay Unit 3. As a result of the promulgation of San Diego Air Pollution Control District Rule 69, the plant was required to reduce NO_X emissions from Unit 3.

South Bay Unit 3, a boiler designed and manufactured by Riley Stoker, is located in Chula Vista, California. Unit 3 is a dry bottom TURBO® Furnace, parallel five gas flow back pass, designed to fire natural gas or fuel oil. The maximum continuous rating (MCR) is 1,151,000 lb/hr steam flow, 1005°F 2150 psig and 1,003,000 lb/hr reheat steam flow, 1005°F, 421 psig and 459°F feedwater temperature. Unit 3 has 12 Riley Directional Flame Burners, one economizer, one Ljungstrom Air Heater, and one forced draft fan.

Rule 69 defined outlet emissions in terms of lb NO_X per MW HR. The value while burning natural gas is 0.15 lb NO_X per MW HR and 0.40 lb NO_X per MW HR for fuel oil. The goal of the project was to comply with the new regulations according to the regulator's schedule and have no adverse impact on power generation.

Some of the challenges of the project include the limited space for the SCR, seismic requirements due to the aspect ratio of the ductwork, penetrations through the SCR ductwork, constructability, load turndown with two fuels over the specified load range, and the required construction schedule.

SYSTEM DESIGN

The system design was based on a specification from Duke Energy that described the requirements of the project. Since the boiler could burn either natural gas or fuel oil, the SCR system had to be designed for both fuels with corresponding inlet NO_X levels and NO_X removal efficiencies. The reagent for NO_X reduction selected by the plant was a 29% solution of aqueous ammonia. There was an existing aqueous ammonia system with storage tanks and pumps to deliver the aqueous ammonia to the new Unit 3 SCR System.

The important SCR design parameters given in the specification were flue gas pressure drop, inlet NO_X concentration and required outlet NO_X concentration for both fuels, allowable ammonia slip, and allowable increase in PM-10. The pressure drop limit was important to remain within the boiler casing design limits. The system is designed for the range of flue gas flow rates between full load and 18% load for natural gas firing.

A feature of the SCR system is the duct layout and the orientation. Due to the available space, physical constraints with foundation placements, and seismic consideration, the ductwork forms a U shape off to one side of the unit with the flow following a horizontal path. See Figure 1 for a photograph of the SCR installation. A common wall was shared by the inlet and outlet ductwork. In addition, there was an indentation in the common wall to provide for the proper flow area and room for turning vanes at the air heater inlet.

Figure 1 SCR Installation

RPI performed baseline testing to characterize the boiler performance and the inlet conditions to the SCR system prior to undertaking the design of the system. This involved the collection of boiler data and traverses of the economizer outlet exit for NO_X, CO_2, CO, O_2, and temperature at various loads. The baseline test results were used to confirm specification design parameters and to provide boundary conditions of flow and composition variation for the physical flow model.

A physical flow model was used to ensure that the flow conditions at the catalyst face were acceptable and also to minimize the system pressure drop. A 1:20 scale of the ductwork system from the boiler economizer outlet through the air heater was constructed of Plexiglas. Appropriate dimensional scaling air was used as the model fluid. The following profiles were examined: temperature, velocity, and NH_3/NO_X-ratio. Mixing devices and vanes were incorporated into the scale model and optimized to meet the required distributions at the catalyst face. See Figure 2 for a photograph of the flow model.

