AIRFLOW SCIENCES CORPORATION

The Airflow Update

Since 1975

Fall 2018

HRSG Ammonia Injection Optimization

Gas turbine engines used for power generation often have a Heat Recovery Steam Generator (HRSG) to increase efficiency. The hot turbine exhaust is used to create steam in heat exchanger tube banks, which may be used to create additional electricity. The emissions control system to clean the gas turbine exhaust consists of both carbon monoxide (CO) and nitrous oxide (NOx) reduction through catalyst elements. The CO is reduced by a dedicated or dual action catalyst. The NOx reduction, via Selective Catalytic Reduction (SCR), requires ammonia to be injected upstream of the catalyst and thoroughly mixed with the turbine exhaust gases. The catalytic reaction of ammonia and NOx converts the NOx to nitrogen (N_2) and water vapor (H_2O) which then exhausts out the plant stack.

To optimize the performance of these catalytic reactions, and thus minimize plant emissions, there are several key design criteria related to the flow characteristics of the HRSG. In particular, after the exhaust gas exits the turbine, it must be carefully controlled such that:

1. Velocity distribution is uniform through the catalysts within 15%
2. Temperature profile is within +/- 20°F through the catalysts
3. Correct stoichiometric ratio of ammonia to NOx is provided through the SCR
4. Pressure drop is minimized

All these factors play a role in the resulting emissions, with the goal of minimizing CO and NOx emitted from the plant. This must be achieved while injecting the minimal amount of ammonia to avoid discharge out the stack (also called "ammonia slip").

HRSG Performance Improvement Project

A western U.S. plant (Figure 1) with two HRSG units that handle the exhaust from 501F turbines was having issues with ammonia distribution and NOx catalyst performance. A redesign and installation of a new ammonia injection grid (AIG) was required to improve the situation. Concord Environmental of Voorhees, New Jersey performed the engineering, procurement, and construction of the AIG, as well as installation of a new catalyst. ASC performed the flow system design optimization. This involved conducting a Computational Fluid Dynamics (CFD) flow study to analyze the current system and recommend design changes to the HRSG and AIG. The goal of the flow modeling was to develop a new design to meet the goals of optimizing the ammonia, velocity, and temperature distribution through the SCR catalyst while minimizing pressure loss.

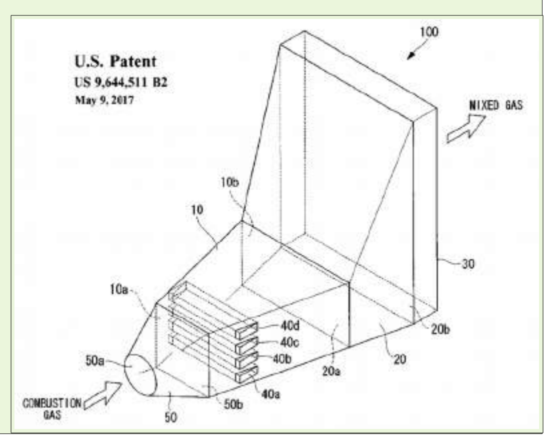
Figure 1. HRSG plant in western U.S.

Staff News

ASC welcomes **Michael Neiger**, a lab technician and fabricator, and **Andrew Threlkeld**, an engineer from Kettering University.

August 2018 was a busy month for grandbabies to be born. First time grandpa **Andy Banka, P.E.** welcomes twins Henry and Felix. **Kim Charette** was excited to meet granddaughter Grace, and now has a grandchild to visit on both coasts.

Congratulations to **Paul Harris, Ph.D.** and **Kevin Linfield, Ph.D., P.E.** who were awarded US Patent 9644511 for "Combustion Gas Cooling Apparatus, Denitration Apparatus, including the Combustion Gas Cooling Apparatus, and Combustion Gas Cooling Method".



