A.2 VENTURI SCRUBBER FOR PM CONTROL–FACILITY B

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
VENTURI SCRUBBER FOR PM CONTROL--FACILITY B

I. Background

A. Emissions Unit

Description:	FCCU catalyst regenerator
Identification:	
Facility:	Facility B Anytown, USA

B. Applicable Regulation, Emission Limits, and Monitoring Requirements

Regulation No.:	40 CFR 60 Subpart J
Regulated pollutant:	Particulate matter
Emission limit (particulate matter):	1 lb/1,000 lb coke burned
Monitoring requirements:	Coke burn rate, air blower rate, number of venturis online (permit) [Note: Although Subpart J requires a COMS, this alternate monitoring approach was approved by the State permitting authority and is reflected in the facility's permit.]

C. Control Technology:

Four parallel venturi scrubbers

II. Monitoring Approach

The key elements of the monitoring approach for particulate matter, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.2-1.

TABLE A.2-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	Liquid to gas ratio	Scrubber exhaust temperature	Coke burn rate
Measurement Approach	Water flow–magnetic flowmeter. Air rate–venturi flowmeter. L/G calculated.	Scrubber exhaust temperature measured using a thermocouple.	Calculated using NSPS (§ 60.106) equation.
II. Indicator Range[a]	An excursion is defined as a 3-hour average liquid to gas ratio less than 8. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 3-hour average scrubber exhaust temperature greater than 165°F. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 3-hour average coke burn rate greater than 56,000 lb/hr. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[b]	The magnetic flow meter (minimum accuracy of ±1.0% of flow rate) is located in the water inlet line. The venturi flowmeter (minimum accuracy of ±0.75% of flow rate) is located in the gas inlet duct.	Thermocouple located at scrubber exhaust with a minimum accuracy of ±3°F.	Analyzers and monitors are located in the regenerator inlet and exhaust duct.
B. Verification of Operational Status	Not applicable	Not applicable	Not applicable
C. QA/QC Practices	Magnetic water flowmeter and venturi flowmeter–calibrated once/ 6 months.	Thermocouple–calibrated once/ 6 months.	Gas analyzers: per 60.13 and Appendix B of 40 CFR 60. Flowmeter, thermocouple, and pressure indicator–calibrated once/ 6 months.
D. Monitoring Frequency	Water flow and air rate are measured continuously.	Temperature is measured continuously.	O_2, CO, CO_2, air rate, off gas temperature and pressure are measured continuously.
Data Collection Procedure	L/G is calculated and recorded each minute.	Temperature is recorded each minute.	A coke burn rate is calculated and recorded each minute.
Averaging Period	3-hour average.	3-hour average.	3-hour average.

[a]An excursion of any single indicator triggers an inspection, corrective action, and a reporting requirement.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant specific emissions unit is particulate matter from the catalyst regenerator of a fluid catalytic cracking unit (FCCU). The catalyst regenerator is equipped with a wet gas scrubber. The catalyst regenerator exhaust gases pass through four parallel venturi scrubbers. These scrubbers are the primary control devices for particulate matter emissions. After passing through the scrubbers, the off gases pass through a separating vessel and a spray grid prior to being vented to the atmosphere. The emission unit is regulated under 40 CFR 60 Subpart J--NSPS for petroleum refineries. The monitoring approach is reflected as a specific permit condition in the air permit. Based on the pollutant specific emissions unit design, bypass of the control device is not possible.

II. Rationale for Selection of Performance Indicators

The following parameters will be monitored:

- Liquid-to-gas (L/G) ratio;
- Scrubber exhaust temperature; and
- Coke burn rate.

The licensor of the wet scrubber provided a graph relating the number of operating scrubbers required to maintain the design liquid to gas ratio, to the FCCU regenerator air blower rate. The regenerator air rate and the number of venturis in operation are an indirect measure of liquid to gas ratio, which is an indicator of scrubber performance. The regenerator air rate and the number of venturis in operation are monitored to ensure that these limitations are met.

Although the air permit only requires monitoring of coke burn rate, air blower rate, and number of venturis online, L/G ratio and scrubber exhaust temperature were added to the monitoring approach in early 1997 as further indicators of control device performance. The L/G ratio is determined by measuring scrubber water flow rate and comparing it to the regenerator air blower rate. In addition, the scrubber temperature is monitored downstream of the spray grid. The scrubber exhaust gas temperature was selected because it is indicative of scrubber operation and adequate water flow. With the scrubber water off, the scrubber exhaust temperature would be noticeably higher.

The coke burn rate is an indication of the PM loading to the scrubber.

III. Rationale for Selection of Indicator Ranges

As mentioned above, a graph relating the regenerator air blower rate to the number of venturis necessary to maintain the design L/G ratio, was provided by the licensor of the scrubber. This graph, presented in Figure A.2-1, shows that at regenerator air rates of less than 100 kscfm at least two scrubbers must be operating to maintain the design L/G ratio. At regenerator air rates of greater than or equal to 100 kscfm to less than 136 kscfm, at least three scrubbers must be operating. At air rates of greater than 136 kscfm all four scrubbers must be operating. The facility monitors the regenerator air rate and the number of venturis in operation to ensure that these limitations are met.

The indicator range for L/G ratio is based on results of a January 1996 performance test and historical data. Three 1-hr test runs were conducted and the average measured PM emissions were

0.78 lb PM/1,000 lb coke burned, which is below the 1 lb/1,000 lb PM emission limit. During the performance test, L/G ratio was measured and recorded continuously, concurrent with each of the 1-hour test runs. The average L/G ratio for the three 1-hour test runs was 7.1. Hourly L/G ratio data for a 3-month period (October through December 1996) following the performance test were reduced to three-hour averages and evaluated to determine whether the L/G ratio during normal operation was above the minimum level selected based on the January 1996 performance test demonstrating compliance. Figure A.2-2 graphically presents these data. During the 3-month period, the 3-hour average L/G ratio ranged from 8.5 to 14.9, and averaged 11.4, showing consistent operation at a L/G ratio above the level where compliance was demonstrated. The indicator range selected is a minimum L/G ratio of 8. No QIP threshold has been established.

The maximum scrubber outlet temperature was selected based on data obtained during a performance test conducted at the facility and historical data. The scrubber exhaust gas temperatures during the test averaged 144°F. Hourly scrubber outlet temperature data over a 3-month period (October through December 1996) were reduced to 3-hour averages and are shown in Figure A.2-3. Scrubber outlet temperatures during this 3-month period generally ranged from 132° to 150°F, and averaged 137.5°F. As seen in Figure A.2-3, a significant drop in temperature occurred over a 24-hour period. During this 24-hour period, the thermocouple was reading ambient temperatures because it had been removed from its housing for testing purposes. These ambient readings were not included in the evaluation of the data.

The selected indicator range for scrubber outlet temperature is less than 165°F. This range was selected by adding a 15 percent buffer to the average temperature demonstrated during the performance test (144°F) to account for variability among the data; the 3-months of monitoring data indicate that this temperature operating range can be achieved consistently. No lower action level is necessary. No QIP threshold has been established.

To date, compliance has been demonstrated at a coke burn rate of 55.5 thousand (M) lb/hr. The performance test data obtained in January of 1996 indicate that while operating at a coke burn rate of 55.5 Mlb/hr (average of three 1-hour runs) the emissions unit was in compliance with the PM emission limit. The indicator range is established as less than 56 Mlb/hr. If operation at a higher coke burn rate is planned, additional testing will be conducted to demonstrate compliance with all emission limitations at the higher burn rate. No QIP threshold has been set for this indicator.

When an excursion of any of the indicator ranges occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

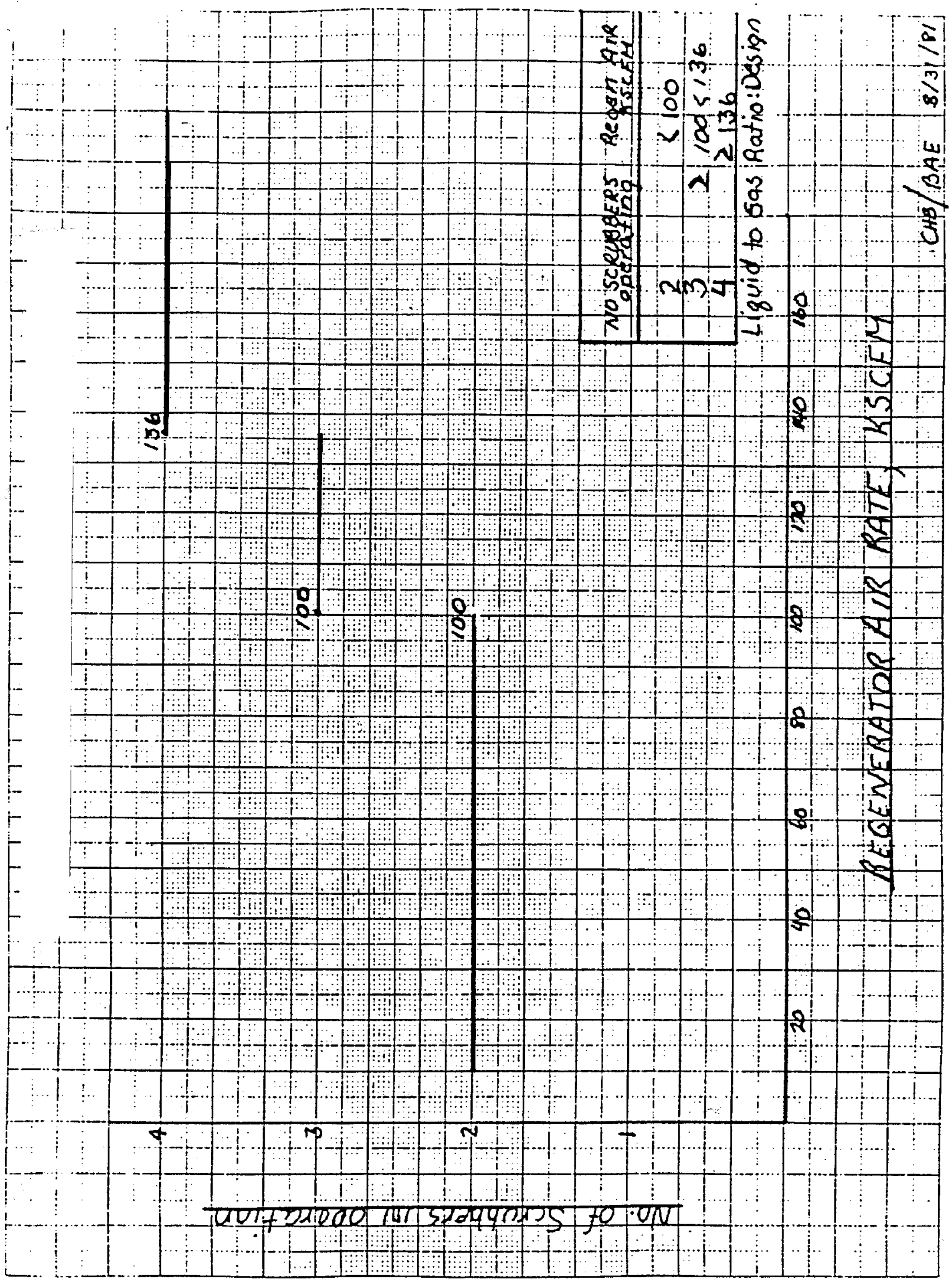

Figure A.2-1. Regenerator Air Rate vs. Number of Scrubbers in Operation.

