SCR Catalyst Pluggage Reduction at Progress Energy's Roxboro Station

Paper # 173

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ABSTRACT

Progress Energy's Roxboro Station Unit 3 is a 745 MW unit in service since 1973. A selective catalytic reduction (SCR) system was installed in 2003 to reduce NOx emissions. Over time, carryover of large particle ash (LPA) to the SCR has resulted in pluggage issues of the catalyst. A wire mesh screen, located at the economizer hopper, is intended to capture LPA and protect the catalyst. The screen experiences pluggage as well, which, in turn, leads to localized erosion due to high flue gas and particulate velocities. LPA passes through the eroded screen and ends up reaching the catalyst.

Regular inspections of the SCR reveal that LPA and fine ash accumulate on the catalyst and plug significant regions. In some instances, pluggage of nearly 50% of the catalyst cross section has occurred. This pluggage results in increased system pressure loss and suboptimal SCR performance.

In 2009, an intensive effort was undertaken to address the catalyst pluggage issues. Flow testing was performed to further diagnose the problem and document baseline performance. The test program included 3-D velocity measurements in the ductwork and in the SCR reactor. In addition, a high-temperature video camera was used to observe ash flow and pluggage patterns at the LPA screen and catalyst.

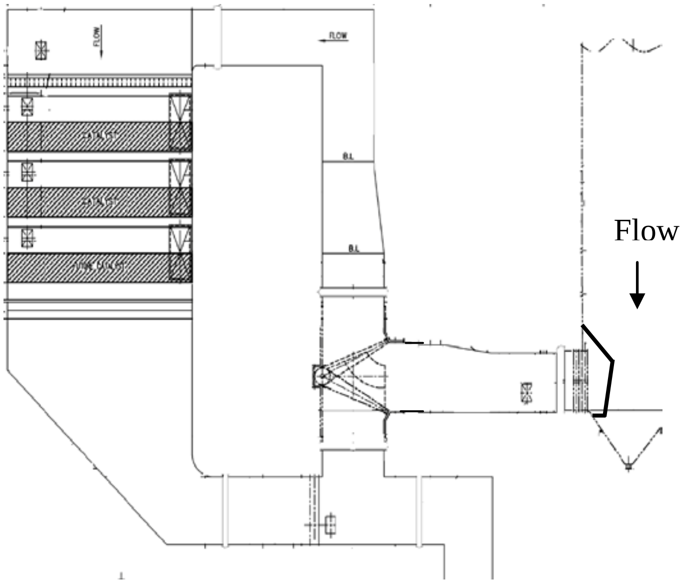
A Computational Fluid Dynamics (CFD) model study was performed to analyze gas and particulate flow patterns at the LPA screen and SCR. The model was used to evaluate a variety of devices to modify and optimize these flow patterns. The result of the modeling was the design of specific flow control devices to alter the particle trajectories and gas profile at the face of the LPA screen. Further modifications in the SCR reactor included alterations to turning vanes and installation of a new sootblower system to minimize ash accumulation potential.

The modifications were incorporated into Roxboro Unit 3 in October 2009. Operation through July 2010 indicates that pressure drop across the SCR is remaining stable with no evidence of significant catalyst pluggage.

INTRODUCTION

Progress Energy’s Roxboro Steam Plant consists of four eastern bituminous coal-fired units. The units were constructed from 1966-1980, and they currently produce a combined 2500 MW. This study focuses on Unit 3, a Riley 745 MW twin furnace with rear wall firing and Atrita mills. In 2003, the unit was retrofitted with a Foster Wheeler SCR system. The two SCR reactors each have capacity for three catalyst layers. At system start up, two layers of Cormetech honeycomb catalyst with 6.9 mm pitch were installed; the third layer was empty. Figure 1 shows a side view of the SCR arrangement.

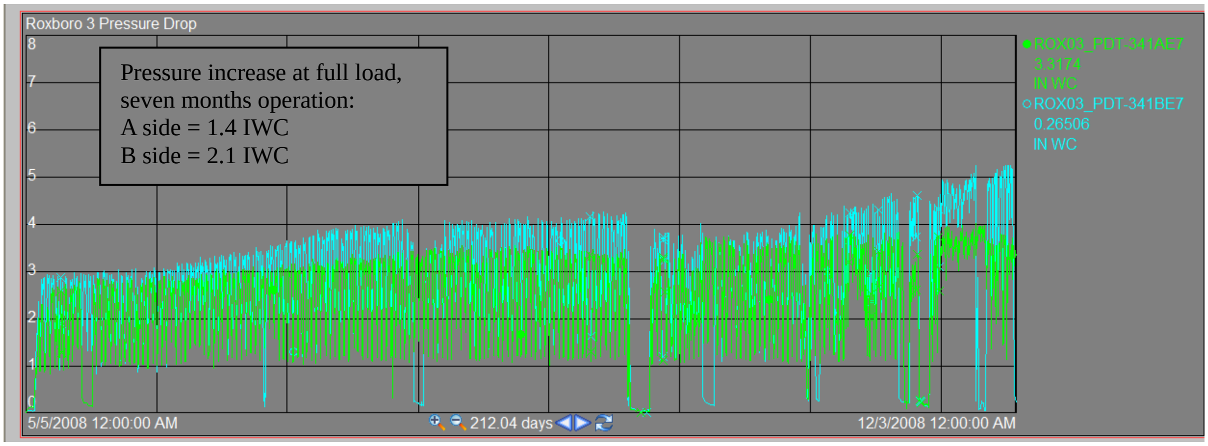
Figure 1. Roxboro Unit 3 SCR Arrangement



