The SCR Retrofit Design For The Seminole Generating Station

William J. Gretta, P.E
Daniel Harajda
Anthony C. Favale, P.E.
Hitachi Power Systems America, Ltd.
Thomas J. Wess, P.E.
Seminole Electric Cooperative, Inc.

ABSTRACT

Units 1 and 2 at the Seminole Generating Station are each nominally rated at 650 MWe and burn eastern bituminous coal. In 2006, the contract for the retrofits of selective catalytic reduction (SCR) for both units was awarded to Hitachi Power Systems America, Ltd (HPSA). The SCR systems are designed for 90% NOx reduction and are equipped with Hitachi low SO_2-oxidation, plate-type catalyst, and a unique ammonia injection grid (AIG)/static mixing system to promote thorough mixing of ammonia and NOx prior to entering the SCR catalyst. The station will be using a urea-based system to generate ammonia for the SCR. This system has unique features including redundant, steam-heated process piping from the urea-ammonia hydrolysers to the SCR reactors. A CFD (Computational Fluid Dynamics) gas flow model study was first performed to design a large particle ash (LPA) screen at the economizer exit. Then a 1/12th scale physical gas flow model study was performed which was used to verify and optimize the performance of the mixing system and flow distribution entering the SCR reactor and catalyst. The design of the SCR reactor and connecting flues was based on a modular construction scheme, minimizing on-site labor and the outage duration. Seminole Electric, with help from their consulting engineer, performed an evaluation to determine the best methodology and project packaging in order to obtain competitive bids in a market that was re-evaluating the risk associated the supply of technology and associated construction of large industrial projects in a post-Katrina environment.

INTRODUCTION

Seminole Generating Station

Seminole Electric Cooperative is one of the largest generation and transmission cooperatives in the U.S. Its primary mission is to provide reliable, competitively-priced wholesale electric power to its 10 member systems, which include three of the largest distribution cooperatives in the nation. More than 1.7 million individuals and businesses in portions of 46 Florida counties rely on Seminole's member systems for electricity. About 90 percent of our members' nearly 900,000 meter connections are residential.

The Cooperative's primary resources include Seminole Generating Station in northeast Florida and Richard J. Midulla Generating Station in south central Florida.

Seminole Generating Station went into commercial service in 1984. It consists of two 650 megawatt coal-fired generating units. This facility is located in Putnam County, near the St. Johns River, south of Jacksonville, Florida. The installation of the SCR's by Hitachi Power Systems America, Ltd. is part of a $300 million emission control upgrade project now underway which will keep this station one of the cleanest coal facilities in the U.S. in terms of regulated emissions.

GENERAL SCR DESIGN

Performance Requirements

The performance requirements for the SCR system dictates the general SCR design. Three primary performance requirements will control the bulk of the SCR system design, thereby establishing reactor size, catalyst volume and design, and auxiliary requirements such as reagent production and storage capacity. These three primary performance requirements are: NO_x reduction, ammonia slip, and SO_2 conversion. Shown in Table 1 are the major SCR design criteria.

Table 1 - Design Criteria for Seminole Units 1 and 2 (MCR Conditions)

Design Parameter	Value
Gas Flow Rate	6,516,886 lb/hr
Temperature	750°F
Inlet NO_x	0.413 lb
Outlet NO_x	0.04 lb
SO_2 Conversion	<0.5%
Ammonia Slip	<2 ppmvd

NO_x Reduction

The required outlet NO_x for SGS Units 1 and 2 was Unit 1 was set 0.04 lb/MMBtu, which equates to a NOx reduction of 90%.. This guaranteed NO_x reduction represents the end-of-life performance after catalyst deactivation has taken place. Thus, excess activity is present in the SCR catalyst during most of the initial guaranteed performance period.

Ammonia Slip

The ammonia slip for SGS Units 1 and 2 was set at a maximum of 2 ppm for the guaranteed conditions. This represents a balance between system cost (associated with increased catalyst volumes) and adverse balance-of-plant impacts related to high slip values.

Flow Distribution

The required flue gas distributions entering the SCR reactor will be governed by the catalyst volume present and by the specified deNO_x and ammonia-slip levels. For SGS Units 1 and 2, an integral AIG/static mixing system was employed. The mixers help to achieve both uniform NH_3/NO_x and temperature distribution at the catalyst inlet, without adversely affecting the flue-gas flow distribution. The AIG and mixers are described later.

The distribution specifications for SGS follow in Table 2.

Table 2 - Reactor Inlet Distribution Specifications for SGS

Parameter	Maximum Allowable Distribution
Catalyst Inlet Velocity	15 percent RMS
NH_3/NOx Ratio	5 percent RMS
Temperature	Average ± 20^oF

RMS= Root Mean Square

SO_2 Conversion

All SCR catalysts will convert/oxidize some of the SO_2 present in the flue gas to SO_3. The guaranteed SO_2 conversion for SGS Units 1 and 2 is a maximum of 0.5% at the specifed conditions.

