

EPA PERFORMANCE TESTS FOR PARTICULATE AND SO<sub>2</sub>  
CONDUCTED AT THE DOE COAL-FIRED FLOW FACILITY

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**ABSTRACT**

Results of Environmental Protection Agency (EPA) performance tests conducted at the DOE's Coal Fired Flow Facility (CFFF) are reported. During 1989 a series of compliance tests for emissions of particulates and SO<sub>2</sub> were conducted under the supervision of the Tennessee Department of Health and Environment's Air Pollution Control Board using standard EPA methods. The CFFF met all compliance requirements for state permitting with mass emissions of approximately 0.05 pounds per million Btu (lb/MMBtu) and sulfur dioxide emissions averaging 0.5 lb/MMBtu. Current limits under state law allow for particulates and SO<sub>2</sub> emissions of 0.19 and 5.0 lb/MMBtu, respectively. Tougher federal New Source Performance Standards (NSPS) for SO<sub>2</sub> emissions were also met by the facility during compliance testing.

**BACKGROUND**

The Coal Fired Flow Facility is an open cycle Magnetohydrodynamics (MHD) test facility operated by the University of Tennessee Space Institute (UTSI) for the U.S.

Department of Energy. Primary objectives of testing at the CFFF include demonstration of the environmental acceptability of the MHD process. As a benchmark for achievement of the environmental objective, the meeting of NSPS limits for stack emissions of SO<sub>2</sub> and particulates is an established goal. Sulfur emission control is obtained by the addition of a sulfur-free potassium seed to the coal prior to combustion. The potassium combines with sulfur as SO<sub>2</sub> to form potassium sulfate in the furnace of the MHD system. Particulate control at the CFFF is completed by a system of a baghouse (BH) and a electrostatic precipitator (ESP) operating in parallel. This arrangement provides the unique opportunity to evaluate BH and ESP performance on an equivalent basis.

Another aspect of the CFFF operation is the compliance with current state regulations. The state of Tennessee specifically regulates air quality pertaining to facilities such as the CFFF in the areas of SO<sub>2</sub> and particulates. SO<sub>2</sub> emissions are limited to 5 lb/MMBtu, while particulate must remain below 0.19 lb/MMBtu of heat input.

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Facility Description

The CFFF Low Mass Flow configuration operates on a heat input of approximately 20 MW, (Figure 1). Coal seeded with potassium carbonate is introduced into the primary combustor system along with vitiated oxidant. In order to simulate 50 % ash rejection in the combustor, approximately one-half of the thermal input is received from #2 fuel oil. After primary combustion at substoichiometric conditions, the resulting combustion gases flow through an aerodynamic channel to the diffuser section. Cooling for reduction of thermal NO<sub>x</sub> takes place in the primary furnace. At the secondary combustor, preheated air is introduced to complete combustion. The hot gases then flow through heat recovery devices in the superheater and air heater sections. In these downstream components, sulfur in the form of SO<sub>2</sub> combines with potassium from the seed material to form potassium sulfate (K<sub>2</sub>SO<sub>4</sub>), thus removing

a large portion of the SO<sub>2</sub>. In addition to the BH and ESP, a venturi scrubber/cyclone system is also utilized when the BH or ESP are inoperable. The relatively particulate free gases are then exhausted to the stack via an induced draft (ID) fan.

Sampling points for the purpose of particulate control evaluation are located at four points along the CFFF test train. The inlet to the BH and ESP systems (location #1) provides a baseline sample for comparison with outlet samples. The BH and ESP sampling locations (#2 and #3) provide an opportunity to evaluate particulate collection efficiencies for each device independently. The ID fan sampling location (#4) is primarily used as an indication of the stack emissions and therefore is used for compliance testing. Such compliance testing is an evaluation of the total facility performance and is not representative of individual device performance. Sampling at this location

