Computer Analysis Helps Reduce NOx 50% at 66% Lower Cost than Retrofit Burners

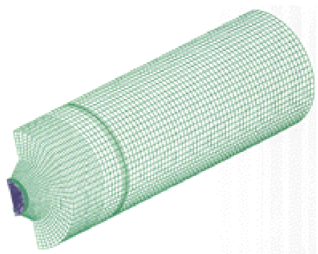

Fig 1. Baseline Burner Model. Surface Grid.

Computer analysis played a key role in the implementation of a circumferentially and radially staged flame stabilizer retrofit that reduced NOx by 50% at a 66% lower cost than traditional retrofit burners. Circumferential and radial staging reduces NOx production by reducing flame temperatures, maximizing the reducing reaction that destroys NOx and minimizing the oxidizing reaction that creates NOx.

Because only two components are added to the burners, a circumferentially and radially staged flame stabilizer and a circumferentially staged fuel delivery device, significant cost reductions can be achieved. Computational fluid dynamics (CFD) simulations were used to develop this second generation low NOx technology and also to evaluate in advance the specific characteristics of Public Service Company of Oklahoma's (PSO) Tulsa Generating Station #4, making it possible to achieve the desired NOx reduction with trouble-free installation and startup.

Radial Staging

Radial staging has been used for a number of years to reduce NOx emissions. Combustion air is directed away from the fuel source, delaying the mixing of air and fuel and creating a fuel-rich, low NOx combustion zone around the central axis of the flame. Delayed air/fuel mixing reduces peak flame temperatures which in turn minimizes thermal NOx. While radial staging is an effective NOx control technique, ignition and flame stability problems arise with excessive restriction of inner zone airflows. For this reason, there are defined limits to the amount of NOx reduction potential that can be achieved with radially staged burners.

Circumferential staging

Circumferential staging is a breakthrough add-on NOx control concept pioneered by RJM Corporation, Ridgefield, Connecticut. Circumferential staging permits deeper staging of fuel rich zones than is possible with radial staging alone. Circumferential staging consists of the staging of fuel and air in discrete sectors circumferentially around the axis of the burner. This technology creates zones of differing fuel/air mixtures. Zones with high concentrations of fuel are matched with low airflow sections of the flame stabilizer. Zones of normal fuel air mixture improve flame stability while multiple fuel rich zones reduce NOx emissions. The fuel rich zones created by these particular dynamics force the bulk of the fuel to be combusted in a reducing atmosphere. These reducing zones prevent fuel bound nitrogen from forming NOx. These zones also decompose entering NOx molecules into nitrogen and oxygen components.

Consequently, the combination of the circumferential and radial staging burners achieve substantial NOx reductions relative to radial staging alone.Since deeply staged fuel rich zones tend to create unstable flame fronts, RJM's process uses two features to ensure flame stability. First, the flame stabilizer

aerodynamics produce a very strong internal recirculating vortex just downstream of the throat of the burner. This vortex anchors the flame front at a fixed position regardless of the load. Second, fuel-lean, rapid ignition zones bordering the fuel rich zones maintain a constant ignition source that sustains the flame front.

Implementation procedure

RJM engineers were asked to evaluate existing burners at Tulsa Generating Station #4 for two reasons. Unstable flame conditions made it a very time-consuming process to put a burner in or out of service and burner rumble was a problem. In addition, PSO desired NOx emissions to be reduced. RJM engineers used the following procedure to modify the existing burners at to implement this method. First, they balanced the combustion airflow within the burners. They used an in-burner secondary airflow measurement technique that can measure burner airflows to within 1.5% with a repeatability of 0.25%. A custom designed probe was inserted down the axis of each burner and erected perpendicular to the secondary air stream in the vicinity of the burner. Over 2400 individual readings were taken about the circumference of the burner throat. Using this method, combustion airflow between burners was balanced to better than +5%. Fuel flow was also balanced to +5% using nodal network analysis.