Pluggage of the catalyst became apparent soon after operation commenced due to Large Particle Ash (LPA) carryover to the SCR from the boiler. An LPA screen was installed at the boiler outlet in 2004, and was updated in 2006. The screen was intended to capture large particles exiting the economizer, thus preventing the LPA from traveling to and plugging the catalyst.

Over time, Unit 3 has experienced significant pluggage of its catalyst layers due to LPA that has bypassed the LPA screen and traveled to the catalyst. Regular plant inspections during unit outages have revealed piles of ash several feet in height over 50% or more of the cross section of both installed catalyst layers. The pluggage results in both an increase in system pressure drop and a reduced catalytic efficiency. As the efficiency decreases, NH_3 usage increases in order to meet NO_x removal requirements; eventually the ammonia slip through the SCR reaches a maximum, affecting optimal NO_x removal. Figure 2 shows the pressure drop across the reactors over a 7 month time period after catalyst cleaning took place.

Figure 2. Roxboro U3 Reactor Pressure Drop, 7 Months Operation
May 2008 to December 2008



Pressure increase at full load, seven months operation:
A side = 1.4 IWC
B side = 2.1 IWC

In 2009, Airflow Sciences Corporation (ASC), of Livonia, Michigan, performed a study with Progress Energy to determine the root cause of the catalyst pluggage in Roxboro Unit 3, and to recommend corrective actions. An inspection was conducted in May to examine the catalyst layers and the LPA screen.

The inspection of the screen revealed that the upper angled section was severely plugged with LPA. This effectively decreases the screen area, causing localized high velocities on the lower screen and leading to erosion. This erosion provided a means for LPA to pass through the screen and travel to the catalyst layers.

Following the inspection of Roxboro Unit 3, Progress Energy and ASC formulated a solution process to address the catalyst pluggage issue. In June, ASC performed diagnostic velocity testing of both the LPA screen area and the SCR catalyst. ASC also performed an online inspection using a high-temperature video camera manufactured by Enertechnix. The camera observations provided further insight into the nature of the pluggage issue. Following the testing, ASC completed a Computational Fluid Dynamics (CFD) model to evaluate several design strategies for improving both the tendency for LPA screen pluggage and the risk of high velocities on the screen. The modifications in the chosen design were implemented in October 2009, and performance has been observed since that time. The solution process will be discussed in greater detail in the following sections.

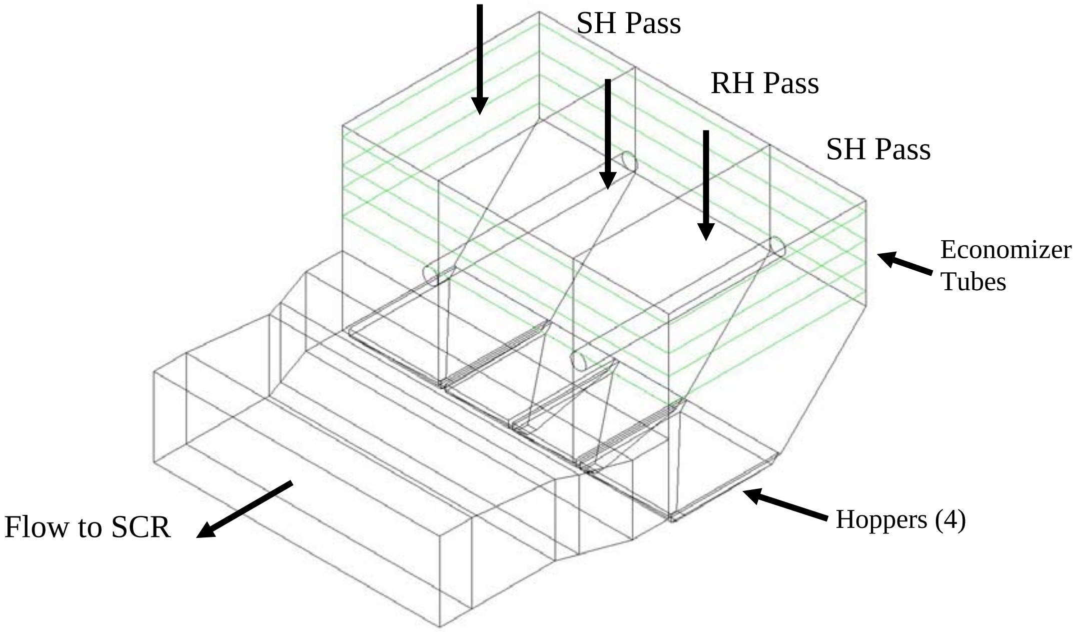
1. Plant Inspection (May 8-15, 2009)

