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United States Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park NC 27711
EPA-450/3-91-004
December 1990
Air

EPA

Municipal Waste Combustion: Background Information for Promulgated Standards and Guidelines - Summary of Public Comments and Responses Appendices A to C

2.1/4.0/4

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1.0 OVERVIEW

1.1 PURPOSE

On December 20, 1989, the U.S. Environmental Protection Agency (EPA) proposed limits on emissions of sulfur dioxide (SO_2) from new and existing municipal waste combustors (MWC's) (54 FR 52209 and 52251). This report presents the results of analyses conducted to determine achievable SO_2 performance levels for spray dryer/fabric filter (SD/FF) systems and spray dryer/electrostatic precipitator (SD/ESP) systems applied to MWC's. The specific objective of these analyses was to assist with selection of appropriate SO_2 emission limits and averaging times, based on data from MWC's using these two control technologies.

1.2 OVERVIEW OF DATA ANALYZED

Continuous emissions monitor (CEM) data for SO_2 were obtained and analyzed from four different MWC's, three with SD/FF systems and one with a SD/ESP. The MWC's with SD/FF systems are located in Bridgeport, Connecticut; York County, Pennsylvania; and Stanislaus County, California. The MWC with the SD/ESP system is located in Millbury, Massachusetts. Hourly average SO_2 CEM data were available at both the SD inlet and the stack (i.e., FF or ESP outlet) from the Bridgeport, York County, and Millbury MWC's. Data from Stanislaus County were limited to hourly stack measurements. Additional information on the extent of data available from each of these facilities is presented in Section 2.0.

1.3 SUMMARY OF STATISTICAL METHODS

Several statistical analysis techniques were used to characterize the variability of MWC SO_2 emissions. These techniques included:

- time series plots to visually examine trends in SO_2 emissions over time and to identify data gaps or anomalies;
- normality testing and cumulative frequency distribution plots to evaluate the distribution of SO_2 data;
- routine summary statistics (mean, median, standard deviation, etc.);
- first-order autoregressive time-series analysis to identify possible underlying time dependencies in the data that could alter their "randomness"; and

- maximum estimated emissions (referred to as "exceedance values") based on the appropriate statistical means and standard deviations for different averaging times.

The hourly SO_2 data[1] were tested for normality using the Shapiro-Wilk statistic. Normality of data is important because inferential statistics, such as probabilities used for predictions, depend on the underlying population being normally distributed. When departures from normality are significant, any predictive statistics can be very unreliable.

Based on general knowledge of environmental data, both the raw SO_2 measurements and the natural logarithms (ln) of the raw data were examined for normality. The top half of Figure 1-1 shows a frequency histogram of the raw hourly SO_2 inlet data from the Bridgeport MWC; the bottom half displays the same data on a ln scale. Clearly, the ln transformation results in a much more symmetrical distribution. The existence of near symmetrically distributed data is a key criteria which must be met if statistical data are to be used for predictive purposes. As a result, predictive statistics derived from ln-transformed data will be more valid than those derived from the raw data. Mean values calculated from ln-transformed data are referred to as geometric means, as opposed to arithmetic means, which are calculated from the raw measurements.

1.4 CONCLUSIONS

Based on analysis of the available data, four primary conclusions were drawn. These are:

- SO_2 emissions from MWC's are highly variable and should be averaged over a 24-hour or longer period. Short-term (e.g., hourly) emissions of SO_2 from MWC's are highly variable due to the heterogeneity of municipal waste. This results in short-term SO_2 emissions that are significantly greater than the long-term (monthly or annual) mean. Therefore, to determine the achievable SO_2 control performance of a SD/FF or SD/ESP system, averaging of hourly data to reduce the impact of short-duration "spikes" in SO_2 levels is necessary. Based on the intensity and duration of these spikes, a 24-hour averaging period is beneficial. Use of a shorter averaging period was not able to significantly reduce the impact of many of the spikes, and expected maximum emission levels

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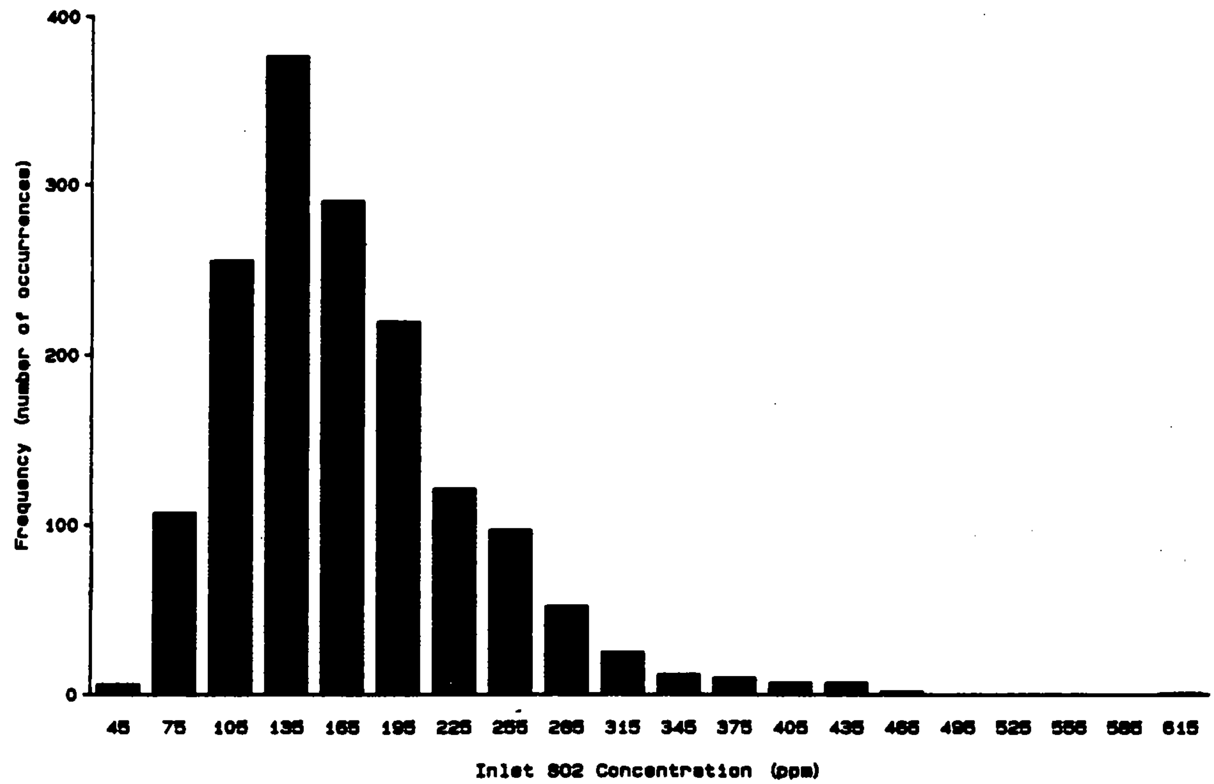
[1]All SO_2 data contained in this report were corrected to 7 percent O_2 prior to statistical analysis.



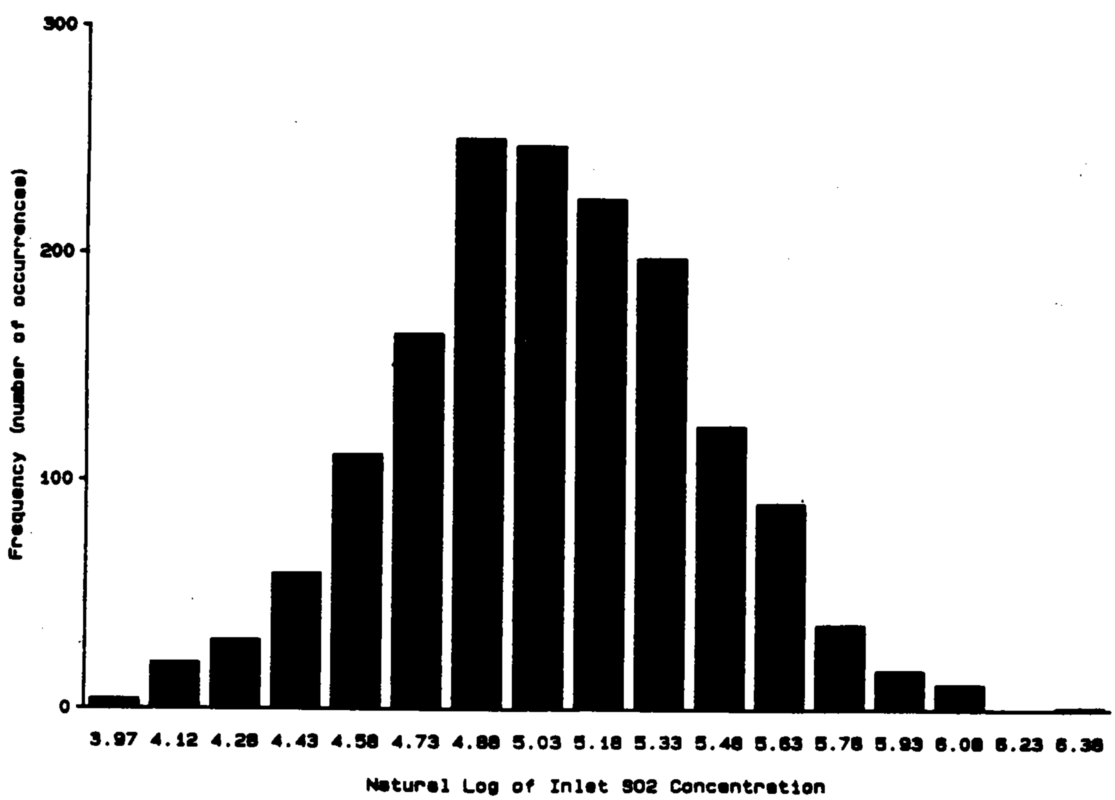


Figure 1-1. Frequency Histograms for Bridgeport Inlet SO2

were much higher than the long-term mean. Use of a longer averaging time had limited impact on lowering the maximum expected average SO_2 level.

- <u>The daily geometric means of uncontrolled SO_2 levels are normally distributed.</u> For each of the three data sets with SD inlet data, the daily geometric means of the uncontrolled SO_2 levels were normally distributed. These MWC's combust different municipal solid wastes and represent different combustor manufacturers and designs. These data were also collected at different times of the year. Based on the similarity in emission from these different facilities, it is expected that the uncontrolled SO_2 levels from other MWC's are similarly distributed and that conclusions reached regarding the continuous compliance performance of the APCD systems examined in this study are applicable to MWC's in general.

- <u>SD/FF systems are capable of continuously achieving SO_2 reductions of greater than 80 percent.</u> Data from the MWC in York County, Pennsylvania, demonstrate that SD/FF systems can achieve long-term SO_2 reductions of greater than 90 percent. However, due to short-term variability in uncontrolled SO_2 levels, lower emission reductions will be frequently encountered. Based on a 24-hour averaging period and use of geometric means to reduce the variability in individual hourly readings, a requirement of 80 percent SO_2 reduction can be continuously achieved.

- <u>SD/ESP systems are capable of continuously achieving 70 percent reductions in SO_2.</u> Data from the MWC in Millbury, Massachusetts, demonstrate that SD/ESP systems can achieve long-term SO_2 reductions of about 80 percent. As with SD/FF systems, however, normal variations in uncontrolled SO_2 levels will frequently result in lower emission reductions. Based on a 24-hour averaging period and use of geometric means to reduce the variability in individual hourly readings, a requirement of 70 percent SO_2 reduction can be continuously achieved.

Supporting information for the first two conclusions is presented in Section 3.0. Analyses supporting the last two conclusions are presented in Sections 4.0 and 5.0, respectively.

2.0 DESCRIPTION OF DATA ANALYZED

The following four sections provide a brief description of each of the four facilities examined in this report and a general overview of the emissions data analyzed.

2.1 MILLBURY, MASSACHUSETTS

2.1.1 Facility Description

The Millbury, Massachusetts facility, developed by Wheelabrator Technologies, Inc., consists of two 750-TPD mass burn combustors. Each of the combustor trains consists of a Von Roll reciprocating grate, a Babcock & Wilcox boiler, and a SD/ESP system supplied by Wheelabrator Air Pollution Control Systems. The plant's permit limits SO_2 emissions to 0.21 lbs/million Btu (equal to roughly 130 ppm). Lime slurry and dilution water are injected into the SD through a dual-fluid nozzle. The slurry feed rate is based on the permitted SO_2 reduction requirements. Dilution water is added to reduce flue gas temperature, which is normally controlled to around 255°F. Dried SD solids and fly ash are collected in a three-field ESP having a design SCA of 333 ft^2/1,000 acfm at a flue gas flow rate of 160,000 acfm.

2.1.2 Emissions Data

Hourly SO_2 data were obtained from the Millbury MWC for a period of 63 consecutive days, from July 15 through September 15, 1988. Figure 2-1 displays the hourly inlet data, hourly outlet data, and hourly percent reduction data. Some periods existed where data were missing. Table 2-1 shows the total number of hours; the mean; and the minimum, median (i.e., 50th percentile), and maximum values for the hourly Millbury data.

Most of the inlet data ranged from 100 to 300 ppm with a mean of roughly 180 ppm, but increased to over 500 ppm during several brief periods (a few hours). Outlet values were generally less than 100 ppm with a mean of less than 40 ppm, but increased to near 200 ppm on several occasions. Most hourly SO_2 percent reductions were greater than 80 percent, but dropped to less than 50 percent during several brief periods of time.

2.2 BRIDGEPORT, CONNECTICUT

2.2.1 Facility Description

The Bridgeport MWC is located in Bridgeport, Connecticut. The facility consists of three 750-TPD mass burn combustor and SD/FF trains. The

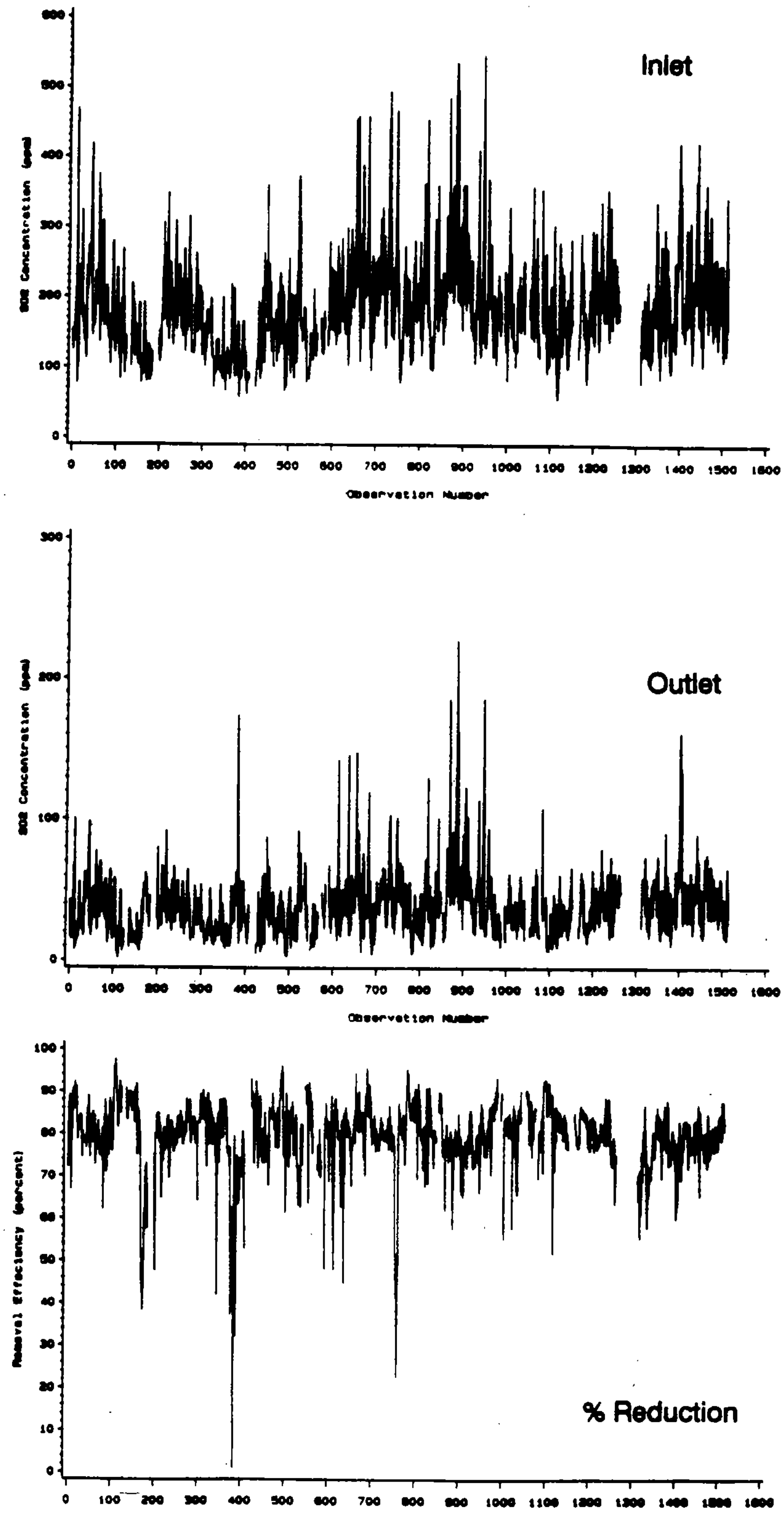


Figure 2-1. Hourly SO2 Data for Millbury

TABLE 2-1. SUMMARY STATISTICS FOR HOURLY SO_2 DATA AT MILLBURY

Summary Statistic	Inlet (ppm)	Outlet (ppm)	Percent Reduction (%)
Number of hours	1343	1343	1343
Mean	182.9	38.0	79.6
Minimum	54.8	1.9	1.0
Median	172.6	34.9	80.5
Maximum	547.2	226.7	97.7

combustors and SD/FF systems were supplied by Wheelabrator Technologies, Inc. The permit limit for SO_2 is 0.32 lbs/million Btu (equal to about 200 ppm) without a stated averaging time. There is no percent reduction requirement. Each SD is equipped with a dual-fluid atomizer. Lime slurry and dilution water flow rates are adjusted to control SD outlet temperature, SO_2 percent reduction, and outlet SO_2 emission rate. The fabric filter consists of ten compartments, each with 180 teflon-coated fiberglass bags. Reverse air is used for bag cleaning. The air-to-cloth ratio with all compartments in service is 2.28 acfm/ft^2. The baghouse can have up to two compartments off line for maintenance, but normally operates with all compartments in service.

2.2.2 Emissions Data

Hourly SO_2 data were obtained for 122 days from the Bridgeport MWC, covering the period of August 1 through November 30, 1989. Figure 2-2 displays the hourly inlet data, hourly outlet data, and hourly percent reduction data. The period roughly between hourly observations 1500 and 1600 was deleted from the data file due to a spray dryer malfunction that was caused by scaling of the slurry delivery system, low delivery pressure, and poor atomization. Wheelabrator indicated that this was the first time in approximately two years of SD operation that this problem had occurred. The missing data near hourly observation 1800 was caused by a maintenance outage following startup of the repaired spray dryer. Table 2-2 summarizes the number of hours; the mean; and the minimum, median, and maximum values for the hourly data.

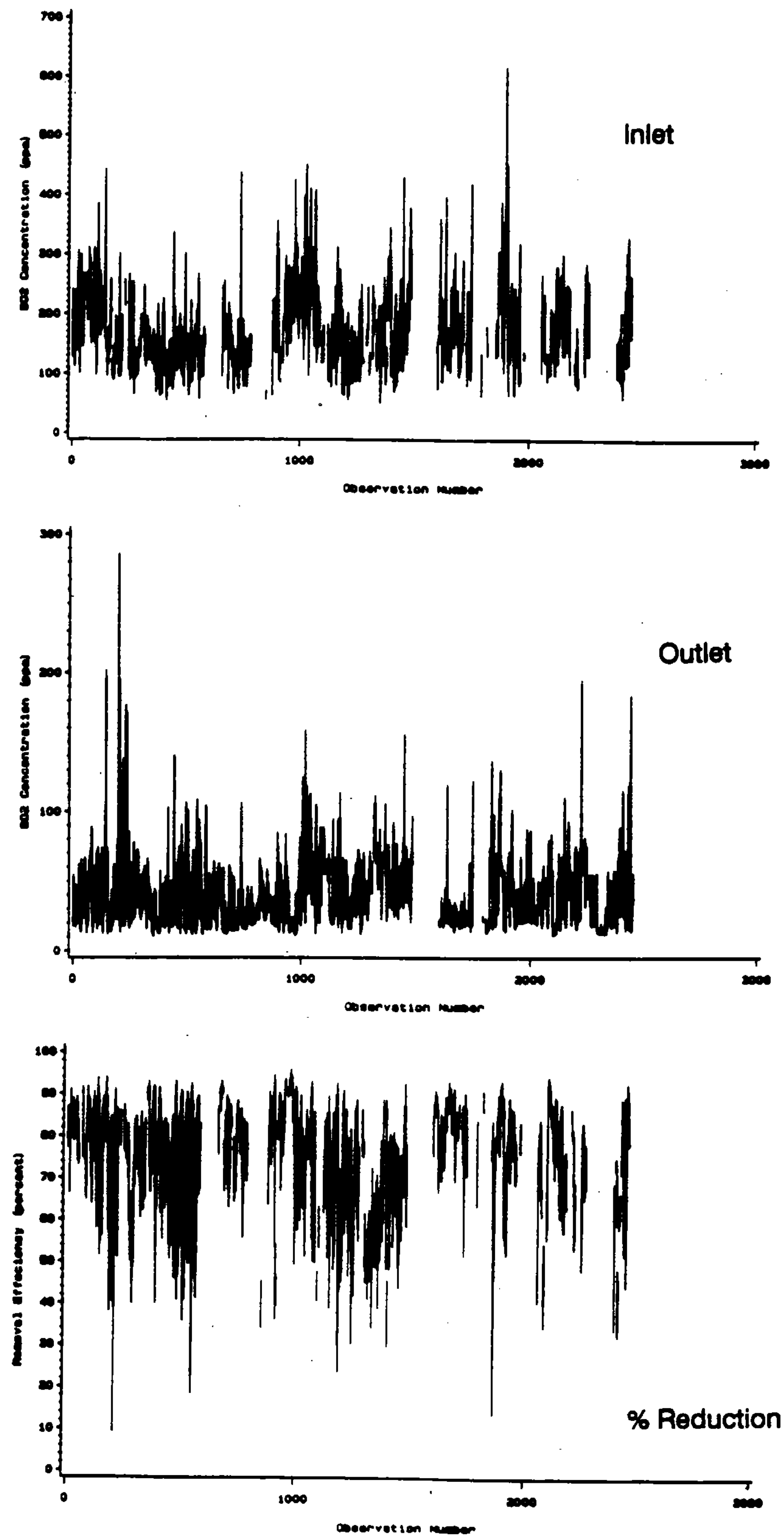


Figure 2-2. Hourly SO2 Data for Bridgeport

TABLE 2-2. SUMMARY STATISTICS FOR HOURLY SO_2 DATA AT BRIDGEPORT

Summary Statistic	Inlet (ppm)	Outlet (ppm)	Percent Reduction (%)
Number of hours	1587	2208	1573
Mean	168.1	38.8	75.1
Minimum	50.3	10.7	9.1
Median	155.3	32.5	78.2
Maximum	617.1	286.4	96.4

The Bridgeport inlet and outlet data are similar to the Millbury data. Most of the inlet data ranged from 100 to 300 ppm with a mean of roughly 170 ppm, but increased to over 400 ppm during several brief periods and were in excess of 600 ppm once. Outlet values were generally less than 100 ppm with a mean of less than 40 ppm, but increased to near 200 ppm on several occasions. Most hourly SO_2 percent reductions were greater than 75 percent, but dropped to less than 50 percent on several occasions.

2.3 YORK COUNTY, PENNSYLVANIA

2.3.1 Facility Description

The York County MWC is located in Manchester Township. The facility consists of three 448-TPD rotary waterwall mass burn combustors supplied by the Resource Energy Systems Division of Westinghouse Electric Corporation. The SD/FF system for each unit was supplied by Joy Technologies, Inc. Permit limits for SO_2 are 30 ppm at 7 percent O_2 or 70 percent removal based on a one-hour averaging period. Each SD is equipped with a rotary atomizer and is designed for a flue gas flow rate of 95,144 acfm at 400°F. During normal operation the SD inlet temperature varies from 350 to 400°F and the outlet temperature is between 260 and 300°F. Lime slurry is fed to the atomizer head tank and then mixed with dilution water based on the SD outlet temperature set point. The ratio of slurry and dilution water is based on signals from the SO_2 CEM's located at the SD inlet and the stack. The fabric filter consists of six compartments with pulse-jet cleaned fiberglass bags. The design gross air-to-cloth ratio is 2.5 acfm/ft^2 at normal flue gas flow and 3.2 acfm/ft^2 at maximum flow.