Edited by Julie Pierce

HRSG Ammonia Injection Optimization (continued)

The geometry of the HRSG is shown in Figure 2. Flow exits that gas turbine and passes through three tube banks (red), the duct burner (gray), and four more tube banks before encountering the CO catalyst (yellow). The ammonia is injected through the AIG and the combined flow passes through the SCR catalyst (blue) and additional tube banks before exiting the stack.

The flow modeling was performed using the [Azore® CFD] program from Azore Software LLC. This is a 3D polyhedral CFD tool that includes flow and heat transfer simulation. The heat addition from the duct burners and the heat removal from the tube banks are included in the simulation.

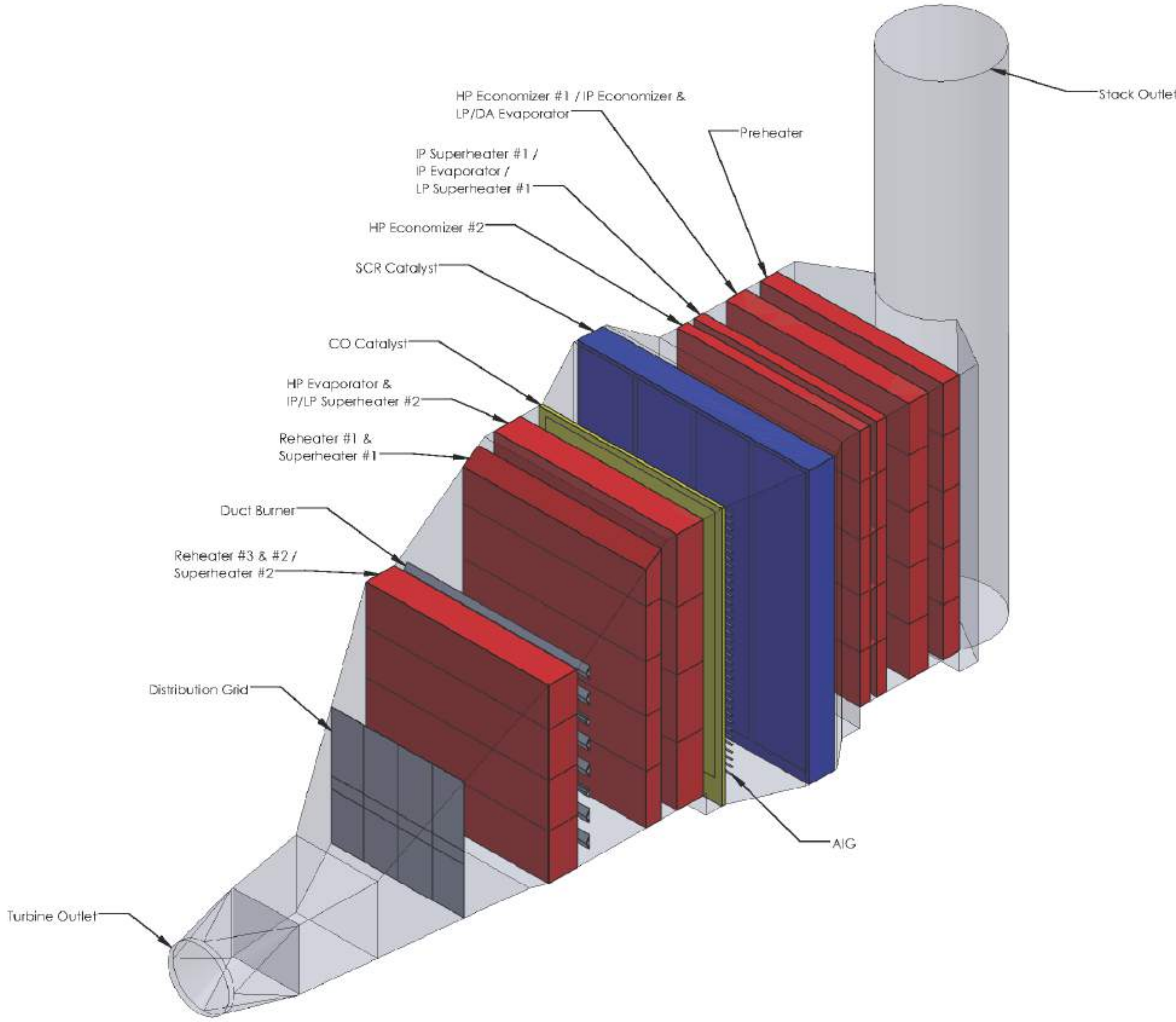


Figure 2. Geometry of HRSG from turbine outlet to stack showing internal tube banks, catalysts, and AIG.