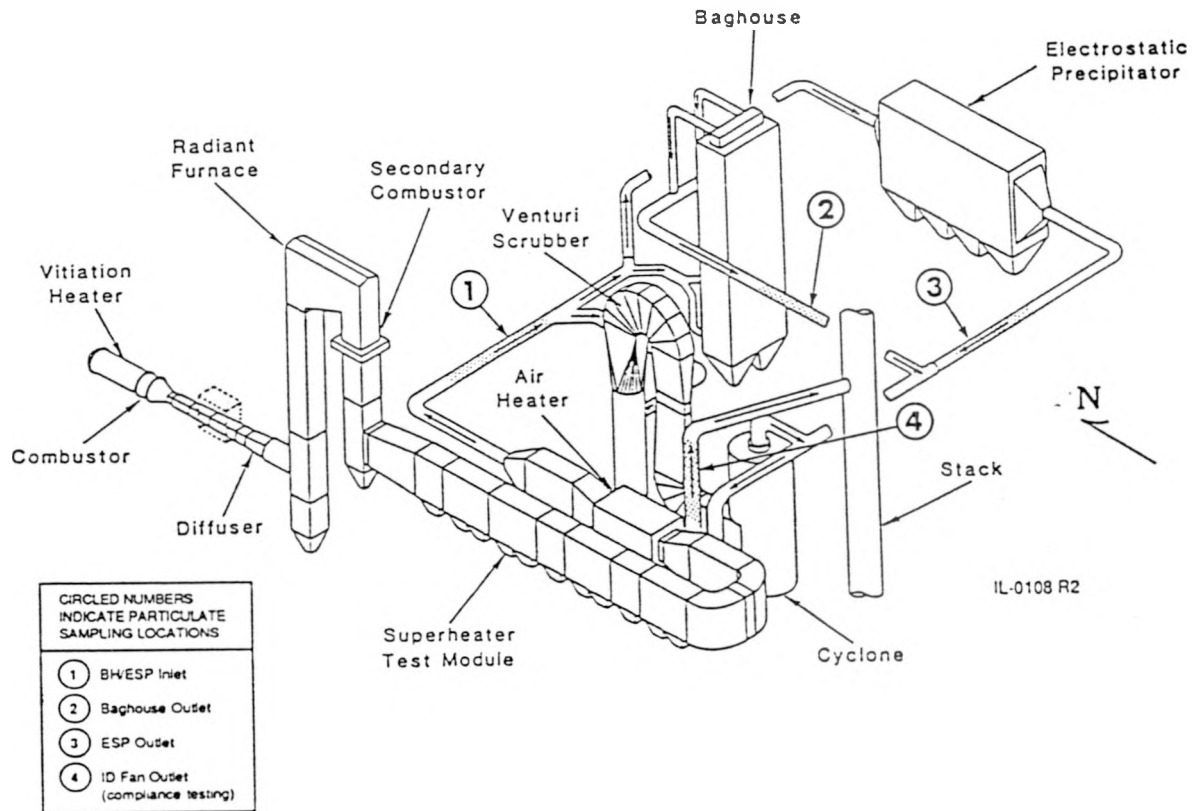


Figure 1 Current CFFF Configuration with Sampling Locations

also accounts for any gas flow diverted through the venturi/cyclone system which normally operates at a lower than acceptable collection efficiency.

#### State of Tennessee Permit Requirements

Under current state law, the CFFF is required to obtain permits for all operations which affect environmental quality. Permitted activities include water, air, and solid waste disposal. Air quality is specifically regulated by the Tennessee Air Pollution Control Division (TAPCD). As a condition of the current permit issued by the TAPCD, UTSI was required to demonstrate compliance for emissions components covered by the permit after the completion of two 100 hour continuous on-coal tests. The permit specifically regulates particulate emissions (under Chapter 1200-3-6 of the Tennessee Air Pollution Regulations) and SO<sub>2</sub> emissions (Chapter 1200-3-14). The permit does not regulate emissions of nitrogen oxides (NO<sub>x</sub>) since the CFFF received a rating as a small boiler.