2.3.2 Emissions Data

Hourly SO_2 data were obtained from all three units at York County for two periods totaling 28 days: March 10-30, 1990, and April 29-May 5, 1990. However, because Unit 3 was out of service for most of this period, the analysis of data was limited to Units 1 and 2. Hourly inlet data, hourly outlet data, and hourly percent reduction data for Units 1 and 2 are presented in Figures 2-3 and 2-4, respectively. These plots do not include several periods when oil was burned to maintain steam production during waste feed problems or during shut down and start up. All data values recorded during the oil burning periods were excluded from further analysis. Table 2-3 shows the number of hours; the mean; and the minimum, median, and maximum values for the hourly data.

The two York County units exhibit similar SO_2 levels, but are noticeably lower at both the inlet and outlet than at Millbury and Bridgeport. Most of the inlet data ranged from 50 to 250 ppm with a mean of roughly 110 ppm, but increased to over 300 ppm during several brief periods. Outlet values were generally less than 100 ppm with a mean of less than 20 ppm, but increased to near 200 ppm on several occasions. Most hourly SO_2 levels were greater than 90 percent, but dropped to less than 50 percent on several occasions.

2.4 STANISLAUS COUNTY, CALIFORNIA

2.4.1 Facility Description

The Stanislaus County MWC, located in Crows Landing, California, consists of two 400-TPD Martin GmbH mass burn waterwall combustors. The overall facility was designed by Ogden Martin Systems, Inc. Ammonia is injected into the upper furnace of each combustor to reduce nitrogen oxide (NO_x) emissions. The SO_2 emissions from each combustor are controlled with a Flakt SD/FF system. Lime slurry is injected into the SD through dual-fluid nozzles, with the slurry feed rate controlled according to the stack SO_2 concentration and the dilution water flow adjusted based on the SD outlet temperature. The design flue gas flow rate exiting the SD is 94,000 acfm at 285°F. The pulse-jet FF has six compartments, each with 266 teflon-coated fiberglass bags. Net air-to-cloth ratio is 3.2 acfm/ft^2. At the time the data used in this analysis were collected, the facility's SO_2 permit was based on an outlet SO_2 emission rate of 30 ppm.

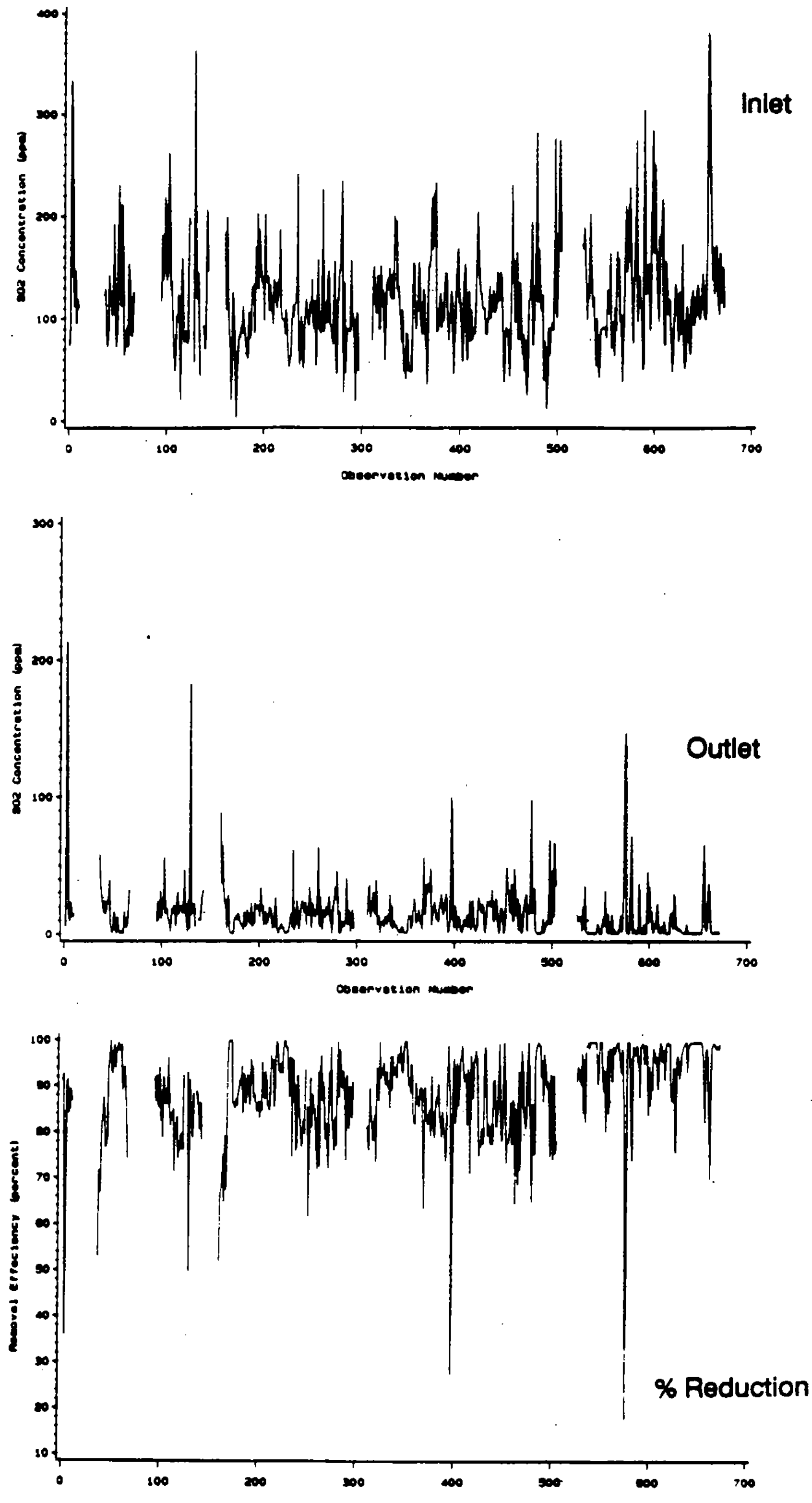


Figure 2-3. Hourly SO2 Data for York County Unit 1

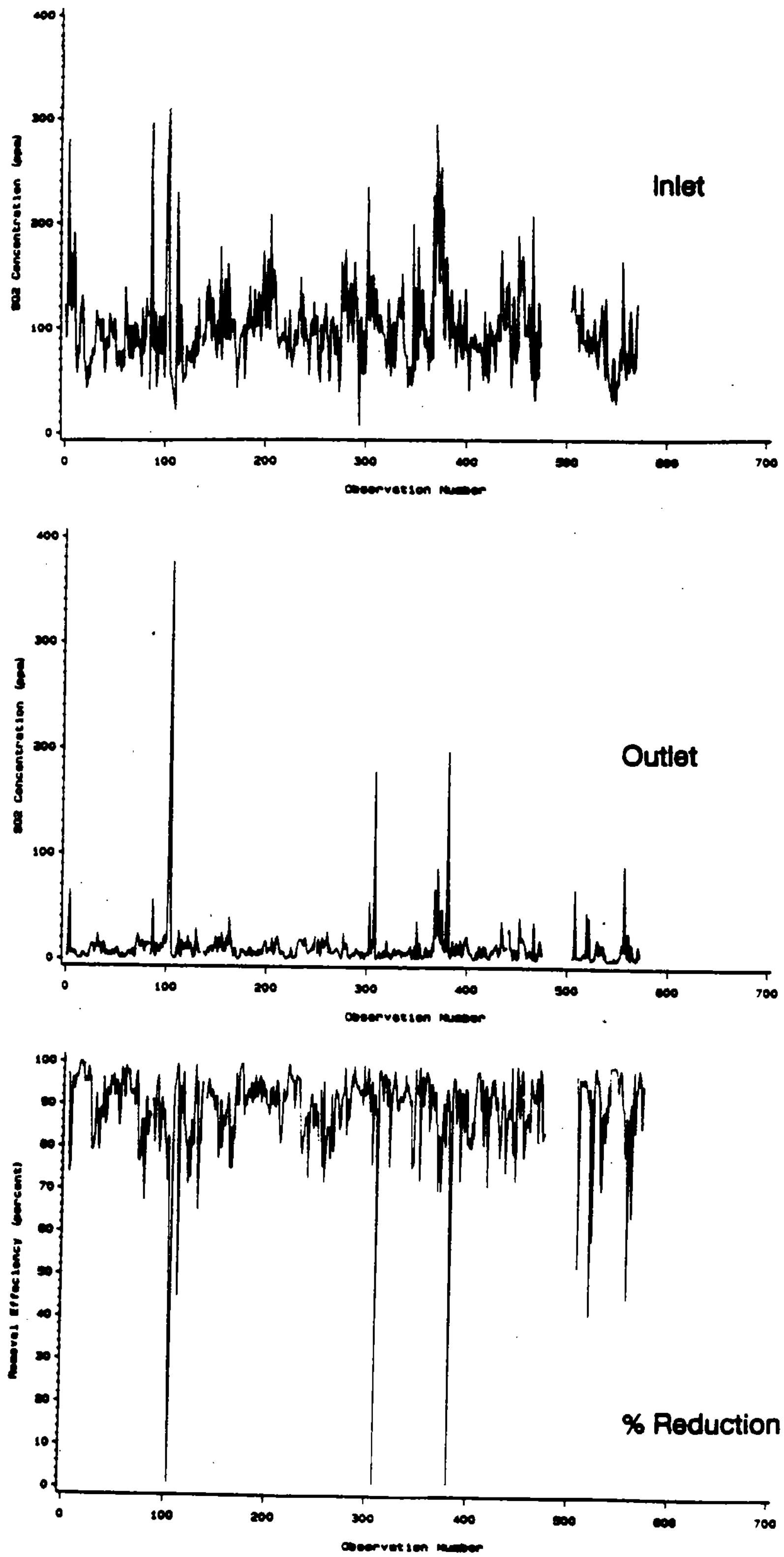


Figure 2-4. Hourly SO2 Data for York County Unit 2

TABLE 2-3. SUMMARY STATISTICS FOR HOURLY SO_2 DATA AT YORK COUNTY

Summary Statistic	Inlet (ppm)		Outlet (ppm)		Percent Reduction (%)	
	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2
Number of hours	563	539	564	537	562	537
Mean	118.5	99.6	15.1	12.2	88.7	89.3
Minimum	2.9	6.5	1.0	1.0	17.4	1.0
Median	110.8	94.0	10.7	7.6	90.6	91.8
Maximum	380.6	310.9	213.3	377.2	99+	99+

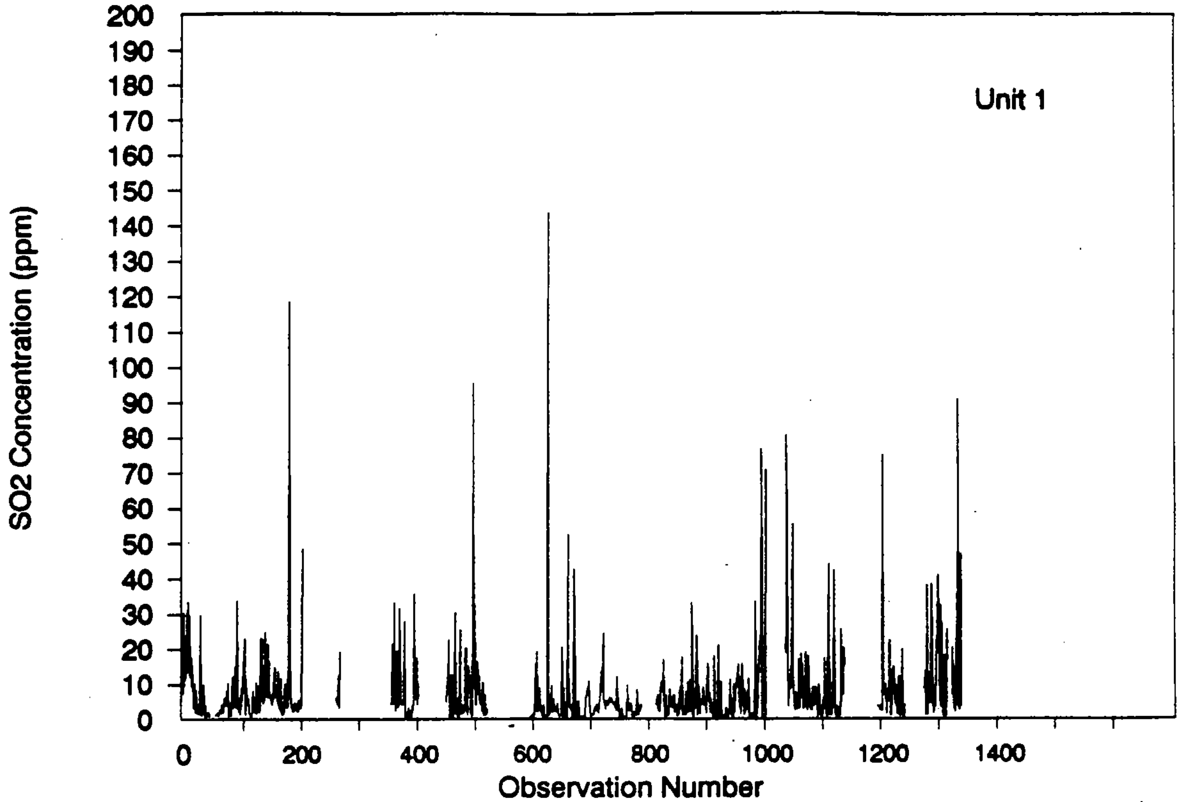
2.4.2 Emissions Data

Hourly SO_2 data were obtained from both units at Stanislaus County for the period between March 16 and May 11, 1989. As indicated above, the facility's permit limit during this period of time required monitoring of SO_2 levels in the stack only. Therefore, no data were collected at the SD inlet and percent reductions in SO_2 cannot be calculated. Figure 2-5 displays the hourly outlet data for both units. Note that there were a significant number of data gaps throughout this period. Table 2-4 shows the number of hours; the mean; and the minimum, median, and maximum values for the hourly data.

TABLE 2-4. SUMMARY FROM STATISTICS FOR HOURLY SO_2 DATA FROM STANISLAUS COUNTY

Summary Statistic	Unit 1 Outlet (ppm)	Unit 2 Outlet (ppm)
Number of hours	920	959
Mean	7.2	9.1
Minimum	0.0	0.0
Median	4.0	5.2
Maximum	143.2	168.7

The two Stanislaus County units exhibited lower outlet SO_2 levels than were encountered at any of the other three MWC's, with most hourly values below 30 ppm and the mean from both units less than 10 ppm. As with the other three MWC's, however, there were several hourly SO_2 levels above 100 ppm. Although these data suggest that the SD/FF systems at Stanislaus County are capable of high levels of SO_2 removal, the lack of inlet SO_2 measurements meant that the Stanislaus County data could not be used to analyze the level of SO_2 reduction that SD/FF systems can achieve. However, during an earlier compliance test at the plant, SO_2 reductions of greater than 90 percent were measured.



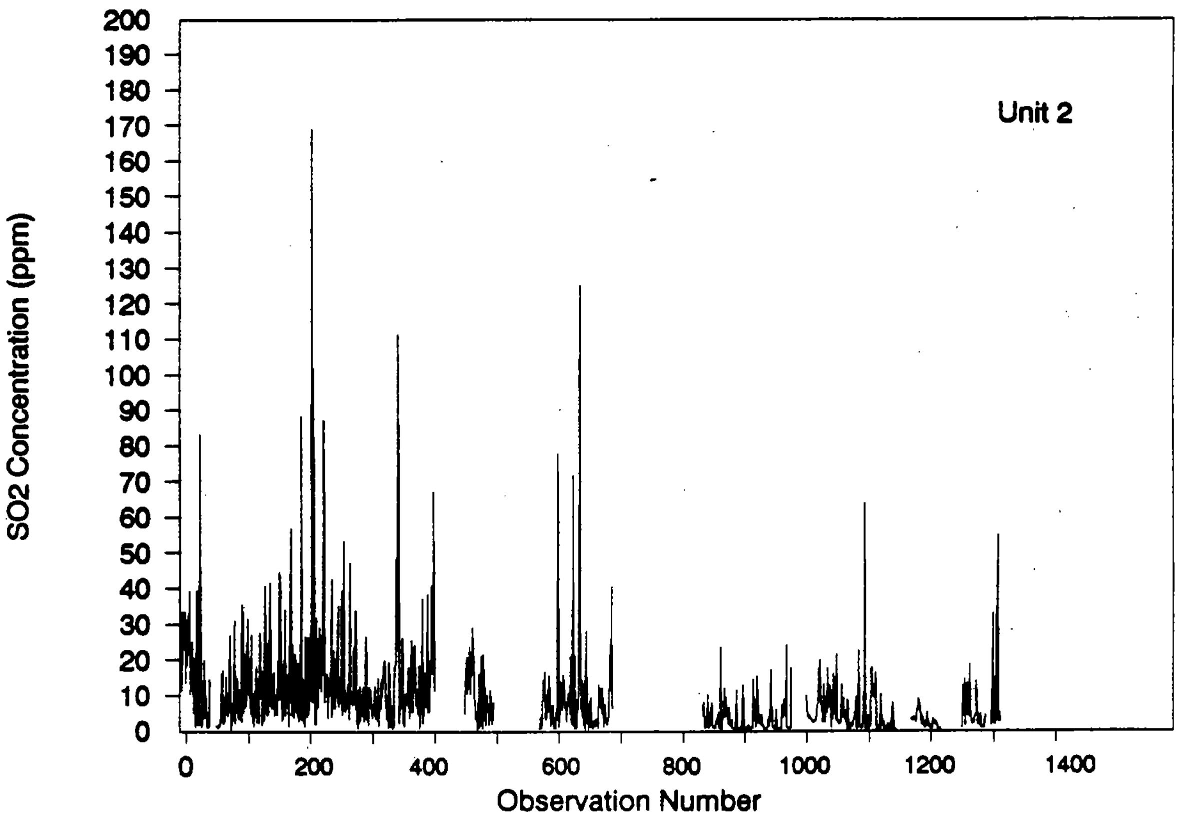


Figure 2-5. Outlet SO2 Data for Stanislaus County

3.0 SPRAY DRYER INLET VALUES

This section describes the analyses of uncontrolled SO_2 emissions from the Millbury, Bridgeport, and York County MWC's. The objective of these analyses was to examine statistical similarities and differences in uncontrolled SO_2 emissions from these three MWC's as an aid in assessing the applicability of conclusions reached from these specific units to MWC's in general.

3.1 SHORT-TERM VARIABILITY

The figures and tables presented in Sections 2.1.2, 2.2.2, and 2.3.2 demonstrate the significant degree of short-term variability in uncontrolled SO_2 data. At all three sites, maximum hourly SO_2 averages at the SD inlet were more than three times greater than the mean value on the same unit. For example, the plot of inlet SO_2 levels at Bridgeport (Figure 2-2) shows several hourly SO_2 spikes that were above 400 ppm and one that was above 600 ppm, even though most of the data were less than 160 ppm.

Note also from the summary statistics for each data set, shown in Table 3-1, that the difference between the minimum value and the median is significantly smaller than between the median and the maximum value. This skew in the data suggests that the inlet SO_2 levels data are not normally distributed.

TABLE 3-1. SUMMARY STATISTICS FOR HOURLY INLET SO_2 DATA (ppm)

Summary Statistic	Millbury	Bridgeport	York County Unit 1	York County Unit 2
Mean	182.9	168.1	118.5	99.6
Minimum	54.8	50.3	2.9	6.5
Median	172.6	155.3	110.8	94.0
Maximum	547.2	617.1	380.6	310.9

Table 3-2 shows the Shapiro-Wilk normality statistic (W) for the hourly SO_2 inlet data and the natural log (ln) of the hourly inlet data. An asterisk by the W-value indicates a normal distribution at the 95 percent confidence level. Frequency histograms help to visually display the differences between the hourly and the ln hourly datasets implied by the W's. Figure 1-1 (presented in Section 1.3) shows the frequency histograms for the Bridgeport hourly inlet data (W = 0.922) and the ln hourly inlet data (W = 0.988).

TABLE 3-2. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR HOURLY INLET DATA

Inlet Dataset	Bridgeport	Millbury	York County Unit 1	York County Unit 2
Hourly	0.922	0.903	0.912	0.889
Ln hourly	0.988*	0.984	0.940	0.972

* Data are normally distribution at the 95% confidence level

Though only the Bridgeport ln hourly data are normally distributed at the 95 percent confidence level, the ln hourly data are more normally distributed than the hourly data at all sites, as indicated by larger W's. Thus, for all sites, statistics generated from the ln hourly data are more valid than statistics generated from the hourly data.

Table 3-3 shows the results of examining the ln hourly inlet data using a first-order autoregressive, AR(1), model. The objective of this analysis was to evaluate underlying time series dependencies in the data. If data are autoregressive, it means that the hour-to-hour variations in SO_2 levels are not truly random and that prediction of the SO_2 level in one time period must consider the SO_2 level in the previous time period. This relationship deviates from conventional statistics which assume that such dependencies do not exist and, thus, that each observation is random.

The longest consecutive segment of data was examined for each site. As can be seen from Table 3-3, the Bridgeport and Millbury data appear to come

TABLE 3-3. TIME SERIES ANALYSIS FOR NATURAL LOG OF HOURLY INLET DATA (LONGEST CONSECUTIVE SEGMENT OF DATA)

Site	Number of Hours	Correlation Coefficient	Do Data Fit AR(1) Model?
York County Unit 1	201	0.61	no
York County Unit 2	337	0.38	no
Bridgeport	166	0.56	close
Millbury	258	0.60	close

close to fitting the AR(1) model, but the correlation coefficients are fairly small, meaning that the impact of autocorrelation on predicted emission levels is small. Hourly inlet data from York County do not fit the AR(1) model. Because of the existence of only weak time dependencies within these three data sets, the AR(1) model was not used in any of the subsequent inlet SO_2 analyses.

3.2 IMPACT OF AVERAGING TIMES

As discussed in Section 3.1, even though ln hourly inlet data were not normally distributed at the 95 percent confidence level for all sites, this data transformation resulted in data distributions that were closer to normal than the original hourly inlet data. For lognormally distributed data, the appropriate method for calculating average values is the geometric mean rather than the arithmetic mean, as is commonly used with normally distributed data.[2]

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[2]The geometric mean is defined as:

$$\text{Geometric Mean} = \left(\prod_{i}^{n} X_i\right)^{1/n}$$

where Π is the process of multiplying each non-zero value of X_i together (i.e., $X_1 \bullet X_2 \bullet \ldots \bullet X_n$), and n is the number of non-zero observations. For computational ease, geometric means can be calculated using the following transformation based on identities of natural logarithms:

$$\left(\prod_{i}^{n} X_i\right)^{1/n} = \exp\left[\ln\left(\prod_{i}^{n} X_i\right)^{1/n}\right] = \exp\left[1/n \ln\left(\prod_{i}^{n} X_i\right)\right] = \exp\left[1/n \sum_{i}^{n} \ln X_i\right]$$

The effect of different averaging periods on the observed variability of uncontrolled SO_2 levels was examined for the ln-transformed data at each of the three MWC's. Averaging times examined were 1-hour, 3-hour, 8-hour, and 24-hour block averages; and 1-day (equal to a 24-hour block), 3-day, and 7-day rolling averages. The 99th percentile inlet SO_2 values resulting from this analysis are presented in Figure 3-1. As can be seen, there is a significant reduction in 99th percentile values between 1 and 24 hours, but a more gradual reduction for averaging periods of greater than 24 hours. Based on this observation, a 24-hour block was selected as the appropriate averaging period for further analysis. The use of a 24-hour averaging period is also consistent with the analysis of outlet SO_2 levels presented in Sections 4.2 and 5.2.

The 24-hour block geometric mean was calculated for each day of record with 18 or more hours of non-missing inlet data as follows:

$$\text{24-hour block geometric mean} = \exp\left[\frac{\sum^{n} (\ln X_i)}{n}\right]$$

where: X_i = hourly inlet SO_2 concentration

n = number of hourly SO_2 values for given 24-hour block (values calculated only for days with 18 or more hours of data)

Table 3-4 shows the W's for the 24-hour block means and the ln 24-hour block means of the SO_2 inlet data for each site. As with the hourly data, the W's are larger for the ln-transformed datasets than for the original datasets. However, in contrast to the hourly data, all ln-transformed datasets pass the normality test and all original datasets but Bridgeport pass as well. This confirms that the ln-transformed data sets are preferred for developing predictive statistics.

