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Air

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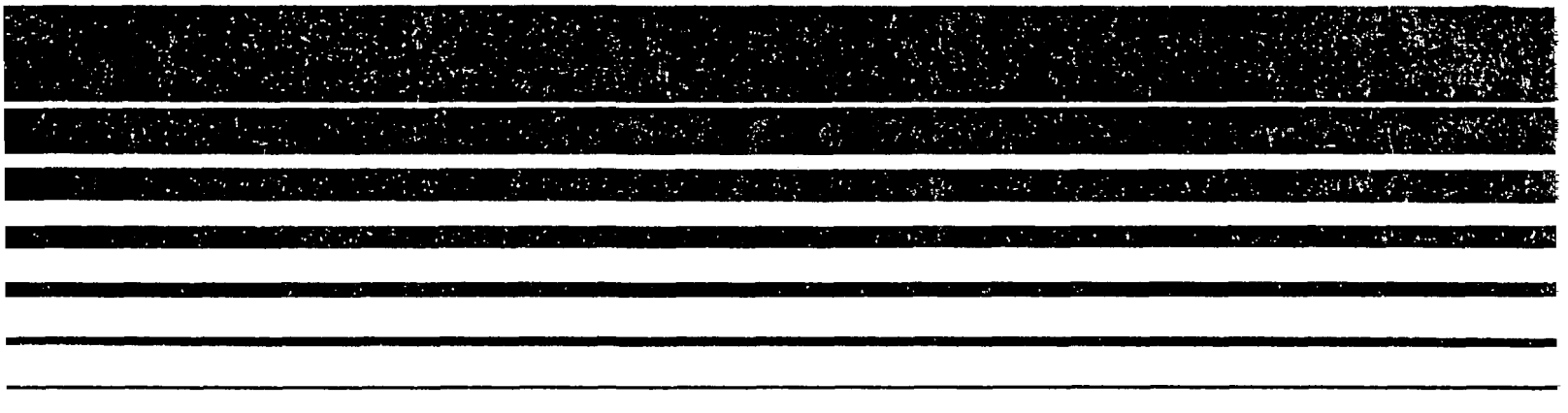
Industrial Boiler Emission Test Report

Tennessee Eastman Company
Boiler No. 24
Kingsport, Tennessee

SUMMARY REPORT



NSPS DEVELOPMENT

OXIDES OF NITROGEN TESTING
BOILER UNIT 24

TENNESSEE EASTMAN COMPANY
KINGSPORT, TENNESSEE

SUMMARY REPORT

JUNE 1984

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TABLE OF CONTENTS

		Page
1.0	Introduction	1-1
2.0	Summary and Discussion of Results	2-1
2.1	Stratification Test	2-1
2.2	NO_x Emissions vs Boiler Operating Parameters	2-1
2.3	Emissions Tests	2-6
2.3.1	TCEMS and Reference Method Results	2-6
2.3.2	CO Results	2-9
2.4	Quality Assurance Results	2-9
3.0	Process and Control Equipment Operating Conditions	3-1
3.1	Process Equipment Operating Conditions	3-1
3.2	Control Equipment Operating Conditions	3-3
4.0	Sampling Locations	4-1
4.1	Description of Sampling Locations	4-1
4.2	Modifications to Existing Facilities	4-1
5.0	Sampling and Analytical Procedures	5-1
5.1	Reference Method Sampling Procedures	5-1
5.2	Non-Reference Method Sampling Procedures	5-1
5.2.1	Effluent Stratification Test	5-1
5.2.2	Continuous Monitoring	5-2
5.2.3	Coal Sampling	5-2
5.3	Process Monitoring Procedures	5-3
5.4	Sample/Data Chain of Custody	5-3
6.0	Quality Assurance	6-1
6.1	Reference Method Sampling Quality Control	6-1
6.1.1	EPA Method 3	6-1
6.1.2	EPA Method 7	6-2
6.2	Non-Reference Method Sampling Quality Control	6-2
6.2.1	TCEMS Sampling	6-2
6.2.2	Coal Sampling	6-2
6.3	Assessment of Sample Representativeness	6-3
7.0	Appendices	
7.1	Results and Calculations	7.1-0

LIST OF TABLES

		Page
Table 2-1.	Stratification Testing Results - No Preheat Boiler Condition	2-2
Table 2-2.	Stratification Testing Results - Full Preheat Boiler Condition	2-3
Table 2-3.	NO_x Emissions vs Boiler Operative Parameters - Continuous Emission Monitoring Summary	2-4
Table 2-4.	Relative Accuracy Test Results for Beckman 951 NO_x/Teledyne 320P-4 O_2 CEMS	2-7
Table 2-5.	Reference Method Sampling Data Summary	2-8
Table 2-6.	Run-by-Run TCEMS/Reference Method Results Comparison	2-10
Table 2-7.	Audit Sample Analysis	2-11
Table 2-8.	Validation of Orsat Analysis Data: 6/6-13/84	2-13
Table 3-1.	Permutations of Boiler Unit 24 Operating Parameters	3-4
Table 7-1.	Continuous Emission Monitoring Results	7.1- 5
Table 7-2.	Accuracy Determination (NO_x, O_2, System)	7.1-14
Table 7-3.	Fuel Sampling Results	7.1-15