Pressure Drop

The overall system pressure drop consists of not only the SCR catalyst, but also the flues losses, static mixers, etc. The total system pressure drop guarantee was established at 6.6 in. w.c. and extended from the economizer outlet to the air heater inlet. This pressure drop from the SCR required resizing of new variable speed induced draft (ID) fans which are being supplied by SECI under a separate contract, but are being installed by HPSA.

Catalyst Life and Management

For the SGS Units 1 and 2, the required guaranteed catalyst life was set at 16,000 hours. The long-term maintenance of catalyst and the resulting potential deNO$_x$ activity will be dictated initially by the "catalyst management plan," which represents a best estimate of when catalyst additions and replacements will be needed during the future life of the facility. In practice, testing and performance data will be used to identify the exact time when catalyst upgrades are actually required; thus, the initial management plan serves only as a general guideline for expected future upgrades.

The SGS reactors are equipped with sufficient space for one spare catalyst layer, which is unused at initial start-up of the facility. Thus, the first catalyst upgrade, representing the end of the initial life guarantee period, will involve adding catalyst to the spare layer. Subsequent upgrades will replace the oldest catalyst layer in the reactor, rotating through each catalyst layer. The timing of these upgrades will dictate the long-term performance of the SCR; thus, the reactor performance can be enhanced by accelerating catalyst upgrades. The catalyst management plan for SGS is shown in Figure 1.

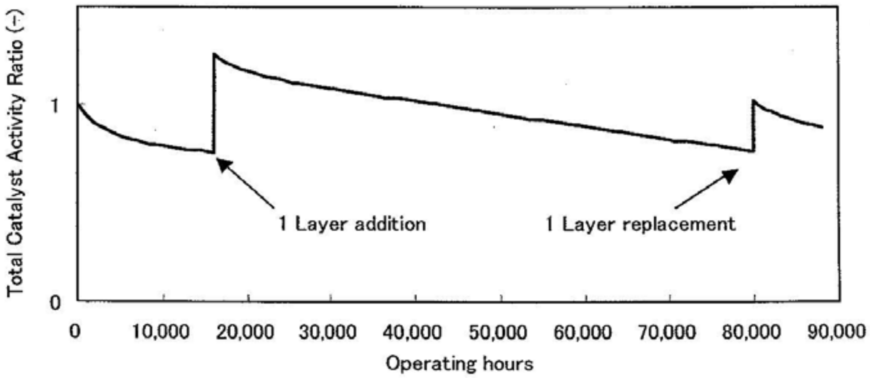
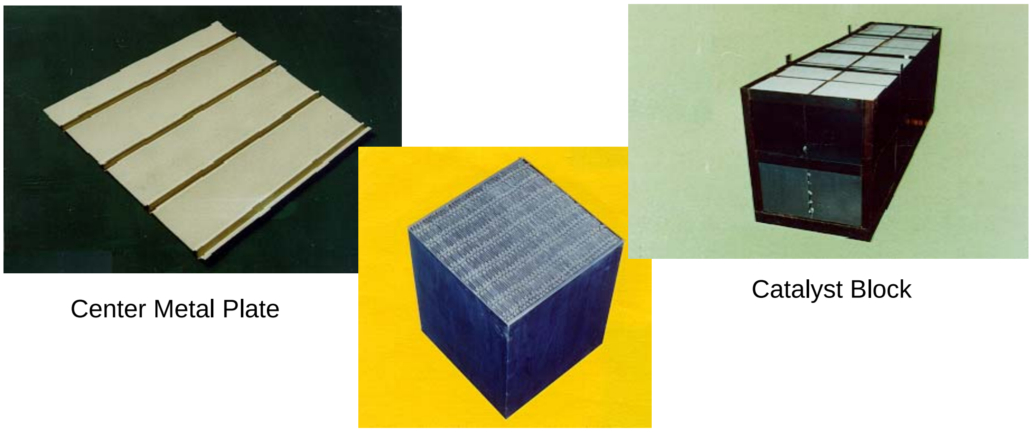


Figure 1 - Catalyst Management Plan for SGS

Catalyst Design

The plate catalyst Hitachi supplied for Seminole was manufactured and designed by HPSA affiliate company Babcock-Hitachi K.K. (BHK) in Akitsu, Japan. BHK was one of the original co-developers of Titanium Oxide based catalyst in the 1970's.

Plate catalyst is made up of individual elements manufactured with active ingredients on a titanium dioxide matrix supported on a stainless steel mesh substrate. Multiple catalyst elements are then assembled in a steel unit case and 16 of these catalyst units are assembled into a welded steel frame as shown in Figure 2-1.