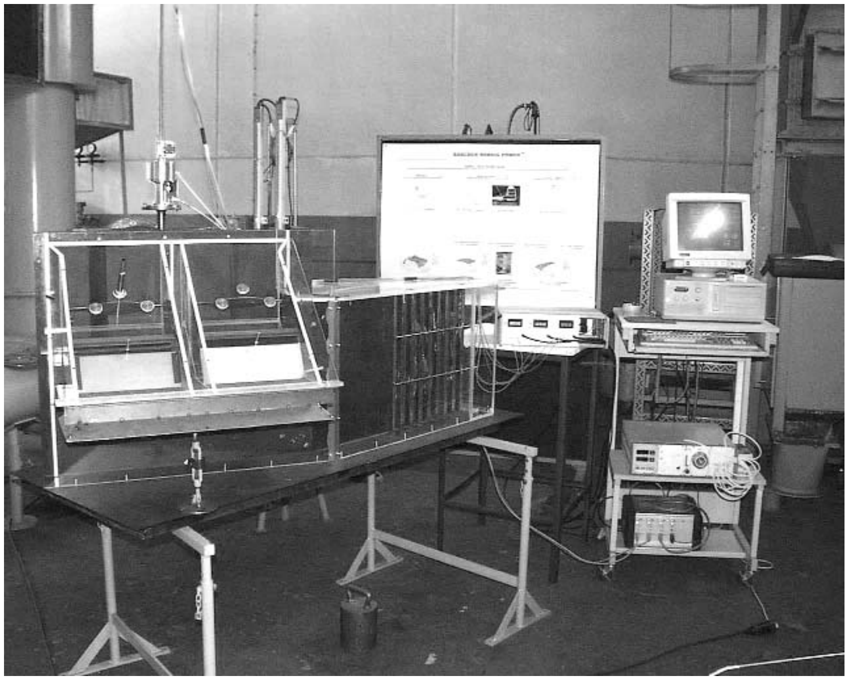

Figure 2 Flow Model with Measurement Equipment

For the flue gas path, new horizontal ductwork was installed from the economizer outlet to the SCR reactor and back to the air heater inlet. There was a limited space of 16.5 feet between the economizer outlet and the air heater inlet for the new ductwork to enter and exit from the reactor. Expansion joints were installed at the following locations: economizer outlet (quantity of two), SCR reactor inlet, SCR reactor outlet, and the air heater inlet. No bypass duct and dampers were required.

Delta Wings®, Riley Power's proprietary mixing devices, were installed at various locations throughout the SCR system to ensure the required distributions upstream of the catalyst and the air heater and also to minimize pressure drop. There are two aqueous ammonia injection points at the economizer outlet with inclined discs to promote mixing of the aqueous ammonia with the flue gas. There is also a separation plate between the economizer exit ducts and the common inlet duct. A set of five inclined discs homogenize the flue gas constituents in the inlet duct to the reactor. A T-bar grid immediately upstream of the catalyst ensures uniform flow across the catalyst face. There is a guide vane from the horizontal flow of the outlet duct to the vertical flow heading towards the air heater inlet, and a guide vane system upstream of the air heater to ensure the correct inlet flow distribution. All of these mixing devices and turning vanes were developed as part of the flow model study and ensure optimum performance.

The reactor size is approximately 34 feet by 31 feet with the catalyst oriented in the vertical plane. The one layer reactor holds 24 modules of catalyst that is arranged in a 3 by 8 configuration. Nippon Shokubai manufactured the honeycomb catalyst that has a 3.7 mm pitch. The total volume of catalyst is 37 m^3. There is a grid on the inlet and outlet faces of the catalyst that is used during optimization for flue gas sampling. The catalyst modules were put in place using a construction crane.

Aqueous ammonia is used as a reagent to convert the NO_X to nitrogen and water in the catalyst. Two dual fluid nozzles are located downstream of the mixing devices after the economizer outlet. These are used to both inject and atomize the aqueous ammonia in the flue gas. This method of reagent delivery directly vaporizes the aqueous ammonia using the flue gas and does not require an external vaporizer vessel or gas stream. The plant had existing aqueous ammonia storage tanks and pumps that deliver the solution to the Unit 3 system. The aqueous ammonia enters the flow control skid through a coriolis mass flow meter, control valve, and biasing valves. The manually set biasing valves serve to proportion the flow to each of the two injection locations during commissioning, based on flue gas composition profiles at the catalyst face in order to optimize the system. The aqueous ammonia then is piped to the dual fluid nozzle and lance at the two injection points. A safety shower/eyewash station and an ammonia detector were installed for personnel safety.

Compressed air is used to atomize the aqueous ammonia. Two redundant 40 horsepower rotary screw compressors were installed on a skid. The two compressors share one 240-gallon receiver tank. The compressed air was piped to the same flow control skid with the aqueous ammonia components. On the flow control skid there is an atomizing air pressure reducing valve and biasing valves. The atomizing air is piped to the dual fluid nozzle lance where it mixes with the aqueous ammonia to form droplets at the injection point. The flue gas evaporates the atomized aqueous ammonia.

