

Computer Simulation Helps Improve Mercury Capture Efficiency

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THE ELECTRICAL POWER GENERATION INDUSTRY is faced with the need to comply with new regulations to reduce the emissions of mercury from coal-fired power plants. Several different technologies will probably be needed to meet the requirements of the varied types of power plants and fuels in use today.

One of the most promising is the injection of a sorbent such as powdered activated carbon (PAC) to capture the mercury and remove it from the emissions stream. The ability of this technology to reduce mercury emissions has already been proven. The challenge is to further reduce both the capital investment and operating costs required to meet the regulations.

Computer simulation, specifically computational fluid dynamics (CFD), is playing a key role by accurately simulating the mercury capture process so that equipment design and operating parameters can be optimized to improve its efficiency.

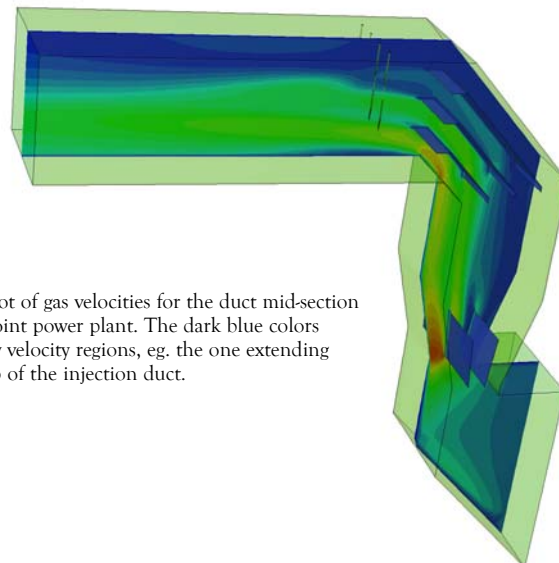
ADA-ES has recently demonstrated the ability of CFD to accurately simulate several key field tests. The diagnostic information provided by simulation made it possible to obtain a much deeper understanding of why the configurations used in the tests performed as they did and suggested several possible areas of improvement.

On March 15, 2005 the Environmental Protection Agency (EPA) issued the Clean Air Mercury Rule to permanently cap and reduce mercury emissions from coal-fired power plants for the first time. The Clean Air Mercury Rule will build on EPA's Clean Air Interstate Rule (CAIR) to significantly reduce emissions from coal-fired power plants, the largest remaining sources of mercury emissions in the country.

Approximately 75 tons of mercury are found in the coal delivered to power plants each year and about two thirds of this mercury is emitted to the air, resulting in about 50 tons being emitted annually.

This 25-ton reduction is currently being achieved in power plant boilers and through existing pollution controls such as fabric filters (FFs) for particulate matter, scrubbers for SO₂, and selective catalytic reduction (SCR) systems for NO_x.

When fully implemented, the new rules will reduce utility emissions of mercury to 15 tons, a reduction of about 70 percent. In addition to relying on existing technologies, several mercury-specific control technologies are in various stages of development, testing, and demonstration. Currently none of these technologies is in commercial operation in power plants in the U.S., but they are expected



A contour plot of gas velocities for the duct mid-section at Brayton Point power plant. The dark blue colors represent low velocity regions, eg. the one extending along the top of the injection duct.

to play a role as the EPA and states require further reductions in mercury emissions in the years to come.

Sorbent injection is proven technology for mercury capture

Injecting a sorbent such as PAC into the flue gas represents one of the simplest and most mature approaches to controlling mercury emissions from coal-fired boilers. Sorbent injection captures both elemental and oxidized mercury and is effective on both bituminous and subbituminous coals, so it is applicable to a large number of units. It requires capital equipment of under \$1 million and can be installed without a plant outage. Operating costs, primary the cost of PAC, are significant, however.

The mercury vapor in the flue gas contacts the sorbent and attaches to its surface. The sorbent is then collected by the existing particle control device - either an electrostatic precipitator (ESP) or fabric filter. The collected material, consisting of 99% fly ash and 1% sorbent, is then either disposed of or beneficially used.