Center Metal Plate

Catalyst Unit

Catalyst Block

Figure 2 – Plate Catalyst

Plate type catalyst offers the following benefits:

- *Higher Erosion Resistance to Fly Ash* – The stainless steel substrate prevents erosion from occurring
- *Higher Resistance to Catalyst Pluggage* - Plate catalyst has the distinct advantage of greater hydraulic diameter over honeycomb type with fewer corners and less low velocity zones. See Table 2.2 below. This feature also promotes easier and more effective cleaning.
- *Higher Mechanical Strength* – The center metal substrate acts as re-rod in reinforced concrete allowing for multiple installations and removes without damage which is required for future regeneration.
- *Easier Recycling* - due to the large metal content

Table 3 - Comparison of Plate and Honeycomb Catalyst Hydraulic Diameter

	Plate	**Honeycomb**	
Nominal Pitch, mm	5.7	6.9	9.0
a, mm	5	6.2	8.0
b, mm	62	6.2	8.0
D_h, mm	9.25	6.2	8.0
Difference vs. Plate	--	**-49%**	**-16%**

$D_h = 2(a \text{ x } b) / (a + b)$

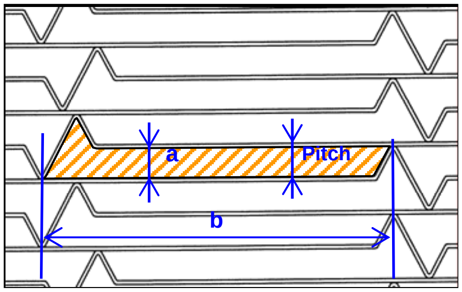
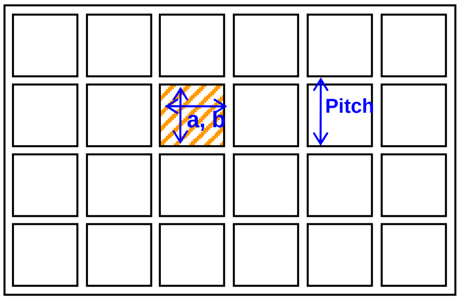


Plate type



Honeycomb type

+SPECIFIC SCR DESIGN ISSUES FOR SGS

Layout Constraints

Most retrofit installations are faced with mechanical and constructability constraints, which must be balanced with process considerations. In the case of a dirty gas environment, this is compounded by the need to manage the ash in the gas stream. In addition, the SCR system design for SGS was required to have full SCR bypass capability, thereby requiring diverter dampers at the SCR inlet. To meet this challenge it was decided to erect the SCR above the existing air pre-heater and connecting flues (see Figures 3 and 4). This allowed for flue runs of sufficient length to provide smooth transitions to and from the SCR, and to minimize pressure drop and ash layout. In addition, the support system for the SCR reactor and flues was designed to be independent from the existing structure. This decision added to the complexity of the steel support system, however it allowed the system to be erected without affecting boiler operation. Shown in Figure 3 is an overall isometric view of the SCR system, including the support steel.