LIST OF FIGURES

		Page
Figure 2-1.	NO_x Emissions Derived from 9 Test Runs.....	2-5
Figure 3-1.	Schematic of Boiler Unit 24.....	3-2
Figure 4-1.	Effluent Sampling Location.....	4-2
Figure 4-2.	Effluent Sample Port Locations.....	4-3
Figure 7-1.	Run No. 1 NO_x Emissions.....	7.1-20
Figure 7-2.	Run No. 2 NO_x Emissions.....	7.1-21
Figure 7-3.	Run No. 3 NO_x Emissions.....	7.1-22
Figure 7-4.	Run No. 4 NO_x Emissions.....	7.1-23
Figure 7-5.	Run No. 5 NO_x Emissions.....	7.1-24
Figure 7-6.	Run No. 6 NO_x Emissions.....	7.1-25
Figure 7-7.	Run No. 7 NO_x Emissions.....	7.1-26
Figure 7-8.	Run No. 8 NO_x Emissions.....	7.1-27
Figure 7-9.	Run No. 9 NO_x Emissions.....	7.1-28

1.0 INTRODUCTION

The Emission Measurement Branch (EMB) of the EPA's Emission Standards and Engineering Division performed NO_x emissions tests on Boiler Unit 24 of the Tennessee Eastman Company's Kingsport, Tennessee facility during the period of June 5 to June 14, 1984. The purpose of the test was to determine the effects of air preheat, heat release rate (load), and oxygen level upon NO_x emissions from a spreader stoker boiler firing eastern coal.

Boiler Unit 24 of the Tennessee Eastman Company is a spreader stoker industrial boiler fired with eastern coal for the cogeneration of process steam and electricity; maximum production rate of the boiler is approximately 320,000 pounds of steam per hour (1450 psi). Effluent from the boiler is ducted through an economizer, a combustion air preheater, an electrostatic precipitator, an induced draft fan, and then into the stack, where it is combined with the effluent from another boiler unit.

Emissions testing was conducted through four ports located in the 10' x 7' duct between the ESP and the stack breeching. A transportable continuous emission monitoring system (TCEMS) was used to evaluate the presence of gaseous stratification and to monitor continuously the effluent concentrations of NO_x, O_2, and CO. In addition, reference method tests were conducted for NO_x (Method 7), O_2 (Method 3), and H_2O (alternate Method 4).

Entropy Environmentalists, Inc. (Entropy) performed all pre-test preparations, including the organization of testing equipment. EMB personnel conducted the on-site testing. Following completion of the field portion of the test, Entropy performed all laboratory analyses and data reduction, and compiled this final test report.

Mr. Terry Harrison of EMB led the on-site EPA field team. Mr. Charles Sedman of ESED's Industrial Studies Branch (ISB) acted as liason to the Tennessee Eastman Company. He also monitored the completion of boiler effluent duct modifications and collected process operation data during the field testing. Mr. Scott Shanklin of Entropy coordinated the Entropy team efforts during the test program. Mr. Joe Davidson, Mr. George Seaton, and Mr. Roger Hall of Tennessee Eastman Company provided assistance during the testing program; their cooperation is gratefully acknowledged.

2.0 SUMMARY AND DISCUSSION OF RESULTS

This section contains the results of the testing program at the Tennessee Eastman plant to determine NO_x emission rates during 2-hour test runs at various boiler operating conditions using a continuous emission monitoring system. Reference method sampling was performed concurrently with the TCEMS sampling to provide additional measurements for comparative results.

2.1 Stratification Test

The results of the stratification tests conducted for the no preheat and full preheat conditions are shown in Tables 2-1 and 2-2, respectively. The tables present, by traverse point: (a) the normalized, measured concentrations of NO_x and O_2; (b) the calculated NO_x emission rate; and (c) the respective percentage deviations computed relative to the corresponding mean concentrations. (The normalized values were computed to eliminate the effects of temporal variations in the effluent concentrations.) The stratification worksheets used to derive these results are presented in Appendix 7.1.

The results of the two tests indicate that there is no significant stratification present at the sample location either on a dry concentration basis (NO_x - ppm_d, O_2 - $\%_d$) or in units of the standard (lb $NO_x/10^6$ Btu) for either of the preheat conditions. The finding of a non-stratified effluent stream allowed for the use of single point sampling for the emissions testing.

The test procedures employed followed the stratification test protocol detailed in Appendix 7.3, except that the number of traverse points sampled from the 4 x 4 matrix layout was reduced to eight. (Figure 4-2 shows the location of the traverse points chosen.) Also, in the case of the no preheat condition, stratification sampling was not performed at the last two traverse points (A2 and A4) due to an electrical storm which necessitated the termination of testing.

2.2 NO_x Emissions vs. Boiler Operating Parameters

Table 2-3 presents a summary of the NO_x emissions results by test run as measured by the TCEMS, and the associated boiler operating conditions. Individual test points (5-minute averages) derived from the TCEMS data are plotted for each run in Figure 2-1 to facilitate comparison of NO_x emissions among the nine test runs. Each run is also separately plotted in additional figures located in Appendix 7.1 to show the stability of the boiler emissions over the duration of each test period.

TABLE 2-1.