A new stand-alone PLC was installed to control and alarm all SCR system functions. A feed forward aqueous ammonia demand calculation using boiler gas flow rate and SCR inlet NO_X concentration determines the required amount of aqueous ammonia for injection. A backtrim PID controller, based on the actual outlet NO_X, trims the demand signal. The control valve modulates based on the demand with backtrim applied. An inlet extractive NO_X and O_2 monitors were installed as part of the project. The existing NO_X CEMS was used as the outlet NO_X monitor.

CONSTRUCTION AND ERECTION

One of the challenges of the project was the required construction schedule. Engineering and design work began on the project in December of 1999. The tie in outage commenced in January of 2001. Startup began in March of 2001.

The ductwork was fabricated in shippable modules where possible and also in flat panels with the corresponding individual truss work. These components were trucked from the fabricator to the site. The compressors and the aqueous ammonia and atomization air flow components were skid mounted to save field labor.

Prior to the outage with the boiler operating ductwork installation started on the east side of the boiler. This consisted of foundation excavation and installation plus the assembly of the reactor modules, inlet and outlet duct modules, and expansion joints. These modules were installed to a common point where the assembly of the loose panels towards the economizer exit and the air heater inlet could begin during the outage.

The outage work was started with the demolition of the existing ductwork. Flat panels and truss work were installed piece by piece from the common point to the east of the boiler structure to the economizer exit and air heater inlet. No ductwork modules were used except for two modules at the economizer outlet. Duct penetration sleeves were constructed in halves to enclose two existing structural steel beams and one existing economizer feed pipe. All turning vanes and mixer plates were field installed.

STARTUP AND COMMISSIONING

The unit was returned to service on schedule after the tie-in outage. Leak checks and final subsystem commissioning was completed on the first day of full load unit operation. On the second day, aqueous ammonia was injected and the ammonia system was placed in automatic. Some minor control signal issues were noted and corrected. During the first week of operation, the SCR was in service and control tuning of the boiler and SCR system for load ramping was completed. Final adjustment of the two ammonia flow-proportioning valves was completed during the second week of operation using local flue gas composition from the catalyst inlet and outlet grids. From the testing, it was determined additional ammonia flow proportioning valves would be required for low load operation. Final acceptance testing of the unit was completed within eight weeks of the initial ammonia injection.

PERFORMANCE PARAMETER GUARANTEES

The summary of the guarantees is as follows:

Pressure Drop

The system pressure drop requirement from the economizer outlet to the air heater inlet for the full load natural gas case was not to exceed 3.85 in w.g.

NO_X Removal and Ammonia Slip

The NO_X removal reduction requirement is described in the following table:

Load	Fuel	Inlet NO_X (ppmvd@ 3% O_2)	Outlet NO_X (ppmvd@ 3% O_2)	Ammonia Slip (ppmvd)
Full	Natural Gas	125	11.6	10
Low	Natural Gas	125	8.5	10

PERFORMANCE TEST RESULTS

A third party testing firm measured the NO_X removal and ammonia slip.

Pressure Drop

The system pressure drop from the economizer outlet to the air heater inlet for the full load natural gas case was below the guarantee requirement of 3.85 in w.g.

NO_X Removal and Ammonia Slip

The NO_X removal reduction results are described in the following table:

Load	Fuel	Inlet NO_x (ppmvd@ 3% O_2)	Outlet NO_x (ppmvd@ 3% O_2)	Ammonia Slip (ppmvd)
Full	Natural Gas	144.4	11.1	5.21
Low	Natural Gas	59.6	8.4	0.91

CONCLUSION

The SCR addition project at Duke Energy South Bay Unit 3 was a success. An innovative approach was taken to route duct and utilize modules where possible to avoid the additional cost and extensive outage that would have been required to physically relocate the FD fan and air heater. Performance guarantees were achieved, and verified by independent third party testing. Commissioning went well, without an inordinate amount of start-up issues. The unit was returned to service on schedule. Operating history demonstrates that the unit continues to meet all current APCD emission limits on gas and oil fuel, with no adverse impact on generating capability.