Progress Energy and ASC inspected both the LPA screen and catalyst layers of the B-side SCR during a May 2009 outage at Roxboro Unit 3. Detailed observations are discussed in the following sections.

1.1 LPA Screen

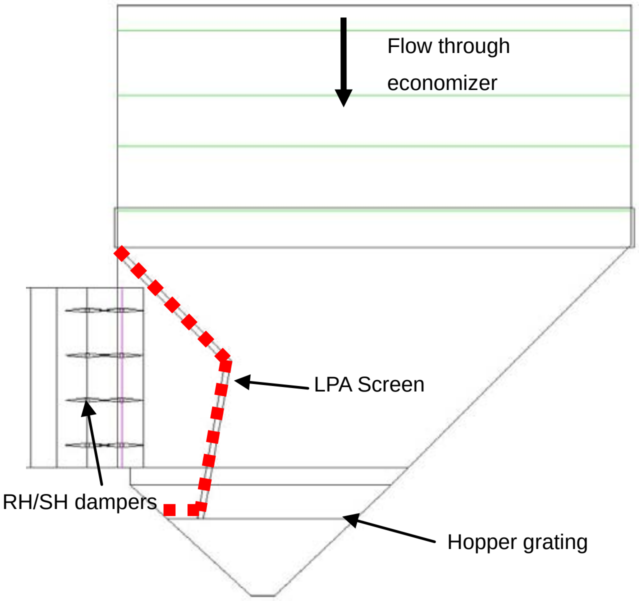
The economizer outlets of the two Roxboro Unit 3 SCRs are each divided into two superheat (SH) passes along the outboard walls, and a reheat (RH) pass in the center, as shown Figure 3.

Figure 3. Schematic of Roxboro 3B Economizer Outlet



The LPA screen is located just upstream of the RH/SH dampers, and is designed to deflect LPA into one of four hoppers. The screen is constructed of a woven wire mesh with 4mm square openings, and was positioned at the economizer exit, just upstream of the reheat/superheat dampers. The upper half of the screen was positioned at a 45-degree angle downward from the horizontal, and the lower section was at 80 degrees from the horizontal. A horizontal section of screen extended along the economizer hopper grating from the edge of the lower screen to the hopper walls. The screen geometry is shown schematically in Figure 4.

Figure 4. Diagram of Roxboro U3 LPA Screen



The May 2009 inspection revealed that the upper section of the screen was plugged with a combination of LPA and fine ash. It is theorized that the angle of the upper screen is not steep enough for LPA to slide down it via gravity. Erosion of the lower screen was observed in a number of locations, especially near the beams of the screen framework and on the floor near the hopper grating. Both pluggage and erosion were most pronounced in the SH passes; the RH passes showed only slight evidence of damage. Repairs to the lower screen were being made during the inspection, and it was observed that it is difficult to patch the screen completely, increasing the risk that LPA could slip past the screen. Figure 5 shows the condition of the upper LPA screen immediately after shutdown for the May 2009 outage. It was estimated that roughly 60% of the upper screen was blocked by ash.

Figure 5. LPA Screen Pluggage, May 2009

1.2 SCR Reactors

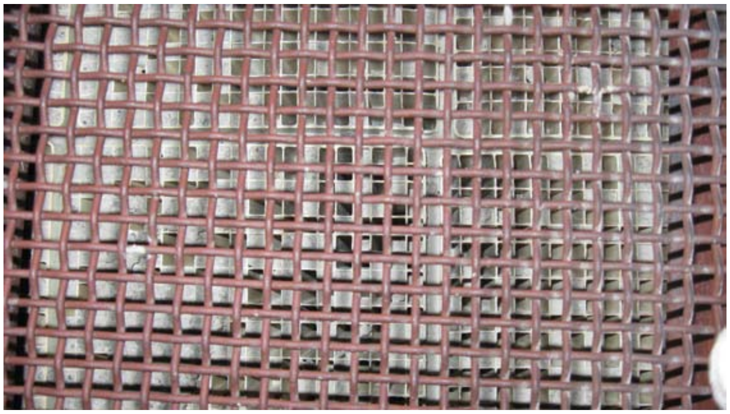
At the time of the inspection, Layer 1 of the SCRs was empty. Layers 2 and 3 contained large dunes of ash several feet in height, starting from the south wall (closest to the boiler) and extending across approximately 50% of the cross-sectional area. The ash accumulation is shown in Figure 6.