HRSG Ammonia Injection Optimization (continued)

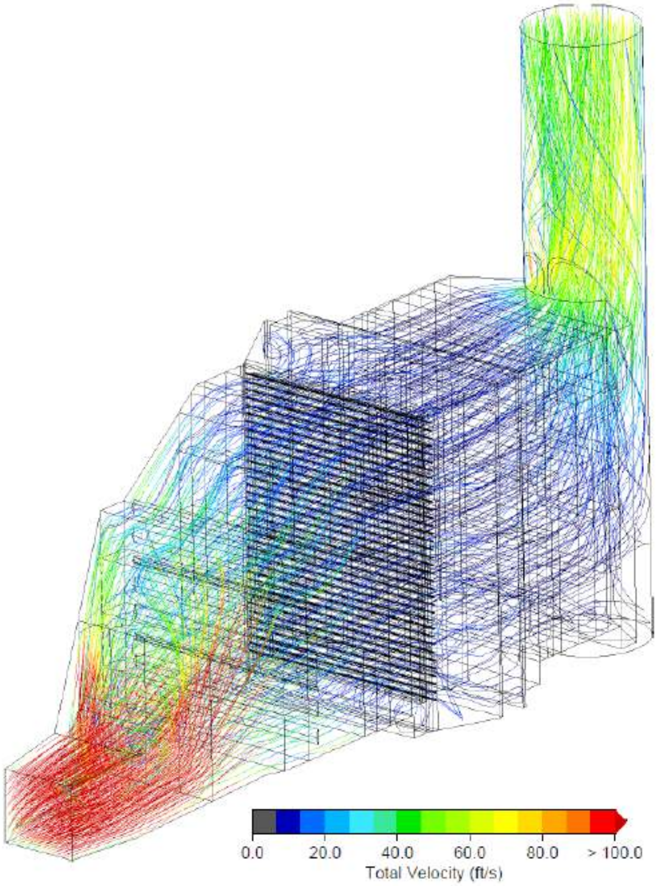


Figure 3. Baseline CFD results represented as flow streamlines.

Baseline CFD Results

The baseline CFD results at full unit load confirm poor ammonia distribution at the SCR catalyst face. Figures 3 and 4 show the overall flow patterns through the full HRSG. Figure 3 provides flow streamlines colored by the gas velocity. This indicates that flow exits the turbine at very high velocity, on the order of 300 ft/s (90 m/s), and then decelerates as the cross sectional area increases. The flow velocity through the tube banks and catalysts is on the order of 15 ft/s (4.5 m/s) and is well behaved.

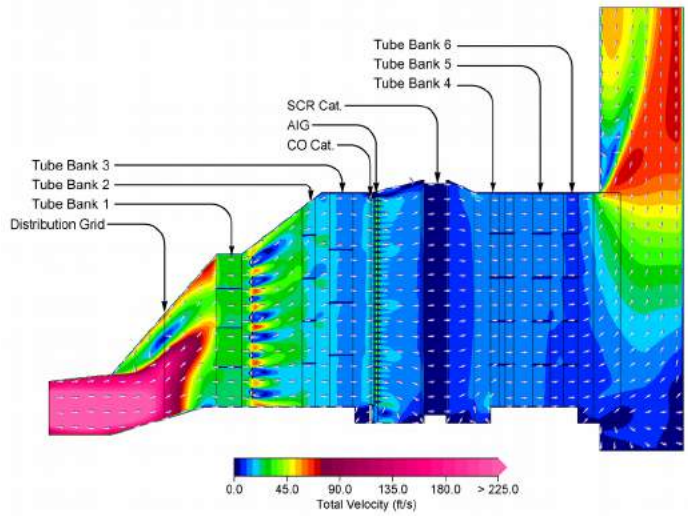


Figure 4. Baseline CFD results, side view, indicate how the gas velocities change through the HRSG.