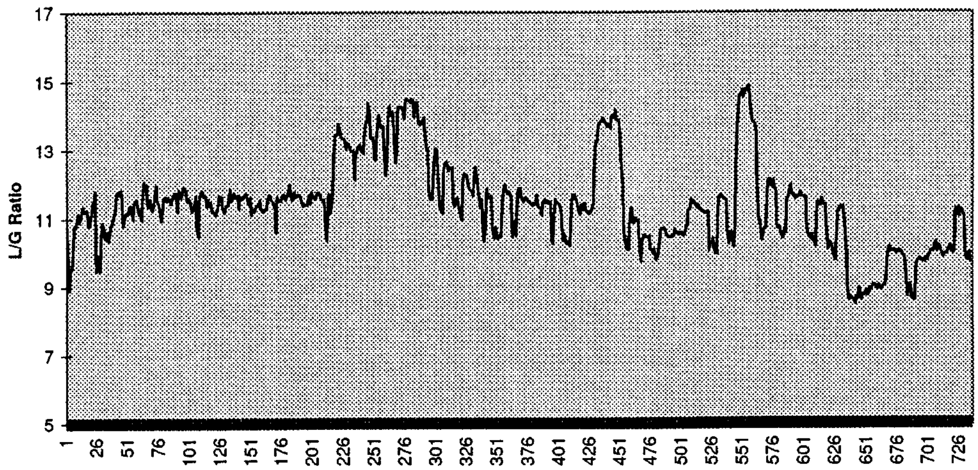

Figure A.2-2. Liquid to Gas Ratios (3-hour averages) for October-December 1996.

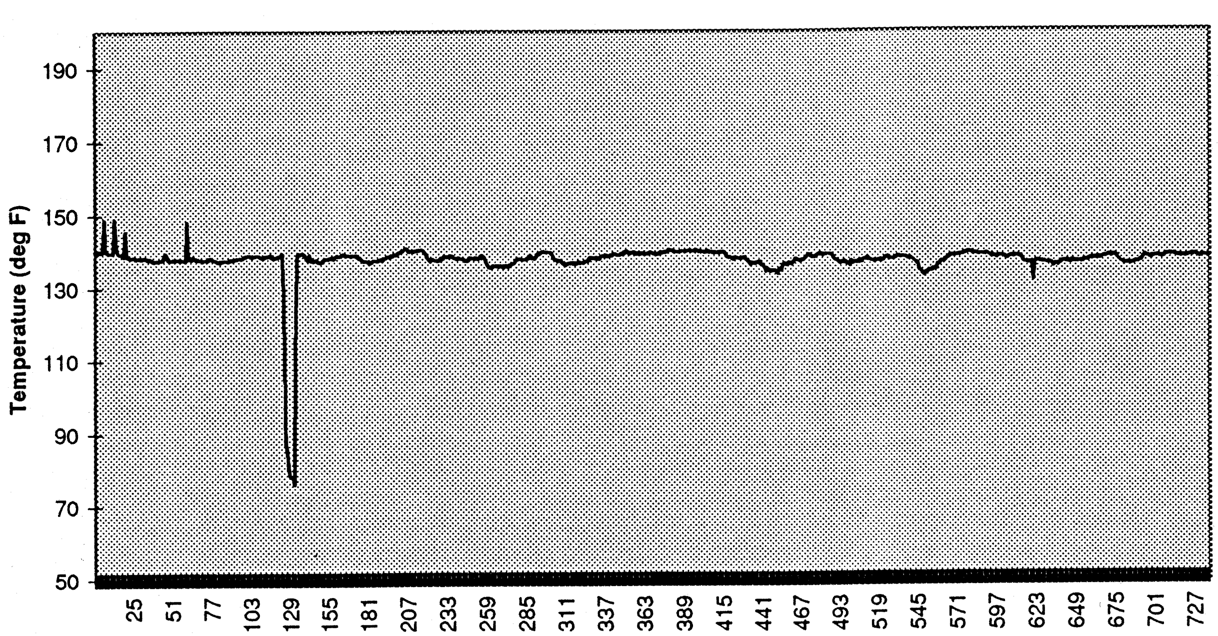

Figure A.2-3. Scrubber Outlet Temperatures (3-hour averages) for October-December 1996.

A.4 SCRUBBER FOR VOC CONTROL--FACILITY D

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
SCRUBBER FOR VOC CONTROL--FACILITY D

I. Background

A. Emissions Unit

Description:	Process tanks
Identification:	B-352-1, Vent A
Facility:	Facility D Anytown, USA

B. Applicable Regulation, Emission Limit and Monitoring Requirements

Regulation No.:	Permit
Regulated pollutant (PSEU)	VOC
Emission limit:	99 percent reduction
Monitoring requirements:	Continuously monitor water flow rate.

C. Control Technology: Packed bed scrubber

II. Monitoring Approach

The key elements of the monitoring approach for VOC, including the indicators to be monitored, indicator ranges, and performance criteria, are presented in Table A.4-1.

TABLE A.4-1. MONITORING APPROACH

	Permit Indicator No. 1
I. Indicator	Water flow rate
Measurement Approach	The water flow rate is monitored with an orifice plate and differential pressure gauge.
II. Indicator Range	An excursion is defined as a daily average scrubber water flow rate of less than 1.2 gal/min. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[a]	The orifice plate is installed in the scrubber water inlet line. The minimum accuracy is ± 0.05 gal/min.
B. Verification of Operational Status	NA
C. Quality Assurance and Control Practices	Weekly zero and quarterly upscale pressure check of transmitter.
D. Monitoring Frequency	Measured continuously.
Data Collection Procedures	Recorded once per minute.
Averaging Period	Hourly averages of 60 1-minute flow rates are calculated. A daily average of all hourly readings is calculated and recorded.

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The PSEU includes the tanks in the acetic anhydride department. Emissions from seven tanks are vented to a packed bed water scrubber. Six of these tanks are batch filled and one is continuously filled. The scrubber is used to reduce VOC emissions. Maximum emissions from these tanks are 39 lb/hr. Based on the PSEU design, bypass of the control device is not possible.

II. Rationale for Selection of Performance Indicators

The emissions from the process tanks are controlled using a packed bed water scrubber using once-through water. The performance indicator selected is liquid flow to the scrubber. To achieve the required emission reduction, a minimum water flow rate must be supplied to absorb the given amount of VOC in the gas stream, given the size of the tower and height of the packed bed. The L/G ratio is a key operating parameter of the scrubber. If the L/G ratio decreases belowz the minimum, sufficient mass transfer of the pollutant from the gas phase to the liquid phase will not occur. The minimum liquid flow required to maintain the proper L/G ratio at the maximum gas flow and vapor loading through the scrubber can be determined. Maintaining this minimum liquid flow, even during periods of reduced gas flow, will ensure the required L/G ratio is achieved at all times.

III. Rationale for Selection of Indicator Ranges

The minimum water flow is based on engineering calculations using ASPEN® programming and historical data. Computer simulation (modeling) of the scrubber system was performed for the maximum gas flow rate and VOC loading to the scrubber; the water flow rate necessary for achieving control at this gas flow rate was determined. The scrubber was modeled using an equilibrium-based distillation method and two ideal stages were assumed. Ideal behavior of the gas phase was assumed; liquid phase activity coefficients were estimated from an in-house vapor-liquid equilibria data base (parameters regressed from actual vapor-liquid equilibria data and UNIFAC) using the Wilson equations for binary systems. The minimum water flow rate to the scrubber (calculated based on maximum VOC emissions and gas flow rate) was determined to be 1.1 gal/min. The water flow rate to the scrubber must be maintained at this level or higher to achieve 99 percent emission reduction.

Monitoring data were reviewed to determine the minimum scrubber water flow rate maintained during normal operation of the process tanks and scrubber. Daily average data for a 60-day period (January 17 through March 17, 1997) were reviewed. The daily average flow rate ranges from 1.18 to 1.39 gal/min with 95 percent of the values equal to or greater than 1.2 gal/min; if values greater than 1.15 are rounded to 1.2, then 100 percent of the daily averages are equal to or greater than 1.2 gal/min. Attachment 1 lists the daily average values for the 60-day period. Hourly average data for a 30-day period (February 17 through March 17) also were reviewed. The hourly averages for this period range from 1.19 to 1.21. The scrubber has been consistently operated with both the hourly and daily average water flow rate equal to or greater than 1.2 gal/min.

The selected indicator range is a minimum daily average water flow rate of 1.2 gal/min (defined as greater than 1.15 gal/min). When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The indicator range was selected by establishing the excursion level at the minimum water flow rate that has been established as the operational level and has been consistently maintained at all times as indicated by 2 months of monitoring data. This water flow rate is above the minimum level (1.1 gal/min) necessary to achieve compliance during maximum gas flow and VOC loading to the scrubber, as established through modeling. A daily average, rather than an hourly average, was selected for the indicator range because the historical data indicate that the flow rate is very constant with little hourly variation. Consequently, the daily average is a sufficient indicator of performance. No performance test has been conducted on the scrubber.

Attachment 1.
Daily average water flow to Vent A scrubber in gal/min.

