IMPLEMENTATION OF SCR SYSTEM AT TVA PARADISE UNIT 2

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Abstract

Implementation of the SCR system installation at TVA's Paradise Unit 2 high sulfur coal-fired boiler will be discussed. General design features, including results of cold flow modeling, catalyst design, and performance features, and start-up schedule will be presented.

Introduction

Tennessee Valley Authority (TVA) individually formed partnerships with ABB-Alstom Power Environmental Systems and Cormetech, Inc. to provide a High Dust Selective Catalytic Reduction (SCR) system for their 700 MW cyclone-fired Paradise Units 1 & 2. Project implementation of Unit 2 started in the summer of 1998 with start-up scheduled for spring of 2000, with Unit 1 following in spring of 2001. In addition to designing the system for firing high sulfur fuel, the project also requires high NOx removal efficiency (90%) while maintaining low ammonia slip (2 ppmvdc).

This paper summarizes SCR system configuration and catalyst design. Catalyst design/performance is discussed as a function of fuel and ash parameters and of system components, i.e. Ammonia Injection Grid (AIG), turning vanes, and distribution devices.

Scope of Supply – Table 1

By TVA

- Gas Monitoring
- Controls Design & Implementation
- Civil/Foundations Engineering
- Startup and Commissioning
- Baseline Testing
- Project Management
- Electrical Modifications
- Insulation & Lagging
- Structural Steel

By ABBES

- SCR Reactor
- Catalyst Seals
- Catalyst Loading System
- Ammonia Vaporization
- Ammonia Injection Grid & Static Mixer (Supply)
- Sootblowers
- Dampers & Seal Air
- Construction Bypass of ESP
- Interconnecting Gas Ductwork
- Access Steel
- Expansion Joints
- Controls Design
- Enclosures
- Engineering
- Startup and Commissioning

By Cormetech

- SCR Catalyst Design and Supply
- Flow Modeling
- AIG & Static Mixer Design
- Performance Guarantees
- Catalyst Management
- System Design Consulting
- Startup and Commissioning

By Others

- Ammonia Unloading & Storage
- Demolition, Construction & Construction Management

Unit Description & Design Data – Table 2

Boiler Type	B&W Cyclone Fired
Start of Operation	Unit 1 – 1963 Unit 2 – 1963
Number/Arrangement of cyclones	14 cyclones, opposed wall
Heat Input, MMBtu/Hr (full load)	6,080-6,142
Air Heater Type	Tubular
Baseline NOx, lbMMBtu	0.86 – 1.6
Particulate Control	Scrubber
Ash Recirculation	None
Fuel	HS Fuel (2 – 3.5% wt) PRB Blending Possible/Allowable
Trace Element Analysis (ppm in coal dry basis)	Design
Arsenic	< 20 ppm
Design Conditions, Full Load	
Flue gas mass flow rate, lb/hr	6,650,000
Flue gas temperature, ^{o}F	689
Particulate Concentration, gr/wacf (@ 689^{o}F)	0.35
H_2O, vol %	7.1 – 8.7
O_2, vol %, dry	4.5
SO_2, ppmvd	1,400 – 2,100
SO_3, ppmvd	5 – 30
Catalyst Pitch, mm	8.2
Catalyst SO_2 conversion, %	0.75 (initial charge)
Catalyst design life, hours	20,000

Catalyst Design Considerations

Catalyst design considerations can be divided into two primary topics, mechanical and chemical. Mechanical aspects include pitch selection and material hardness, while chemical considerations include fuel/ash constituents and boiler operating conditions.

Mechanical

Catalyst Pitch Selection**.** Selection of the most appropriate catalyst pitch is important to assure that ash will not deposit and bridge over the catalyst cells/openings, thus reducing the effective catalyst surface area and causing increased pressure loss. The properties of the ash generated by the Paradise Units 1 & 2 were evaluated under various conditions and with multiple catalyst pitch and open area selections. Further consideration for the use of alternate fuel blends was also assessed. For all cases, it is necessary that the system design i.e. flue gas and ash distribution, is performed such that the catalyst is exposed to a uniform pattern.