Having completed two continuous 100 hour runs (designated tests LMF4-O and LMF4-P), compliance tests were scheduled to be conducted during the remaining tests of FY 1989. During tests LMF4-R and LMF4-S, the staff of UTSI successfully completed these compliance tests to the satisfaction of TAPCD personnel.

#### New Source Performance Standards

Under the 1970 Clean Air Act and subsequent amendments, the federal government established a series of minimum standards which must be met in order for a new or modified facility to operate. These standards, known as New Source Performance Standards (NSPS), are an attempt to maintain air quality at current levels and provide meaningful improvement as pre-1970 operations are retired or updated and replaced by NSPS-specific operations. Common practice in establishing NSPS limits is to set levels at the maximum degree of emission control possible using the best available control technology. For steam electric power plants, NSPS limits have been established since 1971 with significant revisions being made

in 1980. Under current NSPS limits, a steam plant firing bituminous coal (Illinois #6 used by the CFFF) requires a 90 % reduction in sulfur emissions resulting in an upper limit of 0.6 lb/MMBtu at the stack. Similarly, particulate emissions are limited to 0.03 lb/MMBtu of heat input. In addition, the standard limits stack opacity to 20 percent for a 6-minute average.

### **EPA METHODS AND TESTING**

#### Method Descriptions

Particulate emissions compliance tests were performed using the EPA Method 17 flow train. The Method 17 flow train consists of a stainless steel nozzle, primary filter, backup filter, and probe assembly attached to a modular sample case (see Figure 2). The sample case contains glass tubing (used to bypass the heated filtration part of the sample box used in Method 5) and four 250 ml impingers. The impingers are held in an ice bath and are used to extract moisture from the process gas. The first two impingers contain 100 ml of H<sub>2</sub>O, the third is empty, and the fourth contains 200 grams of silica gel. The dry gas then passes through an umbilical line to the control unit that contains a vacuum pump, dry gas meter, orifice, and two incline manometers. The vacuum pump pulls the combustion gas through the Method 17 flow train and the dry gas meter determines the volume of sampled gas. One incline manometer is connected to a probe-mounted, type-S pitot tube to determine the process gas velocity. The second incline manometer measures the orifice pressure drop which determines the isokinetic sample rate based on flue gas velocity. The Method 17 flow train withdraws the process gas isokinetically through the nozzle and collects the particulate material on an in-situ glass fiber filter. The particulate mass is determined gravimetrically after removal of uncombined water. Process gas mass loading, temperature, velocity, and moisture content can be determined by this method.

All SO<sub>2</sub> emissions tests were conducted using a standard EPA-approved modified Method 8 test train. The test train is identical to the Method 17 configuration except that the impingers contain chemicals to facilitate the

