SULFURIC ACID AEROSOL FORMATION AND DISTRIBUTION IN A TWO-STAGE CONDENSING ECONOMIZER

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INTRODUCTION

The Integrated Flue Gas Treatment (IFGT) condensing economizer system was developed into a commercial product for increasing thermal efficiency and reducing pollutant emissions. A small- scale and a pilot- sized unit have been tested to characterize the pollutant removal efficiency of the IFGT for flue gas from the combustion of oil, coal, and Orimulsion®.

The IFGT consists of two heat exchanger sections separated by a transition plenum. To avoid corrosion, normally experienced in the condensing flue gas environment, all surfaces exposed to flue gas are covered with Teflon®. Flue gas flows down through the first heat exchanger section and is cooled to about the dew point of the water vapor. This gas then passes through the transition plenum and upward through the second heat exchanger tube bundle where mostly latent heat is recovered. Feed-water flows through the copper-nickel tubes where it is preheated. At BNL a small-scale prototype two-stage unit which is sized for a firing rate of 300 kW (1,000,000 Btu/hr), is being used to study particulate capture and the potential role of sulfuric acid formation in the measured overall particulate capture and removal as a function of particle size. If acid is very important in measured capture then it may be necessary to operate the IFGT in ways to address acid specifically to achiever higher performance levels. Data also has been obtained from samples generated at McDermott Technology Inc.'s ISGT facility which fired coal and Orimulsion®.

SULFURIC ACID FORMATION/MEASUREMENTS

With the BNL prototype unit, cooling water enters the heat exchanger at 15°C (60°F) and leaves the second stage at about 40 °C (104 °F). Flue gas enters the IFGT at 200 °C (392°F) and exits the second stage at about 22 °C (72 °F). The water vapor content at the inlet and outlet of the IFGT are typically 9% and 3%, respectively. For measured sulfuric acid concentrations on the order of 1 ppm at the inlet to the IFGT, the calculated acid dew point temperature is about 110 °C (230 °F). Conditions in the IFGT favor the condensation of water vapor directly on the tubes. Acid, however, can reach supersaturated conditions in the gas leading to homogeneous aerosol formation and/or condensation directly on particulates.

Sampling and analysis for sulfuric acid was conducted using two different methods, the standard EPA Method 8 with a heated glass fiber filter, for dust capture, between the probe and the first impinger containing the alcohol solution for the capture of sulfuric acid; and the controlled condensation system (CCS).

Test runs from the BNL prototype IFGT were made with No.2/No. 6 distillate oil blend. Sulfur content was raised from a 0.25% by wt., typical for these heating oils, to 1% S by adding t-butyl disulfide. "Low" and "high" sulfur blends were tested to evaluate the effects of fuel sulfur content on sulfuric acid concentrations in the stack, and on the particle size distribution and removal. The filter used to measure total particulates (TSP), under Method 5, was analyzed to determine the relative contributions of sulfuric acid and total soluble sulfates. The total sulfates include metal sulfates and acid that are soluble in water.

Samples also were obtained from a 1800 kW combustor located at McDermott Technology Inc. that was capable of firing coal and Orimulsion.   The sulfur content for the Ohio bituminous coal blend tested and Orimulsion are 3.9% and 2.84%, respectively. The Orimulsion fuel is an emulsion of bitumen and water (28.3%). Particle size distribution was determined using a cascade impactor (Anderson, eight-stage unit). Total sulfates were determined for each stage using ion chromatography.

EXPERIMENTAL RESULTS/DISCUSSION

The results of a preliminary analysis of a TSP filter sampled at the outlet of the IFGT from burning of a distillate/residual oil blend are shown in Table 1. Test 1 was done specifically to measure sulfates; Test two was done to measure acid.