Based on the potential of future fuel blending and owner's preference, an 8.2 mm pitch product was selected. An added benefit of the product selected, beyond the resistance to ash bridging, is a very low pressure loss. Further catalyst pitch optimization for future catalyst additions/replacements will be considered with the benefit of long term operating experience.

Catalyst Hardness. Catalyst erosion is a function of dust loading, velocity, angle of incidence, particle size, time, and catalyst hardness. Paradise Units 1 & 2 conditions compare favorably to the existing experience base.

The environment created in the application for the Paradise Unit 1 & 2 SCRs consists of:
- Standard flue gas velocity (16.6 ft/s at the catalyst)
- Low total dust loading (0.35 gr/wacf (@ 689^{o}F)
- Particle size and duration of exposure within the experience range (mps ≈ 20-60 um)
- Flue/reactor design performed to minimize the angle of incidence to the catalyst

Catalyst hardness is controlled through product porosity i.e. the lower the porosity the harder the product. However, catalyst porosity also dictates catalyst performance potential, i.e. the higher the porosity the greater performance potential. Thus the two parameters counter each other and a trade-off is required.

In order to maximize the catalyst erosion resistance and performance potential, a unique "edge hardening" solution was applied for the Paradise Unit 1 & 2 catalyst. Edge hardening allows a high porosity (high performance) product to be used without sacrificing erosion resistance.

Chemical

Chemical deposits/reactions on or within the catalyst are the primary cause for loss of NOx removal performance over time. General descriptions of catalyst deactivation mechanisms can be read in "Optimizing SCR Catalyst Design and Performance for Coal-Fired Boilers" Pritchard, Et al.

Table 3 below compares Paradise Unit 1 & 2 parameters to the "Experience" for seven primary components of ash and fuel for which catalyst deactivation is typically attributed.

Table 3

Component	Paradise 1 & 2	Experience
Dust Loading, gr/dscf	0.84	0.7 to 10
Arsenic, ppm in fuel	<20	1 – 25
Total CaO, % ash	2 – 14	2.4 – 12
Free CaO, % ash	0.5 – 12	0.9 – 8
Na_2O, % ash	0.2 – 2.2	0.05 – 1.6
P_2O_5, % ash	0.1 – 1.1	0.06 – 1.3
K_2O, % ash	0.4 – 2.3	0.1 – 4.0

The primary focus of catalyst performance degradation associated with the Paradise Units 1 & 2 is attributed to the deposition of gaseous arsenic within the catalyst pore structure. Deactivation caused by CaO, and components such as sodium, potassium, and phosphorous will be relatively small in comparison to arsenic, although some interactions may occur, especially if fuel blending is utilized. Addition of CaO (i.e. through fuel blending) will benefit catalyst performance lifetime due to a chemical interaction that effectively reduces the concentration of gaseous arsenic at the catalyst.

Catalyst Management

Once the catalyst is in service a testing series to monitor the performance capability of the installed bed will be implemented. The testing will aid/confirm the understanding of impacts of various parameters on catalyst performance including, fuel constituents, ash constituents, and boiler operation over time.

This objective will be met through a series of steps. Each step, by itself provides useful information and when combined, fully addresses the performance capability of the catalyst within the application. Each of the individual steps is shown below.

- Catalyst performance potential (Ko) and change in potential over time $(K/Ko)_{time}$ including specific deactivation mechanism(s) via pilot test facility and specific chemical analyses
- Review and analysis of field operating conditions and ash test results
- Review and analysis of catalyst outlet NOx traverse data

The methodology of combining the results is too broad to discuss herein, but will be utilized to construct an optimized catalyst management plan.

SCR System Component Engineering/Design

The design performance for Paradise Units 1 & 2 is 90% from an inlet of 0.86 lb/MMBtu with a maximum of 2 ppmvdc ammonia slip for a minimum of 20,000 operating hours. In order to achieve the stated performance and assure that there is limited impact on downstream equipment, both the system and catalyst must be designed properly. Key components of the system include flues, turning vanes and flow distribution devices, Ammonia Injection Grid (AIG), mixer, and Air Preheater (APH).