Figure 4 shows a side view of the HRSG with velocity contours indicating magnitude and velocity arrows/vectors indicating directionality. Figure 4 has a different color scale than Figure 3 and thus shows the velocities through the tubes and catalysts more clearly.

Mobile Sewer Odor Testing

ASC has been conducting sewer odor tests for several years (read the 2013 Fall newsletter article: “'Fan Test' Helps Design Odor Control Facility” for more details). Sewer odors can be quite offensive, but the odor-causing emissions can be reduced. An increasingly popular odor control technique is to depressurize the sewer system by withdrawing air with a suitably sized and located fan. With location and size optimized, the proper fan will:

- increase negative pressure of sewer system
- reduce odor-causing hydrogen sulfide (H_2S) concentrations emitted.

Airflow Sciences' Mobile Extractive Sewer Sampler (MESS) is equipped with the ductwork and fan necessary for mobile sewer odor control testing. The test rig allows for rapid data collection of pressure at varying fan speeds. These data are used for design validation or optimization prior to committing to the expense of installing a permanent system.

Having sewer odor problems? ASC will send out our MESS to clean up yours.

ASC's Mobile Extractive Sewer Sampler houses all the equipment necessary for efficient mobile sewer testing.

HRSG Ammonia Injection Optimization (continued)

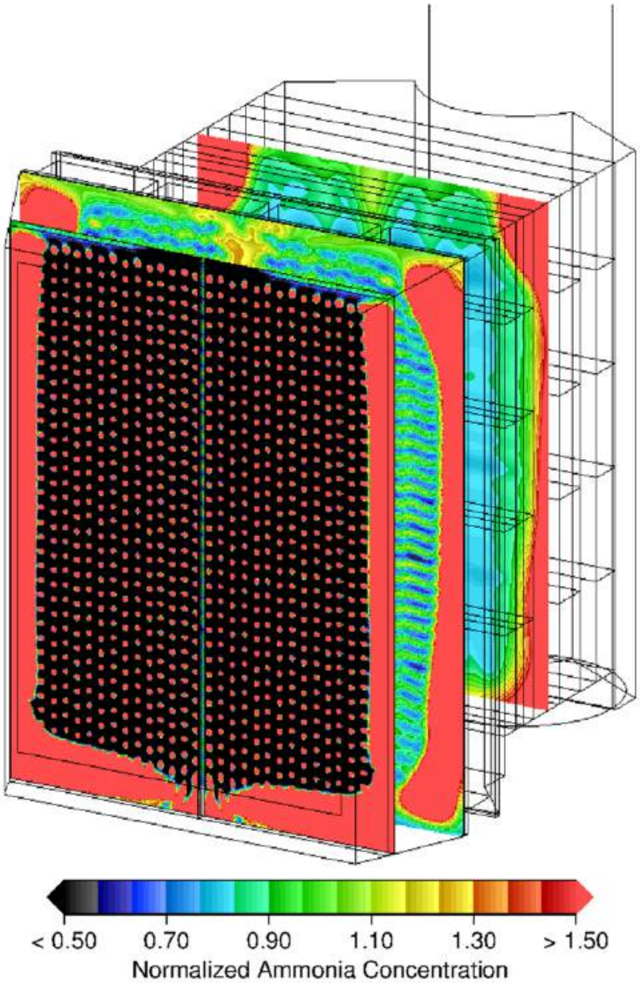


Figure 5. Baseline ammonia concentration, with areas of green being desirable.