STRATIFICATION TESTING RESULTS
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24
Kingsport, Tennessee

No Preheat Boiler Condition
7 June 1984

Traverse Point No.	Normalized Trav. NO_x Conc. (ppm_d)	NO_x[1] Dev. (%)	Normalized Trav. O_2 Conc. ($\%_d$)	O_2[1] Dev. (%)	Normalized E_{NO_x} Rate (lb $NO_x/10^6$ Btu)	E_{NO_x}[1] Dev. (%)
C2	242	0.4	12.0	0.8	0.65	2.4
C4	243	0.8	12.0	0.8	0.65	2.4
D2	234	-2.9	12.2	2.5	0.64	0.8
D4	237	-1.7	11.9	0	0.62	-2.4
B2	244	1.2	11.7	-1.7	0.63	-0.8
B4	244	1.2	11.5	-3.4	0.62	-2.4
A2	*	*	*	*	*	*
A4	*	*	*	*	*	*
AVG.	241		11.9		0.64	

[1] Percent Deviation = $\frac{\text{Normalized Trav. value - Avg. Norm. Trav. value}}{\text{Avg. Norm. Trav. value}} \times 100$

* Test ended prematurely due to thunderstorm.

TABLE 2-2.

STRATIFICATION TESTING RESULTS
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24
Kingsport, Tennessee

Full Preheat Boiler Condition
11 June 1984

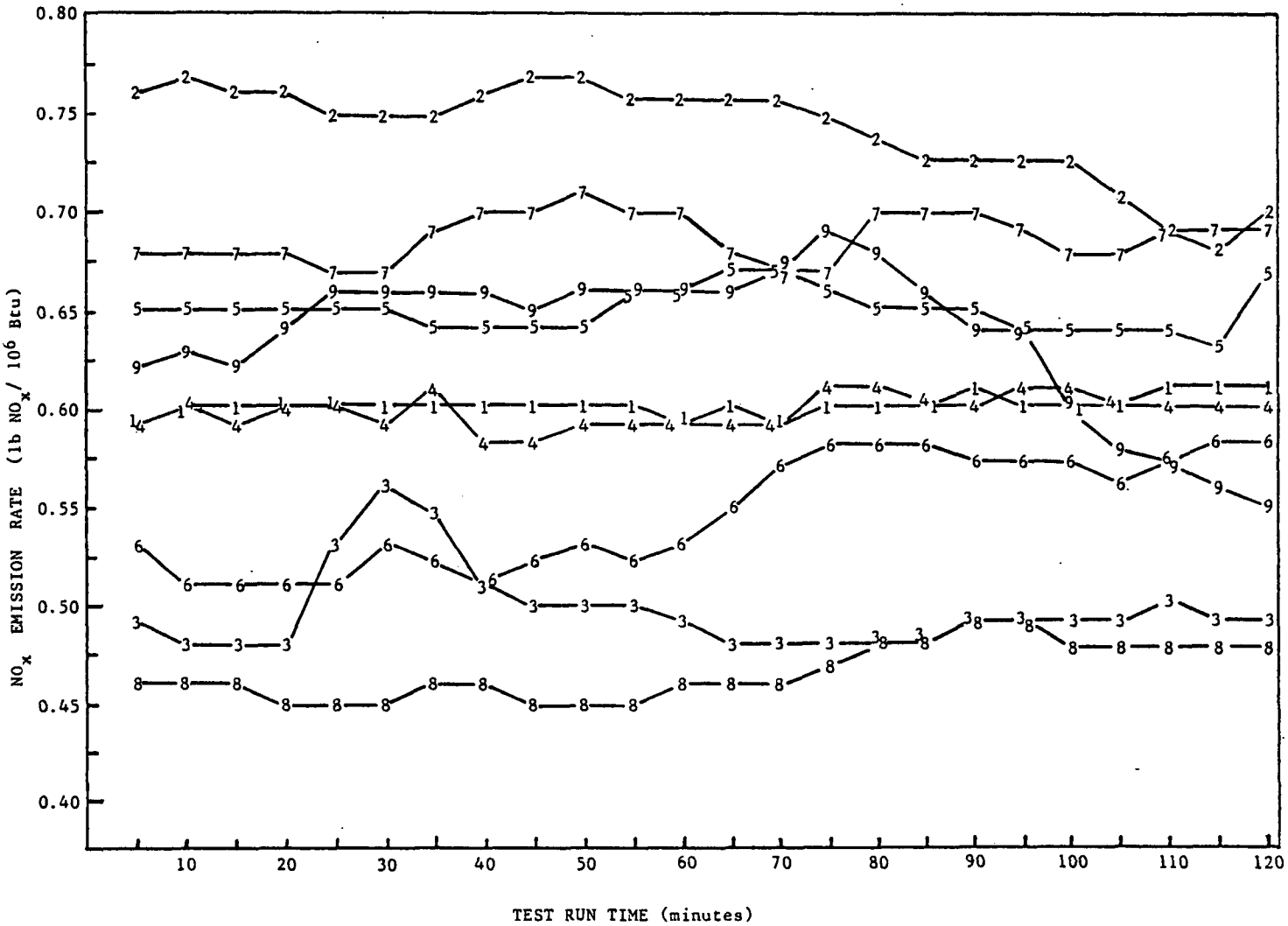
Traverse Point No.	Normalized Trav. NO_x Conc. (ppm_d)	NO_x[1] Dev. (%)	Normalized Trav. O_2 Conc. ($\%_d$)	O_2[1] Dev. (%)	Normalized E_{NO_x} Rate (lb $NO_x/10^6$ Btu)	E_{NO_x}[1] Dev. (%)
C2	328	0.9	8.1	0	0.62	0
C4	327	0.6	8.0	-1.2	0.62	0
D2	320	-1.5	8.0	-1.2	0.61	-1.6
D4	324	-0.3	8.1	0	0.62	0
B2	329	1.2	7.9	-2.5	0.63	1.6
B4	321	-1.2	8.2	1.2	0.62	0
A2	328	0.9	7.8	-3.7	0.61	-1.6
A4	325	0	8.3	2.5	0.63	1.6
AVG.	325		8.1		0.62	

[1] Percent Deviation = $\frac{\text{Normalized Trav. value} - \text{Avg. Norm. Trav. value}}{\text{Avg. Norm. Trav. value}} \times 100$

TABLE 2-3.