DATE	TIME	32FC80
01/17/97	0:00	1.183
01/18/97	0:00	1.392
19/97	0:00	1.211
01/20/97	0:00	1.200
01/21/97	0:00	1.200
01/22/97	0:00	1.200
01/23/97	0:00	1.200
01/24/97	0:00	1.200
01/25/97	0:00	1.200
01/26/97	0:00	1.200
01/27/97	0:00	1.200
01/28/97	0:00	1.200
01/29/97	0:00	1.200
01/30/97	0:00	1.200
01/31/97	0:00	1.200
02/01/97	0:00	1.200
02/02/97	0:00	1.200
02/03/97	0:00	1.200
02/04/97	0:00	1.200
02/05/97	0:00	1.200
02/06/97	0:00	1.200
02/07/97	0:00	1.200
02/08/97	0:00	1.200
02/09/97	0:00	1.200
02/10/97	0:00	1.200
02/11/97	0:00	1.200
02/12/97	0:00	1.200
13/97	0:00	1.200
02/14/97	0:00	1.200
02/15/97	0:00	1.200
02/16/97	0:00	1.200
02/17/97	0:00	1.200
02/18/97	0:00	1.200
02/19/97	0:00	1.200
02/20/97	0:00	1.200
02/21/97	0:00	1.200
02/22/97	0:00	1.200
02/23/97	0:00	1.200
02/24/97	0:00	1.199
02/25/97	0:00	1.200
02/26/97	0:00	1.200
02/27/97	0:00	1.200
02/28/97	0:00	1.200
03/01/97	0:00	1.200
03/02/97	0:00	1.200
03/03/97	0:00	1.200
03/04/97	0:00	1.200
03/05/97	0:00	1.200
03/06/97	0:00	1.200
03/07/97	0:00	1.200
03/08/97	0:00	1.200
03/09/97	0:00	1.200
0/97	0:00	1.200
03/11/97	0:00	1.200
03/12/97	0:00	1.200
03/13/97	0:00	1.200
03/14/97	0:00	1.199
03/15/97	0:00	1.200
03/16/97	0:00	1.200
03/17/97	0:00	1.200

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A.8 SCRUBBER FOR PM CONTROL--FACILITY H

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
SCRUBBER FOR PM CONTROL--FACILITY H

I. Background

A. Emissions Unit

Description:	Dry Dryers 1-4
Identification:	401, 403, 406, 407
Facility:	Facility H Anytown, USA

B. Applicable Regulation and Emission Limit

Regulation No.:	OAR 340-21, permit
Emission limits:	
Particulate matter:	0.2 gr/dscf (3 hour average)
Monitoring requirements:	Scrubber exhaust temperature

C. Control Technology

Wet scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.8-1.

TABLE A.8-1. MONITORING APPROACH

I. Indicator	Wet scrubber exhaust temperature	Work practice: periodic check of scrubber water filter
Measurement Approach	The wet scrubber exhaust temperature is monitored with a thermocouple.	When the scrubber is shut down for weekly maintenance, the scrubber water filter is inspected and cleaned.
II. Indicator Range	An excursion is defined as a scrubber exhaust temperature greater than 150°F for a 6-minute period, continuously. Excursions trigger an inspection, corrective action, and a reporting requirement.	The filter will be replaced as needed; if there is excess buildup of particulate on the filter, the blowdown will be increased if necessary.
QIP Threshold[a]	Six excursions in a 6-month reporting period.	NA
III. Performance Criteria A. Data Representativeness[b]	The monitoring system consists of a thermocouple at the scrubber exhaust with a minimum accuracy of ±4°F or ±0.75%, whichever is greater.	The filter is visually inspected for holes or other damage.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	The thermocouple will be calibrated annually.	NA
D. Monitoring Frequency	The scrubber exhaust temperature is measured continuously.	The filter is inspected and cleaned weekly.
Data Collection Procedures	Temperature is recorded as a 6-minute average by the DAS.	Maintenance records.
Averaging Period	6 minute average.	NA

[a]Note: The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emission units are the four dry dryers (finish dryers) which dry wood chips. The dryers are Heil three pass horizontal rotary drum dryers, and burn natural gas or distillate fuel oil or receive heat indirectly from the boilers via steam. Dryers No. 1 and No. 2 are face material dryers; dryers No. 3 and No. 4 are core material dryers. The main wood species dried is Douglas fir. Wood entering the dryers may range from 10 to 20 percent moisture and exit with 4 to 6 percent moisture prior to particleboard production. The dryer exhaust streams are controlled by American Air Filter wet scrubbers. The scrubber water is filtered and recycled.

II. Rationale for Selection of Performance Indicators

The scrubber exhaust gas temperature was selected because it is indicative of scrubber operation and adequate water flow. When the water flow rate is sufficient, contact between the exhaust gas and the scrubber water causes the temperature of the exhaust gas to drop. The temperature range of the exhaust gas stream during normal operation was determined. With the scrubber water off, the scrubber exhaust is approximately 30°F hotter than normal. When the dryers and scrubbers are shut down for maintenance or cleaning, the temperatures drop.

The scrubber water is filtered and recycled, with a fixed amount of blowdown and makeup water. Checking the filter ensures particulate is being removed from the recycled water. Excess particulate in the scrubber water will reduce control efficiency. Any holes or degradation of the filter will be discovered during the weekly inspection.

The dryer exhaust will only bypass its associated scrubber if the scrubber is shut down for maintenance while the process is operating. These periods are documented and reported.

III. Rationale for Selection of Indicator Range

The selected indicator range for scrubber exhaust temperature is less than 150°F. An excursion is defined as any period during which the scrubber exhaust temperature exceeds 150°F for more than 6 minutes, continuously. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The level for the exhaust temperature was selected based upon the data obtained during normal scrubber operation and the performance test. Examination of operating data show that the scrubber outlet temperature increases slightly as the ambient temperature increases during the year. During normal operation, outlet temperatures approach 150°F during the summer months, and this value was selected as the upper indicator level (see Figure A.8-1 for a typical summer day's scrubber exhaust temperatures). No lower indicator level is necessary.

The most recent performance test using compliance test methods (ODEQ Method 7 for particulate) was conducted at this facility on April 9-11, 1996. Three test runs were conducted on each of the four dry dryers. During testing, the measured PM emissions ranged from 0.024 to 0.054 gr/dscf. During source testing, the scrubber exhaust gas temperatures ranged from 98° to 128°F, and dry dryer scrubber exhausts were found to be well below the compliance limit for particulate emissions. Dryer exhaust temperatures ranged from 149° to 162°F, 30 to 40 degrees hotter than the scrubber exhaust. During the emissions tests, the scrubber exhaust gas temperatures were measured continuously, and 6-minute averages were charted. The complete test results are documented in the test report dated April 1996. During the performance test, the measured particulate emissions were well under the emission limitation of 0.2 gr/dscf.

Three months of operating data (October through December 1996) were reviewed, which include dry dryer scrubber temperature alarm data, maintenance log book entries, and temperature graphs for those days on which alarms occurred. The scrubber temperature alarm was activated on 4 days out of the 3-month operating period for which data were collected. One alarm was caused due to a data processor malfunction, while the others were caused by lack of water flow to the scrubber or excess temperature during shutdown.

Based on the performance test data and a review of historical data, the selected QIP threshold for the wet scrubber exhaust gas temperature is six excursions in a 6-month reporting period (Note: Establishing a proposed QIP threshold in the monitoring submittal is optional). This level is less than 1 percent of the scrubber operating time. If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented.

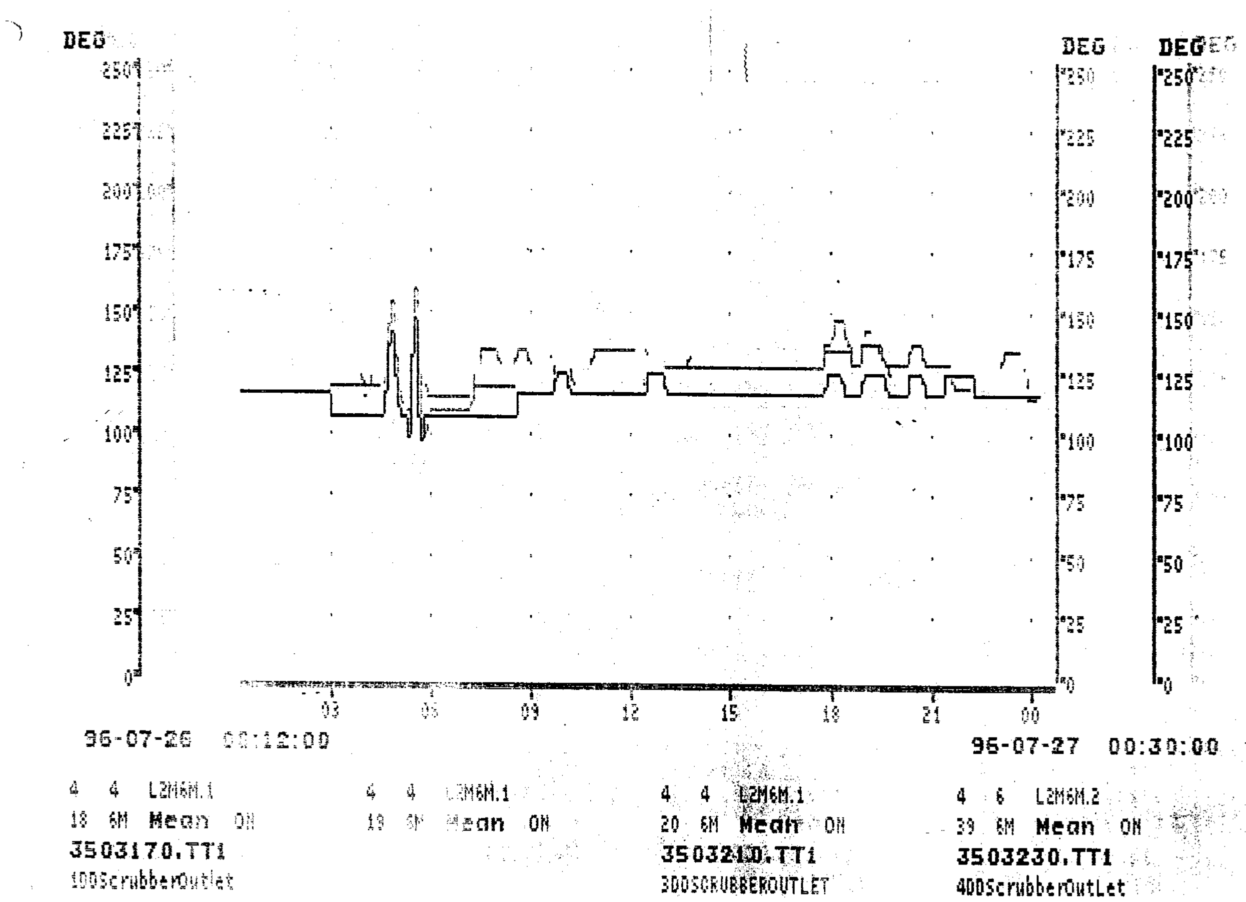

Figure A.8-1. Typical Scrubber Exhaust Temperature (7/27/96)

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A.14 SCRUBBER FOR PM CONTROL--FACILITY N

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EXAMPLE COMPLIANCE ASSURANCE MONITORING: SCRUBBER FOR PM CONTROL--FACILITY N

I. Background

A. Emissions Unit

Description:	Wood Fiber Dryer
Identification:	Dryer No. 3
Facility:	Facility N Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	OAR 340-30-021
Emission limit:	
Particulate matter:	0.55 lb/1,000 sqft dried or 15.5 lb/hr total PM limit for all sources at MDF plant, excluding boiler, truck dump, and storage areas.
Monitoring requirements:	Pressure drop across wet scrubber, scrubber inlet and outlet temperature.

