PREDICTION OF SO_2 REMOVAL FOR POWER PLANTS USING INDUCT INJECTION OF LIME SLURRY

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More than half of SO_2 emissions in the United States come from older coal- fired power plants that have no scrubbers or other devices for SO_2 removal. Pending legislation may require at least 50 percent SO_2 reduction, but it would be difficult to retrofit many of these older plants with large scrubbers of the type used for new plants. Induct injection of lime slurry is a promising method for achieving moderate SO_2 removal by simply spraying lime slurry into the flue gas between the air preheater and the solids collection equipment. The SO_2 is absorbed and neutralized in the short time that it takes for the drops to evaporate, and the nearly dry solids are collected with the fly ash in the existing electrostatic precipitator or baghouse. A flow diagram is shown in Figure 1.

Simple Model for SO_2 Removal

Several studies of induct sorbent injection were recently carried out in pilot units using a slipstream of flue gas from an operating coal-fired utility boiler (Murphy and Samuel, 1988; Murphy et al., 1988; Drummond and Babu, 1988). Extent of SO_2 removal depends on the approach to adiabatic saturation temperature of the flue gas and on parameters describing the reaction of lime and SO_2. The results were correlated using a simple model based on the fundamentals of mass and heat transfer to and within the drops plus some empirical factors (Harriott, 1989a). The equation for fractional removal of SO_2 is:

$$E_{SO_2} = 1 - e^{-x} \quad (1)$$

where

$$X = \frac{A(SR)}{B+SR} \ln \frac{T_{in} - T_{as}}{T_{out} - T_{as}} \quad (2)$$

SR = stoichiometric ratio = $Ca(OH)_2/SO_2$ (molar)

T_{AS}= adiabatic saturation temperature, °F

The factors A and B were obtained by fitting the data and depend on the type of lime and the SO_2 concentration in the gas. A value of A = 1.25 was found for calcitic lime. Based on limited data, B was found to depend on the SO_2 content of the entering flue gas and was correlated as:

$$B = 0.05\ (\text{ppm } SO_2)^{0.5} \quad (3)$$

The predicted SO_2 removal for different values of SR, T_{in}, and (T_{out} - T_{as}) for 1600 ppm SO_2 is shown in Figure 2.

For given inlet conditions, the SO_2 removal can be improved by increasing the stoichiometric ratio or by decreasing the approach to the saturation temperature. However, too close an approach will lead to incomplete drying and deposition of wet solids in the duct or the particulate collection device. Plants that have long ducts or low flue gas velocities to give 2-3 seconds residence time in the longest straight duct could operate with a close approach to saturation and achieve good SO_2 removal with moderate excess of lime. Plants with less than 1 second residence time in a straight length of duct would have to use a larger approach to insure dry solid at the exit and might not get 50% SO_2 removal even with a large excess of lime.

Duct Survey and FORTRAN Program for Utility Boilers

Data on duct dimensions, flue gas velocities, and gas temperatures are available for 316 utility boilers in a Duct Survey data base at PETC (Sarkus and Henzel, 1988). The units surveyed have capacities of at least 50 MWe and SO_2 emissions of 1.8 lb SO_2/MM Btu or greater and are less than 35 years old. Further information on the size rating of the boilers, the coal used, and the coal properties are contained in the ORACLE data base at PETC. This information was used along with the simple model (Equations 1-3) to develop a FORTRAN program for predicting the expected SO_2 removal for each boiler in the survey at different operating conditions and stoichiometric ratios.

A key part of the computation is estimating the permissible approach to saturation. A typical spray was assumed to have a surface mean droplet size of 30 microns and a maximum size of 70 microns. The calculated drying times based on plug flow of gas and zero slip was correlated with the equations:

$$t_{dry} = \frac{60\ F_D\ F_S}{\Delta\ T_{lm}} \quad (4)$$

where

$$F_D = 1 + 0.05\ \frac{(T_{in} - T_{as})}{(T_{out} - T_{as})} \quad (5)$$

$$F_S = \left(\frac{d_{max}}{70}\right)^2 \quad (6)$$

and T_{lm} is the log mean temperature difference between the spray and flue gas at the beginning and end of the straight length of duct. The factor F_D allows for the effect of drop size distribution, which makes the largest drops evaporate more slowly than they would in a monodispersion (Harriott, 1989b). The factor F_S is used if the largest drop size is greater than 70 microns.