NO_x EMISSIONS VS BOILER OPERATIVE PARAMETERS
CONTINUOUS EMISSION MONITORING SUMMARY
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24
Kingsport, Tennessee

Test Run No.	Date	Time	Boiler Test Condition	Boiler Load (% of rated load)	Average Effluent Concentrations			
					NO_x (ppm_d)	O_2 ($\%_d$)	CO (ppm_d)	Emission Rate (lb $NO_x/10^6$ Btu)
1	6/6/84	1235-1435	High Load, Low O_2 No preheat	80.9	317	7.9	29	0.60
2	6/6/84	1650-1850	High Load, High O_2 No preheat	81.9	323	10.1	72	0.74
3	6/7/84	1015-1215	Low Load, Low O_2 No preheat	56.3	223	9.9	29	0.50
4	6/7/84	1430-1630	Low Load, High O_2 No preheat	55.9	233	11.4	50	0.60
5	6/11/84	1345-1545	Full Load, Normal O_2 Full Preheat	100	337	8.2	96	0.65
6	6/12/84	0955-1155	High Load, Low O_2 Full Preheat	81.6	279	8.2	60	0.55
7	6/12/84	1340-1540	High Load, High O_2 Full Preheat	81.3	330	9.3	40	0.69
8	6/13/84	0930-1130	Low Load, Low O_2 Full Preheat	56.9	208	10.0	43	0.47
9	6/13/84	1240-1440	Low Load, High O_2 Full Preheat	57.5	237	11.8	61	0.64



Run No.	Load % of rated load: Full	High	Low	O_2: High	Low	Preheat: Full	No	Boiler $\%O_2$	Stack $\%O_2$	Air Preheat Temp. (^oF)	Stack Temp. (^oF)	Steam Flow (lb/hr)
1		80.9			X		X	5.0	7.9	144	413	259,000
2		81.9		X			X	7.2	10.1	149	443	262,000
3			56.3		X		X	7.4	9.9	137	382	180,000
4			55.9	X			X	9.3	11.4	146	404	179,000
5	100				X	X		5.5	8.2	320	337	320,000
6		81.6			X	X		5.3	8.2	308	309	261,000
7		81.3		X		X		7.1	9.3	314	323	260,000
8			56.9		X	X		7.4	10.0	305	287	182,000
9			57.5	X		X		9.4	11.8	310	308	184,000

FIGURE 2-1. NO_x EMISSIONS DERIVED FROM TCEMS DATA AND ASSOCIATED BOILER CONDITIONS

2.3 Emissions Tests

A series of 2-hour test runs was conducted during nine various boiler operating conditions. Concurrent measurements of NO_x were obtained by the TCEMS and reference methods for the first seven runs. O_2 was measured by both techniques for all nine runs. Concentrations of CO were measured by the TCEMS for all nine of the test runs.

2.3.1 TCEMS and Reference Method Results

In general, good agreement was observed between the TCEMS results and the reference method test results (see Table 2-4). The overall system relative accuracy for the TCEMS was 5.7%, and the relative accuracy computed for the individual NO_x and O_2 channels was 4.2% and 7.7%, respectively. All of these results are well within the relative accuracy limit of $\leq$ 20% contained in Performance Specifications 2 and 3. (See Appendix 7.1, Table 7-2, "Relative Accuracy Worksheet," for the derivation of these relative accuracy values.)

The TCEMS data presented in detail in Table 7-1 (Appendix 7.1) are averaged values over each 5-minute interval for the nine 2-hour test runs. Also presented is the NO_x emission rate calculated for each time interval using: (a) the individual NO_x and O_2 data, and (b) an F-Factor determined by analysis of fuel samples collected during each run. (The fuel analysis results and the calculated F-Factor values are presented in Table 7.3, Appendix 7.1.) No adjustment of the concentration data was made for analyzer drift, since all calibration drift values were less than 2 percent of analyzer full scale (as specified in Reference Method 20). The calibration drift results, as determined by injection of calibration gases before and after each 2-hour test, are presented in Table 7-1 at the end of each test run. (See Appendix 7.2 for the raw data pre-test and post-test calibration data sheets.)

Response time for the monitoring system was determined and accounted for in the interpretation of the strip chart data in order to improve the correlation of the sample times between the TCEMS measurements and the reference method measurements.

Reference method sampling results are summarized in Table 2-5, including data for Methods 3, 7, and alternate 4. Also presented in Table 2-5 are the F-Factors calculated from the results of ultimate analysis of fuel samples collected during each run, and the resultant NO_x emission rates (lb $NO_x/10^6$ Btu).