Figure 3-2 displays the geometric 24-hour block means for inlet data at Millbury, Bridgeport, and York County. These plots show that the day-to-day variability is significantly less than the hour-to-hour variability shown in figures in Section 2. The cumulative frequency distributions curves for the geometric 24-hour block means at each site are shown in Figure 3-3. Though the actual concentrations differ between the sites, the shapes of the curves are rather similar. Based on the fact that all of the inlet geometric means

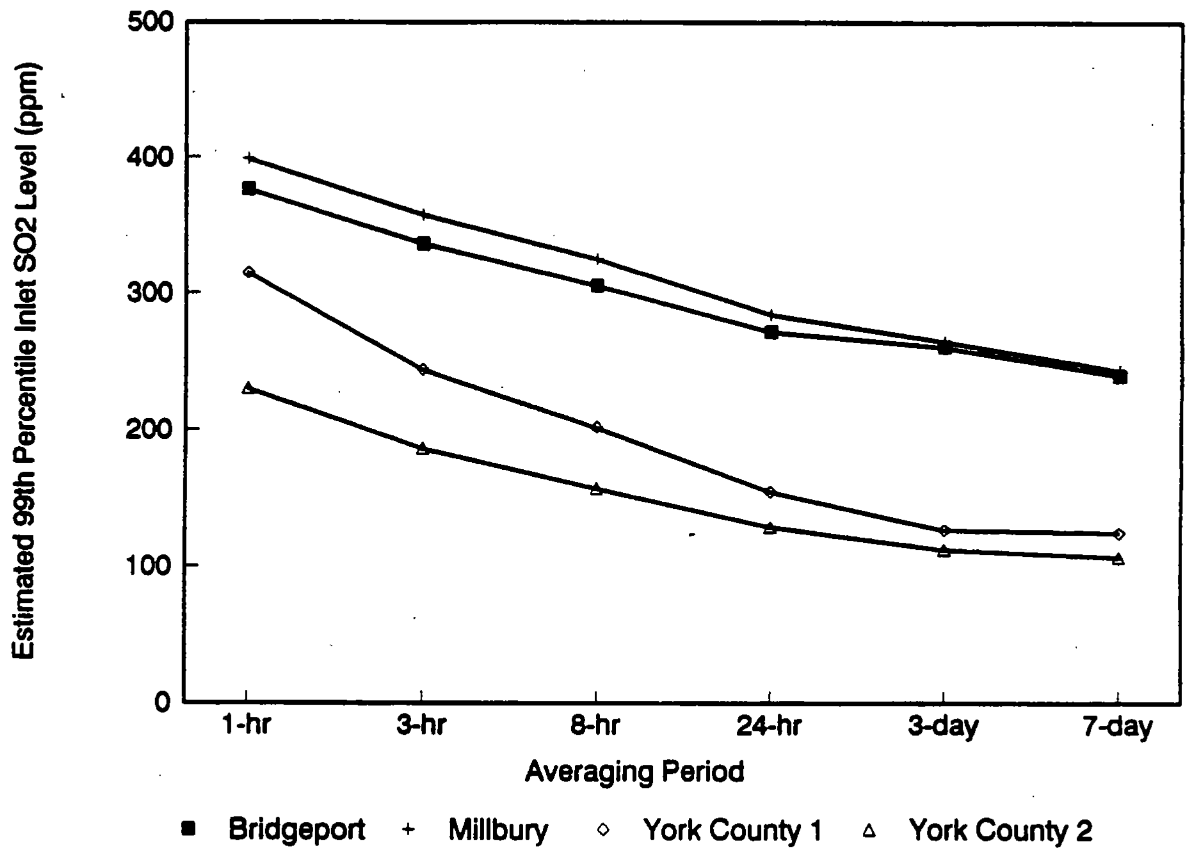


Figure 3-1. Impact of Averaging Time on Uncontrolled SO2 Emissions

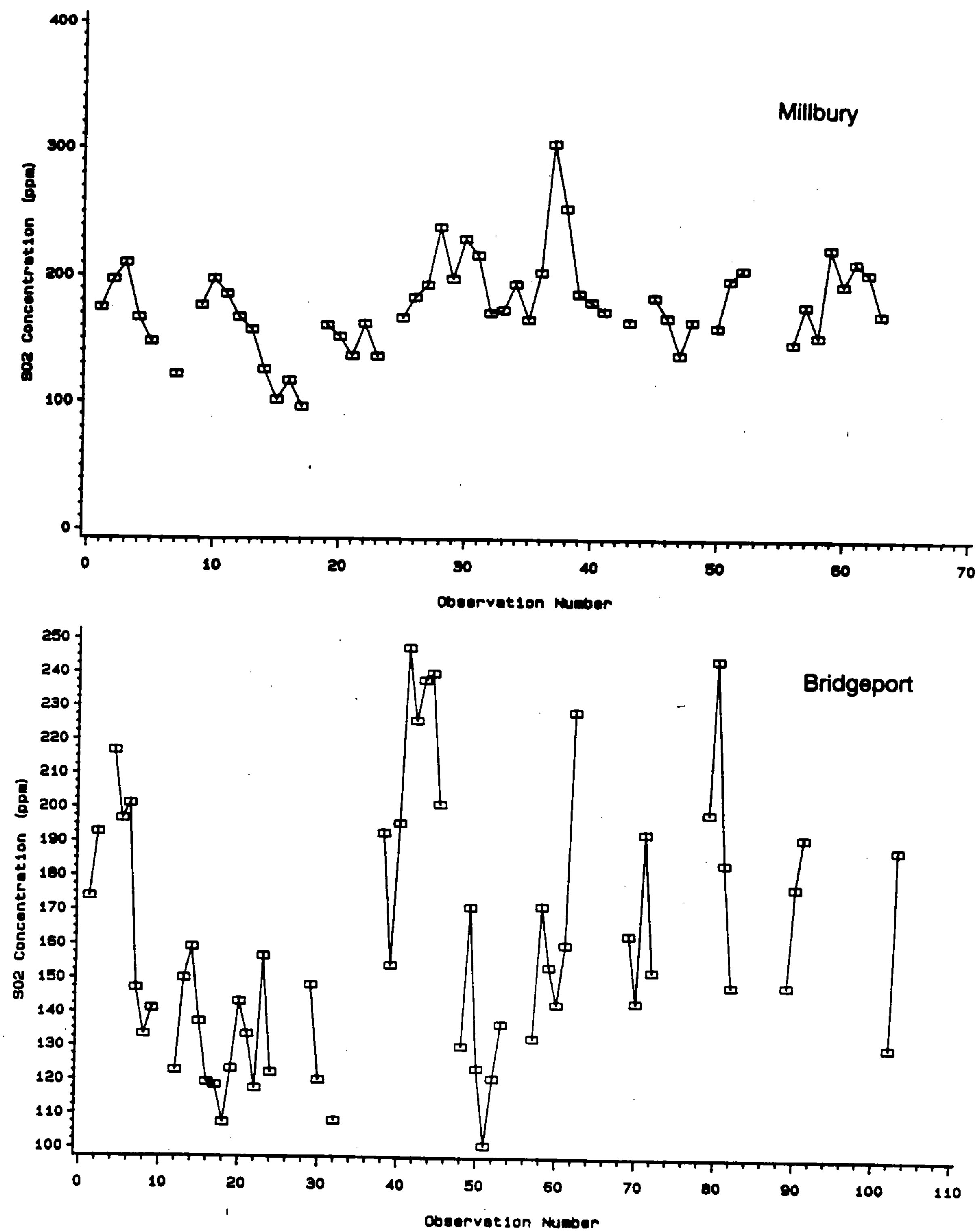
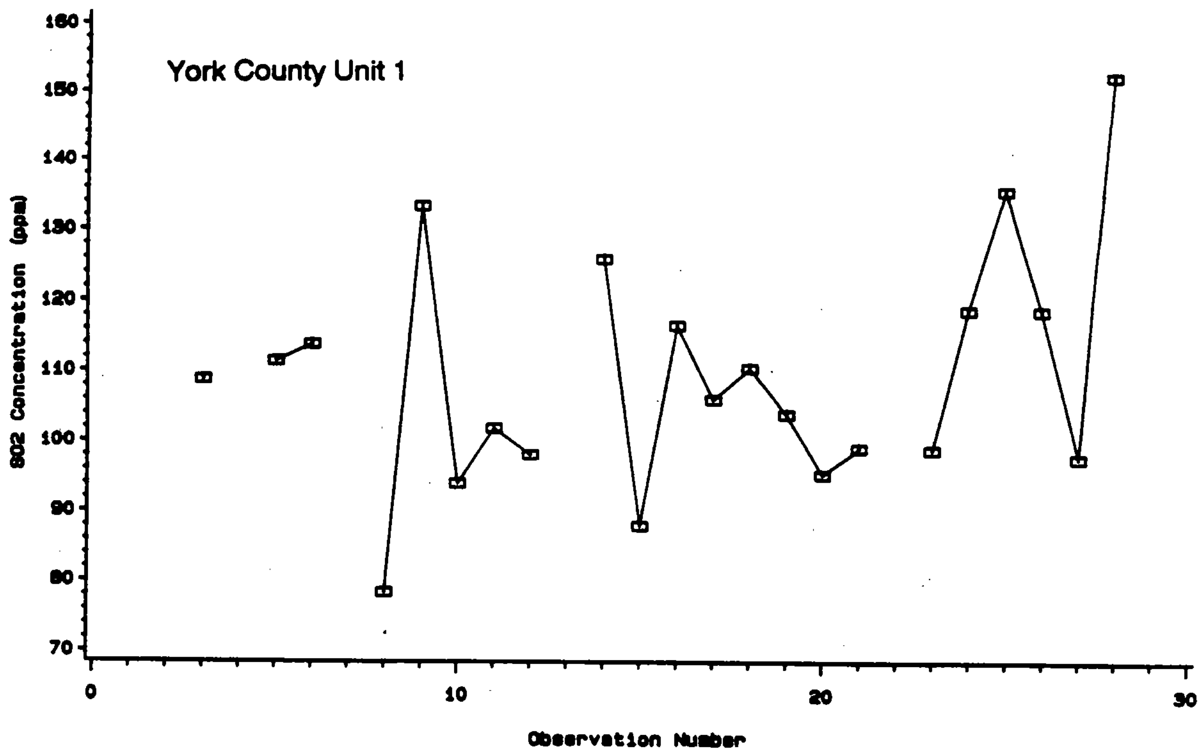


Figure 3-2. 24-Hour Geometric Mean Inlet SO2 Data



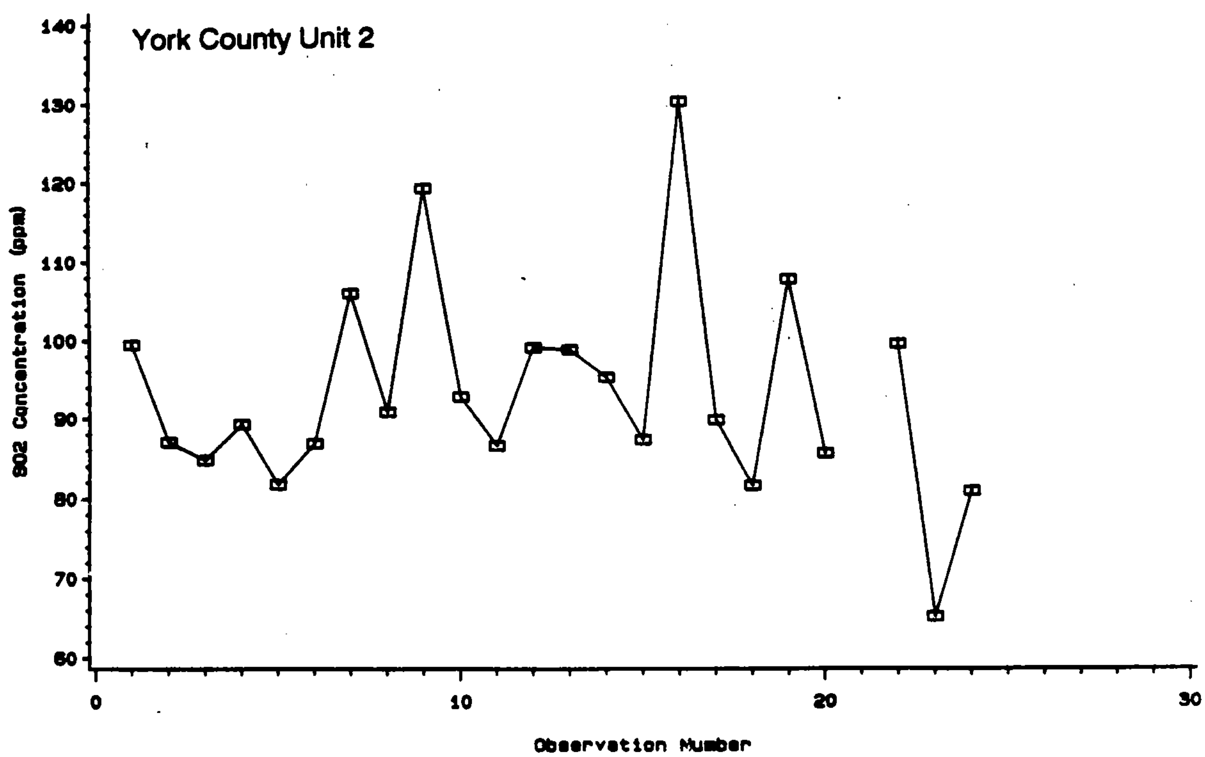


Figure 3-2. 24-Hour Geometric Mean Inlet SO2 Data (Continued)

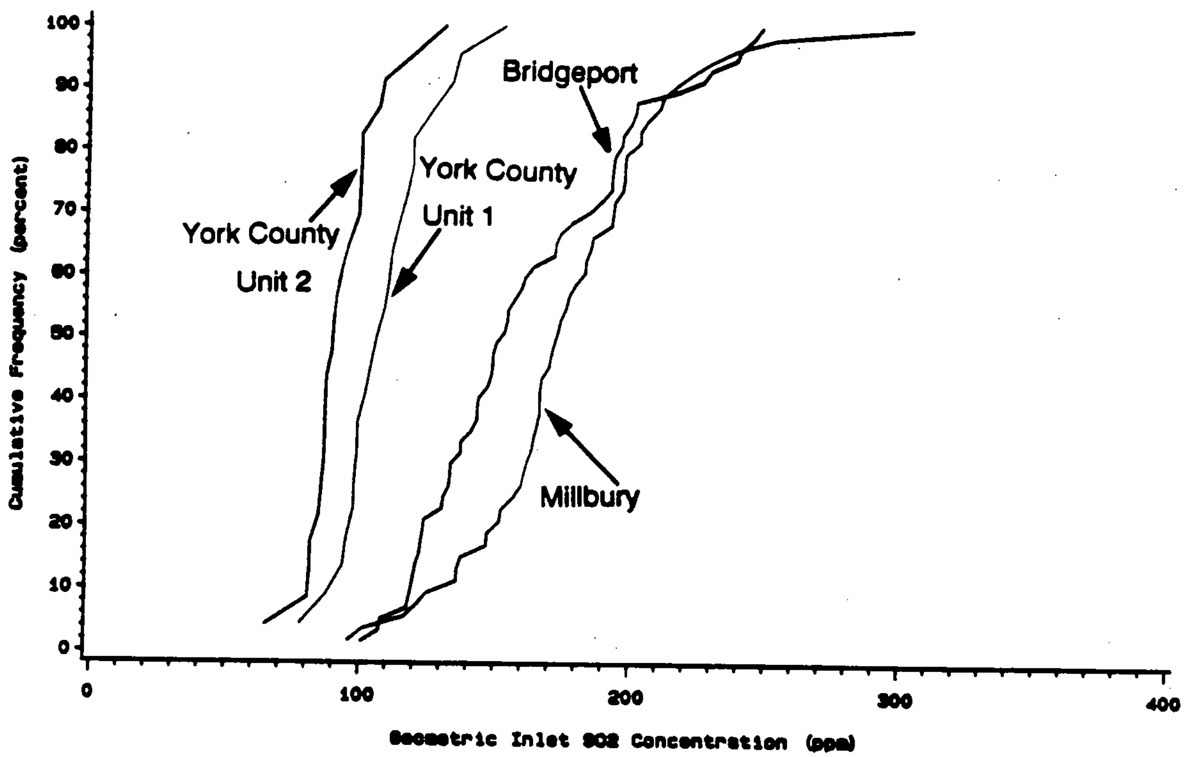


Figure 3-3. Cumulative Frequency Distribution of 24-Hour Geometric Mean Inlet SO2 Data

TABLE 3-4. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR INLET 24-HOUR BLOCK MEANS

Inlet Dataset	Bridgeport	Millbury	York County Unit 1	York County Unit 2
24-hour block mean	0.937	0.969*	0.951*	0.936*
Ln 24-hour block mean	0.957*	0.974*	0.986*	0.949*

* Data are normally distributed at the 95% confidence level.

are normally distributed and that the cumulative probability distributions between sites are similar, it is expected that the inlet SO_2 24-hour geometric means from other MWC's are similarly distributed. It is therefore expected that the results of the analyses presented in Sections 4 and 5 for/FF and SD/ESP systems will be applicable to other MWC's equipped with these APCD systems.

3.3 CONCLUSIONS

Based on the similarities in the inlet data between the three MWC's examined, several general conclusions are reached:

- Maximum hourly SO_2 measurements can exceed the mean value at a given site by more than a factor of three.
- The ln-transformed hourly inlet data from all three facilities were more normally distributed than original data for both 1-hour and for 24-hour blocks, suggesting that uncontrolled SO_2 emissions from MWC's in general are lognormally distributed.
- An AR(1) model of the hourly inlet data was not statistically significant and the correlation coefficients were relatively low.
- Using a 24-hour averaging period can significantly reduce the variability in uncontrolled SO_2 levels. Use of longer averaging times has relatively less impact. Use of shorter averaging times would result in frequent occurrences of high average SO_2 levels due to short-duration excursions in uncontrolled SO_2 levels.

4.0 SO_2 CONTROL PERFORMANCE OF SPRAY DRYER/FABRIC FILTER SYSTEMS

The performance capability of SO_2 control technologies can be defined by the percent reduction in SO_2 levels between the inlet and outlet of the control device. For MWC's with SD/FF systems, two sets of inlet and outlet CEM data were available: Bridgeport and York County. The permitted SO_2 limit at Bridgeport was based on a relatively high outlet SO_2 level, and thus did not require a high level of continuous SO_2 reduction. Therefore, York County provided the primary data set used to analyze the performance capability of SD/FF systems. Although the primary focus of this section is on percent reduction, some analysis of outlet SO_2 concentrations is also presented.

The Stanislaus County data, although having low outlet SO_2 levels, do not include uncontrolled (i.e., inlet) SO_2 levels, and, thus, cannot be used to define continuously achievable SO_2 percent reductions. However, based on the mean measured outlet SO_2 levels of 7-9 ppm (see Table 2-4) and earlier compliance testing of the plant, it appears that the average percent reductions were about 90 percent or greater.

4.1 SHORT-TERM VARIABILITY

The figures and tables presented in Section 2.3.2 demonstrate the variability of the percent reduction data at York County. Although the average percent reductions for both units are near 90 percent and the medians are slightly greater than 90 percent, there are short-duration spikes of less than 20 percent on each unit.

A common convention in analysis of percent reduction data is to calculate emissivity, which is defined as:

Emissivity = 100 - Percent Reduction

Table 4-1 shows the Shapiro-Wilk normality statistic (W) for the hourly emissivity data and the ln-transformed data for York County Units 1 and 2. Though none of the ln hourly emissivity data are normally distributed at the 95 percent confidence level, the ln hourly data are more normally distributed than the hourly data, as indicated by larger W's. Thus, statistics generated from the ln hourly data will be more valid than statistics generated from the hourly data.

An AR(1) time series model was used to examine for time-based autocorrelations in the ln hourly outlet data at York County. The longest

TABLE 4-1. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR HOURLY EMISSIVITY DATA AT YORK COUNTY*

Inlet Dataset	Unit 1	Unit 2	Units 1 and 2 Combined
Hourly	0.841	0.672	0.759
Ln Hourly	0.855	0.953	0.923

* No datasets are normally distributed at the 95% confidence level.

consecutive segment of data was examined for each unit. Table 4-2 shows the number of hours, the correlation coefficients, and a short response (yes, no, or close) for whether the model fits. As can be seen from Table 4-2, the outlet SO_2 data from neither unit appears to fit the AR(1) model and the correlation coefficients are small. As discussed in Section 3.1, the inlet SO_2 data at York County also did not fit an AR(1) model. Therefore, the AR(1) model was not used to analyze the York County emissivity data.

TABLE 4-2. TIME SERIES ANALYSIS FOR NATURAL LOG OF HOURLY OUTLET DATA (LONGEST CONSECUTIVE SEGMENT OF DATA)

Site	Number of Hours	Correlation Coefficient	Do Data Fit AR(1) Model?
York County Unit 1	172	0.45	no
York County Unit 2	190	0.27	no

4.2 IMPACT OF AVERAGING TIMES

As discussed in Section 4.1, even though the ln hourly emissivity data were not normally distributed at the 95 percent confidence level, this data transformation resulted in data distributions that were closer to normal than the original hourly emissivity data. As a result, the geometric mean is a more appropriate statistic to use for analysis of the data.

An examination of the effect of averaging times on the variability in SO_2 emissivity was conducted similarly to that presented in Section 3.2. Based on the lognormal distribution of the hourly emissivity data, geometric means were used to calculate average emissivity values. The results are shown in Figure 4-1. Note that the projected continuously achievable emissivity level (based on an exceedance frequency of one per year) decreases from roughly 35 percent (65 percent reduction) based on a 3-hour block geometric mean to 19 percent (81 percent reduction) based on a 24-hour block geometric mean. If the averaging time was increased to 7 days based on a daily rolling average, the continuously achievable emissivity is estimated at 13 percent. Based on the almost 50 percent reduction in emissivity level at 24 hours versus 3 hours, versus the smaller decrease resulting from increasing the averaging time to 7 days, it was determined that a 24-hour block was the most appropriate averaging period. At this averaging period, high levels of continuous SO_2 removal are needed, while providing allowance for the short-term variability in MSW sulfur content and SD/FF operation that can result in higher emissions.

Table 4-3 shows the W's for the 24-hour arithmetic block means and the 24-hour block geometric means for the emissivity data from York County Units 1 and 2. The 24-hour block geometric means for both units were normally distributed at the 95 percent confidence level and the W's are greater for the geometric means than for the arithmetic means. This supports use of geometric means rather than arithmetic means for predicting expected minimum daily percent reduction levels.

TABLE 4-3. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR EMISSIVITY 24-HOUR BLOCK MEANS AT YORK COUNTY

Inlet Dataset	Unit 1	Unit 2
24-hour block arithmetic mean	0.913*	0.907
24-hour block geometric mean	0.918*	0.939*

* Data are normally distributed at the 95% confidence level.

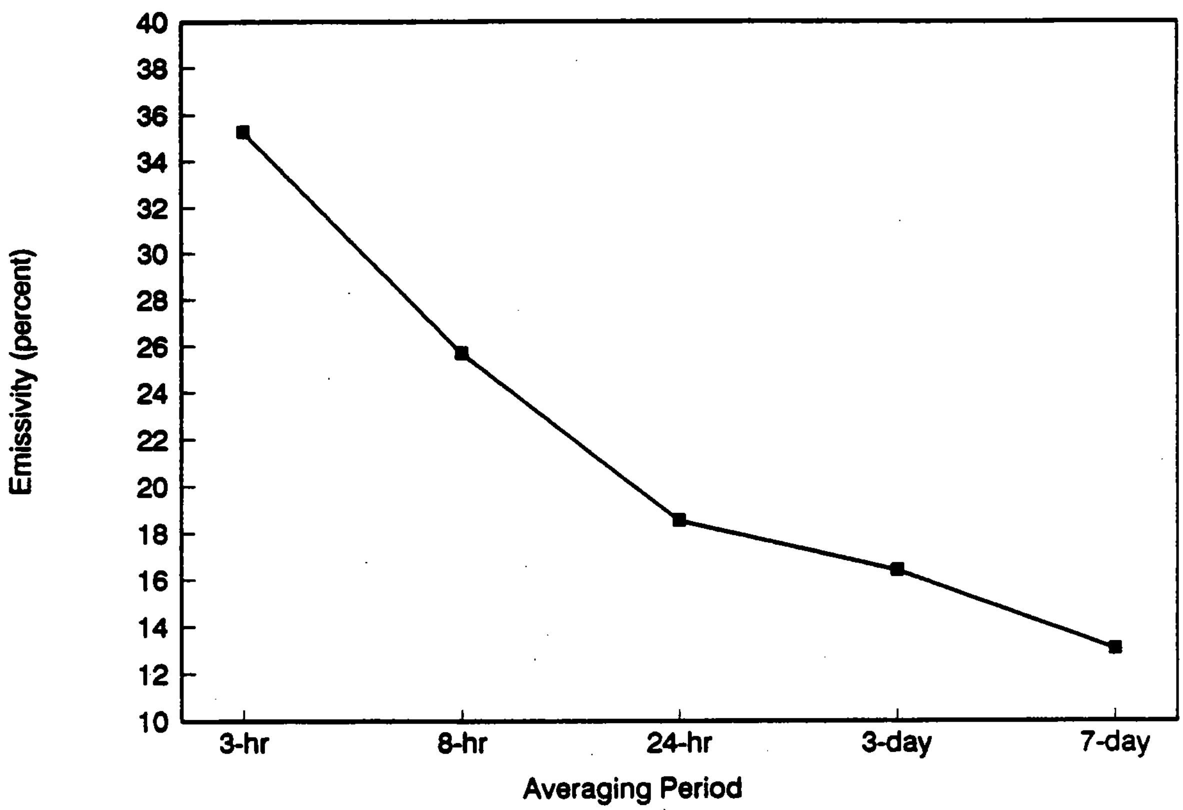


Figure 4-1. Impact of Averaging Time on SO2 Emissivity at York County

Figure 4-2 displays the individual 24-hour block geometric means of emissivity for York County Units 1 and 2. The missing data points are for days during which hourly data were not available for 7 or more hours due to the unit being off-line or other factors. As expected, the day-to-day variability in emissivity is less than the hour-to-hour variability shown in Figure 2-3. The lowest percent removal (corresponding to the highest emissivity) encountered during these 45 days of data was roughly 84 percent.