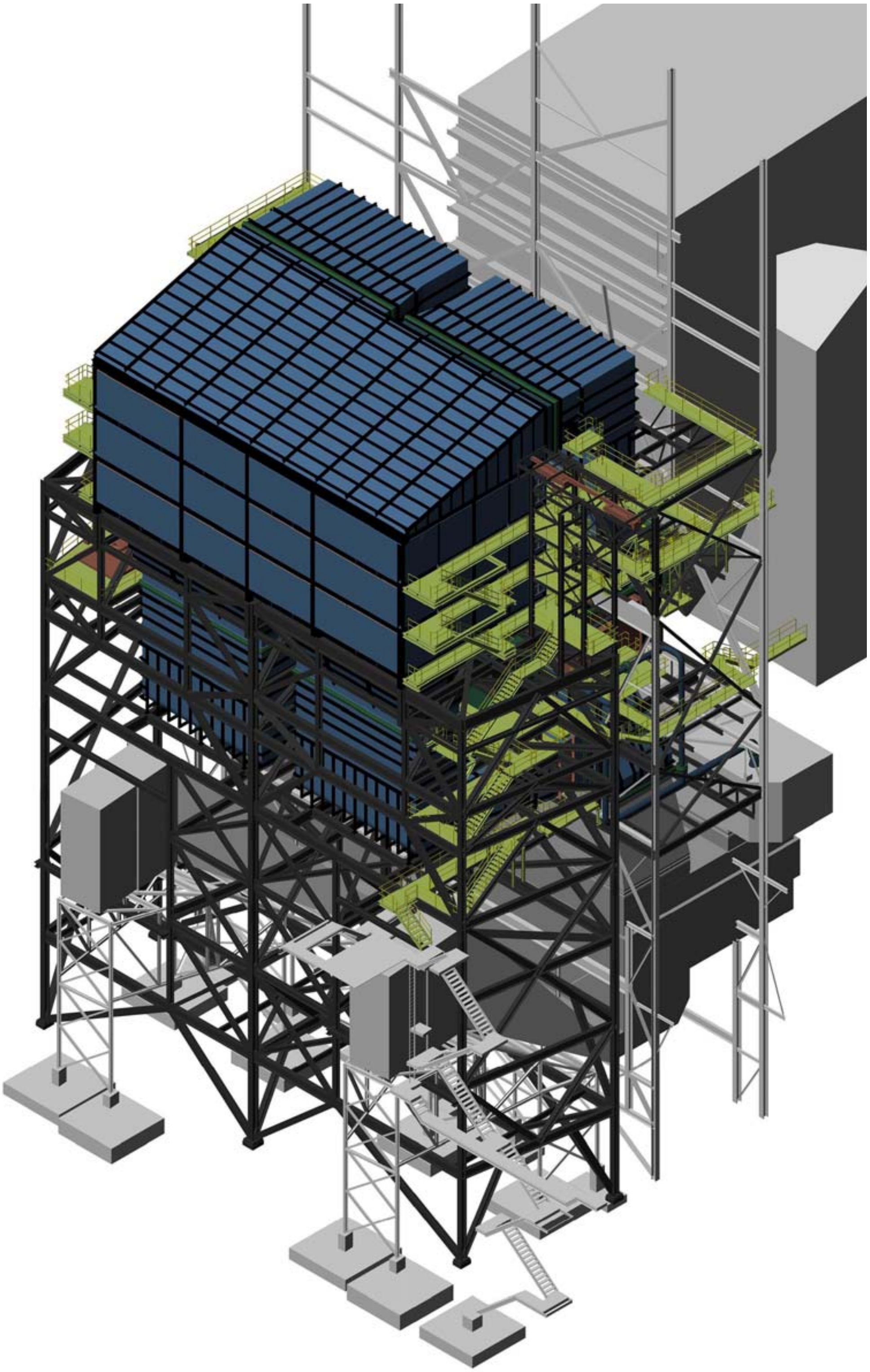


Figure 3 – Overall SCR System

Damper Design

One of the requirements set forth by SECI was to have full SCR bypass capability. During normal SCR operation, the dampers divert the gas from the economizer to the SCR and back to the air heater. In bypass mode, the gas is to be directed from the economizer to the air heater. As shown in Figure 4, the diverter dampers (two per unit) are located on the rear of the unit above the air heaters. These dampers were installed during the first outages for each unit. The construction activities are described further below,

The flap-type diverter dampers were supplied by Bachmann Industries, Inc. These units contain electric actuators and a seal-air system used to provide zero leakage for either SCR or bypass operation. In the SCR outlet are louver dampers to provide gas flow isolation on the outlet side of the SCR when the SCR is in bypass.

AIG and Static Mixer Design

A Sulzer AIG and static mixing system was employed (see Figure 4). The mixer consists of two stages; the first stage is used to help mix gas front-to-back in the flue (in the short direction), the second stage is used to mix the gas side-to-side. The mixers' bent plates redirect the gases and create small and large-scale turbulence, which promotes mixing of multiple constituents and creates a homogeneous downstream mixture.

Constituent differences commonly exist in a flow stream such as O_2, NH_3/NO_x and particulate loading. The mixer was used to improve the homogeneity of all such constituents. As shown in Figure 4, the AIG, located directly upstream of the first mixer, is designed to direct the ammonia/air mixture directly into its "cells". By directing ammonia into the mixer, ammonia distribution benefits by the turbulence of mixing downstream, which creates a homogeneous mixture of ammonia, NO_x, O_2 , temperature and particulate loading at the catalyst. The mixing permits less injection points to be utilized, as compared to zone-type AIG systems. However, each AIG lance (pipe) is equipped with balancing dampers and flow metering elements to make any required, fine-tuning adjustments.