The first step in the program is the calculation of the approximate gas residence time based on the inlet velocity and the longest straight duct length. Space in the straight duct required for atomization equipment is neglected, and the complete gas residence time is assumed to be available for droplet drying. Then the outlet gas temperature is calculated by trial to make the drying time from Eq. (4) match the residence time. The approach to saturation is specified to be at least 20 F^o to insure that the particles are dry enough to prevent sticking on the duct walls. The closest approach to adiabatic saturation that will yield stable operation is yet to be firmly established in full scale operation. The amount of water to be added is then determined by a heat balance. The Ca/S ratio is set at arbitrary values such as 1.5 or 1.8 and the SO_2 removal calculated, or the SO_2 removal is fixed and the Ca/S ratio determined.

Results for Normal and Part-Load Operation

The distribution of residence times in the longest straight duct at full load for the boilers in the survey is shown in Figure 3. Residence time for most boilers falls in the range 0.4 - 1.6 seconds. The projected SO_2 removals for a few plants with residence times ranging from 0.40 - 1.98 seconds at full load are given in Table 1. Over 50% SO_2 removal is possible at SR = 1.8 except for the two plants with the lowest residence times.

To illustrate how SO_2 removal depends on some of the independent variables, a typical boiler has been chosen as a baseline for a process variable study. The boiler chosen, at the Genoa Station in Wisconsin, has a capacity of 350 MWe and a straight duct residence time of 0.60 seconds at full load. Its flue gas contains about 1395 ppm SO_2. The effect of residence time on SO_2 is shown in Figure 4, where the residence time at Genoa Station is treated as if it were an independent variable. The calculations have been performed such that the maximum amount of water was injected subject to the drying conditions and minimal allowable approach to adiabatic saturation described above. It is seen that for all stoichiometries considered, the SO_2 removal would increase significantly at Genoa Station if the duct residence time were increased from 0.60 s to about 1.0 s. The increased removal is due not only to longer reaction time, but also to a closer approach to saturation that is possible with the longer drying time. For times above about 1.2 s little additional SO_2 removal is predicted. This is because the system at 1.2 s residence time is already operating at the closest approach to saturation permitted, and the model predicts little further reaction with almost dry lime particles.

The importance of the approach to saturation is further illustrated in Table 2, where the effect of operating under reduced load conditions is shown for the Genoa Station. Operation of a boiler at part load increases the gas residence time but decreases the gas temperature at the injection point. The increased gas residence time permits operation at a closer approach to adiabatic saturation as well as providing longer reaction time. Both effects improve SO_2 removal. Compared to full load, operation at 80% load is predicted to increase the SO_2 removal by 7 percent absolute.

The increase in SO_2 removal with decreasing approach to saturation is similar to that observed in the dry scrubbing process, where flue gas is contacted with lime slurry in a spray dryer. However, the contact time in the spray dryer is about 10 seconds, in contrast to the typical residence times of 0.5-2 seconds in the duct. When the residence time in the duct is sufficient to allow a 20 F° approach to saturation, the predicted SO_2 removal is still less than that reported for a spray dryer. The difference is probably caused by additional SO_2 absorption in the almost dry solid during the last 8-9 seconds of residence time.

Total Emissions Reduction

The 316 power plant boilers in the survey data base have a total capacity of 85,400 MWe and had uncontrolled emissions of 7.9

million tons SO_2/year in 1985. Using induct injection of lime slurry at Ca/S = 1.8, the model was used to estimate SO_2 removal in each boiler. The total SO_2 removed is computed to be 4.7 million tons/year for an average removal of 57 percent.

The predictions given here are estimates based on limited data. A more thorough laboratory, pilot-plant, and modeling study of the induct process is now being carried out under DOE sponsorship, and a design handbook for the process will be prepared. However, the simple model used here, with corrections to fit current data, may still be useful for quick comparisons or for predicting the effects of changes in plant operation on SO_2 removal.