C. Control Technology

Wet scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.14-1.

TABLE A.14-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Pressure drop across wet scrubber	Wet scrubber inlet and exhaust gas temperatures
Measurement Approach	The pressure drop is monitored with a differential pressure transducer.	The wet scrubber inlet and exhaust gas temperatures are monitored with RTD's.
II. Indicator Range	An excursion is defined as a pressure drop greater than 6.5 inches of water. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 1-hour average scrubber exhaust gas temperature greater than 150°F. Scrubber inlet gas temperature must be greater than the exhaust gas temperature during scrubber operation. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[a]	The monitoring system consists of a differential pressure transducer which compares the pressure in the duct immediately upstream of the water spray to the atmospheric pressure. Its minimum accuracy is ±2 percent.	The monitoring system consists of two RTD's located in the ductwork immedately upsream and downstream of the scrubber. Their minimum accuracy is ±2 percent.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	The differential pressure transducer reading is compared to a U-tube manometer monthly.	The RTD's are calibrated monthly by comparison to a calibrated thermocouple, and annually using a NIST traceable thermometer.
D. Monitoring Frequency	The signal from the differential pressure transducer is sampled several times per minute.	The signal from the RTD is sampled several times per minute.
Data Collection Procedures	1-minute averages are computed and displayed. The PC then computes a 1-hour average using each 1-minute average and stores it.	1-minute averages are computed and displayed. The PC then computes a 1-hour average using each 1-minute average and stores it.
Averaging Period	1-minute and 1-hour averaging periods.	1-minute and 1-hour averaging periods.

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant-specific emission unit is a wood fiber dryer denoted as the face system and used in the manufacture of medium density fiberboard. Fiber from the dryer is removed by a low energy cyclone. The exhaust from the cyclone is ducted to the scrubber. In the last 20 feet of the duct, water is sprayed into the air stream. The emissions then enter the scrubber, where baffling removes the suspended water droplets. The temperature drop across the spray section and the pressure drop between the inlet to the spray section and the scrubber discharge are monitored.

II. Rationale for Selection of Performance Indicators

Pressure drop was selected as a performance indicator because it indicates the water level in the scrubber. Maintaining an adequate water flow insures adequate particulate removal. A high pressure drop indicates the water level in the scrubber is too high. Usually, high water level problems are caused by a malfunction of the scrubber water level controller. A low pressure drop is caused by a loss of water in the scrubber.

Temperature was selected because a temperature drop across the scrubber indicates that the water sprays are operating. A loss of temperature differential indicates little or no water is being applied to the exhaust gas stream, which in turn causes little particulate to be removed from the exhaust. The most common cause of water loss is plugged nozzles due to wood fibers in the recycled water.

Bypass of a scrubber only occurs if the scrubber is shut down during process operation. The dryer is then controlled only by the cyclone. These periods are documented and reported.

III. Rationale for Selection of Indicator Ranges

The selected indicator range for the scrubber exhaust gas temperature is less than 150°F (1 hour average). The selected indicator range for scrubber pressure drop is less than 6.5 in. H_2O. There is no lower limit for the pressure drop, since a high exhaust temperature will indicate a loss of water flow. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The indicator levels for the scrubber pressure drop and inlet and exhaust gas temperatures are based on normal scrubber operation and performance test results. During source testing, the scrubber was operating under normal conditions and the average scrubber exhaust gas temperature was 132°F. With no water flowing through the scrubber, the exhaust temperature would be about 30 degrees hotter. Therefore, the exhaust temperature limit was set at 150°F. During the most recent performance test, the average pressure drop was 5.7 in. H_2O.

The most recent performance test using compliance test methods (ODEQ Method 7 for particulate) was conducted at this facility on November 20-21, 1996. Three test runs were conducted on the fiber dryer. During testing, the measured PM emissions from Dryer No. 3 averaged 0.008 gr/dscf (3.6 lb/hr). During the compliance test the scrubber exhaust particulate emissions were below the permit limit of 15.5 lb/hr. During the emissions test, the pressure drop and the scrubber inlet and outlet temperatures were measured continuously. The complete test results are documented in the test report.

Figures A.14-1 and A-14.2 show average hourly temperature and differential pressure data for scrubber No. 3 for the month of August 1997. The dips in the differential pressure and the temperatures indicate periods when the scrubber was not operating. Figure A.14-1 shows that the facility did not exceed the maximum outlet temperature limit of 150°F, and the inlet temperature exceeded the outlet temperature during periods of scrubber operation. The average hourly scrubber inlet temperature was 157°F, with a maximum hourly inlet temperature of 189°F, and the average scrubber outlet temperature was 129°F, with a maximum hourly outlet temperature of 142°F. The average temperature differential was 28°F. Figure A.14-2 shows that the facility did not exceed the maximum pressure drop during the month of August. The average differential pressure was 4.5 in. H_2O during the month of August, with a maximum of 6 in. H_2O.

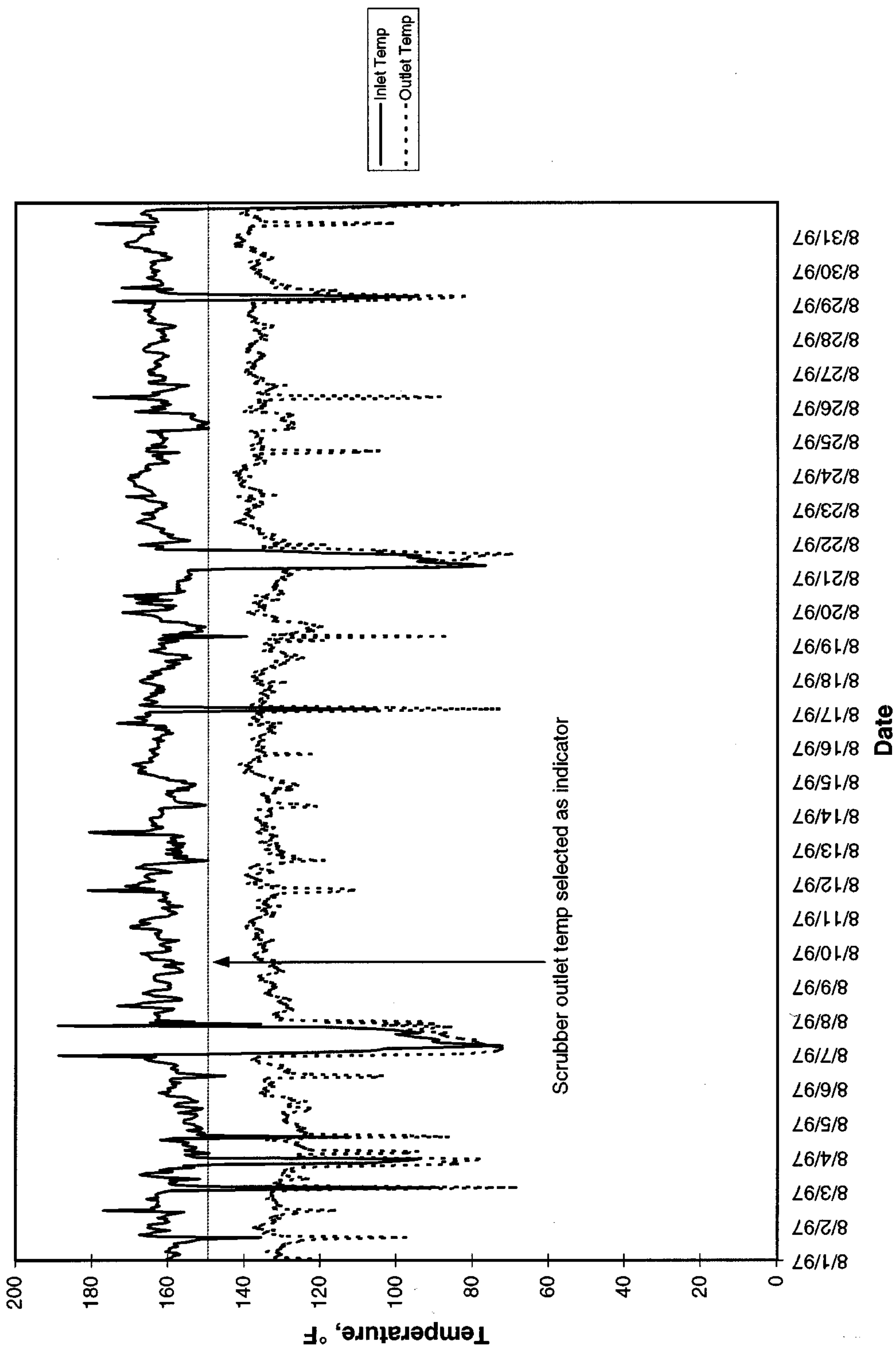

Figure A.14-1. August 1997 scrubber inlet and outlet temperatures.