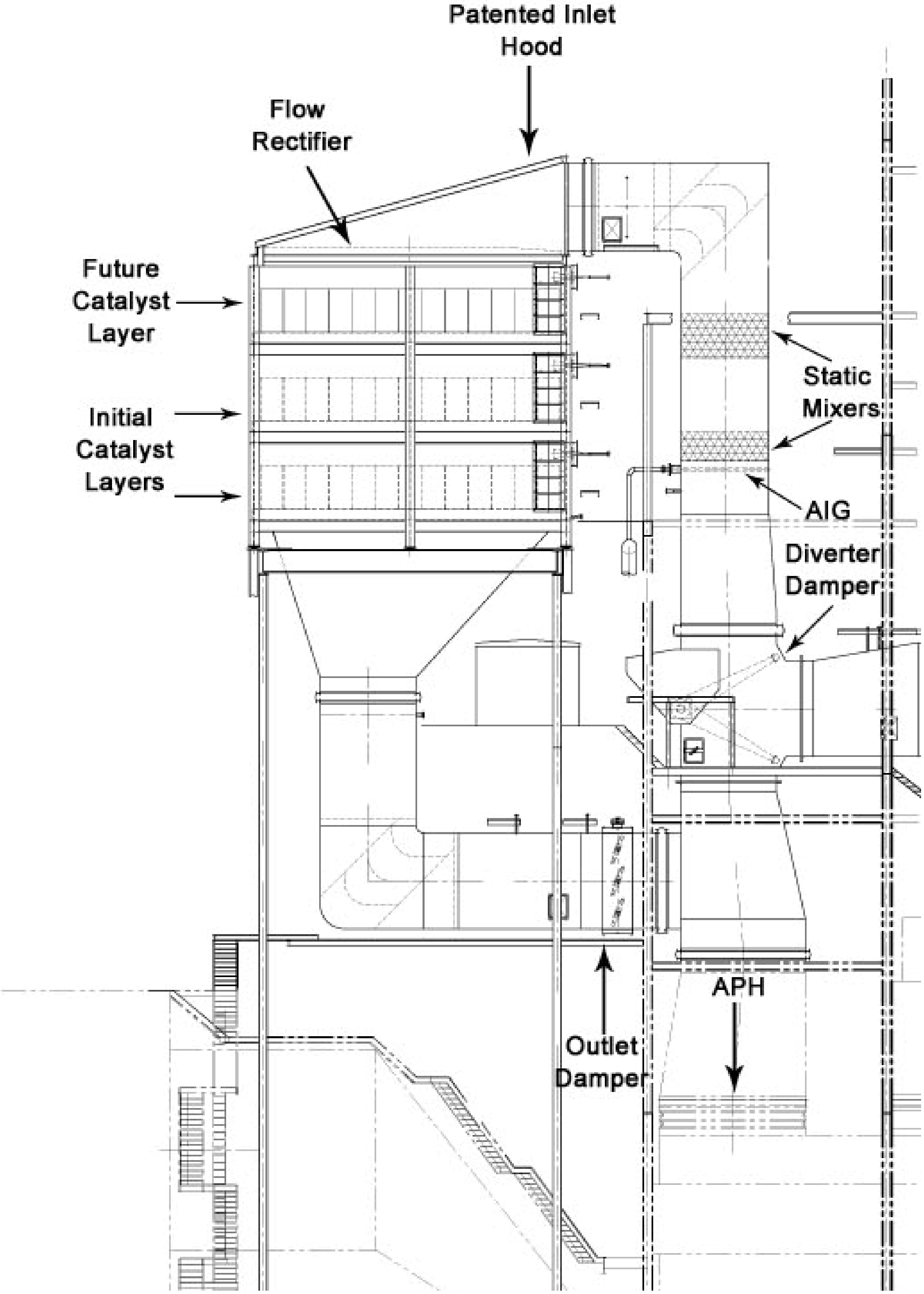


Figure 4 – SCR Side Elevation

Flow Modeling

A critical path activity in executing the SCR project was the flow model study. Both a computational fluid dynamics (CFD) study and physical flow model study were performed. CFD modeling was performed before physical model testing, to evaluate the large particle ash screen design.

<u>CFD Modeling</u>

CFD modeling was be used to design the large particle “popcorn” ash screen at the economizer exit. The 3-D model extended from the economizer tube exit region to the boiler exit flue, and included the reheat and superheat dampers and economizer exit hoppers. The objective of the modeling was to locate the screen in a region where the local gas velocities are low enough to minimize erosion of the screen, which is a common problem in LPA screen applications. Figure 5 shows the overall CFD model domain. Figure 6 shows results at full-load with dampers in their current operating condition. Overall, all screen sections showed peak velocities less than 50 ft/sec, with some regions near the damper near 60 ft/sec and within the design requirements. Once this analysis was completed, the screen design was incorporated into the physical model for verification of pressure drop and distribution effects (if any) on the downstream distributions.