TABLE 2-4.

RELATIVE ACCURACY TEST RESULTS
FOR
BECKMAN 951 NO_x/TELEDYNE 320P-4 O_2 CEMS

Tennessee Eastman Facility: Boiler Unit 24
Kingsport, Tennessee
June 6-12, 1984

Monitor Channel	Reference Method Result	CEMS Results	Mean Difference	95 Percent Confidence Interval	Relative Accuracy (%)
NO_x (ppm_d)	290 ppm	292 ppm	2.1 ppm	10.2 ppm	4.2%
O_2 ($\%_d$)	9.7%	9.5%	-0.32%	0.43%	7.7%
System (lb $NO_x/10^6$ Btu)	0.60	0.62	-0.013	0.021	5.7%

TABLE 2-5.

REFERENCE METHOD SAMPLING DATA SUMMARY
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24
Kingsport, Tennessee

Test Run No.	Date	Time	Alternate RM4[1] Moisture (%)	RM3[1] O_2 ($\%_d$)	RM3[1] CO_2 ($\%_d$)	RM7[2] NO_x (ppm_d)	Calculated F-Factor (dscf/10^6 Btu)	RM Emission Rate (lb NO_x/10^6 Btu)
1	6/06/84	1235-1435	6.6	*	*	307	9876	*
2	6/06/84	1650-1850	6.6	9.9	9.0	334	9967	0.76
3	6/07/84	1015-1215	6.7	9.9	9.2	222	9849	0.50
4	6/07/84	1430-1630	6.3	12.2	7.5	214	9749	0.60
5	6/11/84	1345-1545	7.1	8.7	10.6	331	9811	0.66
6	6/12/84	0955-1155	5.8	8.9	10.3	291	9926	0.60
7	6/12/84	1340-1540	6.7	9.4	10.1	328	9707	0.69
8	6/13/84	0930-1130	6.1	9.5	9.6	---	9801	---
9	6/13/84	1240-1440	5.8	11.9	7.8	---	9810	---

*Suspected Orsat Bag Leak

[1] Integrated sample

[2] Average of six flask samples collected each 20 minutes over the 2-hour test

On occasion, there were discrepancies between the reference method and TCEMS results. For Test Run No. 1, triplicate Method 3 analysis yielded unusually high O_2 concentrations. These results were attributed to a leak in the sample bag; this theory is supported by the fact that the TCEMS results for the same time period indicated lower O_2 concentrations. The Tedlar sample bag in question was not used again during the test program. The Method 3 results for Run No. 6 were atypically high with respect to the TCEMS results, but for a reason not known. Results from two of the six Method 7 flask samples collected for Run No. 4 were significantly low with respect to the concurrent TCEMS data. No apparent reason could be determined for the observed bias during those two time periods. Because no reasons were apparent, all results for Runs No. 4 and No. 6 were included in the relative accuracy calculations.

Tables 2-6 presents the individual reference method measurement data and the corresponding TCEMS measurements for the same time period. Also presented are the NO_x relative accuracies calculated for each test run using the arithmetic mean of the difference between the reference method and TCEMS concentrations, the 95% confidence interval, and the mean of the reference method values.

2.3.2 CO Results

Carbon monoxide emissions, as determined by an NDIR analyzer in accordance with the procedures of Reference Method 10, are presented in Table 2-3. The values presented in the table are corrected for the CO_2 volume removed by the Ascarite II (90 to 92% sodium hydroxide on vermiculite). The CO concentration for Test Runs No. 5 and 6 fluctuated, possibly due to boiler operation. In the remaining test runs the CO concentration remained relatively stable, averaging about 53 ppm.

2.4 Quality Assurance Results

The results from reference method analyses of NO_x, O_2, and CO_2 quality control samples are shown in Table 2-7. Also included in the table are results of the monitoring system responses to the audit gas injections. In general, the TCEMS and reference method audit results conform with the applicable quality control criteria. On two occasions, the CO_2 and/or O_2 reference method result exceeded the specified limit; however, the magnitude of the greater deviation, when applied to the field sample results, alters those results by less