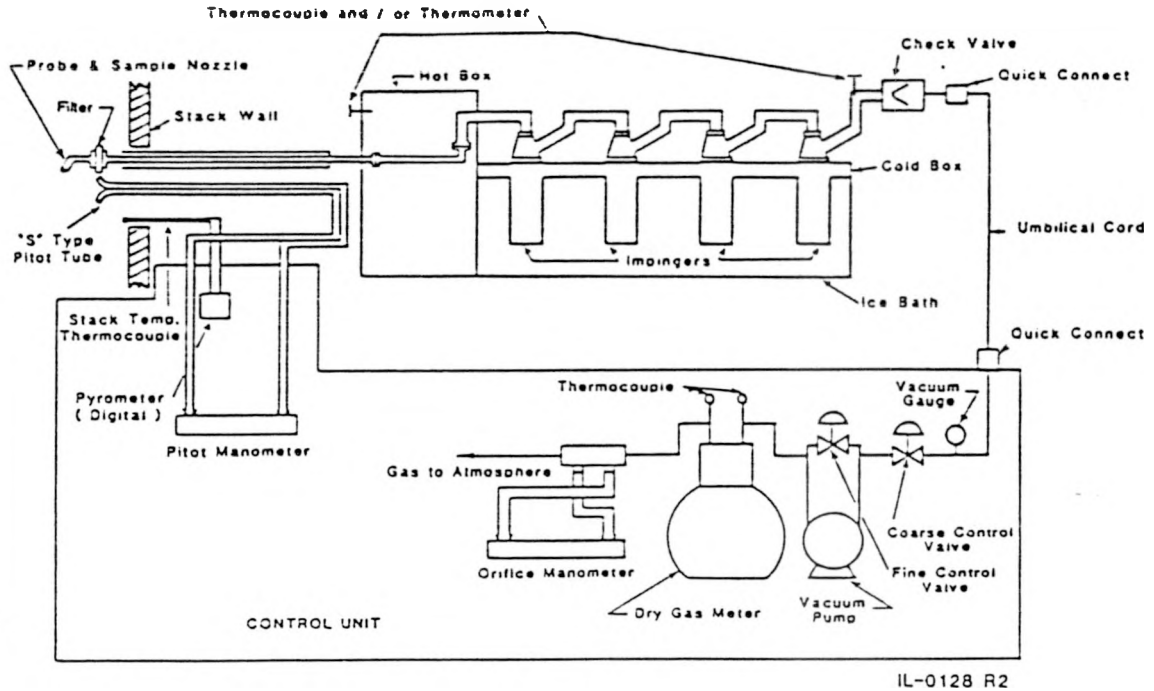


Figure 2 EPA Method 17 Test Train Schematic

removal of sulfur from the gas stream. Impinger #1 contains 100 ml of 80 % isopropanol for the removal of sulfuric acid mist in the form of  $\text{SO}_3$ . The next two impingers collect the sulfur dioxide in a 3% solution of hydrogen peroxide. The final impinger contains silica gel for removal of any remaining trace moisture. Recovery and analysis of the  $\text{SO}_2$  samples for sulfate content is accomplished by thorn titration against a known standard as required by the Method 8 procedure. During the recent CFFF tests, confirmation of the titration results was also obtained by use of ion chromatography. Continuous analyzers located downstream of the BH/ESP systems were also used to determine  $\text{SO}_2$  concentrations.

#### Sample Location

The emissions performance tests were conducted at the outlet ducting of the induced draft fan (Figure 3). Uniform gas flow was obtained by having a minimum of 7.5

duct diameters upstream and 3.6 diameters downstream of any flow disturbance. The sample ports were extended to allow the Method 17 filter assembly to remain in the duct while sampling near the duct wall.

#### Particulate Sampling Computer Code

The MHD flow train was controlled by computer while testing was in progress. Particulate sampling information as well as data on process conditions were provided by a Fortran computer code linked to the CFFF's data acquisition system. The computer code displayed process mass flows, barometric pressure, calculated wet and dry molecular weights, process gas composition, and average duct velocities, process gas temperatures and duct pressures at three sampling locations. The program allowed the user to input a pitot tube reading and dry gas meter temperature and then calculated the correct Method 17 (or Method 8) sample rate using process information

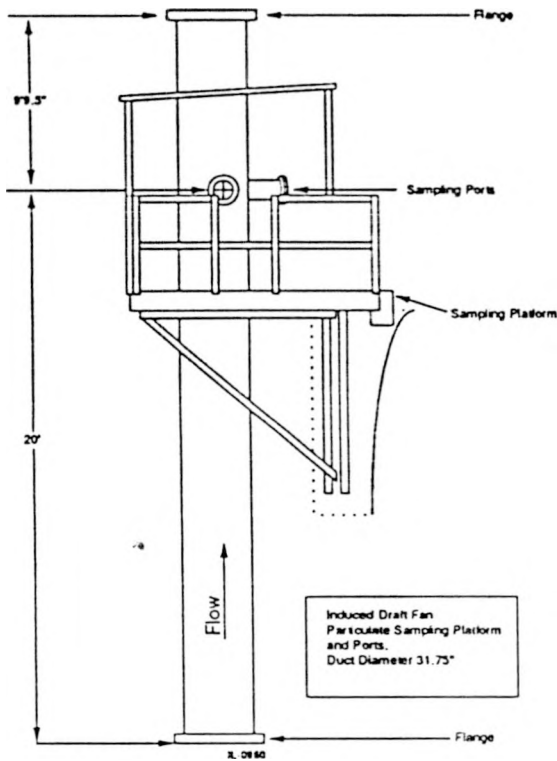


Figure 3 ID Fan Sampling Location

obtained from the data acquisition system. The use of this computer program gave particulate sampling technicians a greater degree of sampling accuracy than normally obtained using a stack sampling nomograph.