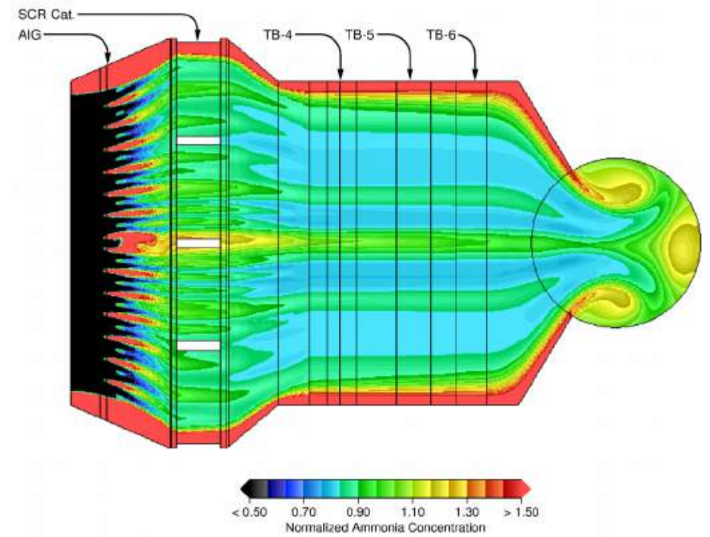


Figure 6. Plan view of baseline ammonia concentration, showing excess ammonia along the walls and entering the stack, i.e. ammonia slip.

Figure 5 is a view of the region starting at the AIG, and depicts the ammonia concentration in several planes downstream of the AIG. Figure 6 is a plan view of the HRSG from the CO catalyst to the stack inlet. Note the high levels of ammonia concentration near the walls of the unit. A fair amount of ammonia does not get mixed into the flow stream, but continues to be trapped near the walls as the gases flow toward the stack inlet. The large red areas correspond to areas of high ammonia slip. The CFD results indicate that non-uniform flow near the AIG is causing the ammonia to be concentrated in recirculation zones, due mainly to an expansion in the cross-sectional area of the HRSG ductwork in the region of the AIG.

Upcoming 2018 / 2019 Conferences/Exhibits

(complete list on website)

ASC will have a booth at each of these expos. Come visit us!

Power Gen
Orlando, FL
December 4-6

AHR (Air-Conditioning, Heating, Refrigerating)
Atlanta, GA
January 14-16

Reinhold NOx Combustion Round Table
Salt Lake City, UT
February 11-12
Presenting

SME (Society for Mining, Metallurgy & Exploration)
Denver, CO
February 24-27

EUEC (Energy, Utility, & Environment)
San Diego, CA
February 25-27
Presenting

Professional Development Hours
Call us to schedule a seminar at your or our facility

HRSG Ammonia Injection Optimization (continued)

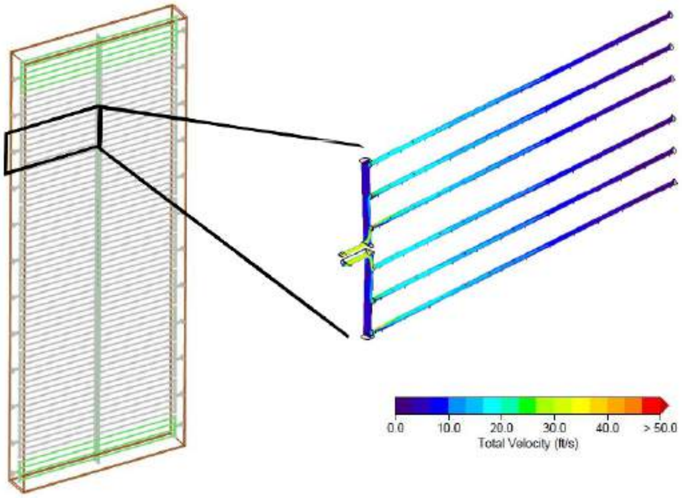


Figure 7. Ammonia velocity through a typical header and lances, with the data used as input for the full HRSG CFD model.