The flue and reactor schematic is shown in Figure 1. Design and optimization of the flue, turning vanes, distribution devices, AIG, and mixer was achieved via physical modeling. Computer modeling was employed to check particle distribution throughout the model under various configurations including the final design layout. A number of different arrangements of the flue internals were checked during the modeling process in order to assure the most technical and economic design.

Details of measurement methodology and location are not discussed in detail herein but should be greatly considered when evaluating results. Therefore it is important to have a good understanding of both flow and catalyst characteristics to achieve meaningful and successful results from a flow model (physical and CFD).

Ammonia Injection Grid (AIG)

The ammonia injection grid is one of the keys to assuring long term successful performance. The design utilizes a multi-zone grid to assure excellent coverage and tuning capability. In order to simplify the tuning of the AIG and assure excellent coverage/mixing, the velocity profile at the inlet to the AIG was controlled to less than $\pm$ 10% across the entire flue. This was achieved via the use of a simple and relatively low pressure loss flow distribution device. Although the mixing length from the AIG to the catalyst is relatively long a patented static mixer design was also employed in order to assure the best mixing of ammonia and NOx prior to the catalyst. Dimensionless ammonia concentration as measured via use of a tracer gas is shown in figure 2. The excellent distribution shown was achieved without any grid tuning and is expected, through AIG tuning procedures, to improve on the full-scale unit. Achieving excellent ammonia:NOx distribution assures the following performance items; 1) long-term high removal efficiency, 2) flat ammonia slip profile at the outlet of the catalyst, minimizing the formation of ammonia bisulfate in the tubular APH.

Figure 1: Flue and Reactor Schematic

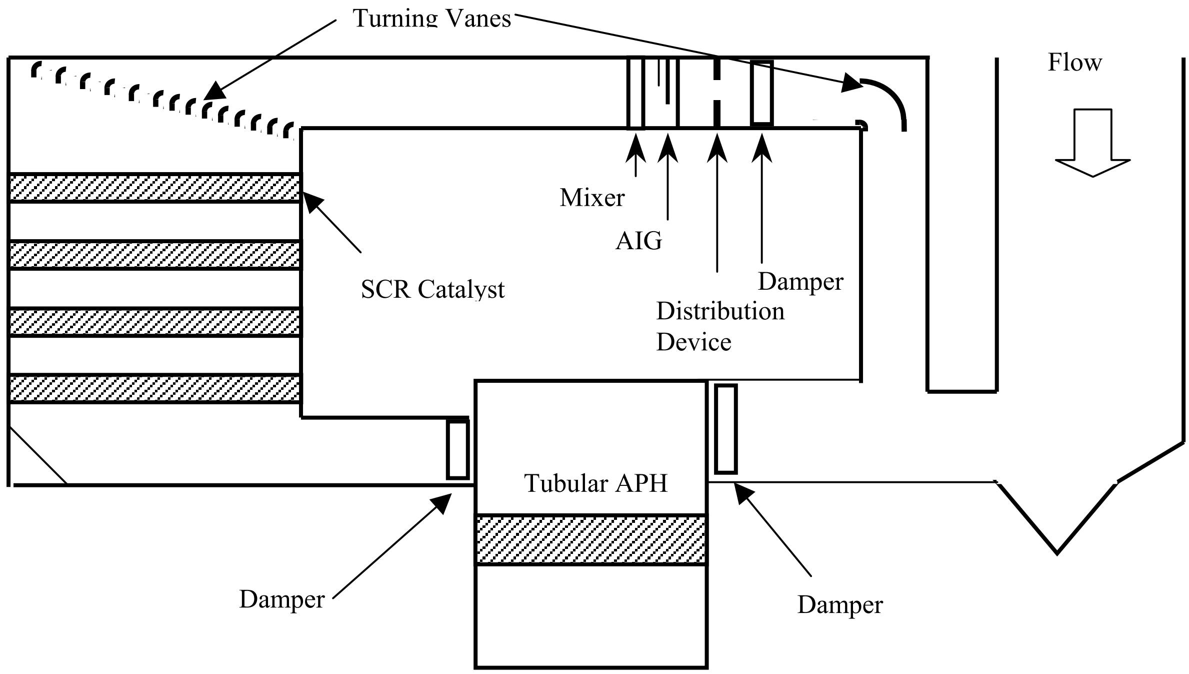
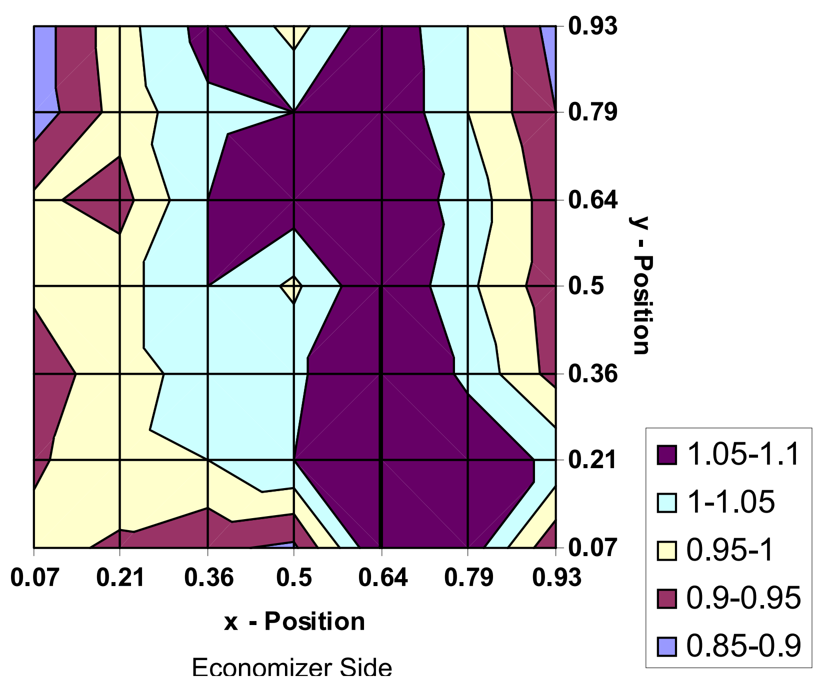