Figure 6. Typical Ash Accumulation on Catalyst Layers Before Vacuuming

Ash build-up was noted on all trusses above the catalyst, including monorail beams, empty first layer trusses, and rectifier support beams. Ash build-up was also observed on several of the SCR inlet turning vanes upstream of the rectifier.

During the outage, the catalyst layers were vacuumed and cleaned. The cleaning process took nearly 3 days. After the ash was vacuumed off the surface of the layers, LPA and fine ash were still present in the channels of the catalyst layers. The photo of Figure 7 shows this situation.

Figure 7. Ash Pluggage of the Catalyst Channels, After Surface Vacuuming



2.0 Field Testing

Following the outage, ASC returned to Roxboro 3 in June 2009 and conducted a series of diagnostic tests. At full load, the velocity profiles were measured at the catalyst and upstream of the LPA screen using a 3-D prism-head pitot probe. A high-temperature video camera probe was also used to capture video of both catalyst layers and the LPA screen to observe the pluggage mechanisms in real time under both high and low load operation.

2.1 Velocity Testing

At the LPA screen, two test ports were installed, one upstream of the upper screen and one upstream of the lower screen. The location of the test ports allowed an evaluation of the outboard SH pass only, which had exhibited the most severe pluggage and erosion during the inspection. Test data are shown in Table 1 below.

Table 1. LPA Screen Velocity Test Results

	Upper port	Lower port
Average velocity (ft/sec)	25.5	40.8
Peak velocity (ft/sec)	41.3	46.3
Average flow direction (degrees CCW)	15.1	45.6
Static pressure (IWC)	-2.79	-2.76
Average temperature (degF)	725	730

At the SCR, velocities were measured through test ports on both the north and south walls. The probe could be inserted 10’ in depth, and thus the velocity traverse covered about 56% of the total cross section of the reactor. The results, shown in Table 2, illustrate the effect of the pluggage of the catalyst channels near the south wall of the reactor, as lower velocities were measured on the south side compared to the north.

Table 2. SCR Velocity Test Results

	North wall ports	South wall ports
Average velocity (ft/sec)	15.0	12.7
Peak velocity (ft/sec)	20.3	17.1
Minimum velocity (ft/sec)	7.8	3.0
Flow balance (% of measured ports)	54.1	45.9

2.2 Video Camera Inspection

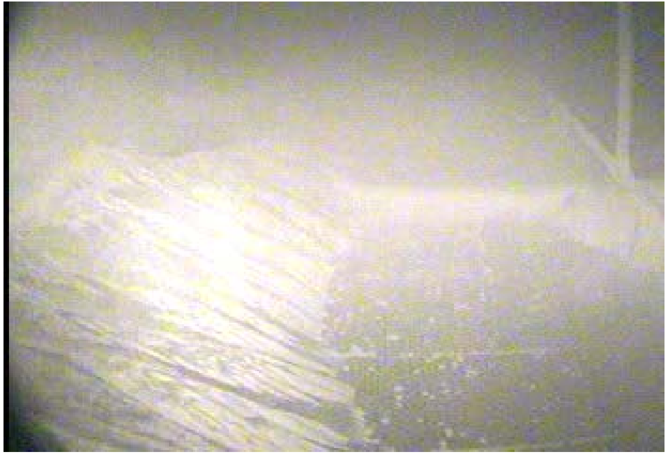
In addition to the velocity testing, a high-temperature video camera was inserted into the ports to examine the LPA screen and catalyst layers. At the LPA screen, it was observed that the upper screen was more plugged with particles than when the unit was off-line. Blockage was estimated at 80-90% compared to ~60% with no gas flow. This is shown in the image of Figure 8. At the lower screen, a small amount of blockage was noted. Long-duration testing allowed the observation of several LPA particles in transit as they fell out of the gas stream onto the screen.