Table 4-4 presents the geometric means, standard deviations, and calculated once-per-year exceedance values based on the emissivity data from each of the York County units and for the two units combined. The mean emissivity for both York County units is near 8 percent, which translates to a percent reduction of near 92 percent. The once-per-year emissivity exceedance values for Units 1 and 2 are 16 and 21 percent, respectively. Given the limited number of data points for each unit (22 for Unit 1 and 23 for Unit 2), the two data sets were combined to reduce the impact of random variation in a small data set on calculated values. Combining the data sets for Units 1 and 2 is considered valid based on the fact that both units fire wastes from the same MSW collection pit (i.e., they have similar variability in uncontrolled SO_2 levels) and have similar SD/FF designs. Using the combined data sets, the once-per-year maximum 24-hour geometric mean emissivity value is 19 percent, corresponding to a percent reduction value of 81 percent.

TABLE 4-4. SUMMARY STATISTICS FOR GEOMETRIC MEANS OF EMISSIVITY (PERCENT) AT YORK COUNTY

Statistic	Unit 1	Unit 2	Units 1 and 2 Combined
Number of blocks	22	23	45
Mean	8.02	7.90	7.96
Standard deviation	4.65	2.89	3.81
Continuous compliance level*	20.95	15.94	18.55

* Based on one exceedance per year (Mean + 2.777*Standard Deviation)

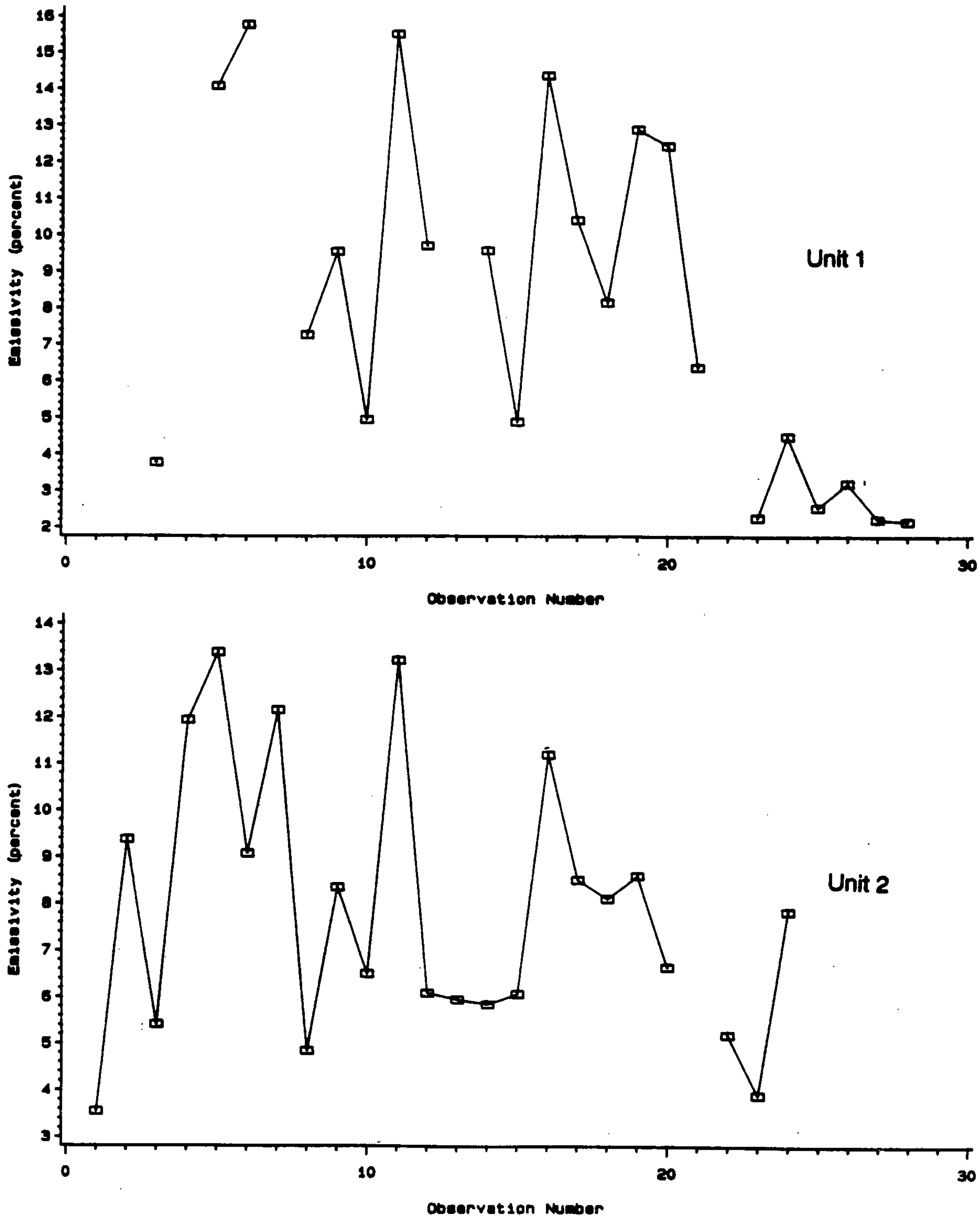


Figure 4-2. York County 24-Hour Geometric Mean Emissivity Values

4.3 CONCLUSIONS

Based on the York County and Stanislaus County data, the following conclusions summarize the SO_2 control performance of SD/FF systems:

- Although average SO_2 reductions of 90 percent are achievable over an extended period, short-duration spikes in hourly percent reduction levels are such that these levels cannot be achieved continuously due to variations in inlet SO_2 levels and normal variations in SD/FF performance.

- Hourly ln-transformed emissivity data approach a normal distribution. This means that geometric means (rather than the more traditionally used arithmetic means) are appropriate for assessing achievable levels of SO_2 control.

- The variability in hourly inlet outlet data did not fit an AR(1) time series model and the correlation coefficients were small.Therefore, consideration of time dependencies was not used in estimating achievable performance levels.

- Based on analysis of the impact of averaging periods on the variability in SO_2 emissions, it was concluded that a 24-hour averaging period was the most appropriate averaging period. Use of a shorter averaging time results in reducing the level of continuously achievable reductions, while longer averaging periods had less of an impact.

- The 24-hour geometric mean emissivity levels are normally distributed. Based on the available data and resulting statistics, a 24-hour block geometric mean SO_2 percent reduction level of 80 percent is achievable from SD/FF systems on a continuous basis.

5.0 SO_2 CONTROL PERFORMANCE OF SPRAY DRYER/ESP SYSTEMS

This section describes the achievability of SO_2 emission reductions at MWC's equipped with SD/ESP systems. This analysis is based on the SO_2 data from the Millbury MWC presented in Section 2.1. Although the primary focus of this section is on percent reduction, some analysis of outlet SO_2 levels is also presented.

5.1 SHORT-TERM VARIABILITY

The figures and tables presented in Section 2.1.2 demonstrate the variability of hourly SO_2 data at Millbury. Although the average percent reduction is roughly 80 percent, there are short-duration spikes below 50 percent.

As with the York County data, percent reduction levels were converted to emissivity levels to aid in the analysis. Table 5-1 shows the Shapiro-Wilk normality statistic (W) for the hourly emissivity data and the ln hourly emissivity data from Millbury. Though the ln hourly data are not normally distributed at the 95 percent confidence level, the ln hourly data are more normally distributed than the hourly data, as indicated by a larger W. Thus, statistics generated from the ln hourly data will be more reliable than statistics generated from the hourly data.

TABLE 5-1. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR HOURLY EMISSIVITY DATA AT MILLBURY*

Inlet Dataset	Unit 1
Hourly	0.846
Ln hourly	0.972

* No datasets are normally distributed at the 95% confidence level.

An AR(1) time series model was used to examine the ln hourly outlet data at Millbury for time-based autocorrelations. Table 5-2 shows the number of hours, correlation coefficients, and a short response (yes, no, or close) for whether the model fits. As can be seen from this table, the Millbury outlet data do not fit the AR(1) model and the correlation coefficient is fairly small. As discussed in Section 3.1, the Millbury SO_2 inlet data approached being AR(1), but did not satisfy the model criteria. Therefore, an AR(1) model was not used to analyze the Millbury emissivity data.

TABLE 5-2. TIME SERIES ANALYSIS FOR NATURAL LOG OF HOURLY OUTLET DATA (LONGEST CONSECUTIVE SEGMENT OF DATA)

Site	Number of Hours	Correlation Coefficient	Do Data Fit AR(1) Model?
Millbury	258	0.56	no

5.2 IMPACT OF AVERAGING TIMES

As in Sections 3.2 and 4.2, several averaging times were examined in an attempt to reduce the data variability. Because of the lognormal distribution of the hourly data, geometric means were used to calculate average emissivities over each time period. The results of this analysis are plotted in Figure 5-1. Note that the projected continuously achievable emissivity level (based on an exceedance frequency of one per year) decreases from roughly 45 percent (55 percent reduction) based on a 3-hour block geometric mean to 30 percent (70 percent reduction) based on a 24-hour block geometric mean. If the averaging time is increased to 7 days based on a daily rolling average, the continuously achievable emissivity is estimated at 25 percent. The lower SO_2 removal by SD/ESP versus SD/FF systems (as discussed in Section 4.2) is caused by the reduced level of SO_2 control achieved by an ESP versus the filter cake in a FF. Based on the lower emissivity level for 24 hours versus 3 hours, and the relatively small decrease in emissivity resulting from increasing the averaging time to 7 days, it was determined that a 24-hour block was also the most appropriate averaging period for SD/ESP systems.

Table 5-3 shows the W normality statistics for the 24-hour block arithmetic and geometric means for the Millbury emissivity data. The 24-hour block geometric mean is normally distributed at the 95 percent confidence level and the W's are greater for the geometric means than for the arithmetic

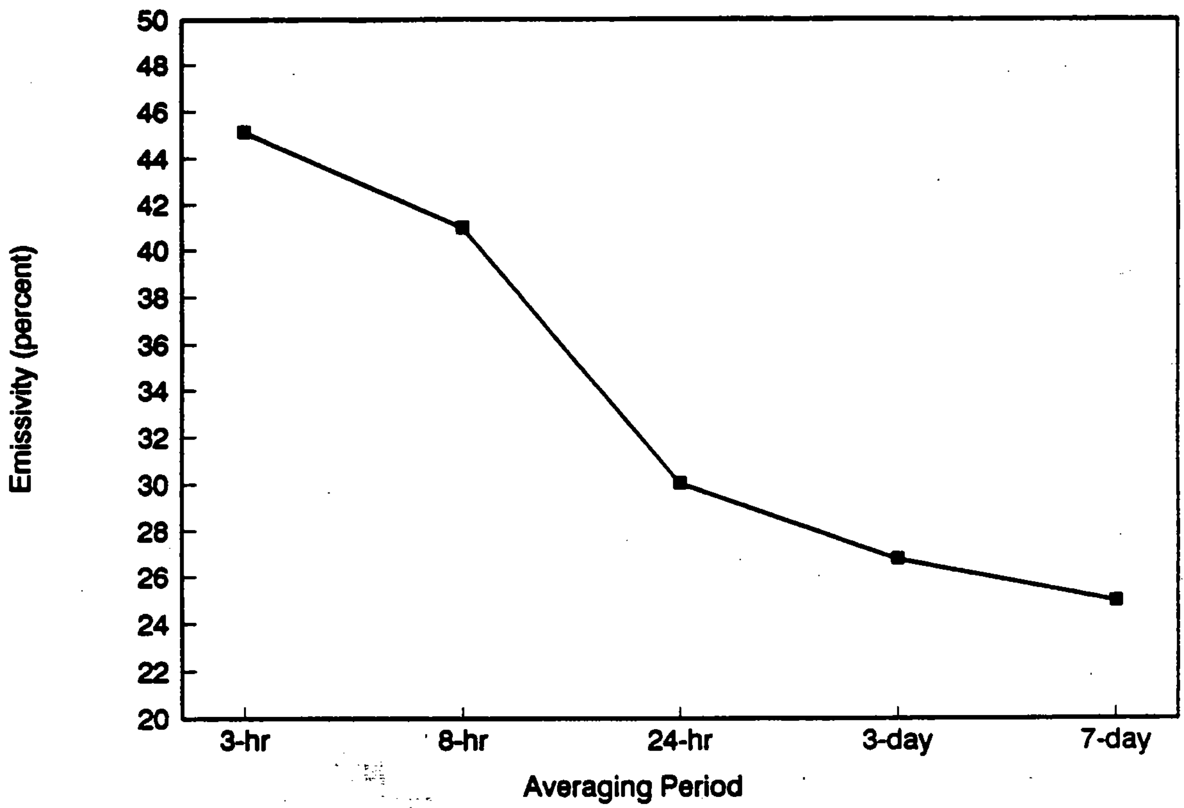


Figure 5-1. Impact of Averaging Time on SO2 Emissivity at Millbury

TABLE 5-3. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR 24-HOUR BLOCK MEANS OF THE EMISSIVITY DATE AT MILLBURY

Inlet Dataset	W
24-hour block arithmetic mean	0.914
24-hour block geometric mean	0.967*

* Data are normally distributed at the 95% confidence level.

means. This supports use of geometric means rather than arithmetic means for predicting expected exceedance levels.

Figure 5-2 displays the individual 24-hour block geometric means of emissivity for Millbury. The missing data points are for days during which hourly data were not available for 7 or more hours due to the unit being off-line or other factors. As expected, the day-to-day variability in emissivity is less than the hour-to-hour variability shown in Figure 2-1. The lowest percent removal (corresponding to the highest emissivity) encountered during these 53 days of data was roughly 70 percent.

Table 5-4 presents the geometric means, standard deviations, and calculated once per year exceedance values based on the emissivity data. The mean emissivity was near 19 percent, which translates to a percent reduction of 81 percent. The once-per-year exceedance emissivity value is estimated at 30 percent, corresponding to a percent reduction of 70 percent.

5.3 CONCLUSIONS

Based on the Millbury data, the following conclusions summarize the achievable SO_2 control performance of SD/ESP systems:

- Although average SO_2 reductions of over 80 percent are achievable over an extended period, short-duration spikes in hourly percent reduction levels are such that these levels cannot be achieved continuously due to variations in inlet SO_2 levels and normal variations in SD/ESP performance.

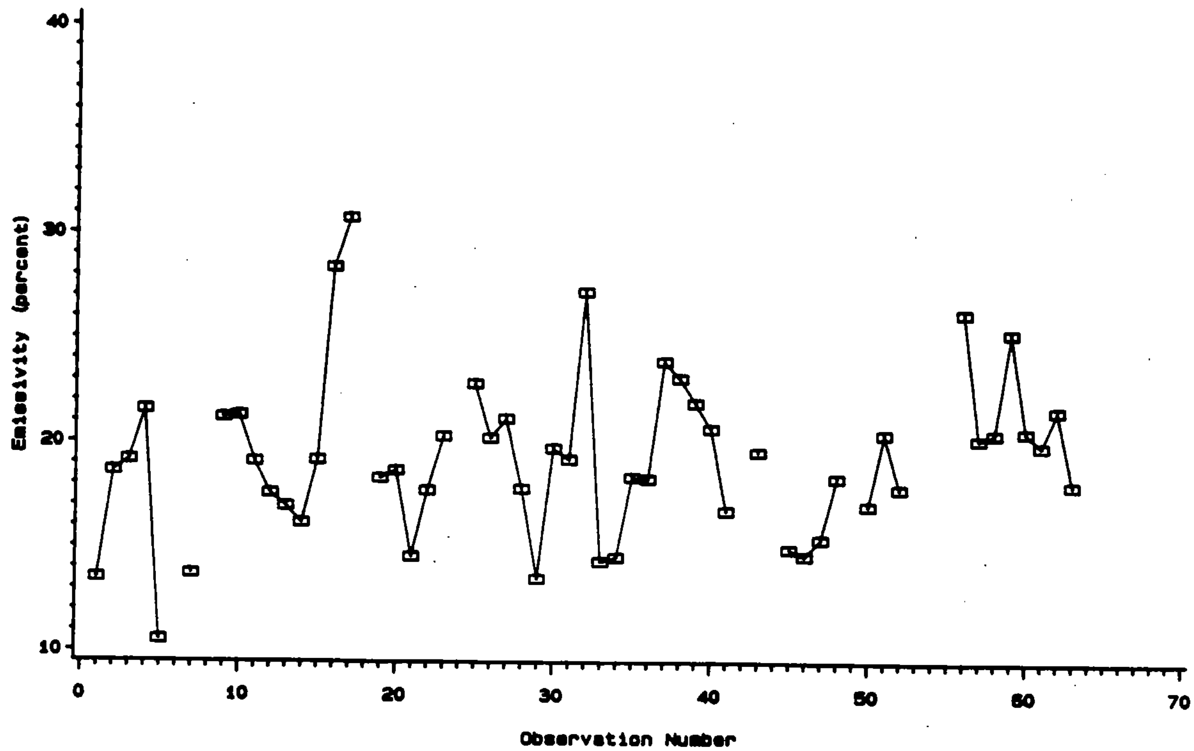


Figure 5-2. Millbury 24-Hour Geometric Mean Emissivity Values

TABLE 5-4. SUMMARY STATISTICS AND EXCEEDANCES FOR GEOMETRIC 24-HOUR BLOCK MEANS OF EMISSIVITY DATA (PERCENT) AT MILLBURY

Statistic	Value
Number of blocks	53
Mean	19.2
Standard deviation	3.9
Continuous compliance level*	30.1

* Based on one exceedence per year (Mean + 2.777 * Standard Deviation).

- Hourly ln-transformed emissivity data approach a normal distribution. This means that geometric means are appropriate for assessing achievable levels of SO_2 control.

- The variability in hourly inlet and outlet data did not fit an AR(1) time series model and the correlation coefficients were small. Therefore, consideration of time dependencies was not used in estimating achievable performance levels.

- Based on analysis of the impact of averaging periods on the variability in SO_2 emissions, it was concluded that a 24-hour averaging period was the most appropriate averaging period. Use of a shorter averaging time results in reducing the level of continuously achievable reductions, while longer averaging periods had relatively less of an impact on achievable levels.

- The 24-hour geometric mean emissivity levels are normally distributed. Based on the available data and resulting statistics, a 24-hour block geometric mean SO_2 percent reduction level of 70 percent is achievable from SD/ESP systems on a continuous basis.

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1.0 OVERVIEW

1.1 PURPOSE

On December 20, 1989, the U.S. Environmental Protection Agency (EPA) proposed limits on emissions of nitrogen oxides (NO_x) from new municipal waste combustors (MWC's) under Section 111 of the Clean Air Act (54 FR 52209). As proposed, these new source performance standards would apply to new MWC's having the capacity to combust more than 250 tons per day (tpd) of municipal solid waste (MSW). The proposal indicated that the Agency was considering a NO_x emission standard of 120-200 ppmv corrected to 7 percent oxygen, and that the final limit would be based on further analyses conducted prior to promulgation. This report presents the results of statistical analyses of NO_x data obtained from a grate-fired mass burn waterwall MWC using selective noncatalytic reduction (SNCR) to reduce NO_x emissions and from a rotary mass burn waterwall MWC designed to limit NO_x emissions through combustion control.

1.2 DESCRIPTION OF DATA ANALYZED

The two data sets used in this analysis are from the Stanislaus County MWC in Crows Landing, California, and the York County MWC in Manchester Township, Pennsylvania.

The Stanislaus County MWC consists of two 400-tpd grate-fired mass burn waterwall combustors. Both units are equipped with Exxon's Thermal $DeNO_x$® SNCR process in which ammonia is injected to reduce NO_x emissions. Hourly NO_x data were available from both units for two months in the Spring of 1989. Daily average NO_x levels were also available from mid-August, 1989, to mid-March, 1990.

The York County MWC consists of three Westinghouse/O'Connor rotary mass burn waterwall combustors, each with a capacity of 448 tpd. Each of the York County units uses a water-cooled rotary combustion chamber that is designed and operated to control combustion conditions so as to inhibit NO_x formation. No supplemental control technology is used to reduce NO_x emissions below the levels formed in the combustor. The York County NO_x data were limited to one month of hourly NO_x emissions from all three units recorded in February, 1990.

1.3 SUMMARY OF STATISTICAL METHODS

Several statistical analysis techniques were used to characterize MWC NOx emissions. These techniques included:

- time series plots to visually examine trends in NOx emissions over time and to identify data gaps or anomalies;
- normality testing and cumulative frequency distribution plots to evaluate the distribution of NOx data;
- routine summary statistics (mean, median, standard deviation, etc.);
- maximum estimated emissions (referred to as "exceedance values") based on the appropriate statistical means and standard deviations for different averaging times.

The hourly and daily NO_x data were tested for normality using the Shapiro-Wilk statistic. These analyses were conducted using both the actual NO_x data (after correction to 12 percent CO_2 or 7 percent O_2) and the natural logarithms (ln) of the actual data.

2.0 SELECTIVE NON-CATALYTIC REDUCTION

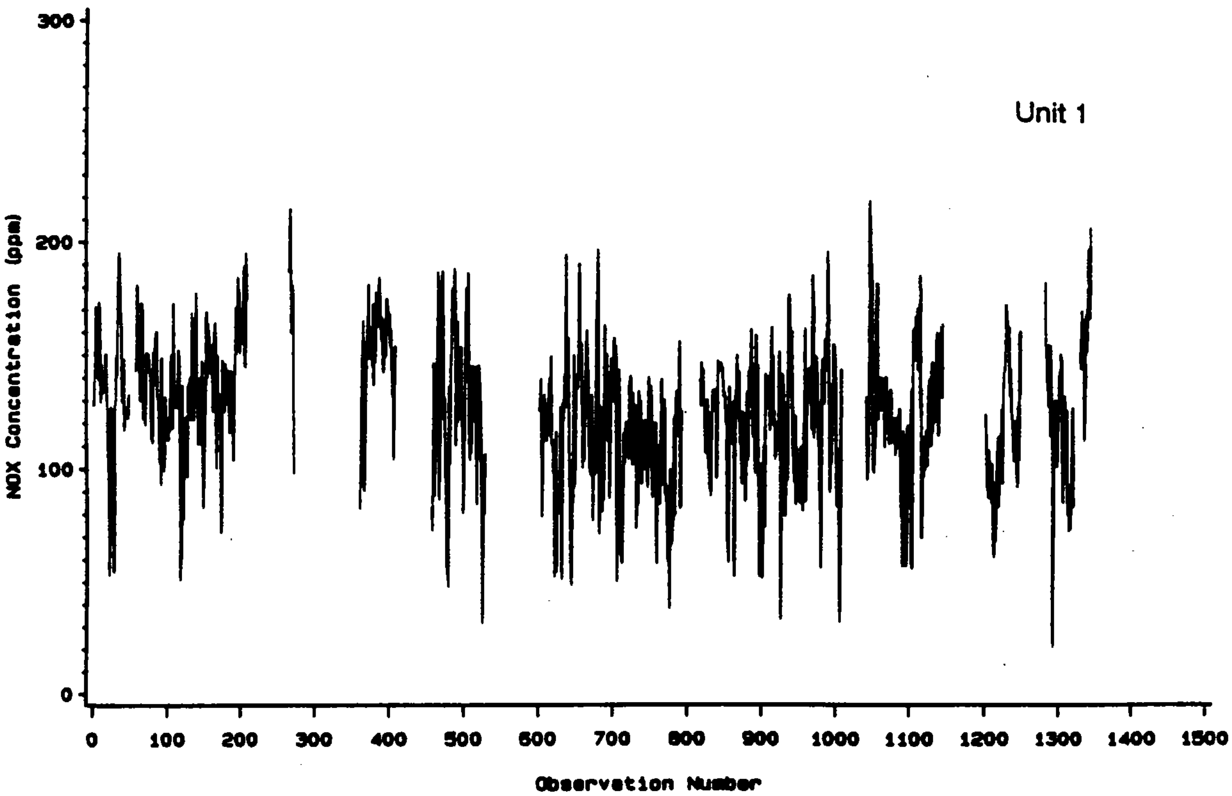
The assessment of the NO_x emissions control performance of SNCR technology was based on data obtained from the Stanislaus County MWC. Section 2.1 describes the facility and the NO_x emissions data analyzed. Section 2.2 summarizes the results of the data analysis. Section 2.3 presents the conclusions regarding the continuous compliance capabilities of SNCR.