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TABLE 1

Predicted SO2 Removal for Selected Plants at SR= 1.8

Station	MWe	PPM	Tin °F	Tout-Tas °F	t sec	ESO2 %
Gibson	668	1874	320	51	0.68	53
Hutsonville	81	1927	300	48	0.73	52
JM Stuart	610	1032	286	29	1.00	70
Joppa	183	1337	320	84	0.50	40
JP Pullian	125	1526	350	108	0.40	34
Lansing	36	2165	305	40	0.77	58
New Castle	105	1006	256	20	1.98	72

TABLE 2

SO_2 REMOVAL EFFICIENCY AT REDUCED FIRING RATES*

Firing Rate	Inlet Temp °F	Residence Time, Sec	Approach to TAS °F	SO_2 Removal Efficiency %
Full	360	0.6	54	54
80%	348**	0.75	37	61
50%	330	1.2	20	71

Notes:

*SO_2 Concentration 1395 PPM, Ca/S Ratio = 1.4.

**Estimated Values

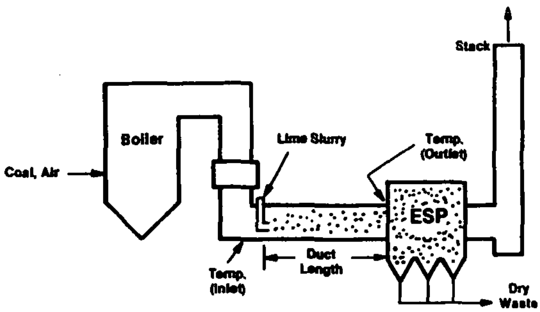

FIGURE 1. INDUCT LIME SLURRY INJECTION PROCESS FLOW DIAGRAM.

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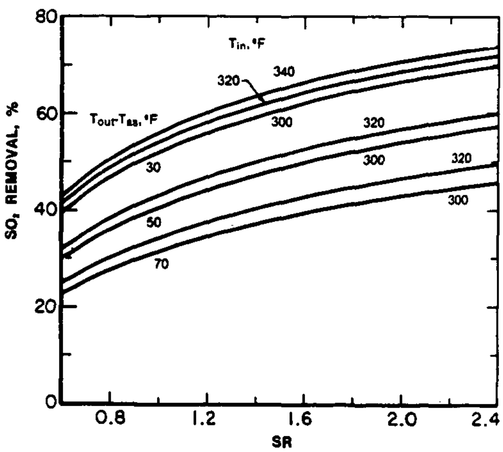

Figure 2. Dependence of SO_2 Removal on Stoichiometric Ratio.

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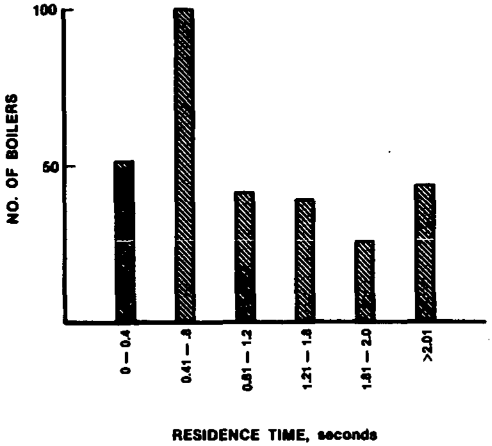

Figure 3. Residence Times in Longest Straight Duct at Full Load for Survey Data.

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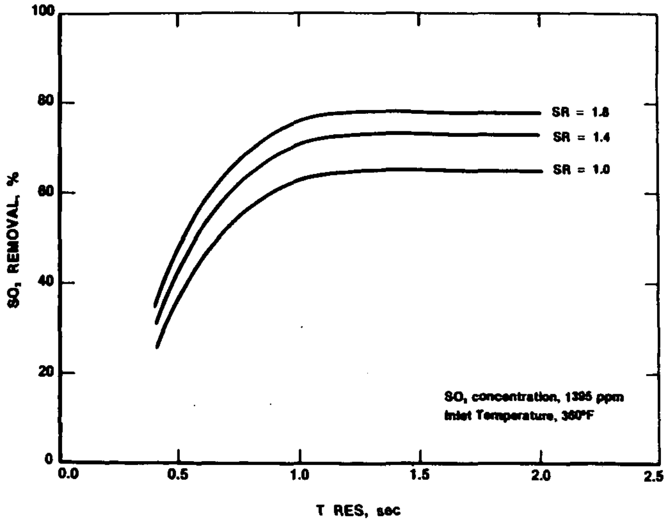

Figure 4. Dependence of SO_2 Removal on Residence Time.

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