#### Equipment Calibration

The probe pitot tube, nozzle, all thermocouples, and the dry gas meter in the Method 17 control box were calibrated prior to the compliance test in accordance with EPA procedures. A post test calibration was also performed on the control box dry gas meter. All thermocouples were calibrated using a certified National Institute of Standards and Technology (NIST, formerly National Bureau of Standards) traceable digital thermometer calibrator. The pitot tubes were calibrated using EPA

Method 2 calibration procedures. The probe nozzle diameter was measured at four different cross-sections and the average nozzle diameter was used.

#### Sampling Procedures

Five Method 17 tests were conducted during LMF4-R at the ID fan outlet sampling location. The duct was divided into three equal areas with two sampling points in each area (Figure 4). The sample location has two ports at 90 degrees to each other that were perpendicular to the gas flow. Each test consisted of two parts. Part one of a typical test would include sampling in the first port at each sample location for six minutes (a total of 36 minutes). At the conclusion of the 36 minute sample period, the probe was removed from the duct and a leak check was performed. The time required to assemble the flow train, take the sample at one port, and leak check was approximately 1 hour. Subsequently, the flow train was disassembled and relocated in the second port. Sampling continued until all points were completed. When sampling was completed at the second port, the flow train was removed from the duct and leak checked for the final time and taken to the laboratory for sample recovery. The leak check procedure consisted of plugging the nozzle and pulling a vacuum of 15 inches of Hg. Any leak greater than two hundredths of a cubic foot during a 60 second period

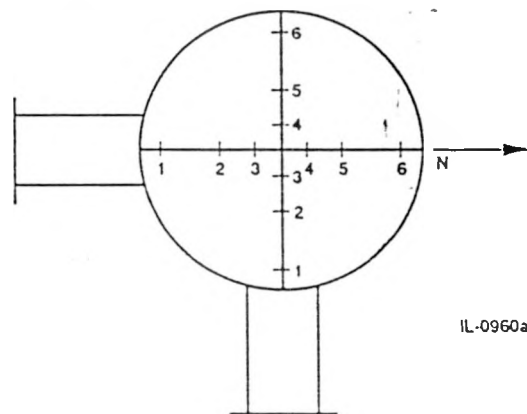


Figure 4 Sampling Port Schematic

would disqualify the test. All laboratory procedures were also in accordance with EPA Stationary Source Sampling Method 17.

Six tests were conducted for the required SO<sub>2</sub> compliance during LMF4-S. The sampling procedure was identical to the Method 17 tests except that the sampling time was reduced to only 20 minutes. Alternate tests were conducted at the south and east ports with the probe positioned in the center of the duct. After completion of each test, the system was checked for leaks as previously described. The contents of each impinger were recovered for chemical analysis by standard EPA Method 8 procedures.

During SO<sub>2</sub> compliance testing confirmation of emission results was obtained by operation of on-line gas sampling instrumentation. The instrumentation samples at the outlet of the BH/ESP upstream of the ID fan and provides analysis of all major gas components including CO<sub>2</sub>, O<sub>2</sub>, CO, SO<sub>2</sub>, and NO<sub>x</sub>.