Because a FF provides better contact with the sorbent particles than an ESP, higher levels of mercury removal can be achieved at lower sorbent rates on units with a fabric filter device. However, more than 80% of U.S. coal-fired units use an ESP for particulate control.

During the sorbent injection process, vapor phase mercury compounds migrate to the large internal surfaces of sorbent particles and then react with the sorbent. This is a mass transfer process in which the rate-limiting step is the movement of the mercury molecules to the solid surfaces.

To maximize mercury capture, the distance between the solid particles has to be minimized, so an even distribution of the sorbent across the flue gas stream is critical. CFD offers the potential to improve sorbent distribution by allowing engineers to quickly evaluate different configurations and get a much better understanding of why a particular configuration performs the way it does.

This is because computational modeling can provide detailed information on flue gas flow, sorbent distribution in the flue gas duct, sorbent residence times, and where the capture takes place. This

information provides practical information that helps improve the understanding of mass transfer limitations at the duct and particle scale, predict necessary sorbent feed rates, and optimize injection systems.

Challenge of modeling sorbent injection

Modeling mercury capture through sorbent injection, however, is a challenging task that has only recently been successfully accomplished. Mercury capture is simulated using a process that begins with Lagrangian tracking of the sorbent particles.

The sorbent particle trajectories are calculated step-wise by integrating the relevant forces on the particles, including drag and gravity. The gaseous mercury concentration profile in the flue gas is solved separately using a set of transport equations.

These two calculations are coupled together for mass and momentum exchange. The amount of mercury adsorption is calculated based on the sorbent trajectories, which determine the sorbent's exposure to the mercury vapors. Mercury adsorption involves three steps.

First, the gas phase mercury adheres to the external surface of the sorbent. Second, the mercury undergoes diffusion mass transfer to the interior of the sorbent particle where third, it is physically/chemically absorbed. During

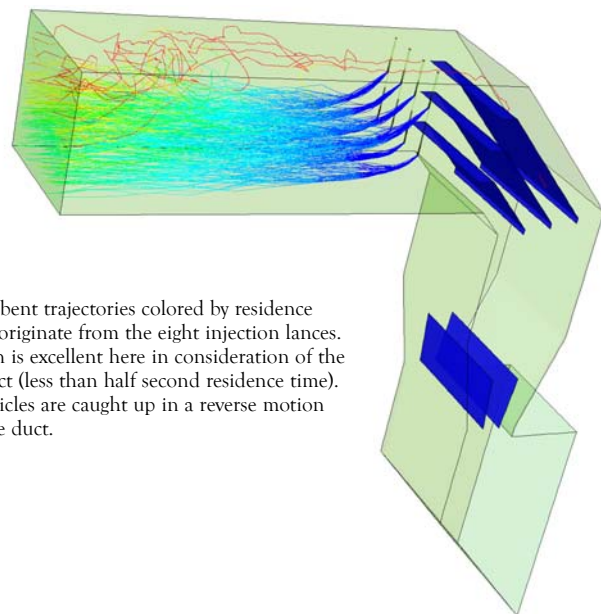
the adsorption process, the mercury field is depleted, and this reduction in mercury is accounted for during the next round of gas phase calculations. The trajectories are recomputed, and the new mercury concentration field is again coupled to the new trajectories. This process is repeated until convergence is reached.

ADA-ES recently worked with consultants at Fluent, Inc. to simulate field tests of sorbent injection at Brayton Point Power Plant in Somerset, Massachusetts. Activated carbon sorbent was injected using a set of eight lances upstream of the second of two ESPs.