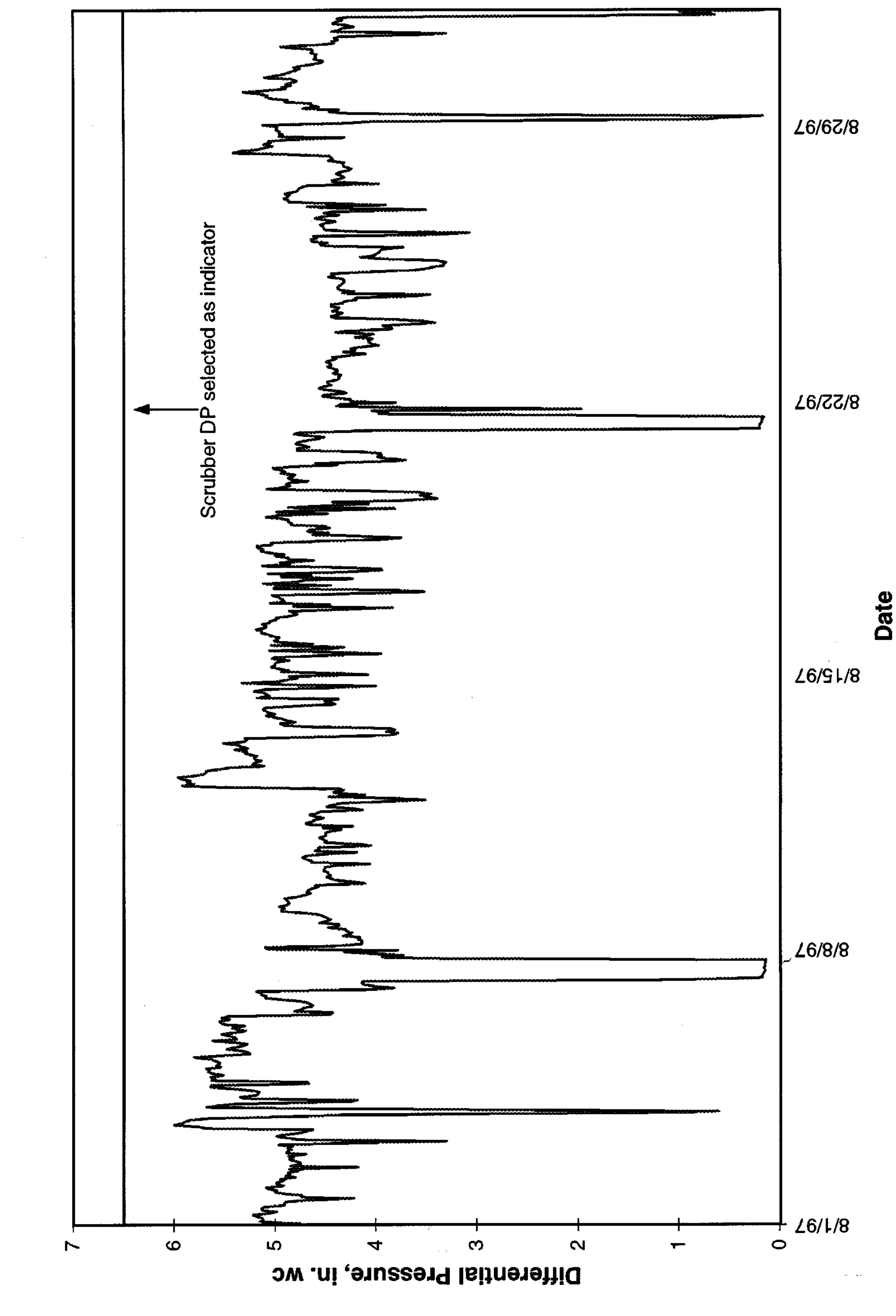

Figure A.14-2. August 1997 scrubber differential pressure.

A.15 VENTURI SCRUBBER FOR PM CONTROL--FACILITY O
(TO BE COMPLETED)

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A.4b PACKED BED SCRUBBER FOR VOC CONTROL OF A BATCH PROCESS – FACILITY Q

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
PACKED BED SCRUBBER FOR VOC CONTROL – FACILITY Q

I. Background

A. Emissions Unit

Description:	Batch mixers and tanks used in a chemical process
Identification:	Scrubber B-67-2
Facility:	Facility Q Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	Permit, State regulation
Emissions limit:	
VOC:	3.6 pounds per hour
Monitoring requirements:	Inlet water flow, acetic acid concentration in scrubber underflow

C. Control Technology — Packed bed scrubber

II. Monitoring Approach

The key elements of the monitoring approach for VOC are presented in Table A.4b-1. The selected indicators of performance are the scrubber inlet water flow rate and the acetic acid concentration in the scrubber water underflow. The scrubber inlet water flow rate is measured continuously and recorded twice daily. The scrubber water underflow is sampled twice daily; the acetic acid concentration of each sample is determined by titration.

TABLE A.4b-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Scrubber inlet water flow rate.	Acetic acid concentration in underflow.
Measurement Approach	The scrubber inlet water flow rate is measured using a radiometer.	A sample of the underflow is taken and the acetic acid concentration determined by titration.
II. Indicator Range	An excursion is defined as any operating condition where the scrubber inlet water flow rate is less than 4 gpm. An excursion will trigger an investigation of the occurrence, corrective action, and a reporting requirement.	An excursion is defined as any operating condition where the underflow acetic acid concentration is greater than 10 percent. An excursion will trigger an investigation of the occurrence, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The scrubber inlet water flow rate is measured using a variable area flow meter (radiometer) located in the scrubber water inlet line. The minimum acceptable accuracy of the meter is ±5 percent of the measured value and the range is 0 to 15 gpm.	The acetic acid concentration in the scrubber water effluent is measured by titrating a water sample extracted from the scrubber underflow.
B. Verification of Operational Status	NA	NA
C. Quality Assurance and Control Practices	Annual calibration and cleaning of radiometer. Acceptance criteria: ±5 percent of the measured value.	Only trained personnel perform sampling and titration. Laboratory QA/QC procedures are followed. Calibration standards are prepared to ensure the sample titration is being performed accurately.
D. Monitoring Frequency	The scrubber inlet water flow rate is measured continuously and recorded twice daily.	The scrubber water outlet acetic acid concentration is measured twice daily.
Data Collection Procedures	The scrubber inlet water flow rate is recorded twice daily. (The post-control emissions from this unit are less than the major source threshold, so continuous monitoring and recording is not required.)	A water sample is taken and titrated manually with phenolphthalein and NaOH solution. (The post-control emissions from this unit are less than the major source threshold, so continuous monitoring and recording is not required.)
Averaging Period	None.	None.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit (PSEU) consists of process equipment in the cellulose esters division controlled by a packed bed scrubber. The process consists of batch mixers that are used to convert cellulose into cellulose ester. Each mixer may be started at a different time and may be used to make several batches per day. While in the mixers, the intermediate product is dissolved in acetic acid. The ester solution is transferred to storage tanks before being pumped into the next step in the process. A vent system collects the vapors from the mixers and tanks and a fan operated at constant speed pulls the vapors through the vent lines and into the scrubber. It is not possible for the gas to bypass the scrubber. The VOC load to the scrubbers in this division primarily consists of acetic acid (and other carboxylic acids).

The scrubber is 4 feet in diameter and has about 8 feet of 2-inch packing. Fresh water is sprayed at the top of the packing at 4 to 6 gpm; water from the underflow is recirculated to the middle of the scrubber. The normal exit gas flow rate is approximately 1800 acfm.

II. Rationale for Selection of Performance Indicators

A packed bed scrubber is used to reduce VOC emissions from part of a chemical manufacturing process. Both batch mixers and process tanks are vented to this scrubber. The processes in this area of the facility are mostly semi-batch operations, so the production rate at any one time varies. Therefore, it is difficult to relate the production rate to the VOC load vented to this scrubber.

To comply with the applicable emission limit, a minimum water flow rate must be supplied to the scrubber to absorb a given amount of VOC in the gas stream, given the size of the tower and height of the packed bed. The liquid to gas (L/G) ratio is a key operating parameter of the scrubber. If the L/G ratio decreases below the minimum, sufficient mass transfer of the pollutant from the gas phase to the liquid phase will not occur. The minimum liquid flow required to maintain the proper L/G ratio at the maximum gas flow and vapor loading through the scrubber can be determined. Maintaining this minimum liquid flow, even during periods of reduced gas flow, will help ensure that the required L/G ratio is achieved at all times. The concentration of acetic acid in the scrubber underflow can be related to the water flow rate and acetic acid emissions, based on emissions test results and process modeling.

III. Rationale for Selection of Indicator Ranges

The indicator ranges were selected based on engineering calculations using ASPEN® process modeling software, emissions test data, and historical data. Computer modeling of the scrubber system was performed for the maximum allowable VOC concentration in the scrubber exhaust; the inlet water flow rate necessary for achieving adequate control was determined for several concentrations of acetic acid in the underflow. The scrubber efficiency was calculated using data obtained from emissions testing. The scrubber was modeled using an equilibrium-based distillation method and ideal behavior of the gas phase was assumed; liquid phase activity coefficients were estimated from a Wilson parameter fit of vapor-liquid equilibria data. It was assumed that the control device delivers three actual stages of counter-current mass transfer with a recycle stream pumped from the effluent to the center of the column to ensure adequate distribution of the liquid over the packing. The engineering model was calibrated for accuracy using the results of source testing conducted while at normal operating conditions.

Figure A.4b-1 is a plot of the modeled operating conditions (inlet water flow and scrubber underflow acetic acid concentration) necessary to maintain compliance. The line represents the operating conditions at maximum allowable emissions (3.6 lb VOC/hr); the scrubber's VOC emissions are below the limit when the scrubber is operated at conditions that fall below this line. For example, operating at a scrubber water flow rate of 4 gpm with an acetic acid concentration in the scrubber underflow of 12 percent provides a margin of compliance with the permitted VOC emission rate. The selected indicator ranges for inlet water flow and underflow acetic acid concentration were chosen based on the compliance curve and normal operating conditions. The indicator range (acceptable operating range) is defined as any operating condition where the scrubber inlet water flow is greater than 4 gpm and the scrubber underflow acetic acid concentration is less than 10 percent.