Figure 8. Full Load Operation – Video Camera View of Upper LPA Screen

At the SCR, several different phenomena were observed that could contribute to pluggage of the catalyst layers. Using ports located on the south wall of the SCR, the surface of the first three catalyst modules on each layer could be observed. Although the unit had been online for only about three weeks since the outage, when the catalyst was vacuumed, piles of ash were already forming near the walls of both layers. Build-up was also observed on the flat surfaces of the catalyst module seals. In places where build-up was severe, the ash pile had started to bridge over the catalyst channels. Finally, some random small piles of ash were observed farther out from the wall, potentially caused by ash avalanching off upstream trusswork or turning vanes. One such avalanche event was captured on video during the analysis, and did not coincide with the reactor sonic horns. Over time, avalanching can lead to catalyst pluggage if the catalyst does not allow large clumps of ash to pass through the channels.

After examining the catalyst layers at full load, testing continued the following day after the unit had run overnight at approximately 50% load. Upon viewing the ash piles along the south wall, it was observed that the piles had grown in size during low load operation. This is shown in Figure 9.

Figure 9. Low Load Operation – Video Camera View of Top Catalyst Layer



3.0 CFD Modeling

Computational Fluid Dynamics (CFD) is used regularly in the power industry to develop design improvements to flow-related problems. For Roxboro Unit 3, two CFD models were created and run using both the Fluent and Azore CFD software packages. Both CFD codes are 3D and are based on control volume solution methods. A custom software sub-module written by ASC was used for LPA particle tracking. This sub-module includes laboratory-derived empirical values for particle rebound on walls and for LPA drag coefficient. This has been found to be important in order to properly track the trajectories of LPA particles due to their unique, non-spherical shapes.

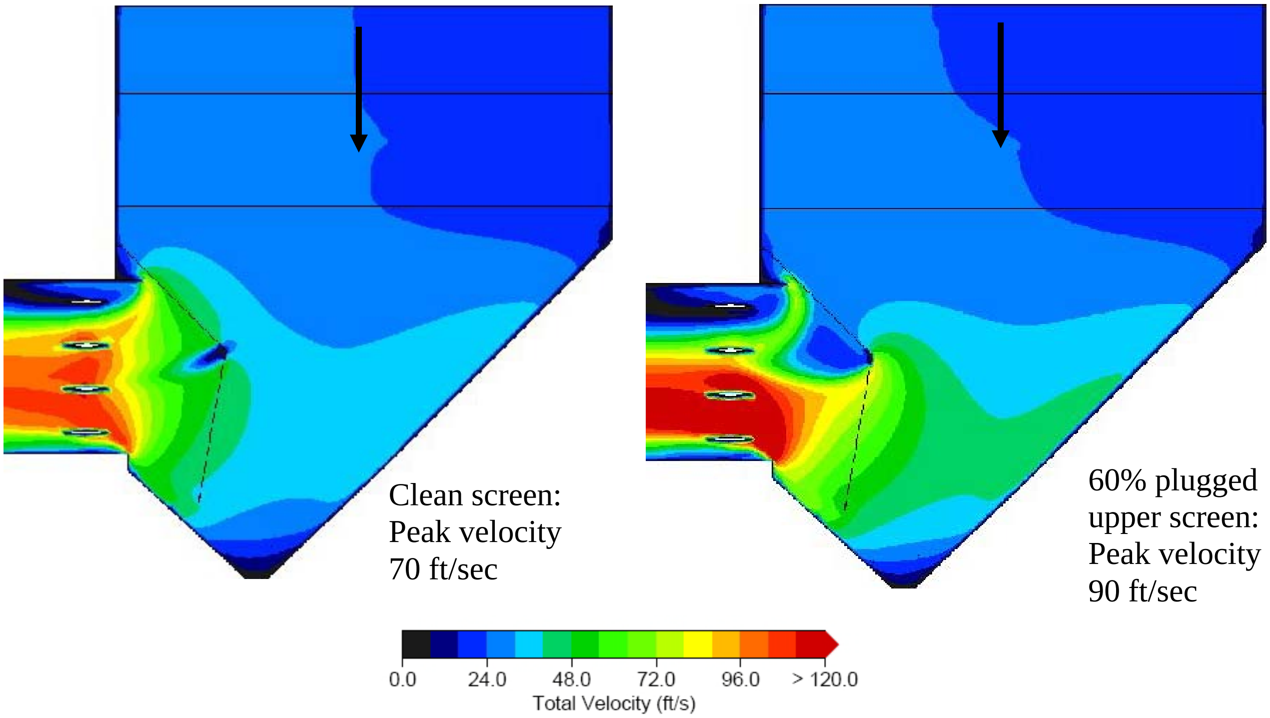
The first CFD model focused on the LPA screen, and encompassed the region from the economizer tubes to the SCR damper, including hoppers, screen, structure, and dampers. The baseline geometry model was run at full load operation representing both a clean screen condition and a partially plugged LPA screen, as observed during the inspections and video testing.