2.1 DESCRIPTION OF STANISLAUS COUNTY MWC

The Stanislaus County MWC, developed by Ogden Martin Systems, Inc., consists of two 400-TPD Martin GmbH grate-fired mass burn waterwall combustors. A Thermal $DeNO_x$® system, installed under license from Exxon Research & Engineering Company, injects ammonia into the upper furnace of each combustor to reduce NO_x emissions. Each unit is also equipped with a Flakt spray dryer and fabric filter system to reduce acid gas, particulate, trace metals, and organic emissions. At the time the data was collected, the facility's permit allowed a maximum NO_x emission level of 165 ppm over a 24-hour averaging period and 175 ppm over a 3-hour averaging period, both of which are corrected to 12 percent CO_2.

Plant construction was completed during the late Summer of 1988. Initial compliance testing was conducted between November 29 and December 10, 1988. The hourly NO_x data used in this analysis was collected between March 16 and May 14, 1989. The total number of hourly observations collected during this period was 920 hours for Unit 1 and 959 hours for Unit 2. Daily arithmetic averages were also obtained for the period between August 17, 1989, and March 12, 1990. The total number of daily observations, including the hourly data collected during the Spring of 1989, was 223 days for Unit 1 and 228 days for Unit 2. Data on the flue gas O_2 content were not available from the plant. Therefore, the NO_x data were corrected to 12 percent CO_2, which is roughly equivalent to correction to 7 percent O_2.

The hourly and daily average NO_x emissions from both units are shown in Figures 2-1 and 2-2, respectively. The daily averages between March 16 and May 14, 1989, are plotted only for those days in which 18 or more hours of data were available. The data capture criteria associated with the other



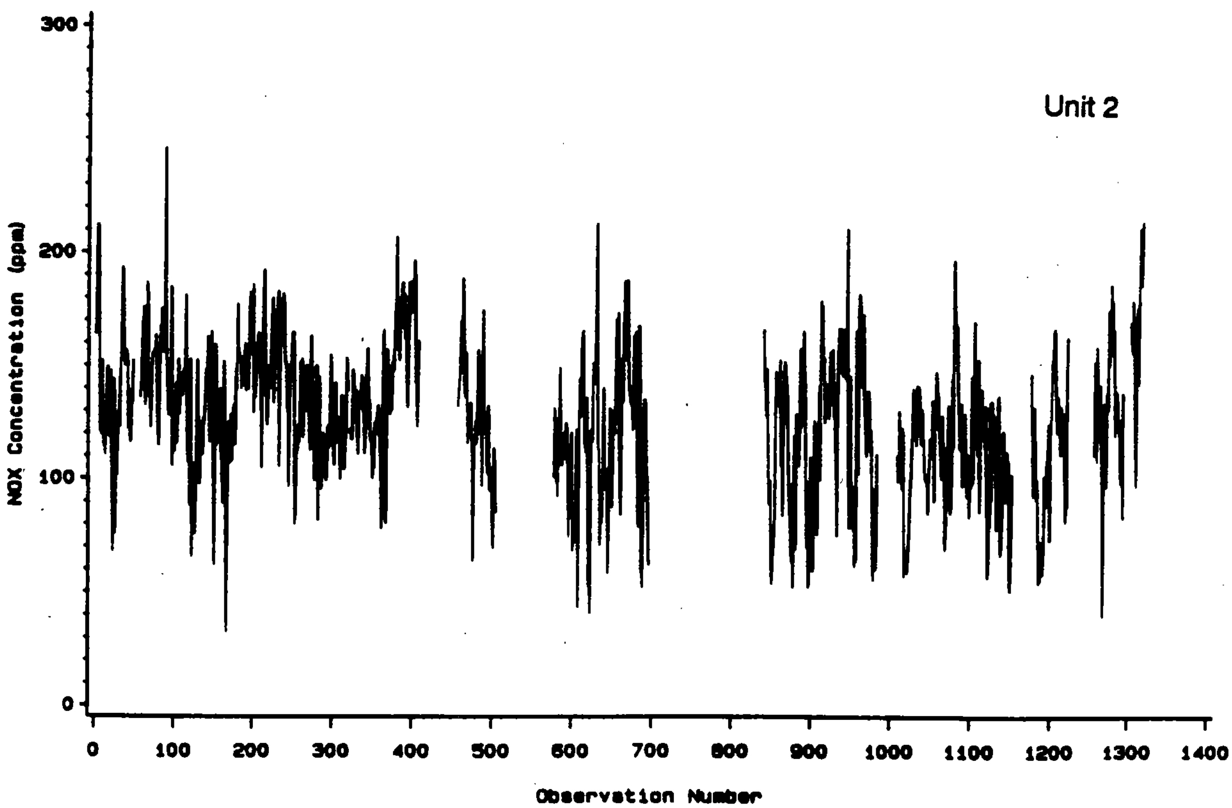
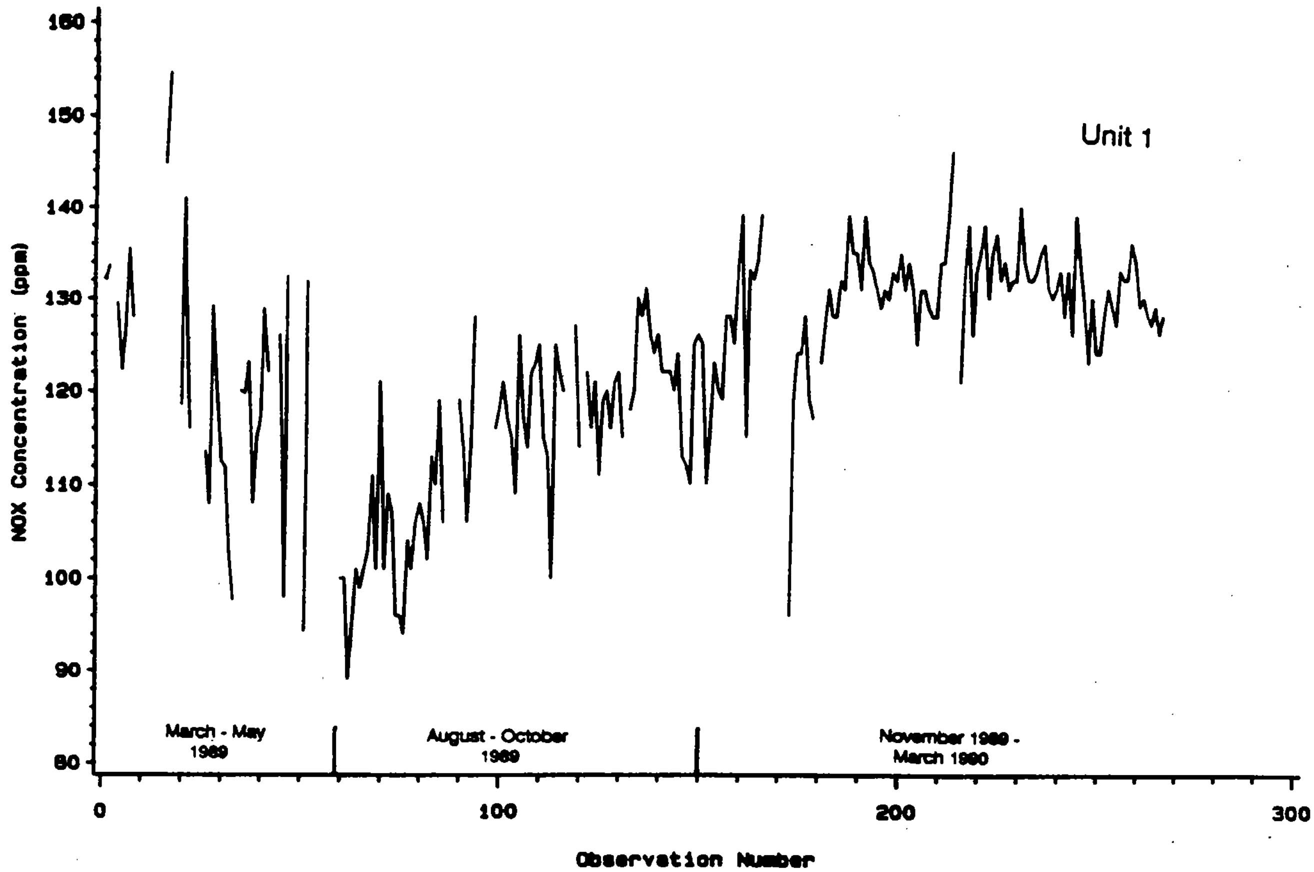


Figure 2-1. Stanislaus County Hourly NOx Concentrations



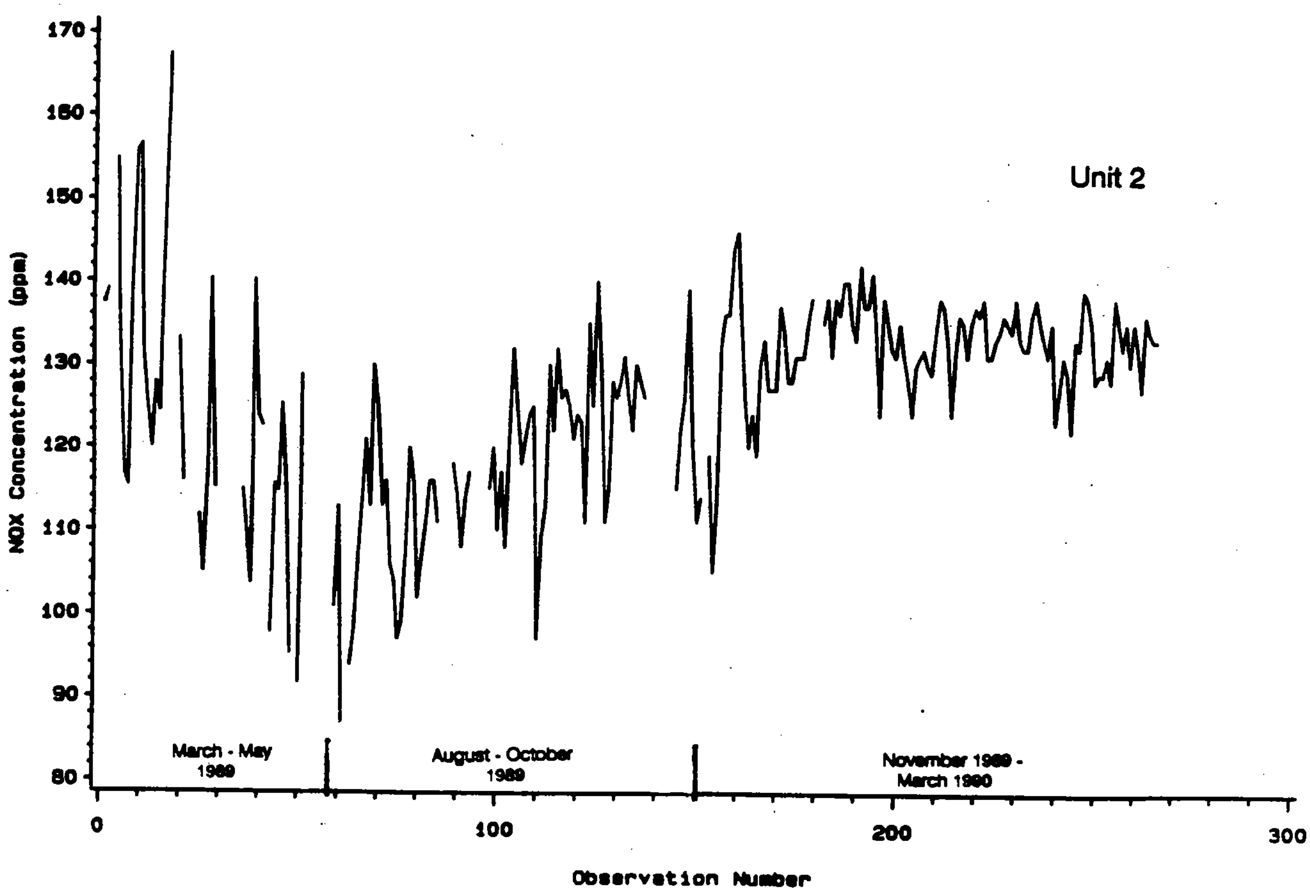


Figure 2-2. Stanislaus County Daily Average NOx Concentrations

daily averages are not known and the average NO_x values are presented as obtained from the plant.

Review of the daily average NO_x values, shown in Figure 2-2, suggests three distinct trends in the data. During the first of these periods, from March 16 to May 14, 1989, there is more day-to-day variability in the data than during subsequent time periods and the daily average NO_x levels exhibit an apparent downward trend over this time period, especially on Unit 2. During the second of these time segments, extending from August 17 to October 30, 1989, there is less day-to-day variability in the data compared to the first time segment, but there is an upward trend in the daily average values. During the third time segment, the daily averages also exhibit relatively low variability and have relatively stable values over time.

There are several possible explanations for these variations. First, the apparent trends in daily average NO_x levels may be due to differences in MSW composition. Specifically, the high nitrogen content of vegetative wastes present in MSW can affect NO_x emissions. Based on a previous study,[1] however, it would be expected that the NO_x levels would be higher in the summer and lower in the winter, which is the opposite of the trends observed in the Stanislaus County data. This may be due to the dry summers and wet winters in the San Joaquin Valley of California, where the plant is located, that result in seasonal variations in waste composition that are different from many other areas of the country. The yard waste composting program implemented within the plant's waste collection service area was also reported to have changed during the time period covered by the data.[2]

Second, the larger apparent variability in daily NO_x levels between March 16 and May 14, 1989, may reflect the plant personnel's lesser familiarity with how to best operate the combustor and ammonia injection system to minimize NO_x emissions during the first few months of the plant operation. The initial Thermal $DeNo_x$® process control system was also being evaluated by the plant during this time period based on actual operating experience.[2] The reduced variability of NO_x emissions during later periods may reflect increased knowledge of how to best operate the plant and modifications in combustor or ammonia injection system design. This increased knowledge of how to operate the combustor and ammonia injection system to control NO_x may also account for the small variability in daily NO_x levels during the third time segment.

Third, the differences in daily NO_x levels may reflect differences in data averaging methods used by Ogden during the last two time segments versus those used by EPA during the first time segment.

2.2 DATA ANALYSIS

Two sets of statistical analyses were conducted--one with the hourly data and the second with the daily data. The objectives of these analyses were to determine the statistical distribution of the data (i.e., normal versus lognormal), the affect of averaging period on the variability in NO_x emissions, and the selection of a continuously achievable NO_x emission level.

2.2.1 Hourly Emissions Data

The hourly data consisted of the period between March 16 and May 14, 1989. Summary statistics for this period for Units 1 and 2 are presented in Table 2-1. Note that the mean (average) and median (50th percentile) values on both units are between 120 and 130 ppm and that the mean and median are both relatively close to the midpoint of the minimum and maximum recorded values. This suggests that both data sets are normally, rather than lognormally, distributed. As shown in Table 2-2, this conclusion is supported by the Shapiro-Wilk normality test that found the measured data from both units to be normally distributed at the 95 percent confidence level, while the ln-transformed data were not normally distributed at the 95 percent confidence level. This finding supports the use of the raw data, rather than ln-transformed data, for estimating potential emission exceedance levels.

TABLE 2-1. SUMMARY STATISTICS FOR HOURLY NO_x DATA FROM STANISLAUS COUNTY (ppm @ 12% CO_2)

Summary Statistic	Unit 1	Unit 2
Mean	124.1	126.3
Minimum	20.2	31.9
Median	126.4	127.9
Maximum	218.4	245.6

TABLE 2-2. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR HOURLY NO_X DATA FROM STANISLAUS COUNTY

Dataset	Unit 1	Unit 2
Hourly	0.98*	0.99*
Ln Hourly	0.92	0.94

*Indicates a normal data distribution at the 95% confidence level.

To assess the impact of different averaging times on the variability in NO_X emission levels, six different averaging periods were examined: 1-hour, 3-hour, 8-hour, and 24-hour block averages, and 3-day and 7-day rolling averages. As shown in Figure 2-3, increasing the averaging time from 1 hour up to 8 hours resulted in about a 10 percent decrease in estimated 99th percentile NO_X emission level. Increasing the averaging time to 24 hours decreased the 99th percentile value by roughly another 15 percent. Further increases in the averaging time to 3 days and 7 days resulted in a further reduction in the estimated NO_X emission level, but the change was smaller than that achieved between 8 and 24 hours. As a result, a 24-hour block (i.e., daily) averaging period was selected for further analyses.

The small change in estimated NO_X levels between 1 and 8 hours suggests that hourly NO_X levels are autocorrelated, meaning that the NO_X level in one hour is a function of the NO_X level during the previous hour. As a result, averaging periods of 8 hours and less have limited impact on reducing the variability in NO_X emissions. By increasing the averaging period to 24 hours, however, it is possible to reduce the variability in estimated NO_X emissions.

The 24-hour block averages calculated with the March through May, 1989, data were used to assess the continuously achievable NO_X emission level. As shown in Table 2-3, this analysis found that a NO_X emission limit of 165-180 ppm could be continuously achieved at an exceedance frequency of one per year.

2.2.2 Daily Emissions Data

The other two periods of daily NO_X data (August to October 1989 and November 1989 to March 1990) were also examined to assess continuously

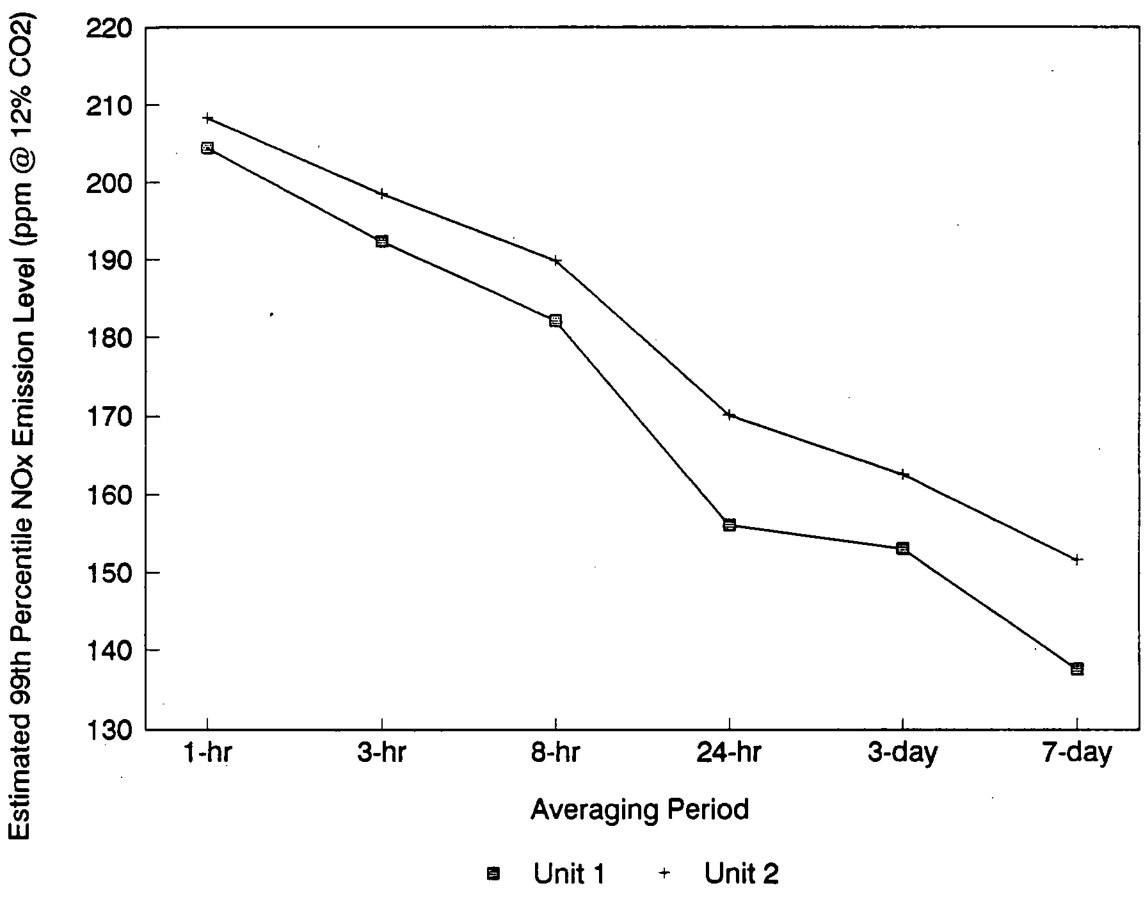


Figure 2-3. Impact of Averaging time on NO_x Emissions from Stanislaus County

TABLE 2-3. SUMMARY STATISTICS FOR DAILY NO_x AVERAGES FROM STANISLAUS COUNTY (ppm @ 12% CO_2)

Statistic	March-May 1989 Unit 1	Unit 2
Number of Blocks	34	38
Mean	121.2	125.3
Standard Deviation	13.6	17.4
Continuous Compliance Level*	163.5	179.5

*Based on one exceedance per year (Mean + 2.777 * Standard Deviation)

achievable NO_x levels and the possible impact of seasonal variations in waste composition on NO_x levels. As discussed in Section 2.1, however, the average NO_x emission level in the March through May, 1989, data set appears to decrease over time, and the average NO_x emission level in the August through October, 1989, data set appears to increase over time. This variation is between a low of about 105 ppm in August and a high of 130 ppm in late October, or a difference of roughly 20 percent. In theory, some of the variability could be statistically compensated for by using a time series model. However, because of the limited number of daily observations within the March-May and August-October time blocks and the significant number of missing daily averages, use of a time series model was not possible.

As a result, the additional analysis of continuously achievable NO_x levels focused on the data collected between November 1989 and March 1990. As shown in Figure 2-2, NO_x emissions during this period varied from day to day, but did not exhibit any general upward or downward trend. An analysis of the statistical distribution of the data on both units for this period, shown in Table 2-4, found that neither the raw data or the ln-transformed data were normally distributed at the 95 percent confidence level. The raw data on both units do have higher Shapiro-Wilk normality statistics, however, indicating that predictive statistics based on the raw data will be more valid than

TABLE 2-4. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR DAILY NO_x DATA FROM STANISLAUS COUNTY*

Dataset	Unit 1	Unit 2
Hourly	0.93	0.92
Ln Hourly	0.91	0.90

*for November 1989 to March 1990.
NOTE: None of the data sets were normally distributed at the 95% confidence level.

statistics based on the ln-transformed data. As shown in Table 2-5, thepredicted continuous compliance levels based on the daily average NO_x emission levels for November 1989 through March 1990 are 148 ppm for Unit 1 and 150 ppm for Unit 2.

TABLE 2-5. SUMMARY STATISTICS FOR DAILY NO_x AVERAGES FROM STANISLAUS COUNTY (ppm @ 12% CO_2)

	Nov. 1989-March 1990	
Statistic	Unit 1	Unit 2
Number of Blocks	124	122
Mean	128.9	131.5
Standard Deviation	7.0	6.6
Continuous Compliance Level*	148.3	149.8

*Based on one exceedance per year (Mean + 2.777 * Standard Deviation)

2.3 CONCLUSIONS

Based on the Stanislaus County data, the following conclusions are reached regarding the continuously achievable NO_x emission level associated with SNCR:

- Long-term average NO_x emissions of less than 130 ppm at 12 percent CO_2 are achievable, but short-term variations in NO_x emissions due to changes in MSW composition, combustion conditions, and SNCR operation, influence the NO_x emission rate that can be continuously achieved.

- The hourly NO_x data appear to be normally distributed, thus supporting the use of the raw (i.e., untransformed) data to estimate continuously achievable emission levels.