TABLE 2-6. RUN-BY-RUN TCEMS/REFERENCE METHOD RESULTS COMPARISON

			TCEMS		REFERENCE METHOD		DIFFERENCE		
RUN NO.	DATE	SAMPLE TIME	NO_x (ppm_d)	O_2 ($\%_d$)	NO_x (ppm_d)	O_2 ($\%_d$)	NO_x (ppm_d)	O_2 ($\%_d$)	NO_x Relative Accuracy
1-1	6/06/84	1239	308	8.0	305		3		
1-2		1255	313	8.0	315		- 2		
1-3		1315	319	7.9	320	Bag	- 1		10.3%
1-4		1335	316	7.8	271	Leak	45		
1-5		1355	324	7.7	300		24		
1-6		1415	319	8.0	330		-11		
AVG.			317	7.9	307	XX	9.7	XX	
2-1	6/06/84	1655	333	10.1	363		-30		
2-2		1715	327	10.1	356		-29		
2-3		1735	332	10.1	325		7		11.6%
2-4		1755	330	10.1	293		37		
2-5		1815	319	10.1	339		-20		
2-6		1835	302	10.1	329		-27		
AVG.			324	10.1	334	9.9	-10.3	0.2	
3-1	6/07/84	1018	218	10.0	211		7		
3-2		1038	241	10.0	253		-12		
3-3		1058	230	9.8	214		16		7.7%
3-4		1118	219	9.8	202		17		
3-5		1138	221	9.8	234		-13		
3-6		1158	220	9.9	216		4		
AVG.			225	9.9	222	9.9	3.2	0	
4-1	6/07/84	1432	230	11.4	229		1		
4-2		1452	237	11.5	240		- 3		
4-3		1512	226	11.4	243		-17		29.4%
4-4		1532	230	11.4	185		45		
4-5		1552	236	11.4	143		93		
4-6		1612	234	11.4	244		-10		
AVG.			232	11.4	214	12.2	18.2	-0.8	
5-1	6/11/84	1350	338	8.1	335		3		
5-2		1410	336	8.2	298		38		
5-3		1430	332	8.2	296		36		10.8%
5-4		1450	347	8.2	375		-28		
5-5		1510	335	8.2	362		-27		
5-6		1530	331	8.2	322		9		
AVG.			337	8.2	331	8.7	5.2	-0.5	
6-1	6/12/84	1000	268	7.9	285		-17		
6-2		1020	272	8.2	291		-19		
6-3		1040	269	8.4	286		-17		7.1%
6-4		1100	289	8.3	291		- 2		
6-5		1120	288	8.3	287		1		
6-6		1140	291	8.3	306		-15		
AVG.			280	8.2	291	8.9	-11.5	-0.7	
7-1	6/12/84	1345	327	9.3	307		20		
7-2		1405	324	9.2	335		-11		
7-3		1425	338	9.3	339		- 1		5.4%
7-4		1445	322	9.3	316		6		
7-5		1505	336	9.2	322		14		
7-6		1525	327	9.4	351		-24		
AVG.			329	9.3	328	9.4	0.7	-0.1	

TABLE 2-7.

AUDIT SAMPLE ANALYSIS:
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24

Audit Sample	Date	Actual Content	Measured Content	Percent Deviation/Difference
Reference Method				
NO_x	6/24/84	1552.8 µg	1575.9 µg	1.5%[1]
	6/12/84	1114.8 µg	1157.8 µg	3.9%[1]
	6/12/84	756.6 µg	777.4 µg	2.7%[1]
CO_2	6/06/84	12.3%	11.9%	-0.4%[2]
	6/07/84	12.3%	12.1%	-0.2%[2]
	6/11/84	12.3%	12.1%	-0.2%[2]
	6/12/84	12.3%	12.1%	-0.2%[2]
	6/13/84	12.3%	12.0%	-0.3%[2]
O_2	6/06/84	8.0%	8.3%	0.3%[2]
	6/07/84	8.0%	8.1%	0.1%[2]
	6/11/84	8.0%	8.0%	0%[2]
	6/12/84	8.0%	7.9%	-0.1%[2]
	6/13/84	8.0%	8.0%	0%[2]
TCEMS				
NO	6/06/84	294 ppm	296 ppm	0.7%[1]
O_2	6/06/84	3.5%	3.6%	0.1%[2]
	6/11/84	3.5%	3.6%	0.1%[2]
CO	6/06/84	106 ppm	107 ppm	0.9%[1]

[1] Percent Deviation = $\frac{\text{Actual Conc.} - \text{Measured Conc.}}{\text{Actual Conc.}}$

[2] Percent Difference = Actual Conc. - Measured Conc.

than 2%. Thus, the two exceedances of the quality control criteria during the audit analyses had no significant impact on the reference method sampling results, a fact which is also supported by the level of agreement between the reference method results and the TCEMS results.

Table 2-8 presents the results obtained from the F_o quality control technique that was applied to the CO_2 and O_2 concentration data afforded by the eight Method 3 determinations (Runs No. 2-9). F_o values were calculated from the Orsat data; these values were then compared to F_o values calculated for each run using the ultimate analysis results of the fuel samples. Although the percent deviation between the two sets of data exceeded the quality control criterion of $\leq$ 5% on three occasions (i.e., Runs No. 2, 3, and 8), all of the F_o values calculated using the Orsat data fall within the F_o range of acceptability for bituminous coal as specified in Method 3: 1.083 - 1.230.

TABLE 2-8.

VALIDATION OF ORSAT ANALYSIS DATA: 6/6-13/84
Tennessee Eastman Company
Kingsport Boiler Unit 24

Test Run	O_2 Concentration (%d)	CO_2 Concentration ($\%_d$)	Calculated[1] F_o	Fuel Factor[2] F_o	Percent Deviation
1	--[3]	--[3]	--[3]	--[3]	--[3]
2	9.9	9.0	1.222	1.121	9.0%
3	9.9	9.2	1.196	1.121	6.7%
4	12.2	7.5	1.160	1.120	3.6%
5	8.7	10.6	1.151	1.124	2.4%
6	8.9	10.3	1.165	1.128	3.3%
7	9.4	10.1	1.139	1.127	1.1%
8	9.5	9.6	1.188	1.119	6.2%
9	11.9	7.8	1.154	1.121	2.9%

[1]Calculated $F_o = (20.9 - \%O_{2_d})/(\%\ CO_{2_d})$, using field data.

Acceptable range of F_o for bituminous coal as specified in Reference Method 3 is 1.083 - 1.230.