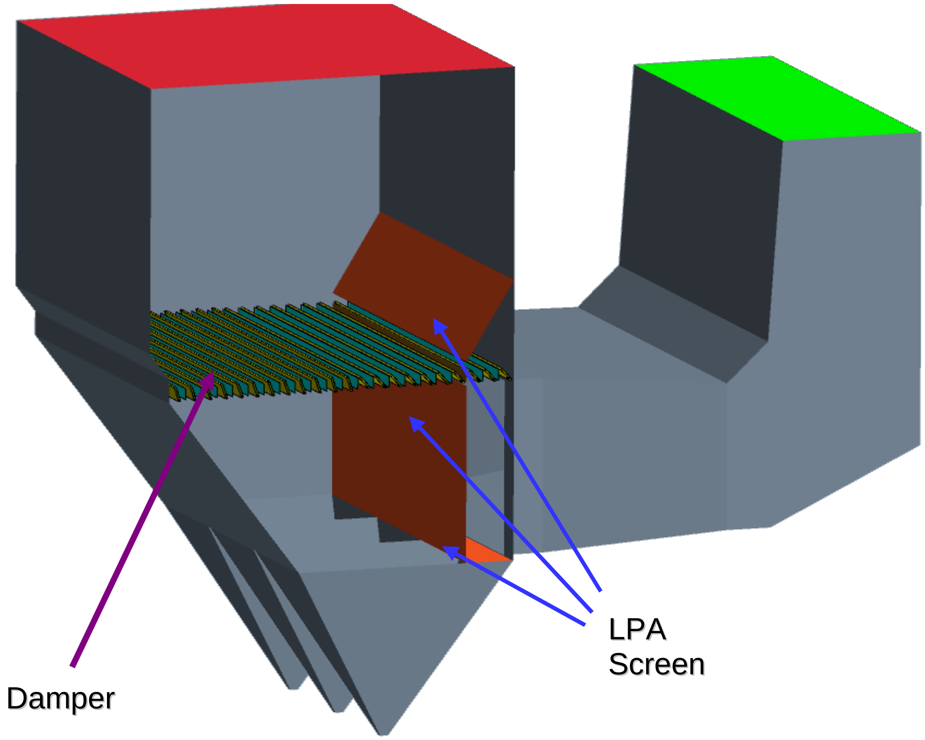


Figure 5 – CFD Model Domain

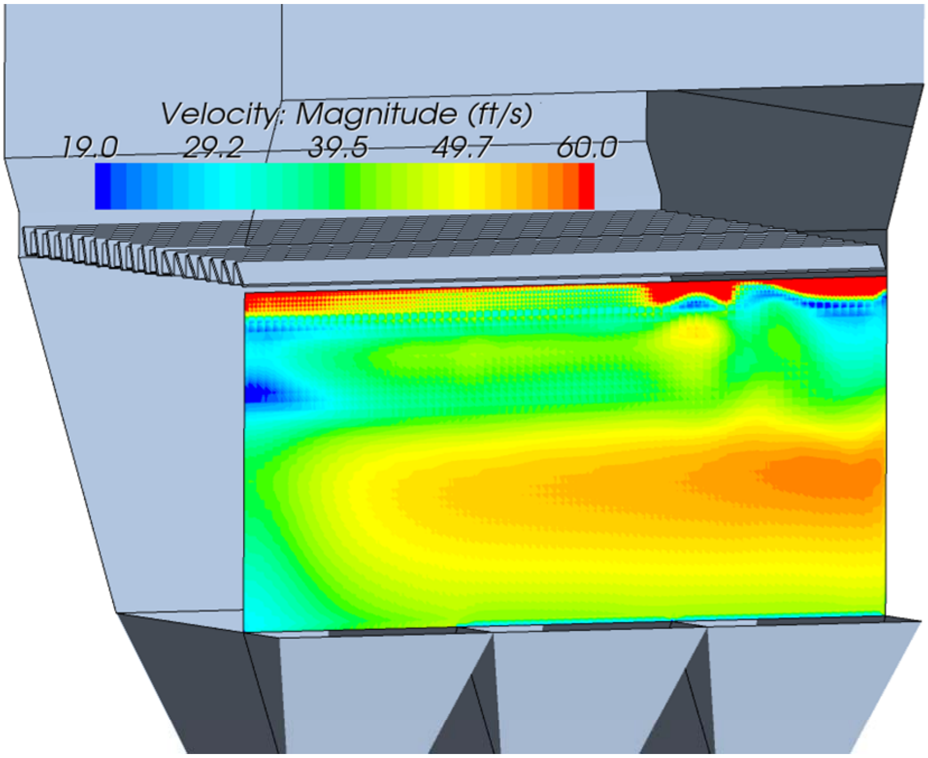


Figure 6 – CFD Model Results – Velocities on Vertical Screen Section

Physical Modeling

A 1/12th scale flow model was used to determine the optimum arrangement of flow control devices needed to meet the flow and ammonia distribution within the SCR. In addition, flues and flow control devices were to be optimized to minimize system pressure drop and ash dropout.

The flow model extended from the exit of the economizer to the air preheaters (see Figure 7). The model included simulations of the SCR inlet/outlet flues, SCR bypass flues, AIG, static mixers, catalyst layers, and air preheaters.

Figure 7 – 1/12th Scale Physical Flow Model

As shown in Table 2, the primary objectives of the modeling were to meet flow distributions at the catalyst inlet. The following procedures were used to simulate and optimize these objectives:

Flow Distribution - Cold flow simulation utilizing ambient air was measured in the model at the point of interest. Standard pitot-static tubes were used to measure velocity distribution in the transport flues, and a hot-wire anemometer was used to measure the velocity field and flow angles at the catalyst inlet. Velocity distribution at the catalyst inlet was measured at 5.6% RMS and flow angles were all less than 15°.

Ammonia Distribution - A tracer gas (CO) was uniformly injected into the 20 AIG pipes, and the CO-concentration field was measured at the catalyst inlet. The distribution of the tracer gas was used to infer ammonia distribution. Ammonia distribution was measured at 4.4% RMS at full-load conditions. Distributions at reduced loads were consistent with the full-load results.

Pressure Drop - Model pressures were measured and then corrected to full-scale flow and temperature conditions. Results from the economizer exit to air heater inlet indicate a 2.7 in. w.c. pressure drop (without catalyst). This was well within the objectives.

Ash Dropout - Model cork-dust particles were injected into the model, taking into account the differences between the actual fly-ash, model scale and temperature/flow conditions. The results gave general indications of where ash dropout could occur in the full-scale system. All inlet and outlet flues showed minimal ash layout at low load, which swept clean at full-load conditions. After the initial drop-out testing was completed, additional turning vanes were added to the SCR outlet flues to eliminate areas where ash dropout had persisted.