Results from the CFD model included gas velocity patterns throughout the domain, flow statistics at the LPA screen, pressure loss, and LPA trajectories for various sized ash particles. Over 28,000 individual particles were tracked and their paths analyzed in order to assess the quantity of ash impacting the screen versus being driven directly into the hoppers. The LPA particle velocities were also examined in order to gauge their potential to plug the screen. Peak velocities at the LPA screen were quantified in order to assess erosion potential. Figure 10 provides plots from the CFD models.

As indicated in Figure 10, velocity through the lower screen increases substantially when the upper screen is plugged. Peak velocities are over 70 ft/sec on the clean screen, but are over 90 ft/sec if the upper screen plugs. This will considerably increase erosion rates of the lower screen, leading to premature failure.

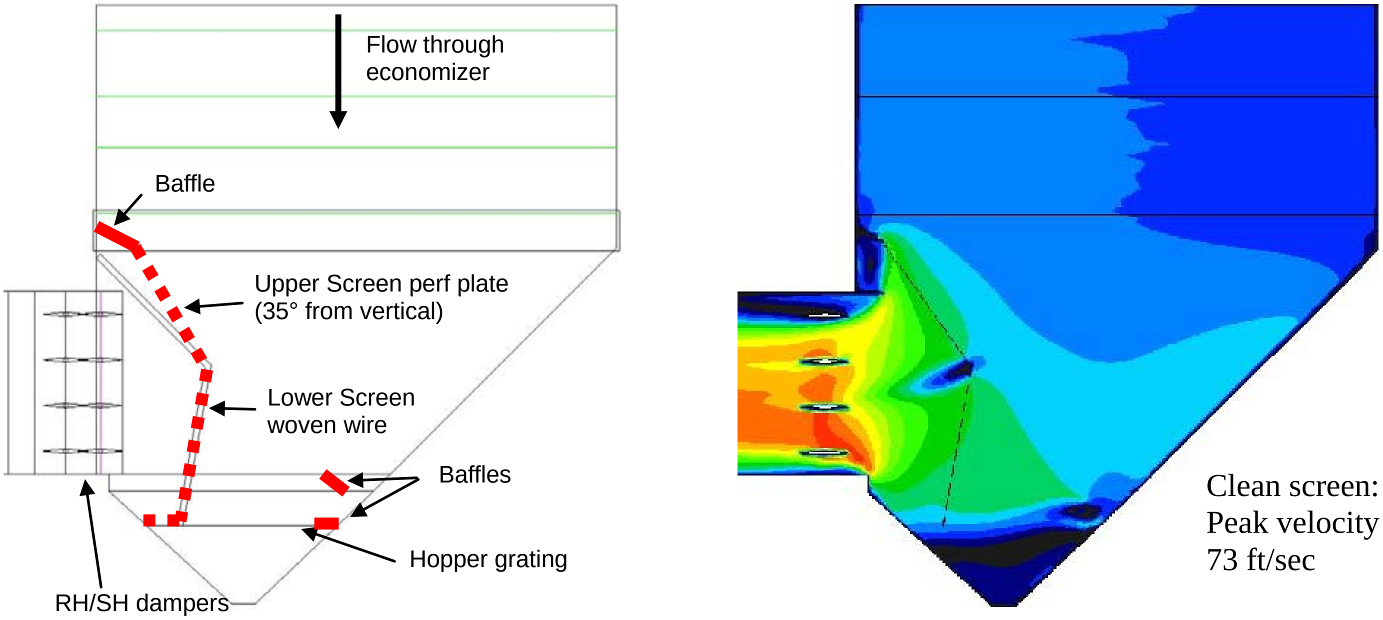
Based on the baseline CFD model and the field tests, certain design objectives were devised for a new LPA screen, still located at the economizer hopper. The primary goal was to have a steeper angle on the upper screen, to reduce potential for LPA lay-out and pluggage. Secondary goals were to minimize the peak velocity on the screen (to reduce erosion potential), reduce the number of particles impacting the screen (to reduce pluggage potential), minimize pressure drop, and to install in Fall 2009.

Figure 10. Full Load CFD Results at the LPA Screen Region



The CFD model was modified in order to represent new screen arrangements, addition of ash deflector baffles, and other flow control devices. The model was run for each of these new geometries and results compared to the baseline. In all, 24 designs were evaluated before compromising on a solution that best met the objectives. The final design featured 3 new solid baffles and a steeper upper screen. The lower screen was unchanged to reduce installation costs and time. Figure 11 provides a schematic of the new screen design and the corresponding CFD velocity results.