The typical AIG consists of an arrangement of pipes that feed vaporized ammonia. A single feed pipe from the vaporizer splits to a number of headers, each of which feeds a number of AIG lances. The lances are arranged over the cross section of the HRSG to provide uniform coverage of injected ammonia. Each lance has a large number of nozzles through which the ammonia is injected into the flow stream. In this case, there were nine headers feeding 36 lances, on either side of the duct. Each lance had 16 nozzles, for a total of 1,024 ammonia injection points over the HRSG cross section. When designing an AIG, common practice is to carefully consider the diameter sizes for the header and lance piping, along with the nozzle size, as well as the layout and number of lances and nozzles. These design factors are critical to achieve balanced flow from the

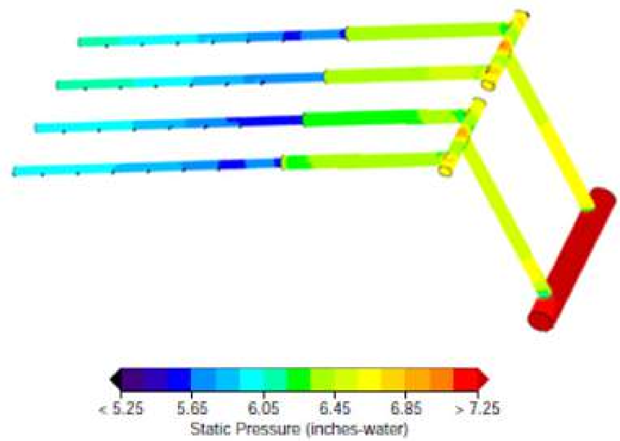


Figure 8. Pressure profile in header and lances, with sufficient pressure being required to eject the ammonia from the furthest nozzle.

thousands of nozzles in order to obtain sufficient mixing and a uniform ammonia distribution at the SCR catalyst.

Detailed AIG Modeling

In modeling an HRSG, it is not correct to simply assume that equal flow exits each nozzle of the AIG. Airflow Sciences' technique is to create a second detailed CFD model of the AIG itself to simulate the internal flows and quantify the flow split between nozzles. Figure 7 shows an example of AIG geometry and the velocity of vaporized ammonia within the header and lances. Figure 8 is a closeup of the nozzle locations on the lances. One of the benefits of this detailed model is an ability to analyze the amount of heat transfer from the gas flowing past the lances to the ammonia within the lances. This abrupt increase in temperature results in a density change for the ammonia mixture, affecting the pressure and velocity within the

3D Velocity Acquisition in a Drying Tunnel

A recent project involved creating a custom data acquisition system for a manufacturing operation. The plant was currently acquiring temperature and humidity data during the drying process; however, the influence of air movement within the drying tunnel was not understood.

An inspection of the plant's drying process and some preliminary velocity data was required to design an accurate system. A 3D (vs 1D) anemometer was needed to understand how the direction of flow affected the drying process. The anemometer selected was capable of providing accurate flow measurements in the 0-100 ft/min velocity range typical in the tunnel.

ASC constructed a data acquisition system that could be mounted in the tunnel without obstructing the process. The programmable battery-powered data logger with sensors for recording air temperature, humidity, and velocity collected data every second, allowing the plant to observe the environmental trends in the manufacturing process. The customer was pleased with the system, and will use the information to improve the current process and for future development efforts.

This 3D anemometer was incorporated into a proprietary system.