Figure 2: Ammonia Distribution at Catalyst Inlet



Static Mixer

The static mixer utilized for the TVA Paradise units 1 & 2 is a Mitsubishi Heavy Industries (MHI) patented design. The mixer works in concert with the AIG by providing local mixing, assuring good ammonia:NOx distribution at the catalyst.

Flow model test results show a reduction in maximum deviations from the mean of ammonia distribution of 50% with use of the static mixer. Mixer pressure loss is low at <0.4 inch wg of the systems 3.6 inch wg total pressure loss (not including fourth layer of catalyst).

Turning Vanes

Turning vanes were installed in the flues to assure good flow distribution to the catalyst and minimize overall system pressure loss. Although the velocity distribution has limited direct impact on overall catalyst NOx reduction performance, it is imperative to assure good ash distribution and to minimize any local high or low velocity points that can attribute to excessive catalyst wear or localized gas recirculation areas.

Two turning vanes were installed at the top of the riser duct in order to prepare the flow to enter the AIG and flow distribution device region. In order to assure good flow distribution to the catalyst, a field of turning vanes was employed at reactor entrance. The vanes were spaced such that the flow was readied for entrance into the SCR reactor. Constant radius vanes were used at the inlet to the SCR reactor. Special attention was paid to assure adequate carrying velocity around the inside of the turn, a notorious place for ash accumulation. Additionally, all vane geometries were designed with consideration to avoid ash accumulation during low load operation.

Results of velocity measurements at the catalyst show velocity distribution of ± 9% RMS at the catalyst, assuring good overall performance of the system.

Economizer and SCR Bypass (APH inlet)

An economizer bypass was physically modeled, however after detailed analysis of a number of parameters versus boiler load (i.e. economizer exit gas temperature, ammonia, water vapor, and SO_3 concentrations) it was determined that an economizer bypass was not necessary.