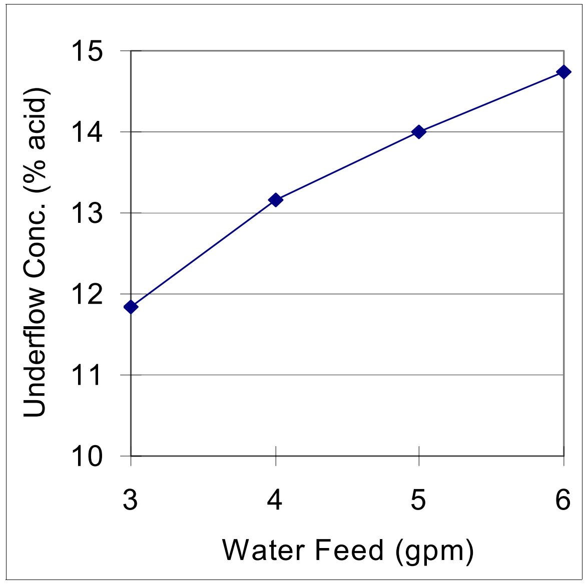

Figure A.4b-1. Compliance curve.

The 4 gpm level was chosen because it is the lower end of the preferred operating range. The 10 percent value was chosen because it is less than any point on the compliance curve (see Figure A.4b-1), and the 1997 historical data show that all measured concentration data were less than 8.4 percent (typical values were between 2 and 6 percent). When an excursion occurs (scrubber inlet water flow of less than 4 gpm and/or scrubber underflow acetic acid concentration of greater than 10 percent), corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The scrubber typically operates at a water flow rate of 4 to 6 gpm. Figure A.4b-2 shows scrubber water flow data collected in 1997. The range for the 1997 data is 3 to 9.5 gpm; the mean scrubber water flow rate was 5.3 gpm. There are four values less than 4 gpm, indicating four excursions. The bulk of the data falls between 5 and 6 gpm. Corrective action typically is taken (the flow is increased) when the scrubber water flow begins to fall below 5 gpm in order to avoid an excursion.

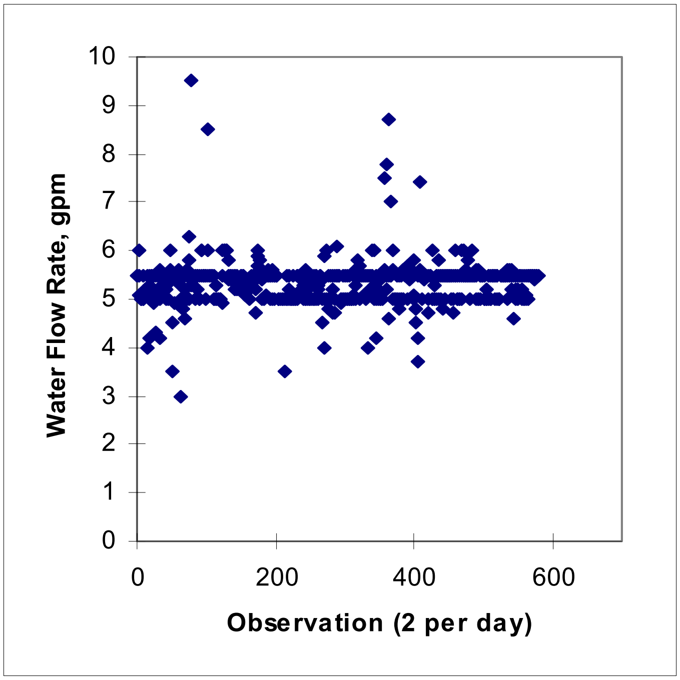

Figure A.4b-2. 1997 scrubber water flow rate data.

Historical data from 1997 show the acetic acid concentration in the underflow is typically less than 6 percent. Figure A.4b-3 shows scrubber underflow acetic acid concentration data for 1997. The maximum concentration was 8.4 percent, which is within the CAM indicator range. The mean concentration was 3.9 percent. The values decrease toward the end of the year because production was decreased due to temporary changes in the market for a key product. This further verifies the correlation between the acid concentration in the underflow and the VOC load to the scrubber. Because historical data show that the scrubber routinely operates within the indicator range, there is not much variability in the data during typical production periods, and the post-control emissions from this scrubber are below the major source threshold, the water flow rate and acid concentration are recorded only twice daily.

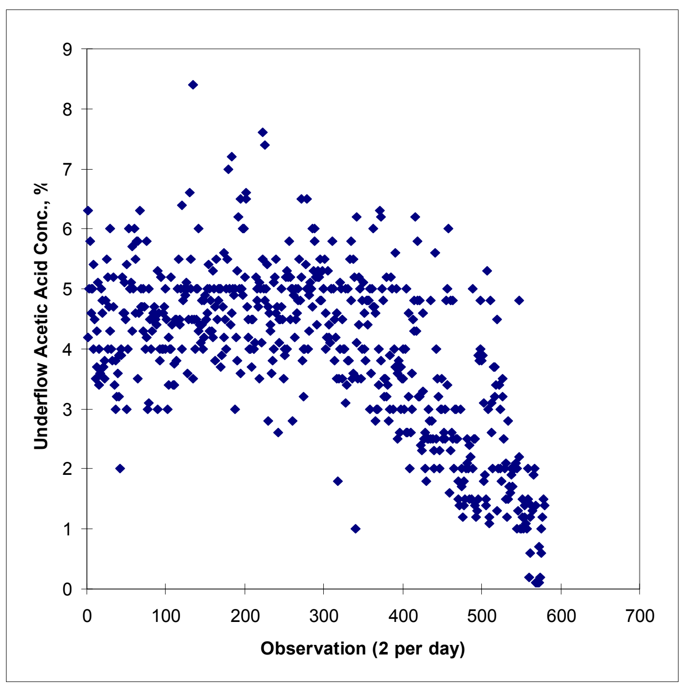

Figure A.4b-3. 1997 underflow acetic acid concentration data.

An emissions test was conducted on this scrubber in December 1994. An acetic acid sampling train validated using EPA Method 301 was used to measure acetic acid emissions and EPA Methods 1 through 4 were used to determine vent gas volumetric flow rates. The permitted emission limit is 3.6 lb VOC/hr. The average emissions during testing were 0.2 lb/hr, well below the emissions allowed for this scrubber. The inlet water flow rate was 5 gpm and the average scrubber underflow acetic acid concentration was 5 percent. The test parameters and measured emissions and underflow concentration were used in the ASPEN® computer model to calculate the efficiency of the scrubber. The model was then used with that same efficiency to generate the compliance curve in Figure A.4b-1.

Figure A.4b-4 shows the underflow acetic acid concentration versus the scrubber water flow rate for 1997. There were four excursions in 1997; the flow rate was less than 4 gpm during those excursions, but the underflow acid concentration was always less than 10 percent.

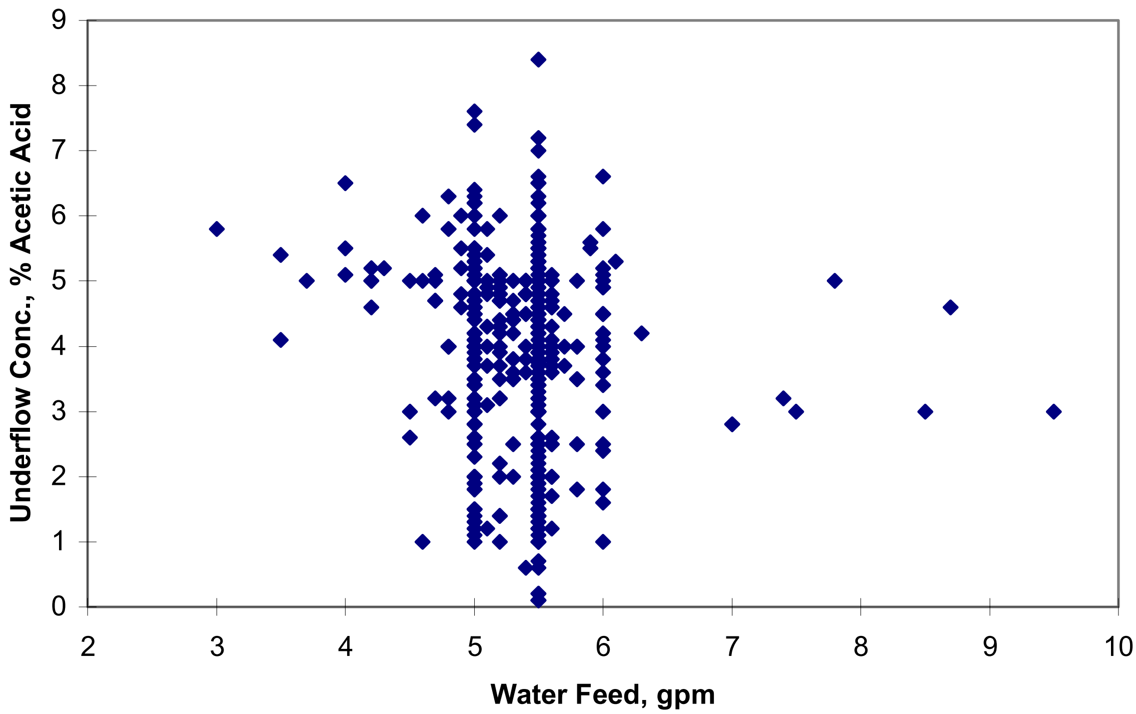

Figure A.4b-4. 1997 underflow acetic acid concentration vs. scrubber water flow.
(2 measurements per day)

A.17 VENTURI SCRUBBER FOR PM CONTROL--FACILITY S

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
VENTURI SCRUBBER FOR PM CONTROL: FACILITY S

I. Background

A. Emissions Unit

Description:	Wood-fired boiler
Identification:	Boiler A
Facility:	Facility S Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation: State regulation (Federally enforceable)

Emissions Limit:
Particulate Matter (PM): Determined using the following equation:

$$P = 0.5 * (10/R)^{0.5}$$

where:

P = allowable weight of emissions of fly ash and/or other PM in lb/mmBtu.

R = heat input of fuel-burning equipment in mmBtu/hr based on the measured percent of O_2 and volumetric flow rate.

The State rule also specifies that the opacity of visible emissions cannot be equal to or greater than 20 percent, except for one 6-minute period per hour of not more than 27 percent.