- An averaging period of 24 hours is beneficial in reducing the variability in average NO_x levels. Averaging periods of 8 hours and less have relatively little impact on lowering the variability in average NO_x emissions. Longer averaging times also have a lower impact than the difference between 8 and 24 hours.

- The daily average NO_x emission rates suggest differences in achievable NO_x levels that are different for the three periods. These variations may be due to seasonal variations in MSW composition, the familiarity of plant operating personnel with operation of the combustion and SNCR systems, or other factors. The Stanislaus County data contained three such time blocks.

- The time block with the greatest variability in NO_x emissions at Stanislaus County occurred between mid-March and mid-May, 1989. Based on the data from this time period, a NO_x emission level of 180 ppm at 12 percent CO_2 with 24 hour-block averaging period can be continuously achieved.

2.4 REFERENCES

1. Hahn, J. L., and D. S. Sofaer, Variability of NO_x Emissions from Modern Mass-fired Resource Recovery Facilities. Paper presented at 81st Annual Meeting of Air Pollution Control Association, Dallas, Texas. June 19-24, 1988.

2. Telecon. Hahn, J. Ogden Martin Systems, Inc., and D. White, Radian Corporation. November 19, 1990. Stanislaus County NO_x data.

3.0 ROTARY WATERWALL COMBUSTOR

The assessment of the NO_x emissions control in a Westinghouse/O'Connor rotary mass burn waterwall combustor was based on data obtained from the York County MWC. Section 3.1 describes the facility and the NO_x emissions data analyzed. Section 3.2 summarizes the results of the data analysis. Section 3.3 presents the conclusions reached regarding continuous compliance capabilities of the Westinghouse/O'Connor combustor.

3.1 DESCRIPTION OF YORK COUNTY MWC

The York County MWC consists of three 448-TPD Westinghouse/O'Connor water-cooled rotary mass burn waterwall combustors supplied by the Resource Energy Systems Division of Westinghouse Electric Corporation. The Westinghouse/O'Connor combustors at York County are designed to inhibit formation of both thermal and fuel-related NO_x by controlling combustion temperatures and fuel-air mixing in the rotary chamber. No supplemental control technology is used to reduce NO_x emissions. Each unit is also equipped with a Joy Technologies, Inc., spray dryer and fabric filter system to reduce acid gas, particulate, trace metals, and organics emissions. The facility does not have a permitted NO_x emission limit.

Plant construction was completed in late 1989 with start-up of the unit in November 1989. The hourly NO_x emissions data used in this analysis were collected between February 1 and February 24, 1990, and were corrected to 7 percent O_2 by the plant. The total number of hourly observations were 538 hours for Unit 1, 558 hours for Unit 2, and 547 hours for Unit 3. The hourly and daily average NO_x emissions from all three units are shown in Figures 3-1 and 3-2, respectively.

Note that the hourly NO_x emission levels from all three units are between 60 and 200 ppm, except for a two-hour period on February 20 from Unit 3. During this time period the unit was in the process of stopping waste feed and starting oil firing. The flue gas O_2 level during this transition period was high and resulted in a large adjustment in NO_x emission level when corrected to 7 percent O_2. Although these two data points could have been deleted based on atypical operation during shutdown of the unit, they were left in the data set that was used for analysis.

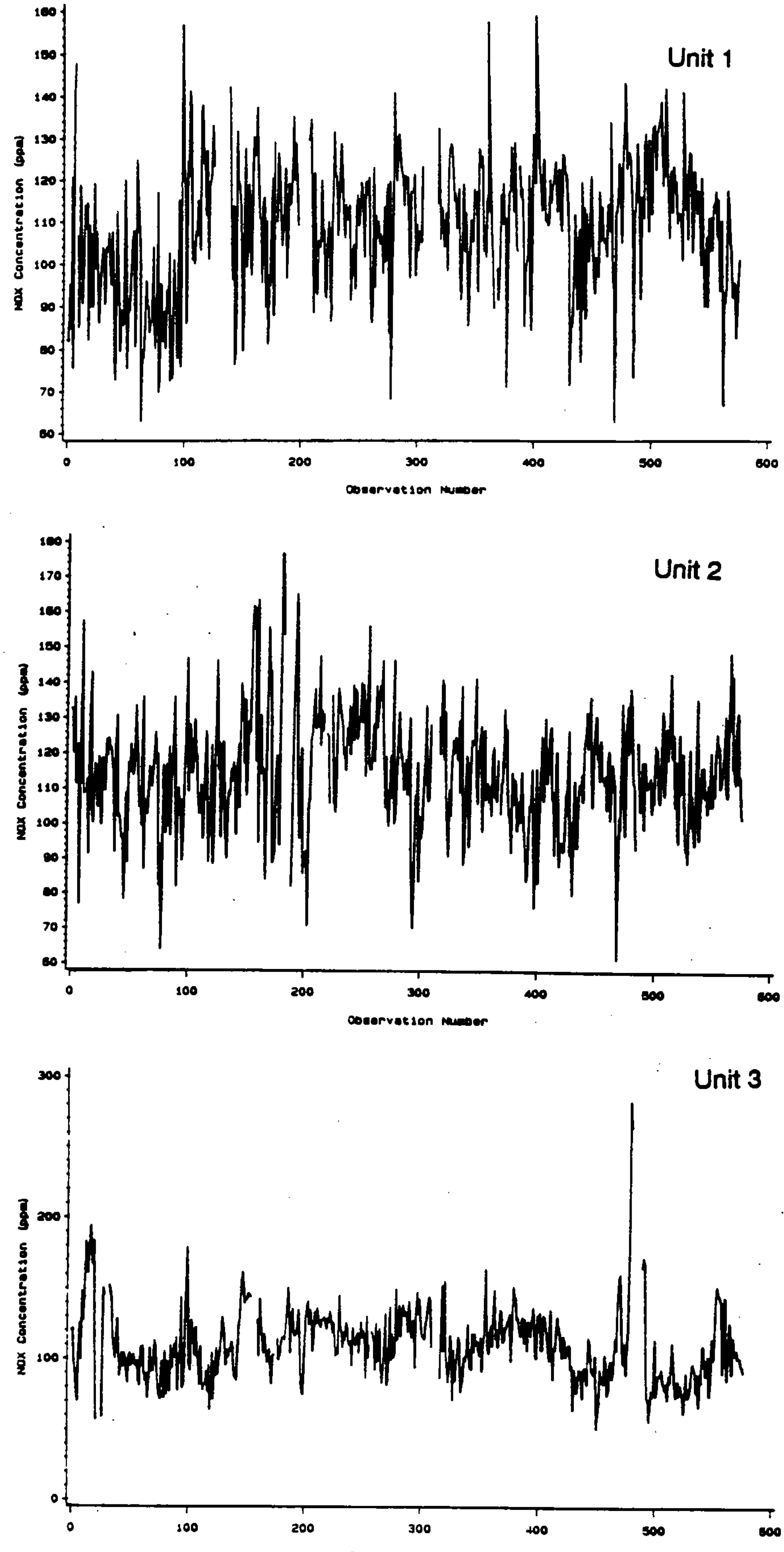


Figure 3-1. York County Hourly NOx Concentrations

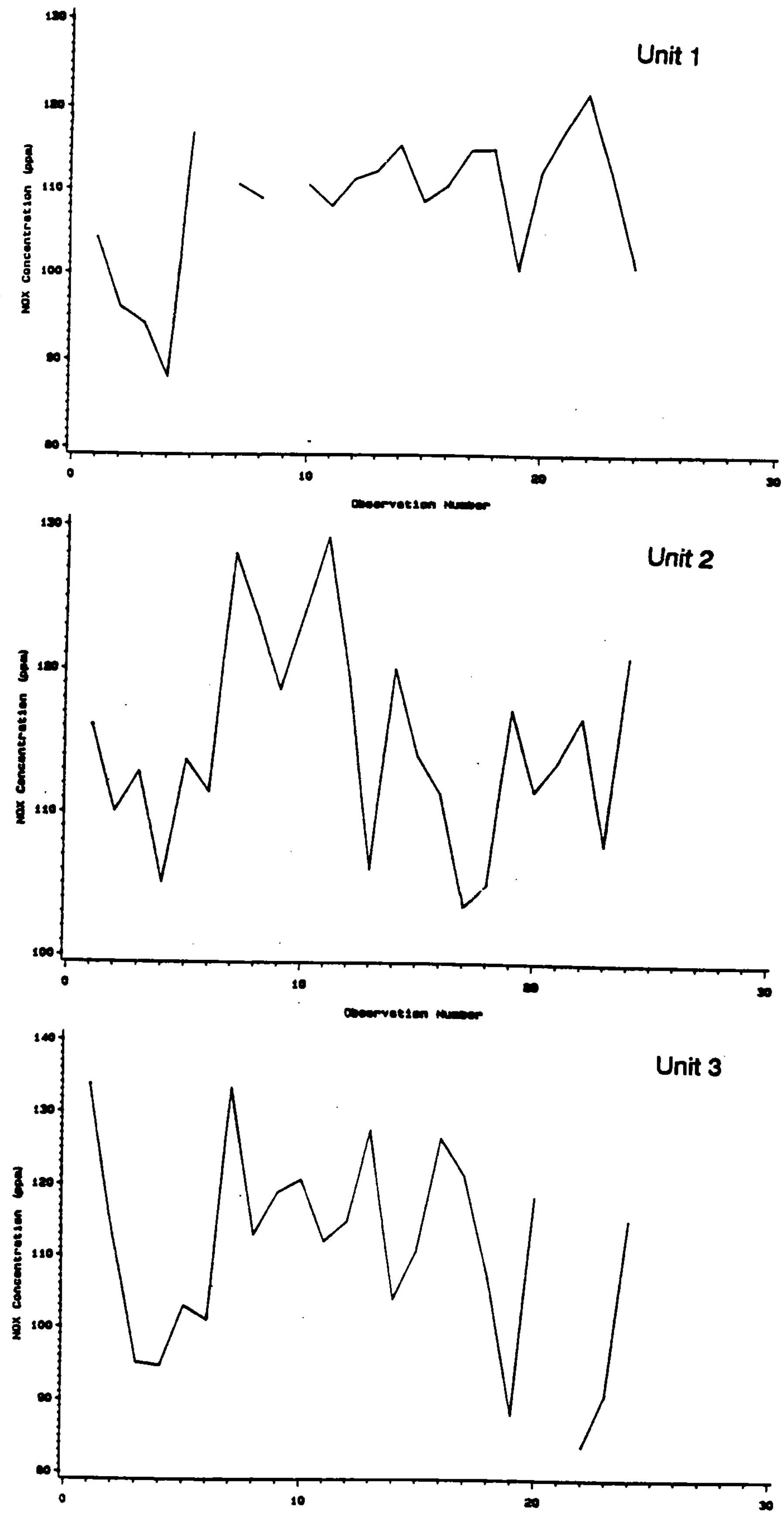


Figure 3-2. York County Daily Average NOx Concentrations

3.2 DATA ANALYSIS

The objectives of the statistical analysis conducted with the York County data were: to determine the distribution of the data, to assess the impact of averaging time on variability in NO_x emissions, and to select a continuously achievable NO_x emissions level. Summary statistics for all three units are presented in Table 3-1. Note that the mean and median values on all three units are between 108 and 115 ppm. These values are roughly at the midpoint of the minimum and maximum NO_x readings, except for the previously noted high NO_x levels recorded on Unit 3. This suggests that the data are normally distributed. This is supported by the results of the Shapiro-Wilk normality test, shown in Table 3-2, that found the hourly NO_x levels on Units 1 and 2 to be normally distributed at the 95 percent confidence level. The ln-transformed NO_x levels for Units 2 and 3 are also normally distributed at the 95 percent confidence level. The higher normality test statistic for Unit 3 reflects the impact of the few hours of high NO_x levels recorded on that unit. If these data were deleted from the data set, the remaining data would appear to be more normally distributed.

TABLE 3-1. SUMMARY STATISTICS FOR HOURLY NO_x DATA FROM YORK COUNTY (ppm @ 7% CO_2)

Summary Statistic	Unit 1	Unit 2	Unit 3
Mean	109.1	114.8	110.1
Minimum	62.8	61.7	51.4
Median	110.3	114.6	107.7
Maximum	159.6	177.2	283.8

To assess the impact of averaging time on NO_x emissions variability, block averaging periods of 1-hour, 3-hours, 8-hours, and 24-hours and rolling averages of 3-days and 7 days were analyzed using the raw NO_x data. The impact of different averaging times on each of the three units is shown in

TABLE 3-2. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR HOURLY NO_x DATA FROM YORK COUNTY

Dataset	Unit 1	Unit 2	Unit 3
Hourly	0.98*	0.98*	0.94
Ln Hourly	0.96	0.98*	0.99*

*Indicates a normal data distribution at the 95% confidence level.

Figure 3-3. The higher estimated 99th percentile NO_x emission levels for Unit 3 for periods of 24 hours or less are caused by the two high NO_x levels measured on February 20, and are not considered representative of normal operating conditions. Selection of an averaging time based on the other two units is less clear than with the Stanislaus County data. For consistency with the Stanislaus County analysis, however, a 24-hour averaging period was used.

As shown in Table 3-3, the 24-hour block means from all three units are normally distributed at the 95 percent confidence level, as are the ln-transformed averages for Units 2 and 3. Further, the normality test statistics on Units 1 and 3 using the natural data are higher than for the ln-transformed data. As a result, the continuously achievable emission rates were estimated based on the assumption that the daily average NO_x levels are normally distributed.

TABLE 3-3. SHAPIRO-WILK NORMALITY TEST STATISTIC (W) FOR DAILY NO_x DATA FROM YORK COUNTY

Dataset	Unit 1	Unit 2	Unit 3
Hourly	0.92*	0.97*	0.97
Ln Hourly	0.90	0.98*	0.96*

*Indicates a normal data distribution at the 95% confidence level.

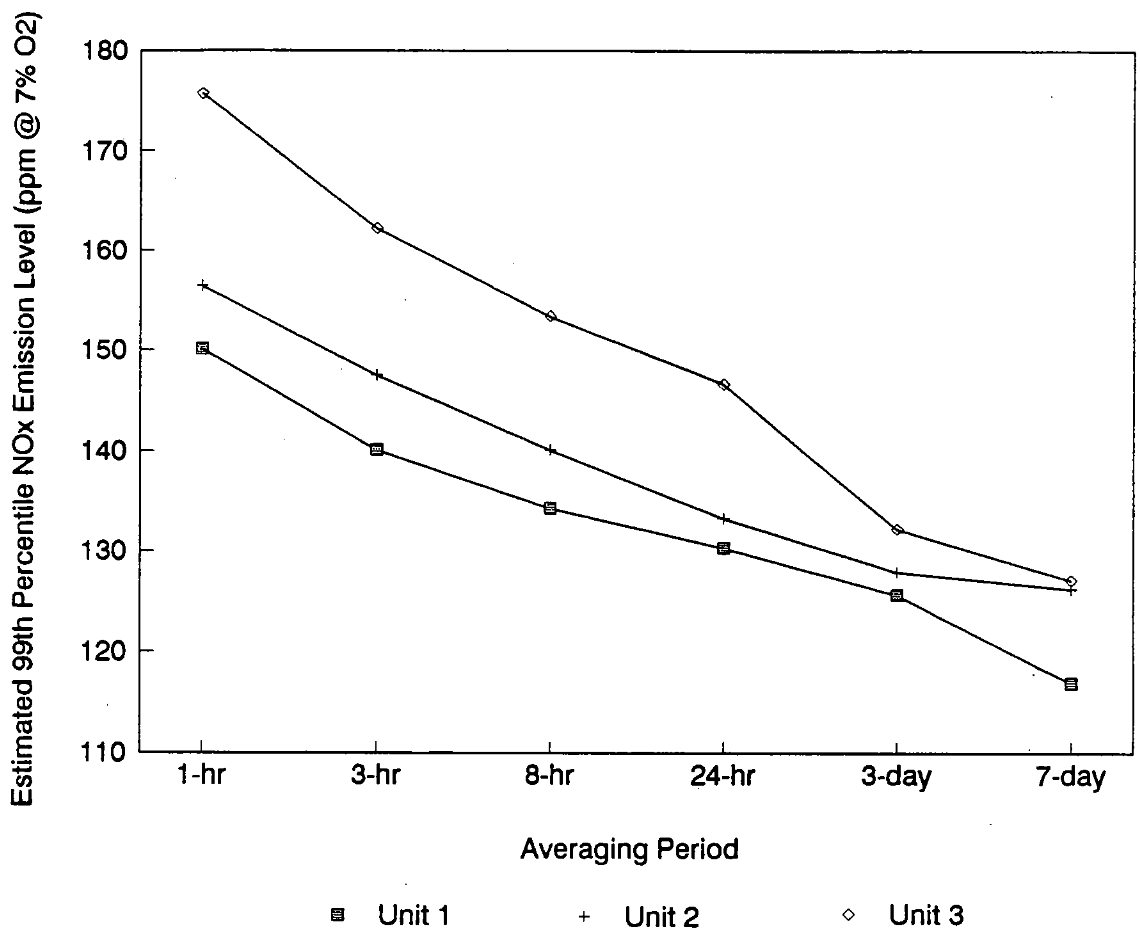


Figure 3-3. Impact of Averaging Time on NO_x Emissions from York County

Based on the one month of available data, it appears that a daily average NO_x emission limit of 140 ppm can be continuously achieved by Units 1 and 2, as shown in Table 3-4. The estimated limit of 150 ppm on Unit 3 is caused by the higher standard deviation in the data resulting from the two hours of high NO_x readings on February 20. However, all of these data were collected in February when less vegetative waste is likely to be present in the data. As a result, the impact of seasonal variations on achievable NO_x levels is uncertain.

TABLE 3-4. SUMMARY STATISTICS FOR DAILY NO_x AVERAGES FROM YORK COUNTY (ppm @ 7% CO_2)

Statistic	Unit 1	Unit 2	Unit 3
Number of Blocks	22	24	23
Mean	108.8	115.0	100.6
Standard Deviation	8.3	7.1	14.0
Continuous Compliance Level*	131.9	134.7	149.4

*Based on one exceedance per year (Mean + 2.777 * Standard Deviation)

3.3 CONCLUSIONS

Based on the York County data, the following conclusions are reached regarding the continuously achievable NO_x emission level associated with Westinghouse/O'Connor combustion systems:

- Long-term average NO_x emissions of less than 115 ppm at 7 percent O_2 are achievable, but short-term variations in operating conditions and fuel composition will influence the NO_x emission level that can be continuously achieved.

- The hourly NO_x data appear to be normally distributed, thus supporting the use of untransformed data to estimate continuously achievable emission levels.

- An averaging period of 24 hours is beneficial in reducing the variability in average NO_x levels.

- The one month of available data is insufficient to conclude what level of NO_x emissions can be achieved during all times of the year. Based on the available data, however, a NO_x level of 140-150 ppm over a 24-hour averaging period can be continuously achieved.

TABLE OF CONTENTS

1.0 BACKGROUND AND OBJECTIVE

Prior to the proposal of performance standards and emission guidelines for municipal waste combustors (MWC's), all available emissions test data collected at a number of MWC's were reviewed to assess the performance of different air pollution control technologies.[1] This appendix reviews data obtained subsequent to the proposal which was collected during testing at four MWC's: Babylon, New York; Rochester, Massachusetts (commonly referred to as SEMASS); Vancouver, British Columbia; and Indianapolis, Indiana. The Babylon and Indianapolis facilities were selected for review because total dioxin/furan (CDD/CDF) emissions were reported to be higher than for similar MWC's that had been previously examined. In the case of SEMASS and Vancouver, there were limited data on the emissions control performance of the air pollution control technologies used at these two MWC's.

2.0 BABYLON[2,3]

The Babylon Resource Recovery facility in West Babylon, New York, consists of two identical mass burn waterwall combustors, each designed to combust 375 tons per day (tpd) of municipal solid waste (MSW). The MSW is combusted in a Martin stoker combustion system equipped with a Zurn waterwall boiler. Each boiler normally produces about 88,000 pounds per hour (lbs/hr) of steam at 680°F and 640 pounds per square inch gauge (psig).

The combustion gases exiting each combustor enter an air pollution control device (APCD) system supplied by Belco Corporation. The APCD system consists of a Deutsche-Babcock-Anlagen (DBA) spray dryer (SD) followed by an American Air Filer pulse-jet fabric filter (FF). The DBA SD uses dual-fluid nozzles and an up-flow reactor. The FF consists of six compartments and uses acid-resistant fiberglass bags. The design air-to-cloth ratio is 2.5 gross and 3.1 net, with one compartment out of service.

In January and February of 1989, emissions testing was performed by Ogden Projects, Inc., to demonstrate compliance with permit conditions. Acid gas, particulate matter (PM), and metals data were collected simultaneously. A continuous emissions monitoring (CEM) system was used to monitor nitrogen oxides (NO_x), carbon dioxide (CO_2), and carbon monoxide (CO) at the SD/FF outlet during these runs. Emissions of CDD/CDF were measured separately. peration of the APCD system during compliance testing was in accordance with directions supplied by DBA based on their experience with units in Europe. The FF inlet temperature for various full-load test runs ranged from 316 to 326°F. The FF inlet temperatures were estimated by adding 15°F to the stack temperatures since the temperature at the inlet to the FF was not monitored. These temperatures are higher than for other SD/FF systems previously examined, where inlet FF temperatures were generally less than 290°F.[1] The somewhat higher operating temperature of the FF during compliance testing at Babylon reflects European vendor concern about wetting of the filter bags by damp filtercake, and the desire to minimize the potential for bag blinding. Operating at these higher temperatures will generally reduce sorbent utilization and SO_2 removal. The impact on HCl is generally small.

Flue gas at the SD/FF inlet and outlet of both units was sampled for acid gases, and the data are presented in Table 2-1. Hydrogen chloride (HCl) wasanalyzed by manual methods and sulfur dioxide (SO_2) was measured by a CEM system. Triplicate runs were made on each unit at normal operating (full-load) conditions. Triplicate runs were also made on Unit 1 at reduced-load conditions (approximately 70 percent of full-load conditions).

Outlet SO_2 concentrations for the six full-load runs on both units ranged from 16 to 40 parts per million (ppm) at 7 percent oxygen (O_2), with an average estimated FF inlet temperature of 318°F. The percent reduction of SO_2 during the full-load runs on Units 1 and 2 ranged from 64 to 87 percent. The lowest percent reduction of SO_2 occurred during the first run on Unit 1 (64 percent) and coincided with the lowest SO_2 inlet concentration of any of the runs. The percent reduction in SO_2 during the other five runs all exceeded 82 percent. The SO_2 concentration at the FF outlet during the reduced-load runs on Unit 1 ranged from 6 to 30 ppm at 7 percent O_2, with an average estimated FF inlet temperature of 293°F. The percent reduction of SO_2 during the reduced-load runs ranged from 87 to 96 percent, with an average percent reduction of 92 percent.

Outlet HCl measurements for the full-load tests ranged from 19 to 22 ppm at 7 percent O_2 on Unit 1 and from 40 to 61 ppm on Unit 2. Reduced-load measurements at the Unit 1 outlet found HCl concentrations of 21 to 26 ppm at 7 percent O_2. During each of the nine test runs, HCl reduction efficiencies ranged from 93 to 98 percent. The higher HCl outlet concentrations during the full-load runs on Unit 2 correspond to higher HCl concentrations at the SD inlet and were not due to significantly decreased HCl removal efficiencies. Stoichiometric ratios could not be calculated because the lime feed rates were not in the available data.

The PM data for Babylon are presented in Table 2-2. Sampling for PM was performed at the SD/FF outlet of each unit simultaneously with the acid gas sampling. Outlet PM concentrations for the six full-load runs on both units ranged from 0.0008 to 0.0022 grains per dry standard cubic feet (gr/dscf) at 12 percent CO_2. The average outlet PM concentration was 0.0017 gr/dscf for Unit 1 and 0.0012 gr/dscf for Unit 2. The outlet PM concentrations for the three reduced-load runs on Unit 1 ranged from 0.0022 to 0.0036 gr/dscf with an

TABLE 2-1. ACID GAS DATA FOR BABYLON

Test Condition	Run Number[a]	FF Inlet Temperature[b] (°F)	Stoichiometric Ratio[c]	Acid Gas Concentration (ppmv, dry at 7% O_2) Inlet		Outlet		Acid Gas Removal Efficiency (%)	
				SO_2	HCl	SO_2	HCl	SO_2	HCl
Combustor = Normal[d]	1-1	316	NA	98	573	36	20	64	96
SD/FF = Normal	1-2	316	NA	251	785	40	19	84	98
	1-3	321	NA	186	794	34	22	82	97
Average Unit 1		318		178	717	37	20	77	97
Combustor = Normal[d]	2-1	319	NA	130	886	23	61	82	93
SD/FF = Normal	2-2	318	NA	125	1,149	16	47	87	96
	2-3	316	NA	169	1,017	24	40	85	96
Average Unit 2		318		141	1,017	21	49	85	95
Combustor = Reduced Load[e]	1-R1	292	NA	188	857	12	26	94	97
SD/FF = Normal	1-R2	293	NA	149	706	6	21	96	97
	1-R3	294	NA	237	723	30	25	87	97
Average Unit 1		293		191	762	16	24	92	97

[a]Run number consists of unit number followed by the run number for that unit. "R" indicates a run at reduced-load conditions.