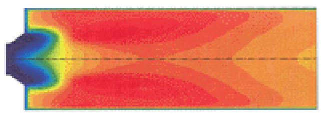

Fig 2. Low NOx Burner -- Model 1. Temperature

Next, RJM engineers made extensive use of CFD simulations to engineer a radially and circumferentially staged flame stabilizer matched to the specific requirements of Generating Station #4 burners. Traditional testing methods are time consuming, expensive, and limited in their ability to provide detailed performance information. CFD software offered engineers on this project an attractive alternative for evaluating design options. CFD simulations provide complete flow field and heat transfer predictions. The results of the analysis allowed engineers to optimize fluid flow patterns and temperature distributions

by adjusting critical system parameters. Detailed parametric studies performed with CFD provided engineers with critical insights into optimal design configurations while dramatically reducing design cycle times and costs.

CFD modeling

RJM engineers performed CFD simulations using CFD software from Fluent Incorporated, Lebanon, New Hampshire. FLUENT software was chosen for its extensive array of physical models for combustion simulations, fully unstructured meshing capabilities and easy-to-use graphical user interface. Engineers run Fluent software on a Dell 6400 workstation with two 400 MHz Pentium II

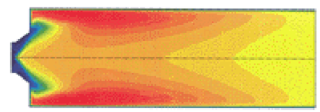

Fig 3. Low NOx Burner -- Model 2. Temperature

processors and a 100 MHz bus. The two-step global mechanism of Westbrook and Dryer for methane oxiditation was used to simulate the primary reaction chemistry in which methane burns in air to form carbon monoxide and water vapor and carbon monoxide reacts with oxygen to form carbon dioxide. Moreover, FLUENT's NOx post-processing module allowed for the estimation of thermal, prompt and fuel NOx formation associated with the combustion process.

RJM engineers were able to use the standard K-epsilon turbulence closure model for robust, economical flow solutions as well as the more rigorous Reynolds stress turbulence model in areas where accuracy was critical such as when dealing with highly swirling internal recirculation zones. FLUENT's preprocessor, GEOMESH, was used to generate a 100,000-cell model of the existing burner. Fluid flow and heat transfer analyses were performed using FLUENT's unstructured solver, FLUENT/UNS.

Engineers compared physical measurements of the existing burner to the results of the computer model to validate the model's accuracy. They established heat release profiles for the unit and evaluated a number of alternative burner add-on design concepts. They then used the modeling results to identify ignition zones and flame stabilizing characteristics for Generating Station #4 burners. They set the final design criteria for the flame stabilizer and staged fuel device and estimated NOx performance improvements. The model estimated a 50% reduction in NOx production without overfired air or burner biasing.

Trouble-free installation

Installation was simple and trouble-free. The flame stabilizers were slipped into place and bolted to the burner. The fuel staging device went in as a direct slip-fit replacement. The complete process took about two hours per burner. Thanks mainly to the use of CFD simulations to prevalidate and optimize the design of the flame stabilizer and fuel staging device, start-up was seamless and required no physical modifications to the burner or retrofit components. The flame conditions were stabilized, allowing burners to be put in and out of service without difficulty. Physical testing showed that the retrofit provides a 50% NOx reduction, nearly exactly what was predicted by the simulations. Combustion performance is better than the original baseline burner since the improved turndown ratio allows operation with all burners in service from 20% to 100% load. Additionally, burner rumble was eliminated. From the operator's standpoint, the control system and burner operation are identical to the original pre-NOx modification equipment, so no retraining was required.

This retrofit project demonstrates how radially and circumferentially staging a burner can dramatically reduce NOx production at a fraction of the cost of a low NOx burner. The key to this process is the use of computer simulation to model the performance of the individual burner in order to optimize critical design parameters of the flame stabilizer and fuel staging device. This concept has been proven on coal, oil and gas installations on all typical burner designs and will work on most unconventional burners as well.

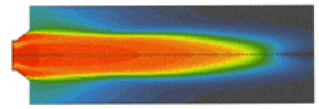

Fig 4. Baseline Burner Model. 02 Mole Fraction