UREA TO AMMONIA SYSTEM DESIGN

Per the SECI's requirements, a urea to ammonia system was incorporated into the SCR system. The U2A™ System was supplied by HPSA from Wahlco, Inc. The system was designed to serve both Units 1 and 2 with a capacity of 2,200 lb/hr NH_3.

The system in located approximately 1,500 ft from the boilers and SCR's. The urea unloading system accepts either dry urea (prill), and also has provisions for 70% liquor solution delivery. The major system components included:

- 18,000 gallon 304 SS dissolver tank (Shop built)
- Dissolver (Circulation) Pump Skid (pumps, heat exchanger, etc.)
- Two (2) 200,000 gallon 304 SS urea solution storage tanks (field erected)
- Urea feed pump skid
- 2 x 100% Urea to Ammonia hydrolysers
- Redundant, steam-heated ammonia product lines

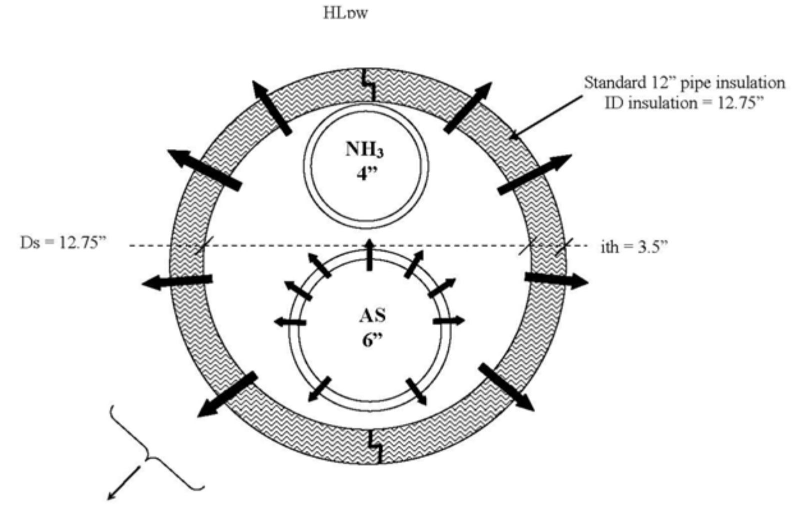
SECI required that the ammonia product lines, the pipes used to deliver NH_3 to the SCR's, were to be designed with one operating and one spare line. To avoid condensation of gases and formation of solid ammonium carbonate and ammonium carbamate in the ammonia products lines, the lines must be heated to a temperature of at least 315°F. The SECI specification did not allow electrical heat tracing, so three alternate methods that were considered

- Steam Jacketing (ammonia pipe encased in a larger steam pipe)
- Steam Tracing (small diameter pipe/tubing wrapped around ammonia pipe)
- Natural Convection (bundled steam and ammonia pipes)

A detailed evaluation was performed on each of the three methods, and the following factors were used in selecting the natural convection option:

- Steam Jacketing
  - Complicated stress analysis and extensive expansion loops
  - Difficult to detect leaks in ammonia pipe, which is encased in steam pipe.
- Steam Tracing
  - High number of circuits and traps (more maintenance of traps)
  - Contact of tracing to pipe degrades over time
- Natural Convection (bundled pipes)
  - Ease of maintenance of ammonia pipes
  - Number of traps based on steam pipe (needed anyway)
  - Used extensively in process plants

Shown in Figure 8 is a diagram of the natural convection option that was selected. Figure 9 shows the natural convection design during construction.



$$HLT = \frac{ki}{ti} \times (Tm - Tam) \times \ Avg$$

$$Aavg = \frac{2 \pi ti}{\ln \ [(Ds + 2 \ ti) / Ds]}$$

Figure 8 – Natural Convection (Bundled steam and ammonia pipes)