## RESULTS

The results of particulate compliance test runs two through six are given in Table 1 and Figure 5. Run #1 of this series was not completed due to an equipment problem. Emissions for tests without a baghouse cleaning cycle generally ranged from 0.03 to 0.05 lb/MMBtu. While these values represent the upper limit of acceptability in terms of NSPS limits, particulate emissions were well below the allowable limit under the state permit. Several reasons can be cited for the reported emissions being higher NSPS guidelines. These include the non-optimized operation of the baghouse and ESP and particularly venturi/cyclone leakage. During testing the flow was split between the baghouse (6000 cubic feet per minute, wet at actual conditions) and ESP (8000 cfm) with no flow set through the venturi/cyclone system. The total gas flow was higher than would be anticipated from the flow train inputs. This can be accounted for in the form of leakage in the test train around the BH and ESP. Gas analysis data taken upstream of the BH and ESP compared with downstream data generally indicates a leak on the order of 10-15

percent. A significant leak such as this contributes to lower collection efficiencies in the BH and ESP due to the increased flow through the devices. Some leakage around the shut-off damper of venturi scrubber/cyclone system has also been identified. Any leakage around this damper would significantly increase particulate emissions since the CFFF venturi/cyclone is a relatively low efficiency collection device under these conditions.

TAPCD personnel required that one run of the particulate emissions tests (run #3) be conducted during a baghouse cleaning cycle. During normal CFFF operation, baghouse cleanings occur approximately every 100 minutes. The test LMF4-R averaged 14.2 cleaning cycles per day of approximately 8.1 minutes each. As expected, particulate emissions during run #3 were found to be slightly higher than other tests at 0.065 lb/MMBtu.

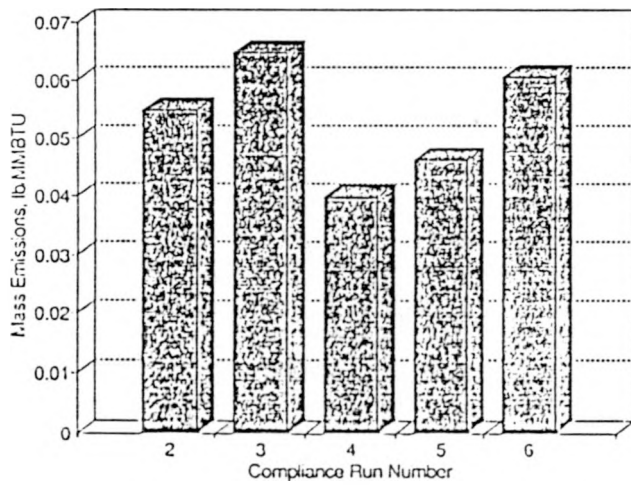
Results of SO<sub>2</sub> compliance tests are shown in Table 2. Run #1 was also not completed due to equipment problems with the sampling system. As given in Table 2, emission rates were well below the permit limit of 5.0 lb/MMBtu. The total potential to emit (PTE) of the CFFF during the compliance testing was calculated to be approximately 2.5 lb/MMBtu. This is based on the total sulfur input from fuel with a collection efficiency of zero percent. Therefore, emission rates from the CFFF cannot exceed the permit limits.

With exception of run #7, all values were also below tougher NSPS limits. The cause for the unusually high reading of run #7 could not be determined. However, it is believed that the sample was contaminated with a sulfur containing species prior to analysis. Due to the low concentrations of sulfate in the Method 8 titrate, a small amount of contaminant could have a large effect on the final value. Analyzer results (Table 3) further confirmed emissions rates, consistently ranging from 5-10 % lower than Method 8 measurements with exception of run #7. Figure 6 gives a comparison of the Method 8 and analyzer results.

**Table 1** Summary of Particulate Compliance Test Results by EPA Method 17

RUN NO.	SAMPLE TIME (min)	VOLUME OF DRY GAS (scf)	PROCESS GAS TEMP (°F)	MOISTURE (%)	FLUE GAS VELOCITY (ft/sec)	VOLUMETRIC WET FLOW RATE (acfm)	IN-DUCT PRESS. (in. Hg)	GRAIN LOADING (grain/dscf)	MASS LOADING (lb/MMBtu)
2	72	40.42	269	13.69	41.37	13648	29.27	0.047	0.0547
3*	72	41.17	258	14.46	42.18	13914	29.27	0.054	0.0647
4	72	40.00	263	14.54	41.33	13633	29.28	0.034	0.0398
5	72	41.33	267	13.71	41.33	13636	29.22	0.040	0.0461
6	72	38.72	265	14.08	42.33	13964	29.25	0.051	0.0605
AVERAGE								0.045	0.0532

\* This test contained a complete baghouse cleaning cycle.