Monitoring Requirements: Continuous Opacity Monitoring System (COMS)

C. Control Technology

Venturi scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.17-1. The indicators of performance are the boiler exhaust O_2 concentration (a measure of excess air level) and the differential pressure across the scrubber venturi.

TABLE A.17-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Exhaust gas oxygen concentration	Scrubber differential pressure
Measurement Approach	O_2 monitor	Differential pressure transducer.
II. Indicator Range	An excursion is defined as an hourly boiler exhaust O_2 concentration of less than 11 or greater than 16 percent. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 1-hour average differential pressure below 10.0 inches of water. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The O_2 monitor is located in the boiler exhaust.	The differential pressure transducer monitors the static pressures upstream and downstream of the scrubber's venturi throat.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	Daily zero and span checks. Adjust when drift exceeds 0.5 percent O_2.	Quarterly comparison to a U-tube manometer. Acceptance criteria is 0.5 in. w.c.
D. Monitoring Frequency	Measured continuously.	Measured continuously.
Data Collection Procedures	1-minute averages are computed and displayed. The PC then computes and stores a 1-hour average using the 1-minute averages.	1-minute averages are computed and displayed. The PC then computes and stores a 1-hour average using the 1-minute averages.
Averaging period	1-hour.	1-hour.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emissions unit (PSEU) is PM from a wood-fired boiler. Particulate matter in the boiler's exhaust stream is controlled by a venturi scrubber. A COMS is required by the applicable State rule. However, water droplets in the boiler exhaust will interfere with the COMS measurements and consequently make the use of a COMS impractical. An alternative monitoring program utilizing parametric monitoring has been proposed. The monitoring approach includes continuous monitoring of the wood-fired boiler's excess air, the steam production rate, and the differential pressure across the scrubber's venturi throat.

II. Rationale for Selection of Performance Indicators

The operating conditions for this type of source (wood-fired boiler) can have a significant impact on the amount of particulate emissions created. Furthermore, for a venturi scrubber, the inlet particulate matter loading to the scrubber will have an impact on the emissions level from the scrubber (i.e., emissions from the scrubber are expected to increase as the loading to the scrubber increases for the same scrubber operating conditions). Site-specific emissions test data confirm these expectations. Therefore, indicators of performance of both the control device and process were selected for this source.

The scrubber differential pressure was selected as the indicator of control device performance. The differential pressure is proportional to the water flow and air flow through the scrubber venturi throat and is an indicator of the energy across the scrubber and the proper operation of the scrubber within established conditions.

Excess air levels can have a significant impact on boiler performance. Excess air is defined as that air exceeding the theoretical amount necessary for combustion. Insufficient excess air will result in incomplete combustion and an increase in emissions. A minimum of about 50 percent excess air is necessary for combustion of wood or bark fuels. Provision of too much excess air causes the furnace to cool and also can result in incomplete combustion. Therefore, the proper excess air level is important for proper operation of the boiler. The percent oxygen in the exhaust gas stream is an indicator of the excess air level (0 percent oxygen would equal 0 percent excess air, 8 percent oxygen is approximately 50 percent excess air, and 12 percent oxygen is approximately 100 percent excess air).

III. Rationale for Selection of Indicator Ranges

Baseline information on the relationship among process operating conditions, control device operating conditions, and emissions was necessary to establish the indicators and ranges. A series of test runs was performed at several different boiler operating conditions because parametric monitoring is being proposed as an alternative to COMS.

Emissions tests were performed to establish a basis for indicator ranges that correspond to compliance with the PM emissions limit. A set of nine test runs was performed on the boiler at three different levels of steam generation (three test runs were performed at each steam generation level). Emissions sampling was based on EPA Methods 1 through 5 (40 CFR 60, Appendix A). The results of the first series of emissions tests indicated a problem meeting the emissions limits at the lower load level; the lack of a means to control excess air levels during boiler operation was suspected as the cause of the excess emissions. A second series of tests were performed a year later after automatic boiler control equipment was installed. The second series of tests also was comprised of nine runs at three operating loads. The results of these 18 tests were used in selecting the indicator ranges. The results of these tests are presented and discussed in the following paragraphs.

Figure 1 graphically presents the excess air level versus the nominal boiler load (steam generation rate) for the tests. During the first series of tests, before automatic boiler controls were added, the boiler operated at a very high level of excess air (over 500 percent) at the low-level operating load, at a high level of excess air (over 200 percent) at the mid level operating load, and below 200 percent at the high-level operating load. Without the automatic boiler controls, the same amount of air was being introduced to the boiler regardless of the operating load (wood feed rate), resulting in a significant increase in excess air levels as wood feed rate decreased. After the automatic controls were added, the excess air was maintained at lower levels for the low-level and mid-level load conditions (less than 300 percent and 200 percent, respectively).

The results of the two test series are summarized in Table A.17-2. Three test runs were performed at each steam generation rate.

TABLE A.17-2. TEST RESULTS[a]

	Nominal steam generation rate (lb/hr)	Venturi differential pressure (in. H_2O)	Boiler exhaust O_2 (%)	Particulate emissions (lb/MMBtu)	Allowable particulate emissions (lb/MMBtu)
Series 1: (Before Boiler Control Modifications)	25,000	15.6	18.1	0.73	0.25
	40,000	22.9	16.2	0.43	0.21
	60,000	22.2	12.6	0.06	0.16
Series 2: (After Boiler Control Modifications)	33,000	12.0	15.5	0.07	0.25
	52,000	12.1	13.9	0.06	0.21
	77,000	12.0	13.0	0.05	0.17

[a] All values are 3-run averages.

At the first level of steam generation (25,000 lb/hr), the amount of excess air ranged from 544 percent to 752 percent by volume. The particulate emissions rate ranged from 0.528 to 1.12 lb/MMBtu. The maximum allowable emissions ranged from 0.23 to 0.27 lb/MMBtu. The maximum allowable emissions varies because it is based on the heat input rate. The allowable emissions rate was exceeded for all three test runs. The second set of test runs was performed at a nominal steam generation level of 40,000 lb/hr. The amount of excess air ranged from 244 to 830 percent. The particulate emissions rate ranged from 0.21 to 0.82 lb/MMBtu. The maximum allowable emissions ranged from 0.17 to 0.28 lb/MMBtu. The maximum allowable emissions rate was exceeded for all three test runs. The third set of test runs was operated at a nominal steam generation level of 60,000 lb/hr. The steam generation level actually ranged from 60,000-70,000 lb/hr but dropped below 50,000 lb/hr midway through the third of the three tests performed. The amount of excess air for these three test runs ranged from 123 to 188 percent. The particulate emissions rate ranged from 0.05 to 0.06 lb/MMBtu. The maximum allowable emissions ranged from 0.15 to 0.17 lb/MMBtu. The boiler was well within the maximum allowable emissions rate for all three test runs.

For the test series conducted after the addition of automatic controls, at the first level of steam generation (33,000 lb/hr nominal), the amount of excess air ranged from 255 to 341 percent by volume (15 to 16 percent oxygen). The particulate emissions rate ranged from 0.062 to 0.081 lb/MMBtu. The maximum allowable emissions ranged from 0.23 to 0.29 lb/MMBtu. The particulate emissions were less than the allowable emissions rate for all three test runs. The second set of test runs was performed at a nominal steam generation level of 77,000 lb/hr. The amount of excess air ranged from 128 to 194 percent (12 to 14 percent oxygen). The particulate emissions rate ranged from 0.045 to 0.057 lb/MMBtu. The maximum allowable emissions ranged from 0.16 to 0.18 lb/MMBtu. The particulate emissions were less than the allowable emissions rate for all three test runs. The third set of test runs was performed at a nominal steam generation level of 52,000 lb/hr. The amount of excess air for these three test runs ranged from 196 to 223 percent (13 to 14 percent oxygen). The particulate emissions rate ranged from 0.056 to 0.067 lb/MMBtu. The maximum allowable emissions ranged from 0.20 to

0.21 lb/MMBtu. The boiler operated within the maximum allowable emissions rate for all three test runs.

Figure 2 presents the particulate emissions rate versus boiler load for the two test series. Figures 3 and 4 present the particulate emissions rate versus excess air and boiler exhaust oxygen level, respectively. The test results show that during the first test series the emissions increase significantly as the excess air increases. The allowable emissions limit was exceeded at the low- and mid-level operating loads. The results of the second test series conducted after automatic boiler controls were added also show a relationship among the excess air level, boiler load, and particulate emissions rates. However, the particulate emissions rates were well within the allowable emissions rates for all test runs at all load conditions. Note that the performance of the system (boiler and venturi scrubber) was significantly better during the second series of tests when the automatic boiler controls were being used to control air levels even though the venturi scrubber was operating at a lower pressure drop (12 versus 22 in. w.c.).

The indicator selected for monitoring boiler operation is exhaust gas oxygen concentration. The selected indicator range for the boiler exhaust gas oxygen is greater than 12 and less than 16 percent O_2 (one-hour average). The indicator range was chosen based upon the 1-hr test run averages for the January 1999 test data. During these tests, the average oxygen concentration was maintained between 12 and 16 percent. The oxygen concentration is measured continuously. An excursion triggers an inspection, corrective action, and a reporting requirement. The selected range will promote maximum efficiency and provide a reasonable assurance that the boiler is operating normally.

The indicator range selected for monitoring venturi scrubber operation is a pressure differential of greater than 10 in. w.c. (one-hour average). An excursion triggers an inspection, corrective action, and a reporting requirement. The differential pressure is measured several times per minute. A one-minute average is calculated, and an hourly average is calculated from the one-minute averages. The selected indicator range was chosen by examining the January 1999 test data. During these tests, the differential pressure was maintained between 10 and 15 in. w.c. The measured particulate emissions limit during these tests at all three boiler loads was approximately one third of the allowable emissions rate (large margin of compliance). Therefore, a differential pressure of greater than 10 in. w.c. was selected as the indicator range.