HRSG Ammonia Injection Optimization (continued)

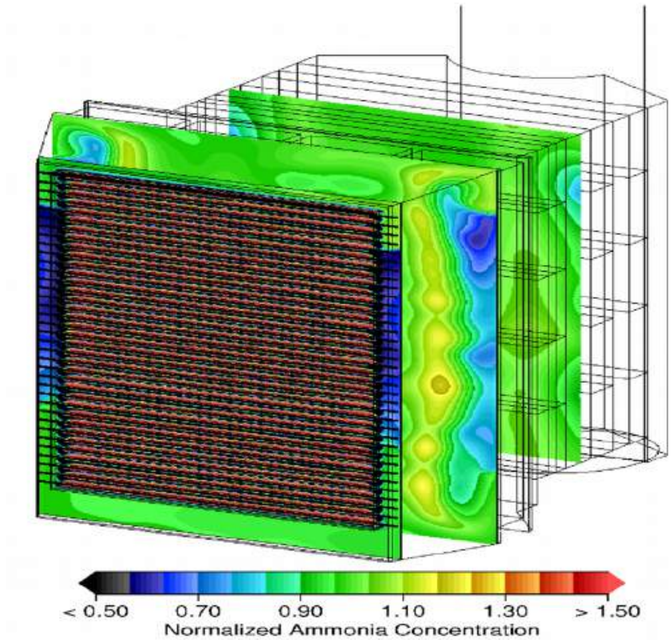


Figure 9. Redesigned ammonia concentration, showing elimination of AIG bypass.

lances. All of these factors were considered for the redesign of the AIG, including a change to the spacing of the lances and nozzles. The general goal of ammonia injection is for the amount from each nozzle to be within 2% of other nozzles to ensure uniform distribution.

CFD Design Optimization

The detailed AIG model data was used for more accurate representation of ammonia injection in the full HRSG ductwork CFD model. The non-uniform flow concerns near the AIG that were discovered in the baseline analysis were corrected with the addition of flow control baffles to redirect flow inward, resulting in an elimination of recirculation zones and a reduction in AIG bypass. In addition, the AIG was redesigned to include a local static mixer to improve ammonia distribution at the SCR. The mixer had very low pressure loss (~0.1 inch H_2O / 25 Pa). The CFD model was run with the final design; Figures 9

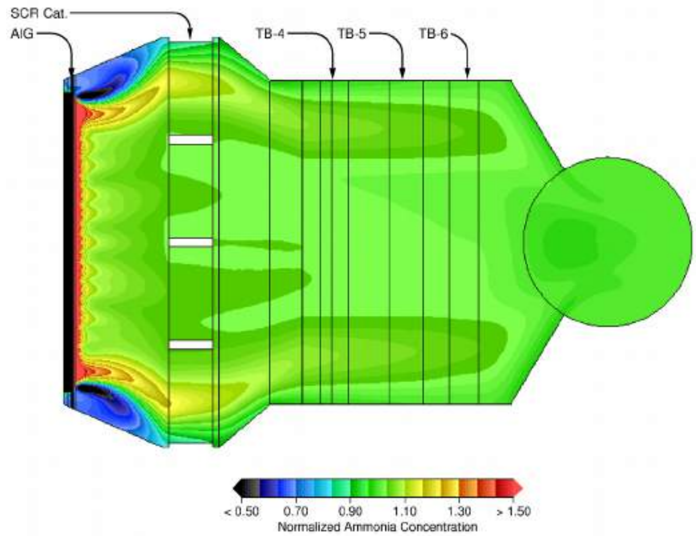


Figure 10. Plan view of redesigned ammonia concentration, showing more uniform distribution.

and 10 show the ammonia concentration results for the same views as the baseline Figures 5 and 6. Most notable is the absence of high ammonia concentrations near the walls. A comparison of the plan views shows more uniform distribution of the ammonia across the width of the HRSG. The amount of ammonia slip is significantly lower in this redesign.