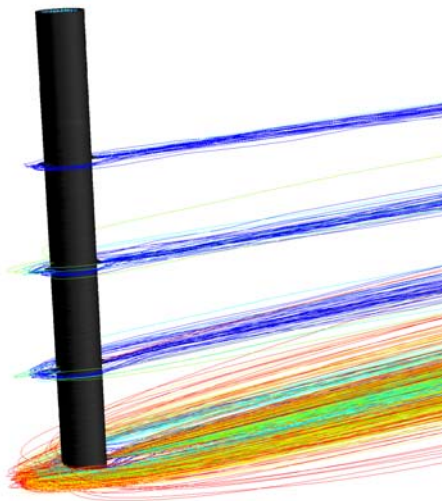
Fluent consultants created a model of the ductwork and injection lances with 350,000 cells. The simulation results showed that the flue gas flow was poorly distributed at the sorbent injection plane, and that a small region of reverse flow occurred, a result of the flow pattern at the exit of the first ESP. The results also illustrated that the flow was predominantly in the lower half of the duct, and affected by some upstream turning vanes.

Modeling the sorbent and lances

The Brayton Point field tests used Darco FGD sorbent with a mean diameter of 18 μm . The sorbent was modeled in the CFD analysis by a Rosin-Rammler distribution of ten particle sizes with different flow rates. The results showed that the larger particles travel in bands across the lower part of the duct because



Representative sorbent trajectories colored by residence time. Trajectories originate from the eight injection lances. Sorbent dispersion is excellent here in consideration of the relatively short duct (less than half second residence time). Some smaller particles are caught up in a reverse motion near the top of the duct.



In this simulation, the interior lance flow was included in order to determine a split of sorbent flow between the eight nozzles (four pairs at different depths). The trajectories are colored by size, with red indicating the largest particles. Most sorbent (~90%) exits the lower set of nozzles. Notice that to provide a meaningful plot, the lance diameter was scaled up by a factor of ten. In reality the lance is much more slender than what this image would lead one to believe.

of their higher inertia. The smaller particles showed a more diffuse motion, with some particles being caught in the reverse flow. The average residence time of the sorbent particles was estimated at 0.45 seconds based on plug-flow conditions.

However, the CFD simulations showed that as a result of the skewed velocity distribution, the actual mean sorbent residence time was only on the

range of 0.25 seconds. In spite of this, ADA-ES measured excellent mercury capture efficiencies of up to 90%. CFD simulations revealed that this success was promoted by uniform sorbent dispersion because of a very high degree of turbulent mixing in the injection duct.

Two different injection lances, a multi-nozzle and a single nozzle design, were evaluated in the Brayton Point tests. The multi-nozzle lance is a slender cylinder with a capped-off end. Eight holes (four pairs) of holes drilled perpendicular to the cylinder axis of revolution served as the nozzles.

Sorbent and a small amount of carrier gas are fed through the inside of the cylinder to these nozzle openings. The tests showed an insignificant difference in performance between the single and multi-nozzle designs, which was surprising since the designers of the nozzles expected the multi-nozzle design to provide superior performance.

The CFD simulation explained that the gas flow is almost evenly distributed around the eight holes of the multi-nozzle lance, while the vast majority (>90%) of sorbent exits from the lowest set of holes. The simulation showed that this is because the bigger particles have too much momentum to make the curve required to exit at the other nozzle openings. The fine particles (under 1 μm diameter) were shown to be much more evenly partitioned among the different nozzles.

The results of the simulations of the Brayton Point tests closely matched the

results of the tests themselves. These simulations clearly demonstrated the value of CFD as a diagnostic tool.

The simulations were performed in a fraction of the time and cost required for the physical tests yet provided far more diagnostic information, such as the distribution of mercury and sorbent at each point in the computational domain. Expectations are that future commercial bids for sorbent injection will include a CFD model of the ductwork in order to optimize the efficiency of mercury removal and minimize sorbent expenses.

A typical 300 megawatt power plant will require between \$1 and \$2 million of sorbent per year and CFD simulation can be expected to reduce that number by about 20%. Cost reductions of this magnitude will substantially reduce the costs of complying with the new mercury reduction regulations. ■

This project was supported in part by the US Department of Energy's National Energy Technology Laboratory (DOE/NETL).