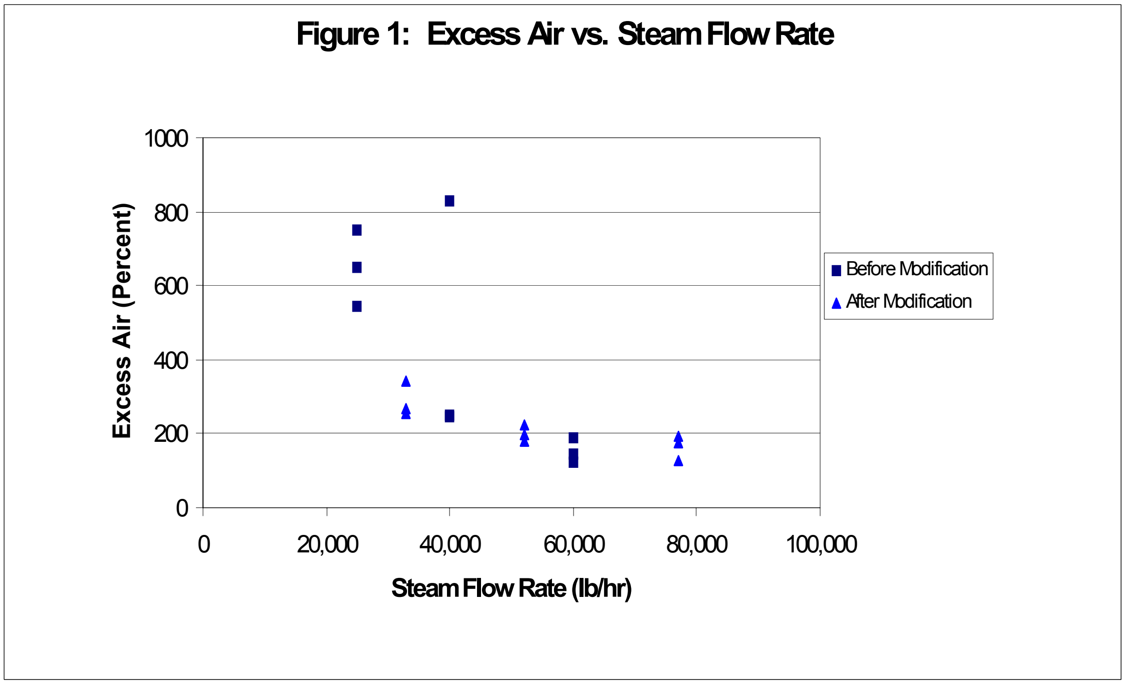
Figure 1: Excess Air vs. Steam Flow Rate
Excess Air (Percent)
1000
800
600
400
200
0
0
20,000
40,000
60,000
80,000
100,000
Steam Flow Rate (lb/hr)
Before Modification
After Modification

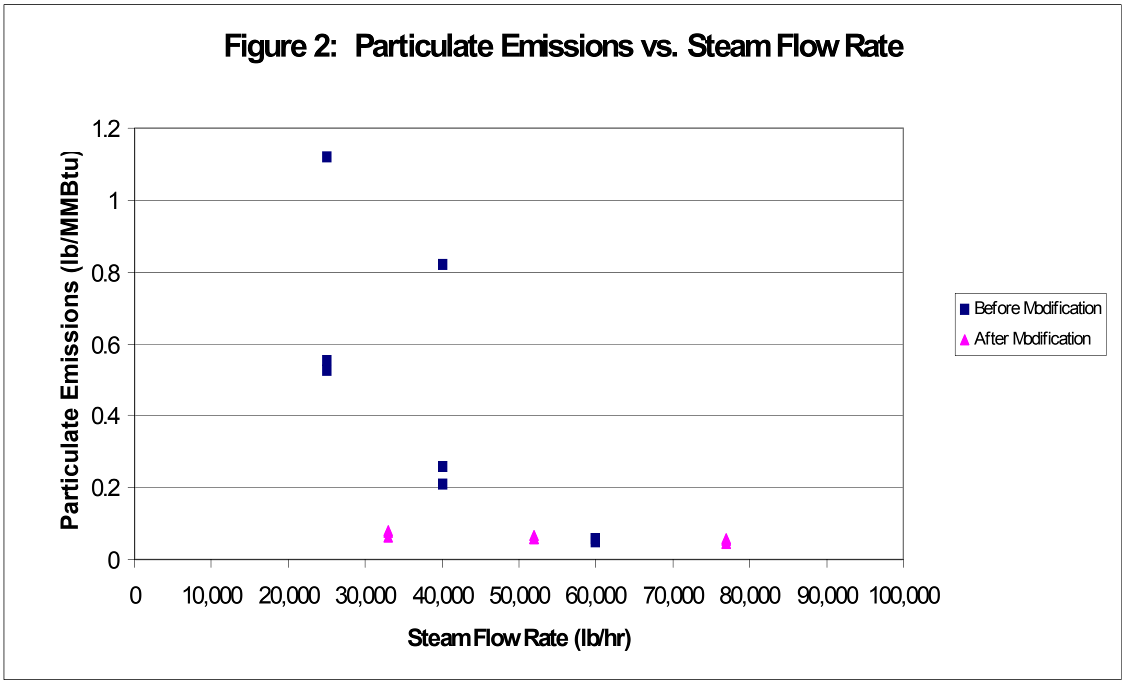
Figure 2: Particulate Emissions vs. Steam Flow Rate
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Steam Flow Rate (lb/hr)
Before Modification
After Modification

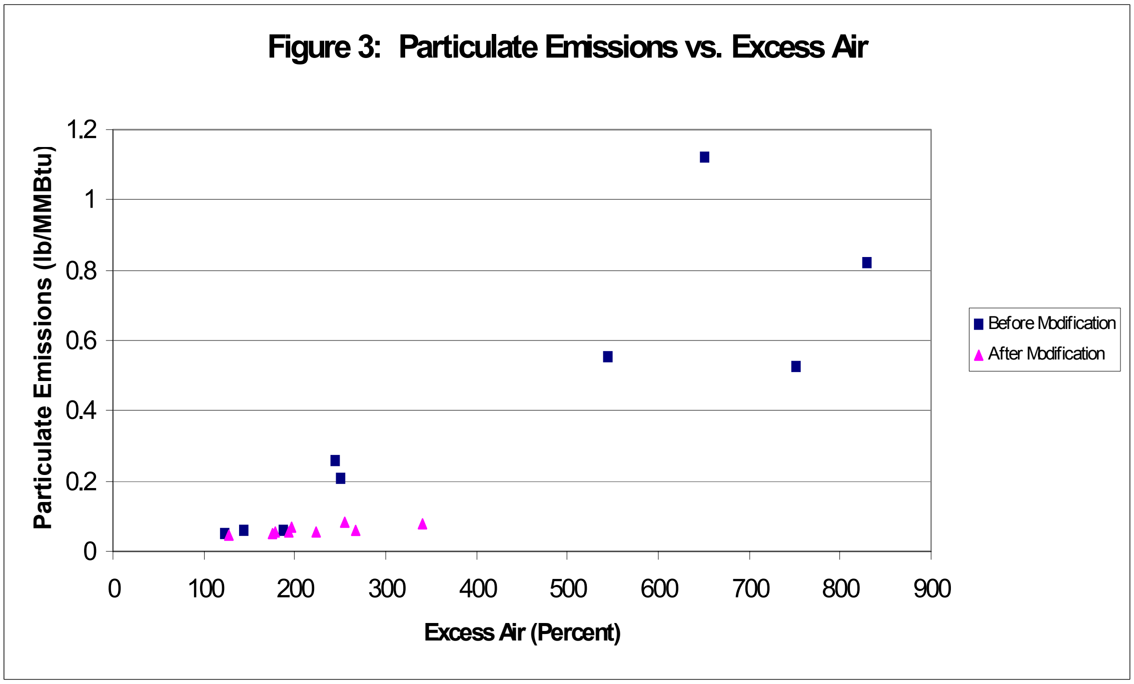

Figure 3: Particulate Emissions vs. Excess Air
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
Excess Air (Percent)
Before Modification
After Modification

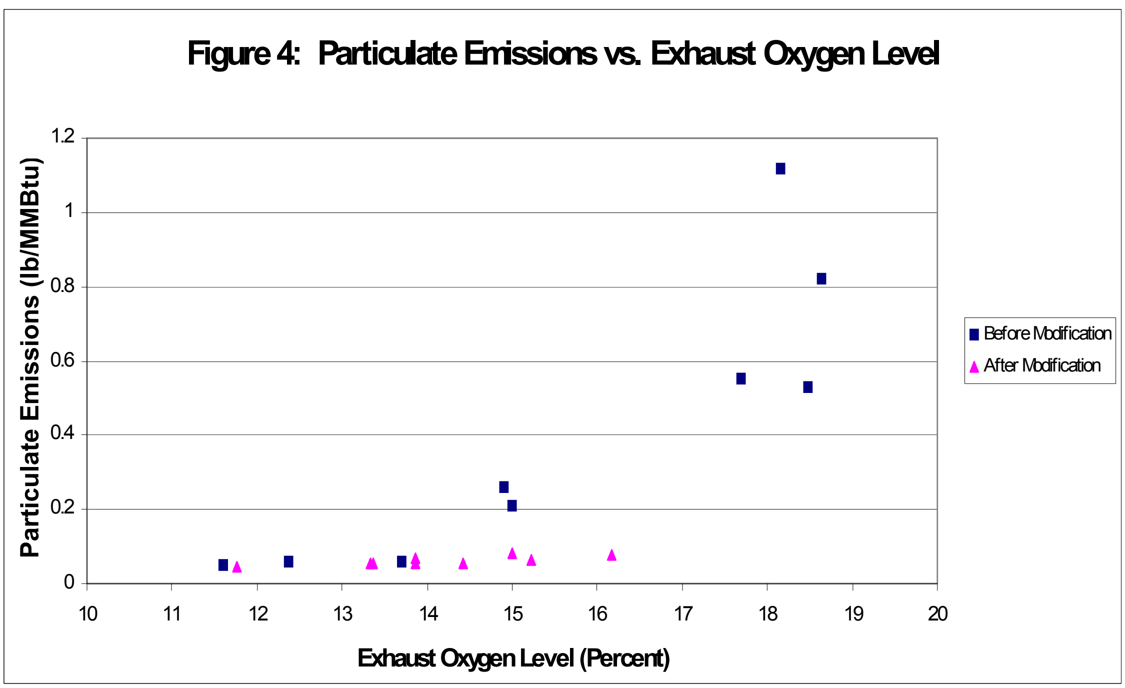

Figure 4: Particulate Emissions vs. Exhaust Oxygen Level
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
10
11
12
13
14
15
16
17
18
19
20
Exhaust Oxygen Level (Percent)
Before Modification
After Modification