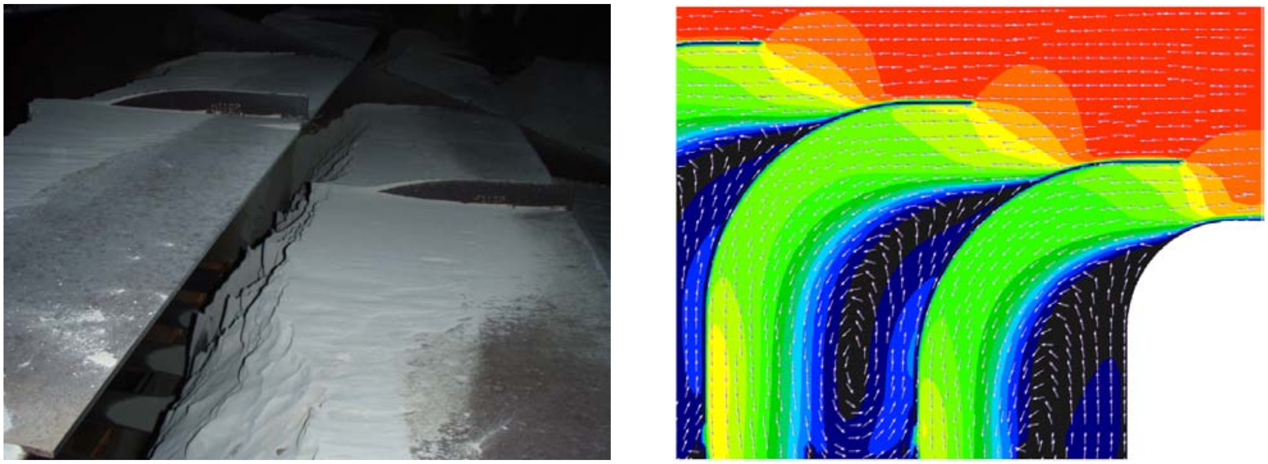
Figure 11. Final Design Geometry and CFD Velocities at Full Load



The final design featured no increase in system pressure drop and only a minor increase in the peak velocity on the screen.

A second, small CFD study was performed within the SCR itself to examine ash accumulation on the turning vanes and structural beams. Results indicate that flow separates from the curved vanes, creating a dead, recirculating flow regions where fine ash may accumulate. As the amount of ash grows, there is an increased potential for it to avalanche onto the catalyst layers. A large volume of ash may tend to impact and plug the catalyst rather than sift through the channels. Model predictions of the separated flow regions matched inspection observations, including ash deposits on the array of SCR inlet turning vanes and internal beams. This is shown in Figure 12.

Figure 12. Ash Build Up on Reactor Inlet Vanes Compared to CFD Model Flow Separation



The CFD model was used to evaluate design alterations, and a final geometry was devised. Slots were cut in the horizontal leading edge of the reactor inlet turning vanes in order to reduce ash build up potential. This had been shown to be successful at other plants in the past, and the modeling was used to ensure that the slot size and position was optimized while ensuring that flow uniformity at the catalyst was not compromised.

4.0 Installation of Modifications

Progress Energy installed the arrangement of modifications during the Fall 2009 outage. This included the new LPA screen and baffles in the hopper region, the slots in the reactor inlet vanes, and a ClydeBergemann soot blower system. The latter featured 3 sootblowers per catalyst layer. The existing sonic horns were left in place but disconnected from operation. All modifications were installed during a 15-day outage which also featured a full catalyst layer change out. Total cost for materials and installation labor was $806,000.

5.0 Status After 7 Months Operation

Unit 3 ran from November 2009 to May 24, 2010, when an outage occurred to repair a tube leak. Progress Energy personnel inspected the LPA screen and SCR reactors, and had the following comments.

- “Screens looked good, no dust in vertical screens, top plate has some holes plugged but it is a lot better than the old screens.” A photo of the screen is shown in Figure 13.

Figure 13. Upper LPA Screen Condition, May 24, 2010

- “3A SCR looked good. A few piles along the south wall, approx. 1/2 row out. Small piles were on top of catalyst screens but clean under. It didn't take much to move the piles on thru the catalyst.” This is shown in Figure 14.