	Test 1 Total Sulfates	Test 2 Sulfuric Acid
Total suspended particulates (TSP), mg/Nm3	17.9	8.2
Stack O2, % dry	8.8	8.9
Total sulfates on a filter, mg/Nm3	2.0	----
Ratio of total sulfates/ TSP	0.11	----
Sulfuric acid on filter, mg/Nm3	----	0.70
Ratio of acid/TSP	----	0.08
Flue gas concentration of acid from filter catch, ppm	----	0.17

Table 1. Analysis of Components of Method 5 (Total Suspended Particulates) Filter

About 11% of the total mass that is accounted for as particulate matter is in the form of total sulfates, in which acid is the major constituent. Prior measurements of the flue gas at the outlet of the IFGT using this same fuel blend showed that the acid concentration is about 0.3 ppm. Test 2, above, indicates that roughly half the amount of acid in the stack, 0.17 ppm, is measured as total particulates.   This seems to indicate that to improve the performance of the IFGT with respect to total particulate removal the control of acid also needs to be considered.

Tables 2 and 3 show the total sulfates on a stage-by-stage basis from the cascade impactor for coal and Orimulsion®. In general, total sulfates, which includes acid, contribute significantly with respect to total particulates. In the case of the Orimulsion® these sulfates are present in relatively large amounts on all stages for both inlet and outlet. For coal, at the IFGT inlet, it seems that sulfates play a greater role with fines smaller than 0.71 µm; at the IFGT outlet sulfates contribute to all stages.

CONCLUSIONS

The current study focuses on several key factors: the fate of sulfates in flue gas from combustion of oil, coal, and Orimulsion, its role in the measurement of total particulate matter, formation of acid aerosols as it passes through a two-stage condensing economizer and the potential for improved particulate removal efficiency in an IFGT designed specifically for pollutant removal. Preliminary measurements thus far indicate that sulfuric acid contributes significantly to TSP measurements. Because the BNL boiler is so small and is operated with low metal surface temperatures, the acid levels achieved were much lower than is typical for industrial and utility boilers. With higher acid levels the acid contribution to measured particulates is expected to be more significant. Some additional tests are being planned with acid levels that are more typical in these systems by directly injecting sulfuric acid into the flue gas upstream of the IFGT. The IFGT has been operated with tube surface temperatures that are much lower than the dewpoint for the acid/water mixture in the flue gas. Acid aerosol can form under local supersaturated conditions between the surface and bulk gas. The strategy being considered is to operate the first stage of the IFGT with surface temperatures high enough to allow direct condensation on the tubes with no supersaturation and aerosol formation. As a result, increased acid condensation should improve overall particulate removal.

Coal blend - IFGT Inlet			Coal blend - IFGT Outlet		
50% Cut diameter, µm	Total Mass on Filter, mg	% of Total sulfate/ Total mass	50% Cut diameter, µm	Total Mass on Filter, mg	% of Total sulfate/ Total mass
8.75	7.3	6.4	9.03	0.6	55
5.42	8.2	5.8	5.6	0.4	69
3.64	12.4	5.3	3.77	0.5	69
2.45	9.4	6.4	2.55	1.4	26
1.54	14.5	4.3	1.61	4.4	12
0.71	3.4	16	0.76	5.2	13
0.4	0.6	84	0.44	2.3	50
0.22	0.8	69	0.26	3.3	41
Backup filter	2.8	41	Backup filter	2.0	41

Table 2. Analyses of Cascade Impactor Stages for Total Sulfates (Ohio Coal Blend)

Orimulsion - IFGT Inlet			Orimulsion - IFGT Outlet		
50% Cut diameter, µm	Total Mass on Filter, mg	% of Total sulfate/ Total mass	50% Cut diameter, µm	Total Mass on Filter, mg	% of Total sulfate/ Total mass
5.80	5.5	35	5.25	1.7	54
4.00	5.8	38	3.60	4.8	44
2.51	11.7	39	2.25	10.8	37
1.25	23.0	42	1.21	26.4	33
0.74	26.5	42	0.70	52.3	34
0.52	28.9	43	0.47	90.3	33
Backup filter	88.1	49	Backup filter	62.6	35

Table 3. Analyses of Cascade Impactor Stages for Total Sulfates (Orimulsion®)