[2]F_o was calculated for each run using the equation:

$$F_o = (20.9)\frac{F_d}{F_c 100}$$

where:

$$F_d = \frac{10^6(3.64\%H + 1.53\%C + 0.57\%S + 0.14\%N - 0.46\%O)}{\text{Gross Calorific Value (GCV)}}$$

$$F_c = \frac{10^6(0.321\%C)}{GVC}$$

Concentrations were obtained from the source's ultimate analyses of the bituminous coal samples collected during each sample test run.

[3]Orsat bag leak.

3.0 PROCESS AND CONTROL EQUIPMENT OPERATING CONDITIONS

The Unit 24 boiler is a rated 320,000 lb/hr spreader stoker boiler designed by Combustion Engineering Company to fire eastern bituminous coal. The boiler produces high quality steam for the cogeneration of process steam and electricity. Combustion air is normally preheated to approximately 320° F, and the design grate heat release rate is substantially higher for boiler Unit 24 (i.e., > 700,000 Btu/hr/ft^2) than it is for most boilers. The boiler receives coal via eight Detroit Stoker rotograte feeders, and reinjects flyash via a flooded hopper return across the rear portion. A substanital effort was made in late 1983 to seal up air leaks and to improve boiler operation; an O_2 trim system was also recently added. The boiler also features a burner which periodically injects chemical by-product fuels with a high heat content above the stoker bed. For the series of tests conducted for this testing program, the by-product fuel burner was blocked and covered with insulation to eliminate any air-inleakage.

3.1 Process Equipment Operating Conditions

The Unit 24 boiler was operated under a variety of conditions during the NO_x emissions testing. Primarily, there were three operating parameters of interest: (1) load; (2) O_2 (excess air); and (3) availability of combustion air preheating; these three parameters were varied by plant personnel to achieve desired test conditions. The boiler load was varied (i.e., 50%, 80%, and 100%) by adjusting the feedwater and fuel inlet flow rates (see Figure 3-1). The level of O_2 in the combustion chamber (i.e., 5%, 7.5%, 9.5% O_2) was varied by increasing or decreasing the level of excess air. Finally, the availability of combustion air preheat was varied to test conditions at maximum preheat (300°F) and no preheat (150°F).

The process variables monitored during the testing program included: (1) steam flow (lb/hr), (2) air flow (%), (3) steam pressure (psig), (4) steam temperature (°F), (5) feed water temperature (°F), (6) air preheat temperature (°F), (7) boiler O_2 (%), and (8) stack opacity (%). This information was obtained from chart recording devices located in the control room. The data were read from the boiler charts and then recorded on logsheets at 15-minute intervals during the testing program. The process data logsheets and the boiler charts for steam load and O_2 are included in Appendix 7.7. It should be noted that documentation of the calibrations of the plant-operated process measuring and recording devices were not available for inclusion into the report.