[b]Estimated by adding 15°F to average stack temperature.

[c]Lime feed rate data not available, therefore, stoichiometric ratio cannot be calculated.

[d]Full-load conditions = 375 tpd.

[e]70 percent of full-load conditions = 263 tpd.

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TABLE 2-2. PM DATA FOR BABYLON

Condition	Run Number[a]	FF Inlet Temperature[b] (°F)	Flue Gas Flow (acfm)	Outlet PM Concentration (gr/dscf at 12% CO_2)
Combustor = Normal[c]	1-1	316	58,500	0.0016
SD/FF = Normal	1-2	316	59,300	0.0022
	1-3	321	59,300	0.0012
Average Unit 1		318	59,000	0.0017
Combustor = Normal[c]	2-1	319	61,000	0.0013
SD/FF = Normal	2-2	318	60,500	0.0008
	2-3	316	56,200	0.0016
Average Unit 2		318	59,200	0.0012
Combustor = Reduced load[d]	1-R1	292	38,300	0.0022
	1-R2	293	39,400	0.0036
SD/FF = Normal	1-R2	294	39,900	0.0029
Average Unit 1		293	39,200	0.0029

[a]Run number consists of unit number followed by the run number for that unit. "R" indicates a run at reduced-load conditions.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 375 tpd.

[d]70 percent of full-load conditions = 263 tpd.

average of 0.0029 gr/dscf. Removal efficiencies for PM could not be determined because PM concentrations at the SD/FF inlet were not measured.

Table 2-3 presents the metals emissions data. Triplicate runs for metals concentrations were performed at the SD/FF outlet of Unit 2 only. These samples were analyzed for beryllium, lead, mercury, arsenic, cadmium, chromium, nickel, antimony, cobalt, copper, manganese, selenium, vanadium, and zinc. Outlet lead concentrations ranged from 0.8 to 2.5 micrograms per dry standard cubic meter (μg/dscm) at 7 percent O_2 with an average concentration of 1.4 μg/dscm. Average mercury emissions were 451 μg/dscm, ranging from 190 to 620 μg/dscm. Arsenic, cadmium, chromium, and nickel emission levels were below detection limits. Metals concentrations at the SD inlet were not measured. Based on typical inlet concentrations of lead and mercury from other mass burn MWC's,[1] lead reductions exceeded 99.9 percent while mercury reductions appeared negligible.

A separate set of three runs were performed for CDD/CDF and polycyclic aromatic hydrocarbons/polychlorinated biphenyls (PAH/PCB) at the SD/FF outlet of Unit 1. The CDD/CDF data are presented in Table 2-4. Outlet concentrations ranged from 12.6 to 27.2 nanograms per dry standard cubic meter (ng/dscm) at 7 percent O_2 over three runs and averaged 21.9 ng/dscm. Inlet CDD/CDF concentrations were not measured and removal efficiencies could not be calculated. Temperatures at the FF inlet during these runs ranged from 314 to 326°F.

TABLE 2-3. METALS EMISSIONS DATA FOR BABYLON

Test Condition	Run Number[a]	FF Inlet Temperature[b] (°F)	PM Concentration (gr/dscf at 12% CO_2)	Outlet Concentration (µg/dscm at 7% O_2) As	Cd	Cr	Pb	Hg	Ni
Combustor = Normal[c]	2-1	319	0.0013	ND[d]	ND	ND	0.8	544	ND
SD/FF = Normal	2-2	318	0.0008	ND	ND	ND	2.5	620	ND
	2-3	316	0.0016	ND	ND	ND	1.0	190	ND
Average Unit 2		318	0.0012				1.4	451	

[a]Run number consists of unit number followed by the run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 375 tpd.

[d]ND = Not detected. Considered as zero when calculating averages.

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TABLE 2-4. CDD/CDF DATA FOR BABYLON

Test Condition	Run Number[a]	FF Inlet Temperature[b] (°F)	Inlet CDD/CDF Concentration (ng/dscm at 7% O_2)	Outlet CDD/CDF Concentration (ng/dscm at 7% O_2)
Combustor = Normal[c]	1-1	317	NM[d]	12.6
SD/FF = Normal	1-2	314	NM	25.9
	1-3	326	NM	27.2
Average Unit 1		319		21.9

[a]Run number consists of unit number followed by the run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 375 tpd.

[d]NM = Not measured.

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3.0 SEMASS[4]

The SEMASS Waste-to-Energy Resource Recovery facility in Rochester, Massachusetts, consists of two identical refuse-derived fuel (RDF) fired MWC's, each rated 900 tpd of RDF. The units are identical semi-suspension fired Riley boilers which are capable of firing both fuel oil and RDF. Fuel oil is burned during start-up, shutdown, and process upset conditions to maintain a minimum furnace temperature of 1,800°F. Combustion gases from each boiler pass through a spray dryer and a 5-field electrostatic precipitator (SD/ESP) supplied by Joy Manufacturing.

Emission testing was conducted from February 15 through April 18, 1989, to determine compliance with the emission standards set by the Massachusetts Department of Environmental Quality and Engineering and the Southeastern Massachusetts Air Pollution Control District. The facility was tested while firing No. 2 fuel oil and while firing RDF. Only the results of the RDF firing are summarized in this report. Testing was conducted while the facility was operating at or near its rated capacity. During these tests, only four of the five ESP fields were in operation.

Triplicate runs were made to measure PM and SO_2 at the inlet and outlet of the SD/ESP of each unit. During these tests, hydrogen fluoride (HF), CO, and NO_x were also measured at the SD/ESP outlet. A separate set of triplicate runs was performed at the SD/ESP outlet of both units to determine the concentrations of trace metals including lead, mercury, arsenic, cadmium, chromium, and nickel. A third set of three runs was made at the SD/ESP outlet to determine concentrations of CDD/CDF.

Acid gas data for SEMASS are presented in Table 3-1. Outlet concentrations of SO_2 averaged 67 ppm at 7 percent O_2 over three test runs for Unit 1 and 55 ppm for Unit 2, with average estimated ESP inlet temperatures of 294 and 300°F, respectively. The outlet SO_2 concentrations on Unit 1 varied from 51 to 75 ppm and on Unit 2 from 9 to 96 ppm. Average removal efficiencies were 56 percent for Unit 1 and 65 percent for Unit 2. Available data do not explain the variability in SO_2 emissions from Unit 2. Data for HCl were not reported.

TABLE 3-1. ACID GAS DATA FOR SEMASS

Test Condition	Run Number[a]	ESP Inlet Temperature (°F)[b]	Stoichiometric Ratio[c]	Acid Gas Concentration (ppmv, dry at 7% O_2) Inlet SO_2	Inlet HCl[d]	Outlet SO_2	Outlet HCl[d]	Acid Gas Removal Efficiency (%) SO_2	HCl[d]
Combustor = Normal[e]	1-1	295	NA	154	NA	75	NA	51	NA
SD/ESP = Normal	1-2	294	NA	157	NA	74	NA	53	NA
	1-3	294	NA	150	NA	51	NA	65	NA
Average Unit 1		294	NA	154	NA	67	NA	56	NA
Combustor = Normal[e]	2-1	300	NA	155	NA	9	NA	94	NA
SD/ESP = Normal	2-2	301	NA	142	NA	96	NA	32	NA
	2-3	299	NA	190	NA	60	NA	68	NA
Average Unit 2		300	NA	162	NA	55	NA	65	NA

[a]Run number consists of unit number followed by run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Stoichiometric ratio cannot be determined since HCl data were not reported.

[d]Information on the HCl tests is not available.

[e]Full-load conditions = 900 tpd.

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90-3-1.tbl

The PM data for SEMASS are presented in Table 3-2. Outlet PM concentrations on Unit 1 averaged 0.0080 gr/dscf at 12 percent CO_2 over three runs with a removal efficiency of 99.8 percent (with 4 ESP fields operating). Unit 2 exhibited an average outlet PM concentration of 0.0120 gr/dscf at a removal efficiency of 99.7 percent (with 4 ESP fields operating).

Table 3-3 presents the metal emissions data for the triplicate runs conducted at the SD/ESP outlet of both units. Average mercury emissions were 59 μg/dscm at 7 percent O_2 for Unit 1 and 105 μg/dscm for Unit 2. Concentrations of arsenic, cadmium, and lead were relatively consistent for all runs and averaged 0.7, 9.6, and 300 μg/dscm, respectively, for Unit 1, and 1.5, 6.8, and 235 μg/dscm, respectively, for Unit 2. Concentrations of nickel and chromium were relatively consistent for all runs on Unit 1, averaging 6.8 and 6.5 μg/dscm, respectively. These levels are similar to the nickel and chromium concentrations measured during Run 2 on Unit 2. During Runs 1 and 3 on Unit 2, however, the nickel and chromium concentrations were an order-of-magnitude higher. There is no discussion in the test report indicating whether these elevated levels of chromium and nickel may have been caused by a sampling or analytical error.

Average metals emission levels were calculated using all of the data. Based on typical inlet concentrations of these metals at other MWC's,[1] removal efficiencies were greater than 75 percent for mercury and greater than 99 percent for arsenic, cadmium, chromium, and lead. Estimated removal efficiencies for nickel were 99 percent for Unit 1 and 97 percent for Unit 2.

The CDD/CDF data for the SD/ESP outlet of Units 1 and 2 are presented in Table 3-4. Outlet concentrations for Unit 1 ranged from 5.1 to 13.6 ng/dscm at 7 percent O_2 for three test runs and averaged 9.3 ng/dscm. The CDD/CDF levels during the three test runs on Unit 2 were 18.0, 6.6, and 907 ng/dscm. The high reading during the third run was attributed in the compliance test report to unsteady MWC operating conditions. The average CDD/CDF concentration for Unit 2, excluding the high value, was 12.3 ng/dscm. No measurements of uncontrolled CDD/CDF emissions were made.

TABLE 3-2. PM DATA FOR SEMASS

Condition	Run Number[a]	ESP Inlet Temperature (°F)[b]	Flue Gas Flow (acfm)	Inlet PM Concentration (gr/dscf at 12% CO_2)	Outlet PM Concentration[c] (gr/dscf at 12% CO_2)	Removal Efficiency (%)
Combustor = Normal[d]	1-1	295	180,000	4.09	0.0090	99.7
SD/ESP = Normal	1-2	294	182,000	4.10	0.0080	99.8
	1-3	294	176,000	4.65	0.0080	99.8
Average Unit 1		294	179,000	4.28	0.0080	99.8
Combustor = Normal[d]	2-1	300	213,000	3.76	0.0170	99.5
SD/ESP = Normal	2-2	301	218,000	4.31	0.0120	99.7
	2-3	299	209,000	3.50	0.0070	99.8
Average Unit 2		300	213,000	3.86	0.0120	99.7

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated by adding 15°F to average stack temperature.

[c]4 of 5 ESP fields operating.

[d]Full-load conditions = 900 tpd.

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TABLE 3-3. METALS EMISSIONS DATA FOR SEMASS

Test Condition	Run Number[a]	ESP Inlet Temperature[b] (^oF)	Particulate Concentration (gr/dscf at 12% CO_2)	Outlet Concentration (µg/dscm at 7% O_2)					
				As	Cd	Cr	Pb	Hg	Ni
Combustor = Normal[c]	1-1	287	--	0.2	5.2	4.0	177	70	4.6
SD/ESP = Normal	1-2	288	--	1.8	6.5	8.3	213	53	10.7
	1-3	287	--	0.2	17.0	7.3	509	55	5.1
Average Unit 1		287	0.0080[d]	0.7	9.6	6.5	300	59	6.8
Combustor = Normal[c]	2-2[e]	293	--	1.9	6.5	26.6	220	141	62.2
SD/ESP = Normal	2-3	292	--	2.5	6.3	5.7	267	100	6.3
	2-4	293	--	0.2	7.5	14.4	219	75	28.8
Average Unit 2		293	0.0120[d]	1.5	6.8	15.6	235	105	32.4

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated by adding 15^oF to average stack temperature.

[c]Full-load conditions = 900 tpd.

[d]Average of results from separate PM testing.

[e]Run numbers consistent with those used in test report. No information was provided in test report regarding missing runs.

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90-3-3.tbl

TABLE 3-4. CDD/CDF DATA FOR SEMASS

Unit	Run Number[a]	ESP Inlet Temperature (°F)[b]	Outlet CDD/CDF Concentration (ng/dscm at 7% O_2)
Combustor = Normal[c]	1-2[d]	298	5.1
SD/ESP = Normal	1-3	300	13.6
	1-5	295	9.2
Average Unit 1		298	9.3
Combustor = Normal[c]	2-1	298	18.0
SD/ESP = Normal	2-2	295	6.6
	2-5	300	907[e]
Average Unit 1		298	12.3

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 900 tpd.

[d]Run numbers consistent with those used in test report. No information was provided in test report regarding missing runs.

[e]High value suspected to have been caused by unsteady conditions during sampling. Number not included in average.

4.0 VANCOUVER[5,6,7,8]

The Greater Vancouver Regional District MWC in Burnaby, British Columbia, Canada, consists of three Martin mass burn waterwall combustors each with a capacity of 265 tpd of MSW. The combustion gases from each unit enter an APCD system which consists of a dry sorbent injection system followed by a fabric filter (DSI/FF). The DSI system was designed by Flakt and consists of a quench chamber, into which water is sprayed to cool the gases, followed by a reaction chamber where dry hydrated lime is injected to remove acid gases. Sodium sulfide is injected through a separate spray system at the entrance to the quench chamber to enhance the removal of mercury from the flue gas.

In November of 1988, emissions tests were conducted to demonstrate compliance with Environment Canada emission regulations. Particulate matter emissions were measured in accordance with the British Columbia Ministry of Environment's (BCMOE) Source Testing Code using a U. S. Environmental Protection Agency (EPA) Method 5 sampling train. Triplicate runs were conducted at the DSI/FF outlet (stack) of each unit. Concurrent with each of the PM emissions tests, flue gas was sampled for SO_2, HCl, and HF (Unit 3 only) by manual methods. Triplicate runs were made for SO_2 according to BCMOE Method 6 at both the DSI/FF system inlet and outlet. A separate EPA Method 5 sampling train was used to measure HCl emissions. In addition, CEM's were used to measure SO_2, HCl, CO, and NO_x at the exit to the DSI/FF. On Unit 3, an EPA Modified Method 5 sampling train was also used to sample metal emissions (arsenic, cadmium, chromium, lead, mercury, and nickel) at the DSI/FF outlet. Sampling was conducted according to the British Columbia Source Testing Code for the Measurement of Emissions of Particulates from Stationary Sources. In addition, flue gas at the DSI/FF inlet and outlet of Unit 3 was sampled for CDD/CDF emissions using a California Air Resources Board Semi-VOST sample train. The CDD/CDF runs were conducted separately and do not correspond to the run numbers for metals, particulate, and acid gas.

Additional testing of mercury emissions was performed between March and December 1989 to study the effect of sodium sulfide injection on mercury emissions.

Emissions of SO_2 and HCl are summarized in Table 4-1. The unbracketed values are SO_2 and HCl emissions taken by manual methods. The values shown in parentheses indicate averaged data taken from the CEM system at the exit of the DSI/FF. Removal efficiencies in parentheses are values calculated from manual data at the DSI/FF inlet and CEM data at the DSI/FF outlet. Inlet concentrations of SO_2 averaged 139 ppm at 7 percent O_2 over three runs for Unit 1, 157 ppm for Unit 2, and 161 ppm for Unit 3. Outlet SO_2 concentrations based on the manual sampling method averaged 15 ppm on Unit 1, 31 ppm on Unit 2, and 18 ppm on Unit 3. This corresponds to average SO_2 removal efficiencies of 90 percent, 79 percent, and 89 percent, respectively.

Average inlet concentrations of HCl were 194 ppm at 7 percent O_2 over three runs for Unit 1, 238 ppm for Unit 2, and 270 ppm for Unit 3. Outlet HCl concentrations for these units (based on the manual sampling method) averaged 9 ppm, 17 ppm, and 17 ppm, respectively. High wind conditions during the testing of Unit 2 resulted in outlet HCl data for only two runs. The resulting average HCl removal efficiencies were 95 percent for Unit 1, and 93 percent for Units 2 and 3.

Data of the PM emissions for Vancouver are presented in Table 4-2. Average PM concentrations at the DSI/FF outlet averaged 0.0079 gr/dscf at 7 percent O_2 over three runs on Unit 1, 0.0143 gr/dscf on Unit 2, and 0.0044 gr/dscf on Unit 3. The Unit 2 average includes only two runs due to cancellation of one run because of high winds.

Metals emission data from the DSI/FF inlet and outlet of Unit 3 are presented in Table 4-3. Mercury emissions ranged from approximately 300 to 750 µg/dscm over three runs with average emissions of 485 µg/dscm, suggesting little or no mercury removal based on an average measured mercury concentration at the DSI/FF inlet of 525 µg/dscm. Outlet arsenic, cadmium, and lead emissions were fairly uniform between runs and averaged 1.6, 3.7, and 78 µg/dscm at 7 percent O_2, respectively. Outlet emissions of chromium and nickel were highly variable during the three runs. The variability in outlet levels of chromium and nickel during Run 3 versus Runs 1 and 2 may be attributable to sampling problems. When the high values from Run 3-3 are excluded, the average chromium concentration is 41 µg/dscm at 7 percent O_2

TABLE 4-1. ACID GAS DATA FOR VANCOUVER

Test Condition	Run Number[a]	FF Outlet Temperature[b] (°F)	Stoichiometric Ratio[c]	Acid Gas Concentration[d] (ppmv, dry at 7% O_2) Inlet SO_2	Inlet HCl	Outlet SO_2	Outlet HCl	Acid Gas Removal Efficiency (%) SO_2	HCl
Combustor = Normal[e]	1-1	295	NA	162	184	31(55)	19(21)	81(66)	90(89)
DSI/FF = Normal	1-2	295	NA	128	183	9(6)	3(4)	93(96)	98(99)
	1-3	295	NA	128	214	6(1)	4(3)	95(99)	98(98)
Average Unit 1		295		139	194	15(21)	9(9)	90(87)	95(95)
Combustor = Normal[e]	2-1	295	NA	136	NM[f]	27(14)	NM(NM)	80(89)	NA(NA)
DSI/FF = Normal	2-2	295	NA	189	225	28(22)	NM(NM)	85(88)	NA(NA)
	2-3	295	NA	145	265	39(41)	21(24)	73(71)	92(91)
	2-4	295	NA	NM	225	NM(NM)	13(15)	NA(NA)	94(93)
Average Unit 2		295		157	238	31(26)	17(20)	79(83)	93(92)
Combustor = Normal	3-1	295	NA	195	299	25(68)	15(11)	87(65)	95(96)
DSI/FF = Normal	3-2	295	NA	142	294	6(39)	14(17)	96(73)	95(94)
	3-3	295	NA	145	216	22(4)	23(6)	85(97)	89(97)
Average Unit 3		295		161	270	18(37)	17(11)	89(78)	93(96)

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated based on stack temperature data, which were reported to be 12.5 to 30°F higher than temperatures measured by the CEMs at the FF outlet. (Plant personnel indicated this increase was not unusual.) The plant also reports normal operating temperatures at the FF outlet between 284 and 302°F.

[c]Lime feedrate data not available, therefore, stoichiometric ratio cannot be calculated.

[d]Quantities in parentheses denote values obtained from average of CEM data analysis at the DSI/FF outlet (stack).

[e]Full-load conditions = 265 tpd.

[f]NM = not measured. High winds resulted in the cancellation of HCl measurement at stack during Run 2-2. Run 2-4 conducted for HCl only.

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TABLE 4-2. PM DATA FOR VANCOUVER

Condition	Run Number[a]	FF Outlet Temperature[b] (°F)	Flue Gas Flow (acfm)	Outlet PM Concentration (gr/dscf at 7% O_2)[c]
Combustor = Normal[d]	1-1	295	32,400	0.0144
DSI/FF = Normal	1-2	295	30,900	0.0050
	1-3	295	28,100	0.0042
Average Unit 1		295	30,500	0.0079
Combustor = Normal[d]	2-1	295	NM[e]	NM[e]
DSI/FF = Normal	2-2	295	31,500	0.0117
	2-3	295	30,200	0.0169
Average Unit 2		295	30,900	0.0143
Combustor = Normal[d]	3-1	295	30,700	0.0043
DSI/FF = Normal	3-2	295	30,500	0.0040
	3-3	295	30,700	0.0048
Average Unit 3		295	30,600	0.0044

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated based on stack temperature data, which were reported to be 12.5 to 30°F higher than temperatures measured by the CEMs at the FF outlet. (Plant personnel indicated this increase was not unusual.) The plant also reports normal operating temperatures at the FF outlet between 284 and 302°F.

[c]CO_2 data not available, therefore, corrections were made to 7 percent O_2.

[d]Full-load conditions = 265 tpd.

[e]NM = not measured; cancelled because of high winds.

TABLE 4-3. METALS EMISSIONS DATA FOR VANCOUVER

Test Condition	Run Number[a]	FF Outlet Temp.(oF)	Outlet PM Concentration (gr/dscf at 7%O2)[b]	Inlet Concentration (ug/dscm at 7% O2)[c]						Outlet Concentration (ug/dscm at 7% O2)[c]						Removal Efficiency (%)					
				As	Cd	Cr	Pb	Hg	Ni	As	Cd	Cr	Pb	Hg	Ni	As	Cd	Cr	Pb	Hg	Ni
Combustor = Normal[d]	3-1	295	0.0043	1080	1490	475	38200	795	3300	1.7	4.3	7.4	85	300	7.6	99.8	99.7	98.4	99.8	62.3	99.8
DSI/FF = Normal	3-2	295	0.0040	1090	1140	380	33100	595	2500	1.6	3.9	74	75	750	15.9	99.9	99.7	80.4	99.8	-26.1	99.4
	3-3	295	0.0048	100	840	485	19800	190	615	1.4	2.9	490e	75	400	436e	98.6	99.7	-1.0e	99.6	-111.0	29.1e
Average Unit 3		295	0.0044	760	1160	445	30400	525	2140	1.6	3.7	41	78	485	11.8	99.4	99.7	89.4	99.7	-25	99.6

a Run number consists of unit number followed by the run number for that test.

b Estimated based on stack temperature data, which were reported to be 12.5 to 30°F higher than temperatures measured by the CEMs at the FF outlet. (Plant personnel indicated this increase was not unusual.) The plant also reports normal operating temperatures at the FF outlet between 284 and 302°F.

c CO_2 data not available, therefore, corrections were made to 7 percent O_2.

d Full-load conditions = 265 tpd.

e Suspiciously high numbers may be due to sampling problem. These numbers are not included in averages.

and the average nickel concentration is 11.8 μg/dscm. Removal efficiencies were greater than 99 percent for arsenic, cadmium, lead, and nickel, and approximately 90 percent for chromium.

Due to the relatively high mercury emissions measured during the compliance testing in November 1988, tests were run to investigate the effect of injecting a sodium sulfide solution at the quench chamber inlet on mercury removal efficiency. Table 4-4 presents the results of these tests for all three units.

In March 1989, three runs were made at the DSI/FF inlet and outlet of Unit 1. During the tests, a 10 percent solution of sodium sulfide was sprayed into the quench chamber inlet at rates ranging from 1 to 2 kilograms per hour (kg/hr) of sodium sulfide. Outlet mercury concentration averaged 456 μg/dscm. The removal efficiency for the three runs ranged from 59 to 66 percent, averaging 62 percent. Increasing the spray rates did not appear to enhance mercury removal.

Testing was repeated in April 1989, this time a with solution concentration of 15 percent sodium sulfide. Three sampling runs were conducted at the DSI/FF inlet and outlet on Unit 1 to detect mercury emissions. The sodium sulfide injection rate was 3 kg/hr. The average inlet concentration was 1,357 μg/dscm at 7 percent O_2 and the average outlet concentration was 632 μg/dscm. This resulted in an average removal efficiency of 53 percent.