The SCR bypass flow profile was modeled with the use of a Computational Fluid Dynamic (CFD) computer model. Flow profiles were analyzed at the entrance to the APH in both SCR bypass and SCR operational modes. Results, though difficult to measure, showed similar, but inverted profiles. Some modifications were made to the SCR outlet flues as a result of the modeling. However, due to the large plenum above the tubular APH, the nature of the opposed ductwork feeds (i.e. from economizer versus from

SCR), and damper positioning, specific flow corrections were not recommended. In addition, the large difference between the local velocity head and loss coefficient of the tubular APH is expected to have the largest influence on the flow profile, further reducing any impact on APH performance from "pre-SCR" operation.

Engineering and Construction

The engineering and construction aspects of the project are too large to detailed herein; therefore just a few of the key items are discussed. Items include construction bypass, dampers and seal air system, expansion joints, and catalyst loading.

Construction Bypass

The plan for the installation of the SCR project included the creative design to utilize the existing scrubber to satisfy the particulate emission requirements of each unit. This allowed the SCR reactor to be placed in the space that would be vacated by the existing ESP. In order to complete the project within the planned outage schedule a significant portion of the work had to be performed while the unit was on-line. Therefore the ESP had to be demolished while the unit was on-line. In order to accomplish the objective, an ESP or construction bypass was designed to run from the APH outlet to the scrubber inlet. The bypass was designed to accomplish a number of items; 1) installation during a short "tie-in" outage, 2) it was re-usable for unit 1 construction, and 3) limited impact on boiler performance.

Installation went well on unit 2 and after a few modifications had limited impact on boiler performance. It is now operating on unit 1 awaiting SCR system installation.

Dampers

A style of double louver dampers is utilized at all locations (SCR inlet, SCR outlet and SCR bypass). Seal air is provided from the secondary air source after partial heating through the APH (note: this air source is also used for the ammonia dilution/carrier air.). Advantages of the double louver style include flow stability, "zero" leakage, and the capability to independently actuate individual sections, if desired. The last advantage mentioned is used to maintain a clear flow path through the SCR bypass during continuous SCR operation via periodic cycling over the lower louver.

Expansion Joints

After considerable investigation of both metal and fabric expansion joints, ABB-Alstom Power and TVA agreed on the use of a fabric joints for the project. Fabric joints offer a reasonable economic life while saving space and potentially allowing simplification of the support structure.

Catalyst Loading

Catalyst loading was designed for use of an external hoist, internal hoist and trolley, lifting tool and internal cart. During actual loading a small hydraulic crane was used in lieu of the external hoist for lifting catalyst modules from grade to the platform level. Multiple lifting tools were used to expedite the module transfer from crane to internal hoist. Once at the loading level the internal hoist/trolley was used to transfer the module into the reactor and onto a cart. The cart operated within the web of the catalyst support beams and was used to place the catalyst module into final position. Catalyst loading was fairly efficient operating on a 2 x 10-hour shift, 6-day/week basis with one crew per shift required approximately 15 days for 540 modules (not including installation of seals). Seals were installed in parallel with the modules on a staggered basis and were completed within 5 days after the final catalyst module placement.

Start-Up

TVA, AAPES and Cormetech will work closely on various aspects of the start-up. The SCR system start-up is planned for March-April of 2000. The tentative start-up schedule is shown below:

Task	Schedule
System checkout (dilution air system, ammonia delivery/vaporization, electrical)	3-5 days
SCR system characterization & tuning	7 days – 10 days (dependent upon AIG tuning intervals and boiler load stability)
Controls (set point checks, automatic operation configuration)	3-5 days

Further information regarding the actual performance of the unit will potentially be discussed in future papers/presentations.

Summary

- The SCR systems for TVA's Paradise Units 1 & 2 have been designed for high NOx removal efficiency with low ammonia slip while firing a range of fuels from high sulfur to high sulfur/PRB blends.

- The integration of system and catalyst design is crucial to assuring long term successful operation. A unique and complimentary working relationship between TVA, AAPES, and Cormetech was used for project implementation.

- Ammonia:NOx distribution is critical to assuring performance of 90% reduction with 2 ppmvd ammonia slip.

- An integrated catalyst and system parameter test program is required to fully optimize the catalyst management over time.

- The total system design/BOP must be considered when retrofitting SCR to a given application in order to minimize the capital and life cycle costs.