Figure 14. Reactor 3A Top Catalyst Layer Condition, May 24, 2010

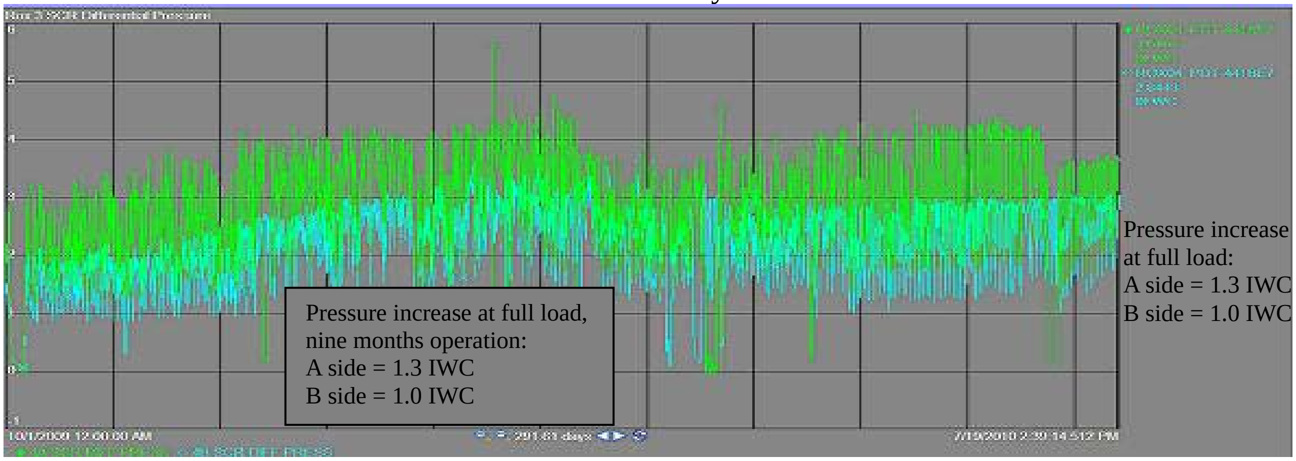
- “3B SCR had a dust pile on the south wall, covering 1 row and up about 24" on the wall.” This is shown in Figure 15.

Figure 15. Reactor 3B Top Catalyst Layer Condition, May 24, 2010

- "There were some small piles around on top of the screens, but the catalyst was clean under the piles. It did not take much to move the dust thru the screen and thru the catalyst. I noticed in 'B' SCR that there was a lot of dust falling from the beams and overhead that I didn't notice in 'A'. This dust would fall and sit on top of the screens until I disturbed it. Maybe this occurred during shutdown."

In addition, the pressure drop through the reactor has stabilized. Figure 16 shows the pressure drop versus time from October 2009 to July 2010. The B side in particular is showing an increase of only 1.0 IWC over 9 months of operation compared to 2.1 IWC over 7 months with the previous configuration.

Figure 16. Roxboro U3 Pressure Drop Across the Catalyst, 9 Months Operation
October 2009 to July 2010



Pressure increase at full load, nine months operation:
A side = 1.3 IWC
B side = 1.0 IWC

Pressure increase at full load:
A side = 1.3 IWC
B side = 1.0 IWC

6.0 Summary

The Roxboro Unit 3 SCRs had suffered from severe pluggage of the catalysts for several years. In 2009, an intensive analysis was performed through plant inspections, field testing, and CFD modeling. The results indicated that the LPA screen was subject to pluggage due to the shallow angle of its upper section. LPA would impact on the upper screen and either plug the holes directly by wedging into them or be pinned against the screen by the force of the gas flow. This resulted in the higher gas velocities through the lower screen, which would erode the screen over time, allowing LPA to pass through to the catalyst.

The LPA particles would plug the catalyst openings, allowing large piles of fine ash to accumulate on top of all catalyst layers. The pluggage would grow from the south wall (nearest the boiler) and cover over 50% of the catalyst surface in less than a year. The sonic horns were not affective once these large piles began to form. The pressure drop across the catalyst was observed to increase steadily over time, with up to a 2 IWC increase over 7 months of operation. The analysis also indicated that low velocity zones existed in the reactor where ash could accumulate and avalanche onto the catalyst.

A CFD model was used to redesign the LPA screen to reduce potential for pluggage and erosion. Modeling was also utilized to alter the design of the SCR inlet turning vanes to minimize ash accumulation and the potential for ash avalanches off the vanes.

After installation of the modifications in October 2009, the system has operated very well. Through the date of this paper in July 2010, the pressure drop across the catalyst has increased slightly, but at a reduced rate compared to the previous system. This allows for optimal NOx reduction and minimal ammonia slip. An inspection of the SCR during an outage in May 2010 showed very little ash accumulation on the catalyst and only slight pluggage of the upper LPA screen. Plant personnel indicate that the system operation is significantly improved with the new modifications.

7.0 Acknowledgements

The authors wish to thank Progress Energy Roxboro personnel for their assistance throughout the project. In particular, the authors thank Charles Beaudry, who performed numerous tasks during the field testing and completed the May 2010 inspection.

8.0 Keywords

The following keywords are applicable to the content of this paper:

Selective Catalytic Reduction (SCR)
Large Particle Ash (LPA)
LPA screen design
Pluggage
Erosion
Computational Fluid Dynamics (CFD)
Flow testing
Progress Energy
Roxboro Station
Airflow Sciences Corporation