Improving Effectiveness of SO_3 Mitigation Systems with CFD Modeling

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Summary

Recent additions and modifications to coal-fired power plant air pollution control devices have led to significant reductions in airborne emissions such as NO_x and SO_2. This has also produced unexpected side effects in some instances. One such issue is increased SO_3 emissions and the resulting increase in stack opacity, a phenomenon sometimes referred to as the "blue plume" effect. This has been particularly true on coal-fired boilers that burn high sulfur coals and use selective catalytic reduction (SCR) systems. There are a number of potential approaches for reducing SO_3 emissions, but recent implementation and operation of SO_3 control technologies has proven challenging for several utilities due to the variability between units and the general lack of experience with SO_3 control technologies. Computational fluid dynamics (CFD) provides a method for improving the design and operation of SO_3 control systems, both before and after installation.

This presentation describes two projects where CFD modeling was used to guide design of potential SO_3 control technologies on utility boilers. The first project involved injection of magnesium hydroxide in a furnace; the second project involved sorbent injection in flue gas ductwork upstream of an ESP.

For the first case, a previously developed CFD model for a 1300 MW steam generator was updated for appropriate current operating conditions and used to provide conceptual design of in-furnace $Mg(OH)_2$ slurry injection for SO_3 mitigation. The key injection parameters that were evaluated included: 1) number of injection nozzles, 2) nozzle locations, and 3) droplet size distribution.

Performance was based on: 1) distribution of MgO in the flue gas, and 2) extent of water droplet evaporation at convective pass entrance. The distribution of MgO in the flue gas was quantified through calculation of a "mixing number" at the exit of the upper furnace model. Two initial full load simulations assumed a total $Mg(OH)_2$ slurry flow rate of 75 gpm, while the remaining five simulations assumed a slurry flow rate of 112 gpm. Designs were evaluated according to high exit mixing number, complete evaporation of H_2O, all injectors identical (all injector sprays with droplets of the same SMD), and commercial availability of a nozzle. Using these criteria, the final recommended design was based on the results of seven full-load cases. The recommended design had eight front wall injectors and 10 rear wall injectors and predicted all slurry moisture to be evaporated before the pendant region of the furnace. The predicted upper furnace exit mixing number under full-load conditions was 0.70 (where 0 is perfectly unmixed and 1 is perfectly mixed or uniform).

The results of the seven full-load simulations showed a range of mixing numbers from 0.63 to 0.73. The design that produced the highest mixing number also resulted in unevaporated water entering the pendant region which introduces the potential of fouling. Both configurations where side wall nozzles were evaluated also had this problem. The best exit mixing numbers were achieved using 10 rather than 8 rear wall injectors; these configurations predicted full load exit mixing numbers of 0.69 – 0.70 with no unevaporated liquid entering the pendant region. Injection through the rear wall GT ports helped greatly in producing high MgO mixing numbers, since reagent injected from these locations traveled to the center of the upper furnace exit, while reagent injected from front wall nozzles tended to be more segregated in the upper part of the exit near the furnace roof.

For the second case, CFD modeling was used to aid in the design of a sorbent injection system for SO_3 control in the flue gas ductwork downstream of the air heater and upstream of the ESP at a 1300 MW boiler. The duct section selected for study was identified as having the worst temperature and SO_3 distributions at the entrance of the duct. This was important since the performance of SO_3 removal system depends to a large extent on the flue gas temperature into which the sorbent particles are injected and the degree of mixing between the sorbent particles and SO_3-containing flue gas.

The injection system design was governed by two design objectives. One design objective was to control the temperature of the flue gas below 350 °F before injecting sorbent particles. To achieve this objective, a thermal mixing device and quench air injection were considered. The other design objective was to optimize the locations of sorbent injection such that the sorbent particles were well dispersed to the regions where SO_3 concentrations were highest. Additional design constraints were that the combination of the thermal mixing device, quench air injectors and sorbent injectors not cause over 1 in-H_2O additional pressure drop and that the number of sorbent injectors be minimized.

The CFD modeling results showed simple turning vanes were inadequate to mix the flue gas and provide the desired degree of temperature uniformity. A more complex vane arrangement was predicted to provide sufficient mixing and temperature uniformity. A quench air injection design was also identified that minimized the duct flow regions that were either too hot or too cold. Sorbent injection scenarios evaluated trade-offs between injection location, injector design and particle size distribution. The best designs identified included a balance between injection velocity and particle size such that the sorbent particles had sufficient momentum to mix with the flue gas but not so much momentum that they crossed the duct to the opposite wall.

In both projects, predictions illustrated the importance of tailoring technology implementation to address specific characteristics (e.g., geometry, fuel, load, flue gas temperature and species concentrations) of each system.