In July 1989, more testing was performed utilizing a 1 percent solution of sodium sulfide at liquid flowrates of 200 to 500 liters per hour (l/hr). Results of the tests were not found in the available data. In August 1989, five runs were conducted. Measurement of mercury concentrations were made at the DSI/FF inlet and outlet on Unit 2. Sodium sulfide solution ranged from 2 to 4 percent, and flow rates ranging from 2 to 6 kg/hr were tested. The average inlet concentration was 661 μg/dscm at 7 percent O_2 and the average outlet concentration was 95 μg/dscm over five test runs. The mercury removal efficiency during each run ranged from 76 to 88 percent and did not show any trend with sodium sulfide feed rate.

In December 1989, the Burnaby MWC started continuous injection of sodium sulfide on all three units to reduce mercury emission levels. Tests on

TABLE 4-4. MERCURY DATA FOR VANCOUVER

Date	Test Conditions	Run Number[a]	FF Outlet Temperature (°F)	Na_2S Flowrate (kg/hr)	Inlet Mercury Concentration (μg/dscm at 7% O_2)	Outlet Mercury Concentration (μg/dscm at 7% O_2)	Removal Efficiency (%)
11/88	Combustor = Normal[b]	3-1	295c	0	795	303	62
	DSI/FF = Normal	3-2	295c	0	597	752	-26
		3-3	295c	0	188	400	-113
	Average		295c		527	485	-26
03/89	Combustor = Normal[b]	1[d]	NA[e]	1.0	1,465	570	61
	DSI/FF = Normal	2[d]	NA[e]	2.0	993	406	59
		3[d]	NA[e]	2.0	1,151	393	66
	Average			1.7	1,203	456	62
04/89	Combustor = Normal[b]	1-1	NA[f]	3.0	1,423	670	53
	DSI/FF = Normal	1-2	NA[f]	3.0	1,443	750	48
		1-3	NA[f]	3.0	1,205	473	61
	Average		295[c]	3.0	1,357	632	53
08/89	Combustor = Normal[b]	2-1	NA[e]	2.5	406	98	76
	DSI/FF = Normal	2-2	NA[e]	6.0	775	91	88
		2-3	NA[e]	2.0	670	84	88
		2-4	NA[e]	3.0	793	101	87
		2-5	NA[e]	6.0	661	103	84
	Average			3.9	661	95	85
12/89	Combustor = Normal[b]	1-1	NA[e]	4.0	NM[g]	138	--
	DSI/FF = Normal	1-2	NA[e]	4.0	NM[g]	67	--
		1-3	NA[e]	4.0	NM[g]	146	--
	Average			4.0		117	--
		2-1	NA[e]	4.0	NM[g]	149	--
		2-2	NA[e]	4.0	NM[g]	115	--
		2-3	NA[e]	4.0	NM[g]	118	--
	Average			4.0		127	--
		3-1	NA[e]	4.0	NM[g]	152	--
		3-2	NA[e]	4.0	NM[g]	159	--
	Average			4.0		156	--

Continued

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TABLE 4-4. FOOTNOTES (CONCLUDED)

[a]Run number consists of unit followed by the run number for that test.

[b]Full-load conditions = 265 tpd.

[c]Estimated based on stack temperature data, which were reported to be 12.5 to 30°F higher than temperatures measured by the CEMs at the FF outlet. (Plant personnel indicated this increase was not unusual.) The plant also reports normal operating temperatures at the FF outlet between 284 and 302°F.

[d]Unit not known.

[e]Temperature data not available. Plant normally operates between 284 and 302°F at the FF outlet.

[f]Only the average temperature for three tests was reported.

[g]Not measured.

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Units 1, 2, and 3 were conducted with a 2-percent sodium sulfide solution and a 4 kg/hr feed rate. Average outlet concentrations were 117 μg/dscm at 7 percent O_2 over three test runs on Unit 1 and 127 μg/dscm at Unit 2. The average outlet level for Unit 3 was 156 μg/dscm over two test runs. Although inlet mercury concentrations were not reported for tests at any of the units, an 80-percent removal efficiency is suggested, based on the average inlet levels during the August 1989 tests.

Inlet and outlet CDD/CDF data for Unit 3 are shown in Table 4-5. Only two runs were reported due to the discovery that portions of the inlet and outlet samples from Run 3-3 had been mixed together inadvertently. Run 1 exhibited an inlet CDD/CDF concentration of 101 ng/dscm at 7 percent O_2 and an outlet concentration of 0.03 ng/dscm, resulting in a removal efficiency of 99.9 percent. The inlet concentration for Run 2 was 55 ng/dscm at 7 percent O_2 and the outlet concentration was 9.25 ng/dscm, resulting in a CDD/CDF removal efficiency of 83.3 percent. The average outlet CDD/CDF concentration based on these two runs was 4.6 ng/dscm, corresponding to a removal efficiency of 92 percent.

TABLE 4-5. CDD/CDF DATA FOR VANCOUVER

Test Condition	Run Number[a]	FF Outlet Temperature	Inlet CDD/CDF Concentration (ng/dscm at 7% O_2)	Outlet CDD/CDF Concentration (ng/dscm at 7% O_2)	CDD/CDF Removal Efficiency (%)
Combustor = Normal[b]	3-1	NA[c]	101	0.03	99.9
DSI/FF = Normal	3-2	NA[c]	55	9.25	83.3
	3-3	NA[c]	NA[d]	NA[d]	NA[d]
Average Unit 3			78	4.64	92

[a]Run number consists of unit number followed by the run number for that test. CDD/CDF test runs were independent and these run numbers do not correspond to the run numbers for the metals, particulate, and acid gas tests.

[b]Full-load conditions = 265 tpd.

[c]Temperatures data not available. Plant normally operates between 284 and 302°F at the FF exit.

[d]Sample was not analyzed after it was discovered that portions of the inlet and outlet samples had been accidentally mixed.

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5.0 INDIANAPOLIS[9]

The Indianapolis Resource Recovery facility in Indianapolis, Indiana, consists of three Martin grates equipped with waterwall boilers. Each unit has a capacity to process 787 tpd of MSW and is rated at 167,000 lb/hr of steam. Each boiler train is equipped with a SD/FF APCD system supplied by Environmental Elements. Each SD has three rotary atomizers to introduce lime slurry into the combustion gas stream. Following each SD is a pulse-jet FF which has 10 modules and uses acid-resistant fiberglass bags. The design air-to-cloth ratio is 3.0 gross and 3.3 net, with one compartment out of service.

From June 27 through July 1, 1989, Ogden Projects, Inc., conducted tests to demonstrate compliance with permit conditions for all three units. Simultaneous PM and HCl samples were collected from each unit using an EPA Method 5 sampling train. Separate runs were conducted to measure metals (lead and mercury) and CDD/CDF from Unit 1 only. Lead and mercury sampling was conducted using a combined Method 12/101A train. Sampling for CDD/CDF was done with a Modified Method 5 train. Sampling was limited to triplicate samples collected at the stack for all pollutants.

Acid gas (HCl) data are presented in Table 5-1. Outlet HCl concentrations ranged from 4 to 35 ppm at 7 percent O_2 over three test runs on Unit 1, from 0.1 to 0.5 ppm on Unit 2, and from 0.2 to 0.7 ppm for Unit 3. No explanation is available for the variation in HCl measured on Unit 1 versus Units 2 and 3. The estimated FF inlet temperatures averaged 307^{o}F, 309^{o}F and 310^{o}F for each unit respectively. Data for HCl inlet concentrations were not reported, therefore, removal efficiencies could not be determined. Data for SO_2 were not reported.

The PM data for Indianapolis are presented in Table 5-2. Outlet PM concentrations for triplicate runs on Unit 1 averaged .0040 gr/dscf at 12 percent CO_2. For Unit 2, the average was .0041 gr/dscf. Unit 3 had an average of .0026 gr/dscf. Removal efficiencies could not be determined since inlet PM values were not measured.

Table 5-3 lists the test results for lead and mercury emissions from Unit 1. Outlet concentrations for lead, based on three runs, averaged

TABLE 5-1. ACID GAS DATA FOR INDIANAPOLIS

Unit	Run Number[a]	FF Inlet Temperature (°F)[b]	Stoichiometric Ratio[c]	Acid Gas Concentration (ppmv, dry at 7% O_2) Inlet SO_2	Inlet HCl	Outlet SO_2	Outlet HCl	Acid Gas Removal Efficiency (%) SO_2	HCl
Combustor = Normal[d]	1-1	306	NA	NA	NA	NA	35.0	NA	NA
SD/FF = Normal	1-2	307	NA	NA	NA	NA	11.1	NA	NA
	1-3	307	NA	NA	NA	NA	4.4	NA	NA
Average Unit 1		307	NA	NA	NA	NA	16.8	NA	NA
Combustor = Normal[d]	2-1	310	NA	NA	NA	NA	0.5	NA	NA
SD/FF = Normal	2-2	308	NA	NA	NA	NA	0.1	NA	NA
	2-3	310	NA	NA	NA	NA	0.1	NA	NA
Average Unit 2		309	NA	NA	NA	NA	0.2	NA	NA
Combustor = Normal[d]	3-1	307	NA	NA	NA	NA	0.7	NA	NA
SD/FF = Normal	3-2	311	NA	NA	NA	NA	0.5	NA	NA
	3-3	311	NA	NA	NA	NA	0.2	NA	NA
Average Unit 3		310	NA	NA	NA	NA	0.5	NA	NA

[a]Run number consists of unit number followed by run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Stoichiometric ratio cannot be determined since lime feedrate data is unavailable for Unit 1. Stoichiometric data for Unit 2 will be included in the final memorandum.

[d]Full-load conditions = 787 tpd.

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TABLE 5-2. PM DATA FOR INDIANAPOLIS

Unit	Run Number[a]	FF Inlet Temperature[b] (°F)	Flue Gas Flow (acfm)	Outlet PM Concentration (gr/dscf at 12% CO_2)
Combustor = Normal[c]	1-1	306	171,000	.0064
SD/FF = Normal	1-2	307	171,000	.0021
	1-3	307	177,000	.0036
Average Unit 1		307	173,000	.0040
Combustor = Normal[c]	2-1	310	187,000	.0038
SD/FF = Normal	2-2	308	171,000	.0050
	2-3	310	175,000	.0034
Average Unit 2		309	178,000	.0041
Combustor = Normal[c]	3-1	307	169,000	.0031
SD/FF = Normal	3-2	311	170,000	.0011
	3-3	311	173,000	.0035
Average Unit 3		310	171,000	.0026

[a]Run number consists of unit number followed by the run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 787 tpd.

TABLE 5-3. METALS EMISSIONS DATA FOR INDIANAPOLIS

Unit	Run Number[a]	FF Inlet Temperature (°F)[b]	Particulate Concentration (gr/dscf at 12% CO_2)	Outlet Concentration (µg/dscm at 7% O_2) Pb	Hg
Combustor = Normal[c]	1-1	309	--	4.22	354
SD/FF = Normal	1-2	308	--	4.16	210
	1-3	304	--	4.39	285
Average Unit 1		307	0.00359[d]	4.26	283

[a]Run number consists of unit number followed by the run number for that test.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 787 tpd.

[d]Average of results from separate PM testing.

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4.26 μg/dscm at 7 percent O_2. The outlet values for mercury ranged from 210 to 354 μg/dscm, and averaged 283 μg/dscm. The average estimated FF inlet temperature was 307°F. Based on typical uncontrolled lead and mercury levels from other MWC's,[1] the estimated reduction is greater than 99 percent for lead, but relatively low for mercury.

Outlet concentrations of CDD/CDF for Unit 2 are shown in Table 5-4. The three CDD/CDF test runs gave values ranging from 6.1 to 15 ng/dscm at 7 percent O_2, with an average value of 11.3 ng/dscm. The average estimated FF inlet temperature was 311°F. Inlet concentrations were not reported, therefore, removal efficiencies could not be calculated.

TABLE 5-4. CDD/CDF DATA FOR INDIANAPOLIS

Unit	Run Number[a]	FF Inlet Temperature[b]	Inlet CDD/CDF Concentration (ng/dscm at 7% O_2)	Outlet CDD/CDF Concentration (ng/dscm at 7% O_2)
Combustor = Normal[c]	2-1	310	NM[d]	12.7
SD/FF = Normal	2-2	311	NM	15.0
	2-3	312	NM	6.1
Average Unit 2		311		11.3

[a]Run number consists of unit number followed by the run number for that unit.

[b]Estimated by adding 15°F to average stack temperature.

[c]Full-load conditions = 787 tpd.

[d]NM = not measured.

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6.0 SUMMARY OF PERFORMANCE

Three types of APCD systems are reviewed in this appendix: SD/FF (Babylon and Indianapolis), SD/ESP (SEMASS), and DSI/FF (Vancouver). Section 6.1 evaluates SD/FF performance, Section 6.2 evaluates SD/ESP performance, and Section 6.3 evaluates DSI/FF performance. This data is similar to those found in the background information document (BID) entitled "Municipal Waste Combustors - Background Information for Proposed Standards: Post-Combustion Technology Performance".[1]

6.1 SPRAY DRYER/FABRIC FILTER PERFORMANCE (BABYLON AND INDIANAPOLIS)

6.1.1 Acid Gas

Sulfur dioxide data were reported for Babylon only. For the full-load tests, SO_2 removal was between 82 and 87 percent on five of six runs. During the sixth run, the inlet SO_2 level (95 ppm) was lower than during the other runs and the SO_2 reduction was 64 percent. For the reduced-load tests, the SO_2 removal efficiency averaged 92 percent over 3 runs.

The BID concluded that a 90 percent SO_2 removal efficiency is achievable for SD/FF systems with increased stoichiometric ratios and low FF inlet temperatures (<300°F). The relationship between stoichiometric ratio and SO_2 removal efficiency cannot be determined at Babylon since lime feedrate data were not available. The FF inlet temperatures at Babylon were estimated to be between 315 to 320°F during the full-load tests and 290 to 295°F during the reduced-load tests. Since the SO_2 removal efficiency during the reduced-load tests exceeded 90 percent, the results appear to support the importance of temperature on SO_2 removal efficiency. However, the higher removal efficiencies could also be the result of increased stoichiometric ratios and longer flue gas residence times in the SD and FF during the reduced-load tests.

The HCl data at Babylon show removal efficiencies of approximately 95 to 97 percent for full-load tests. Average outlet levels ranged from approximately 20 to 50 ppm at 7 percent O_2. Reduced-load tests averaged 97 percent removal, with outlet levels of 21 to 26 ppm. At Indianapolis, HCl outlet levels averaged less than 20 ppm on Unit and 1 and less than 1 ppm on Units 2 and 3, which are among the lowest HCl levels measured. These results are consistent with the BID's conclusion that 97 percent removal of HCl is achievable for SD/FF systems operting at low inlet temperatures and high stoichiometric ratios.

6.1.2 Particulate Matter

The average PM outlet levels were less than 0.003 gr/dscf at Babylon, and less than 0.004 gr/dscf at Indianapolis. These levels are similar to those in the BID for SD/FF systems.

6.1.3 Metals

At Indianapolis and Babylon, measurable levels of metals were recorded for lead and mercury only. Data on other metals were not measured at Indianapolis and emissions of arsenic, cadmium, chromium, and nickel were below detection levels at Babylon. Although inlet levels of lead and mercury were not measured at either facility, removal efficiencies for lead exceeded 99 percent based on typical inlet levels at other MWC's, which supports the 99 percent removal efficiency cited in the BID.

Indianapolis had an average outlet mercury level of 283 µg/dscm over three runs, and Babylon averaged 451 µg/dscm over 3 runs. Although inlet levels were not measured at either MWC, the outlet levels suggest little mercury reduction was achieved. In the BID it was noted that the level of mercury removal with the SD/FF system varied from site to site, but stated that an outlet level of 300 µg/dscm is achievable with SD/FF systems. This is not supported by the Babylon data.

6.1.4 Dioxins/Furans

The average CDD/CDF outlet levels at Babylon and Indianapolis were 21.9 ng/dscm and 11.3 ng/dscm, respectively. These levels are higher than the CDD/CDF level of less than 10 ng/dscm concluded in the BID to be achievable by SD/FF systems operating at FF inlet temperatures of 300°F or less. The higher CDD/CDF emissions during the tests conducted at Babylon and Indianapolis may have been due to the FF inlet temperatures experienced during these tests, which were greater than 300°F. However, the effect of temperature is not conclusive, and other process conditions may also play a role in CDD/CDF control by SD/FF systems.

6.2 SPRAY DRYER/ELECTROSTATIC PRECIPITATOR PERFORMANCE (SEMASS)

6.2.1 Acid Gas

Only SO_2 data were reported at SEMASS. Removal efficiencies were generally between 50 and 70 percent for six runs. This is lower than the reported 75 percent removal efficiency for other SD/ESP systems operating at similar ESP inlet temperature levels (<300°F).[1] The average outlet levels of 60 ppm are consistent with emission limits achievable with a SD/ESP system, however. Because HCl and lime feed rates were not reported at SEMASS, the stoichiometric ratio cannot be determined and the relationship between the stoichiometric ratio and removal efficiencies cannot be established.

6.2.2 Particulate Matter

The PM results at SEMASS show three run-average removal efficiencies of 99.7 for Unit 1 and 99.8 percent for Unit 2, corresponding to 0.012 and 0.008 gr/dscf, respectively. These results are similar to the 0.01 gr/dscf PM levels reported to be achievable by a SD/ESP system.[1]

6.2.3 Metals

Although uncontrolled metals concentrations were not measured at SEMASS, estimated removal efficiencies for arsenic, cadmium, chromium, and lead were greater than 99 percent. Estimated removal efficiencies for nickel were 99 percent for Unit 1 and 97 percent for Unit 2. These removal efficiencies are comparable to those reported in the BID, which indicated that SD/ESP systems are capable of reducing arsenic, cadmium, lead, and nickel by 98 percent and chromium by 95 percent.

The average mercury levels from SEMASS were 60 and 105 µg/dscm over three runs for Unit 1 and Unit 2, respectively. These outlet data indicate an estimated 75 percent removal efficiency, based on typical mercury inlet levels.[1] The estimated 75 percent reduction in mercury disagrees with the earlier conclusion reached in the BID that mercury is not effectively removed by a SD/ESP system. As discussed in the BID, it has been theorized that mercury removal is enhanced by carbon in the flyash, which provides adsorption sites for the mercury. The observed mercury control at SEMASS may be related to the RDF semi-suspension firing method used, which may result in increased flyash carryover, and thus, increased mercury adsorption onto flyash.

6.2.4 Dioxins/Furans

The outlet CDD/CDF levels at SEMASS during five of the six runs were between 5 and 20 ng/dscm. These levels are lower than those reported for SD/ESP equipped facilities, which ranged from 40 to over 250 ng/dscm.[1] The CDD/CDF emission rates from SEMASS are similar to those at Babylon and Indianapolis, but are somewhat higher than those recorded at most other SD/FF-equipped MWC's. The SEMASS data, along with other data from SD/ESP-equipped systems, suggest that SD/ESP systems are less efficient at control of CDD/CDF emissions than SD/FF systems.

The CDD/CDF level was 907 ng/dscm during the sixth run at SEMASS. The test report stated that plant operating records indicated that several periods of unsteady combustion conditions occurred during this run. Similar increases in CDD/CDF emissions from SD/FF systems have not been reported. This suggests that SD/ESP systems may be more sensitive to combustor operating conditions than SD/FF systems.

6.3 DRY SORBENT INJECTION/FABRIC FILTER PERFORMANCE (VANCOUVER)

6.3.1 Acid Gas

The SO_2 data at Vancouver indicate removal efficiencies of 80 to 90 percent. Hydrogen chloride data at Vancouver indicate removal efficiencies of 93 to 95 percent. Flue gas temperatures at the FF outlet were an estimated 295^{o}F, but lime feed rates were not reported. These results are generally lower than the 90 percent SO_2 reduction and 95 percent HCl reduction which were determined to be achievable by DSI/FF systems in the BID.

6.3.2 Particulate Matter

The average outlet PM concentrations from Units 1 and 3 at Vancouver were 0.0079 gr/dscf and 0.0044 gr/dscf, respectively. The PM data collected for two runs on Unit 2 were slightly higher, averaging 0.0143 gr/dscf. These results therefore, support an achievable PM level of 0.015 gr/dscf, rather than the average PM outlet level of 0.01 gr/dscf determined in the BID to be achievable by DSI/FF systems.

6.3.3 Metals

Average removal efficiencies for arsenic, cadmium, lead, and nickel at Vancouver were greater than 99 percent. The average removal efficiency for chromium was 90 percent. A 99 percent reduction of arsenic, cadmium, and lead and a 96 percent removal of nickel and chromium was determined to be achievable for DSI/FF systems from previous data. With the exception of chromium, the results from Vancouver for these metals support the data in the BID. As indicated above, the large variations in the chromium (and nickel) data may have been due to sampling problems.

Mercury data indicated a 70 percent removal efficiency for DSI systems operating at FF inlet temperatures below 300°F. At Vancouver, mercury removal without sodium sulfide injection was minimal. With sodium sulfide injection, actual removal efficiencies ranged from 60 to 85 percent. The levels of mercury removal achieved during the August 1989 tests were 75 to 85 percent. These higher levels, compared to the earlier tests, are believed to be the result of improved atomization and mixing when feeding higher volumes of lower concentration solution versus lower volumes of high concentration solutions.

6.3.4 Dioxins/Furans

The CDD/CDF emissions at Vancouver averaged 4.6 ng/dscm over two runs, with a removal efficiency of 92 percent. These results are consistent with previous data, which indicate that a level of less than 10 ng/dscm is achievable at FF inlet temperatures less than 300°F. The FF inlet temperature was not available at Vancouver, but was believed to have been relatively constant at around 295°F.

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TABLE 4-3. METALS EMISSIONS DATA FOR VANCOUVER

Test Condition	Run Number[a]	FF Outlet Temp.(°F)[b]	Outlet PM Concentration (gr/dscf at 7%O2)	Inlet Concentration (ug/dscm at 7% O2)[c]						Outlet Concentration (ug/dscm at 7% O2)[c]						Removal Efficiency (%)					
				As	Cd	Cr	Pb	Hg	Ni	As	Cd	Cr	Pb	Hg	Ni	As	Cd	Cr	Pb	Hg	Ni
Combustor = Normal[d]	3-1	295	0.0043	1080	1490	475	38200	795	3300	1.7	4.3	7.4	85	300	7.6	99.8	99.7	98.4	99.8	62.3	99.8
DSI/FF = Normal	3-2	295	0.0040	1090	1140	380	33100	595	2500	1.6	3.9	74	75	750	15.9	99.9	99.7	80.4	99.8	-26.1	99.4
	3-3	295	0.0048	100	840	485	19800	190	615	1.4	2.9	490e	75	400	436e	98.6	99.7	-1.0e	99.6	-111.0	29.1e
Average Unit 3		295	0.0044	760	1160	445	30400	525	2140	1.6	3.7	41	78	485	11.8	99.4	99.7	89.4	99.7	-25	99.6

a Run number consists of unit number followed by the run number for that test.

b Estimated based on stack temperature data, which were reported to be 12.5 to 30°F higher than temperatures measured by the CEMs at the FF outlet. (Plant personnel indicated this increase was not unusual.) The plant also reports normal operating temperatures at the FF outlet between 284 and 302°F.

c CO_2 data not available, therefore, corrections were made to 7 percent O_2.

d Full-load conditions = 265 tpd.

e Suspiciously high numbers may be due to sampling problem. These numbers are not included in averages.

TECHNICAL REPORT DATA

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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-450/3-91-004		

4. TITLE AND SUBTITLE	5. REPORT DATE
Municipal Waste Combustion: Background Information for Promulgated Standards and Guidelines - Summary of Public Comments and Responses Appendices A to C	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-4378
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE 200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Appendices A to C to the "Municipal Waste Combustion: Background Information for Promulgated Standards and Guidelines - Summary of Public Comments and Responses" (EPA-450/3-91-004), address key technical issues related to the promulgated rules for municipal waste combustors (MWC's).

Appendix A provides analysis of the continuous SO_2 control capabilities of spray dryer/fabric filter (SD/FF) and spray dryer/electrostatic precipitator (SD/ESP) control systems for MWC's. Achievable SO_2 performance levels for these systems are determined based on the analysis.

Similarly, Appendix B provides analysis of continuous NO_x emissions data from MWC's. Results are presented for the statistical analysis of NO_x data obtained from a grate-fired mass burn waterwall MWC using selective noncatalytic reduction (SNCR) to reduce NO_x emissions and from a rotary mass burn waterwall MWC designed to limit NO_x emissions through combustion control.

Appendix C provides additional MWC emissions test data which became available following proposal of the standards and guidelines for MWC's on December 20, 1989. The appendix reviews data at four MWC's with either unique air pollution control technologies or emissions which are higher than for similarly controlled MWC's that had been previously examined.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Municipal Waste Combustors Incineration Pollution Control Costs	Air Pollution Control	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	Unclassified	118
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

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