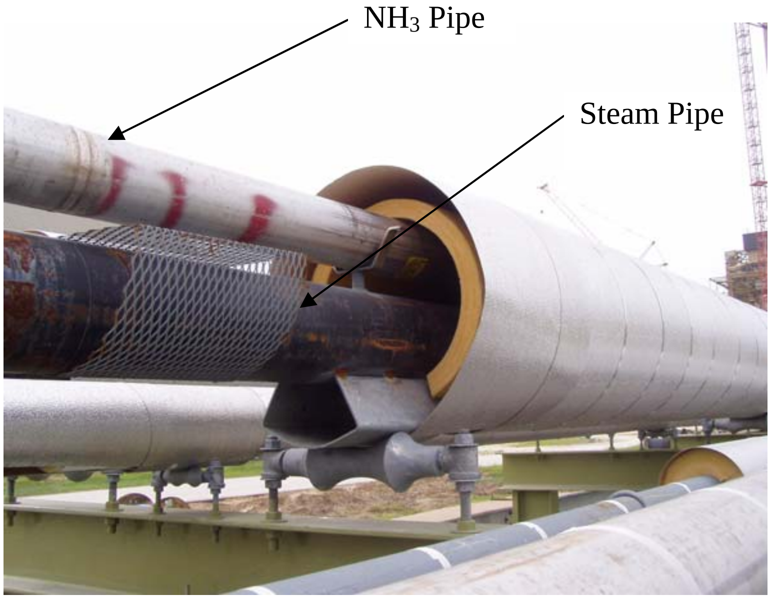


Figure 9 –Bundled steam and ammonia pipes

CONSTRUCTION AND START-UP

Modular Shop Construction

The original SCR construction plan was based on shipping all components to the job-site in largest possible sizes and with maximum shop assembly. Size of the shop assembled components would be limited to *legal load* dimensions. In reality, a large majority of the flues were shop-assembled to a larger extent than originally planned, resulting in significant number of *oversized* loads. This reduced and simplified the extent of field assembly.

SCR inlet flues were shop assembled into spool sections. Static mixers and the Ammonia Injection Grid were all shop installed into these spools, checked for proper alignment in the shop by the mixer/AIG supplier, and shipped assembled. The only sections of the SCR inlet flues that could not be assembled into spools due to shipping limitations were the 90 deg. elbows.

The SCR Reactor was shop assembled and shipped to the site in large panels. Each reactor level consisted of a total of seven shop assembled panels, each panel measuring roughly 40’ long x 12’ high. Catalyst support beams were also shop connected into “modules”, with three beams to a module. To simplify and expedite the installation of the catalyst, grating was added to all catalyst layers and was also shop-installed into support beam modules.

The shop preassembled components were further assembled at the site into large modules. These modules were insulated and lagged at grade. The size and the extent of site modularization was restricted by crane limitations only. Site modularization was performed in the lay-down yard as well as in areas adjacent to the SCR. Generally, modules that could be easily transported around the site were assembled in the lay-down yard. The larger modules, such as the reactor levels, were assembled within the reach of the crane (see Figure 10).

All process equipment was skid-mounted and shipped to the site accordingly. The balance of field work included interconnection of field wiring and piping to the skid boundary limits. HPSA supplied the following skids in the SCR proper (quantities listed are on a per-unit basis): One Ammonia Flow Control Unit, one blower skid and one Condensate Tank skid. In addition, one shop assembled/pre-wired MCC building with all analyzers, DCS upgrade and MCC equipment contained within it was provided for each SCR.

The equipment supplied in the U2A™ area was also shop preassembled to the maximum extent possible. The urea dilution tank was delivered to the site completely assembled. Due to their size, the urea storage tanks had to be field erected. The rest of the equipment in the U2A™ area was all skid mounted, with the exception of the interconnecting piping and wiring. Most of the interconnection piping was spooled at the erection contractor's shop.

Construction

The erection contractor mobilized at the site in February 2007, approximately three months after full NTP. The purpose of such early mobilization was to start working on the long piping run between the U2A™ system and the SCR area, which is roughly 1,500'. This plan has worked well, as it allowed well as it completed this work early in the projects without much impediments resulting from other on-site construction activities.

The majority of the SCR erection has been done with the units in service. Some work, however, had to be executed with the units out of service and such work was/will be performed during the two contractually scheduled outages. During the first outage, all tie-in preparation work necessary for interface of the new SCR with the existing boiler outlet flues was completed. This work consisted of demolishing the existing economizer to air heater flues and replacing them with new flues and diverter dampers (see Figure 11). The geometry/arrangement of these new components is such that it allows for complete erection of the SCR with the unit in service.

During the second outage, the actual SCR tie-in work will be minimal and will consist of connecting a total of four fabric expansion joints to the modified economizer outlet flues and removal of temporary isolation plates at these four interface points. The challenging, critical path, components of the second outage will be the replacement of the ID Fans and upgrade of the air heater modules.

Although the original construction plan called for only one major crane for erection of both SCR's, a decision was made to utilize a second crane in order to have one crane for each SCR erection. Consequently, erection of the two SCRs is being executed in parallel. Although this decision will have no impact on the Unit 1 SCR, it is anticipated that the erection of Unit 2 SCR will be completed considerably earlier than expected.

Figure 10 – Ground Fabrication of Reactor (top catalyst layer with inlet hood)

Figure 11 – Diverter Damper Being Lifted into Place (October 2007 Outage)

SUMMARY

The SCR at Seminole Units 1 and 2 is HPSA's first US SCR system installation. The SCR is system is designed for 90% NOx removal and utilizes Hitachi's plate-type catalyst which has been used in hundreds of coal-fired DeNox applications in the U.S. and worldwide applications. The SCR design posed some unique design and installation challenges, which have all been met. All project milestones, including a tight erection erection schedule, have been completed on-time or ahead of schedule. The challenging nature of this project and its ultimate success will demonstrate the maturity of the U.S. SCR industry in meeting stringent NOx control levels on difficult retrofit applications.