An isometric view of the ammonia concentration for the new design geometry is depicted in Figures 11 and 12 for

Worldwide projects

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HRSG Ammonia Injection Optimization (continued)

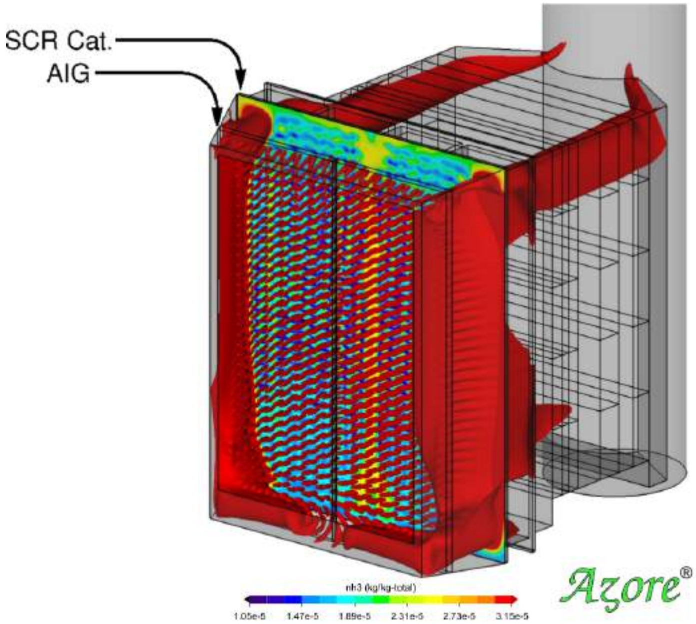

Figure 11. Baseline ammonia concentration, showing AIG bypass at the injection locations as well as along the edges.

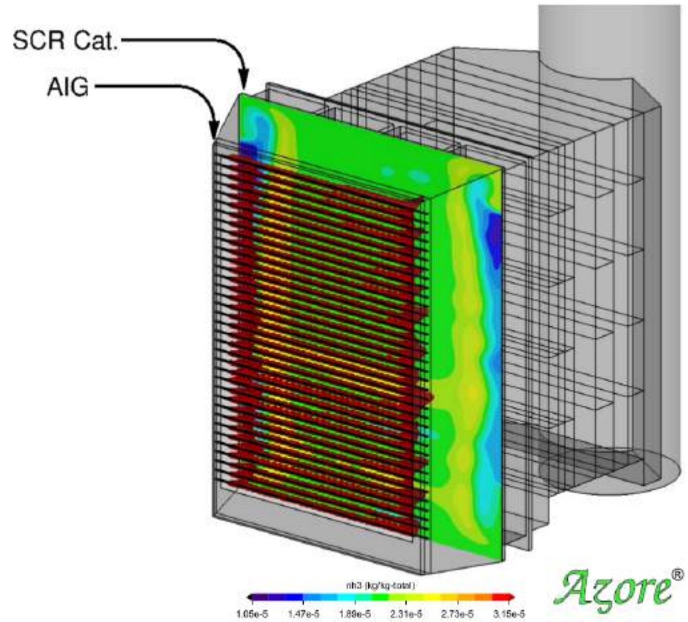

Figure 12. Redesigned ammonia concentration, indicating improved ammonia flow into the gas stream and uniform profile at the SCR catalyst.

comparison. In addition to the redesign of the AIG and the baffles at the edges to redirect flow, the position of the AIG was moved upstream. This new placement allowed for more residence time for mixing prior to the SCR catalyst and prevented ammonia from flowing upstream. The baseline ammonia RMS of 69% at the SCR catalyst face was reduced to 7% with the redesign, indicating a significant improvement in uniformity.

Plant Results

The CFD modeling conducted by Airflow Sciences successfully solved the poor ammonia distribution issue in the HRSG. The recommended AIG and flow control devices were installed by Concord Environmental in late 2017. The unit has operated well since coming back online. Plant operating experience has confirmed that since the installation of the redesigned AIG, NOx control has improved and that ammonia usage has decreased 15-25% depending on load and other conditions. In addition, ammonia salt formation had dropped off significantly on the tube banks downstream of the SCR catalyst. This was evident during a recent outage when less debris needed to be cleaned from the tubes compared to previous operating experience. The plant representative stated that the AIG redesign “appears to be a great success”.