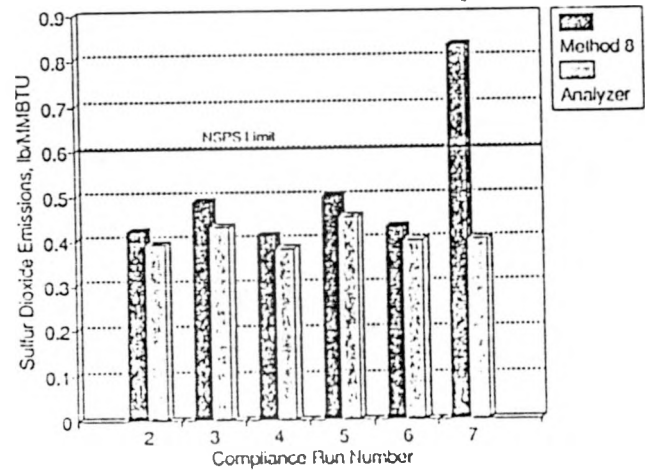


**Figure 5** Particulate Compliance Test Results

**CONCLUSIONS**

Recent tests resulted in the CFFF completing all requirements for compliance. Particulate emissions were

approximately 25 percent of the permit limit. Likewise, average SO<sub>2</sub> emissions were about 10 percent of permit limitations. The continued operation of the CFFF in an environmentally acceptable manner is therefore assured. Although the recent compliance test series indicated that the CFFF did not meet NSPS limits for particulates, a number of reasons can be cited. Prior tests at the BH and ESP outlets (excluding the venturi/cyclone system) have consistently shown that NSPS limits can be met. NSPS limits for sulfur dioxide emissions were met during the test series.



**Figure 6** Sulfur Dioxide Compliance Test Results

Table 2 Summary of SO<sub>2</sub> Compliance Test Results by EPA Method 8

Run No.	Dry Gas Flow (scfm)	SO <sub>2</sub> Concentration (lb/scf)	Heat Input Rate (MMBtu/min)	Emission Rate (lb/MMBtu)	Percentage of NSPS Limit (%)
2	11808.72	3.630 x 10 <sup>-5</sup>	61.03	0.4214	70.2
3	11733.87	4.215 x 10 <sup>-5</sup>	60.97	0.4867	81.1
4	11826.85	3.528 x 10 <sup>-5</sup>	60.92	0.4110	68.5
5	11754.60	4.300 x 10 <sup>-5</sup>	60.90	0.4980	83.0
6	11977.22	3.629 x 10 <sup>-5</sup>	60.59	0.4305	71.7
7	11983.92	7.014 x 10 <sup>-5</sup>	60.66	0.8314	138.6
AVERAGE				0.5132	74.9

Table 3 Method 8 Confirmation by Continuous Analyzer

Run No.	Analyzer SO <sub>2</sub> (ppm)	C <sub>SO<sub>2</sub></sub> by Analyzer (lb/dscf)	Flow at Analyzer (dscf/min)	Emission Rate by Analyzer (lb/MMBtu)	Relative Error (%)
2	263.90	4.304 x 10 <sup>-5</sup>	9309.87	0.3913	-6.51
3	288.50	4.705 x 10 <sup>-5</sup>	9378.82	0.4314	-10.78
4	243.84	3.977 x 10 <sup>-5</sup>	9784.39	0.3807	-6.75
5	291.18	4.749 x 10 <sup>-5</sup>	9744.05	0.4529	-8.45
6	256.01	4.175 x 10 <sup>-5</sup>	9663.44	0.3969	-7.17
7	257.77	4.204 x 10 <sup>-5</sup>	9646.03	0.3984	-51.75

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