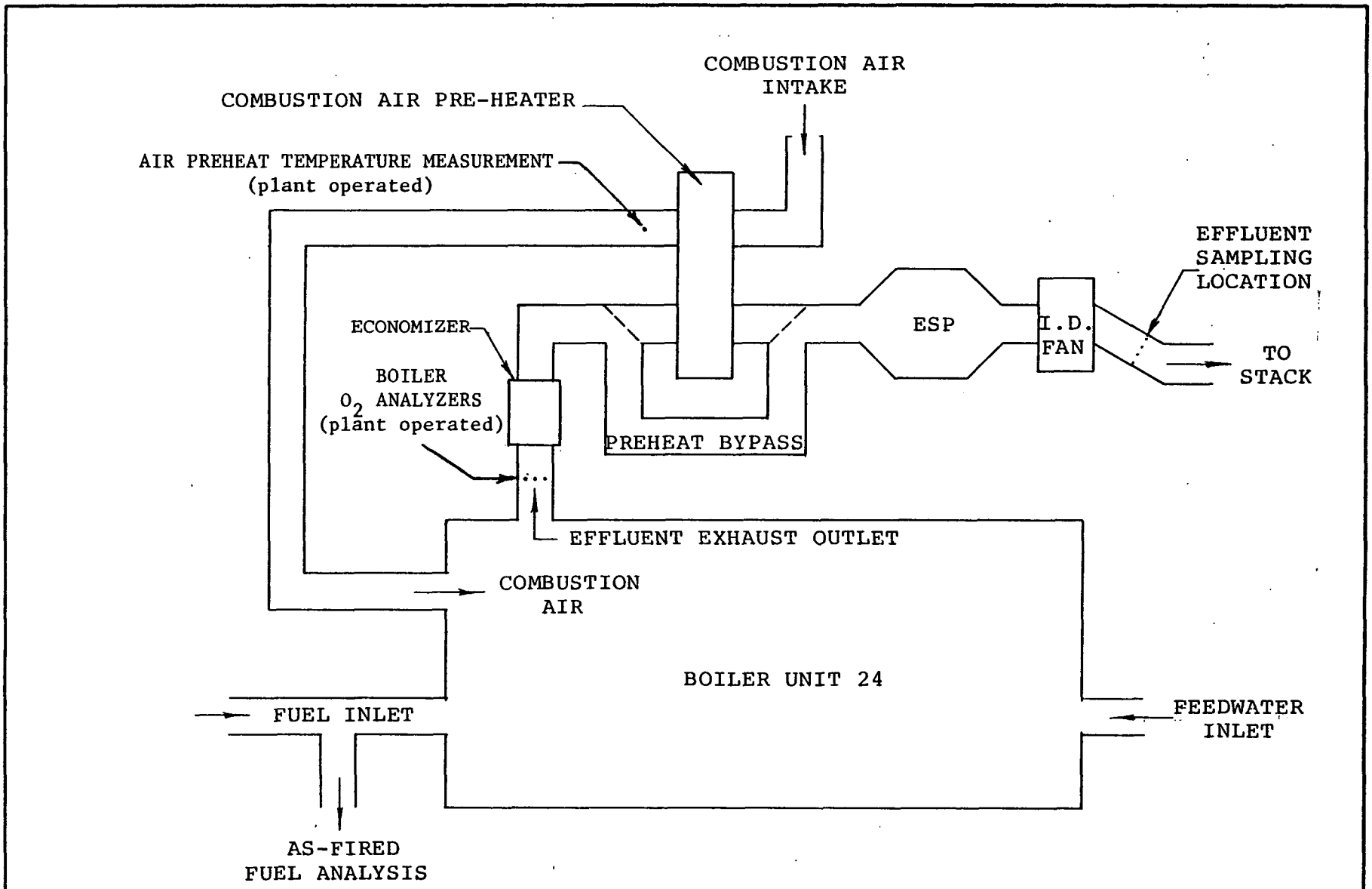


FIGURE 3-1. SCHEMATIC OF BOILER UNIT 24

Initially, it was intended that the preheat unit would be bypassed, by modification of the effluent ductwork, to produce a no preheat condition. Later, the preheat would be restored in the effluent outlet duct, and a series of tests (duplicating the boiler conditions of the initial tests) would be conducted under full preheat conditions. During the initial tests, it was found that the boiler could not be operated at 100% load when the preheater was bypassed, because the induced draft fan was drawing considerably more actual volume of flue gas per steam load. As a result, "full" load conditions with no preheat were limited to approximately 80% of boiler capacity. In order to investigate the normal 100% rated load condition, one test run was performed (Test Run No. 5) at 100% load with combustion air preheat systems operating, and % O_2 at its normal level of 5.5%.

Table 3-1 illustrates the permutations of load, O_2, and preheat that were evaluated during the on-site testing. Because it was imperative that the impact of each of these independent variables upon the boiler NO_x emissions be isolated and individually quantified, nine separate test runs were conducted, each run containing a variation of only one of the three variables, except as noted above.

3.2 Control Equipment Operating Conditions

The ESP operating parameters were not monitored, nor were they varied as a part of the testing program, since the performance of the ESP would have, at most, a negligible impact on the NO_x emissions being investigated in this testing program.

TABLE 3-1.
PERMUTATIONS OF BOILER UNIT 24
OPERATING PARAMETERS

TEST RUN #	% LOAD[1]	% O_2[2]	PREHEAT AIR TEMP ^oF[3]
1	80.9	5.0	144
2	81.9	7.2	149
3	56.3	7.4	137
4	55.9	9.3	146
5	100	5.5	320
6	81.6	5.3	308
7	81.3	7.1	314
8	56.9	7.4	305
9	57.5	9.4	310

[1]Percent of full load is a function of fuel, air, and feedwater rates. The boiler at full load is rated at 320,000 lb steam/hr.

[2]O_2 level is a function of the fuel and combustion air flow rates, an average measurement obtained from three O_2 analyzers at the boiler outlet.

[3]Preheat availability is determined by the use of the preheat bypass duct.

4.0 SAMPLING LOCATIONS

Sampling locations and modifications to existing facilities are illustrated and discussed in this section.

4.1 Description of Sampling Locations

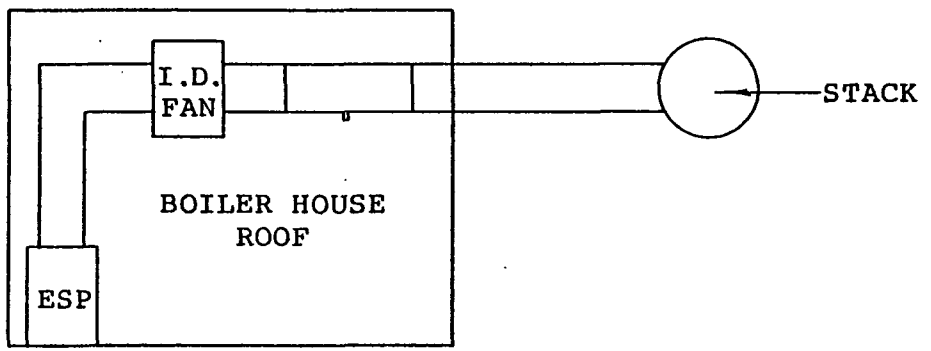
All effluent gas sampling was performed at the sample port location between the ESP outlet (downstream from the induced draft (ID) fan) and the stack breeching. This site is on the roof of the boiler house, approximately 100 feet above ground (See Figure 4-1).

Reference method and TCEMS samples were drawn through separate probes inserted in one of four 4-inch diameter flanged ports (Port "C") located in the side of the 10' x 7'6" duct, on a downward angled duct section. Sampling equipment was set up on a platform immediately beneath the four ports (See Figure 4-2). Electrical power was available in the vicinity of the sampling location, and sample lines for the TCEMS were run across the boiler house roof and down to the EPA test van on the ground.

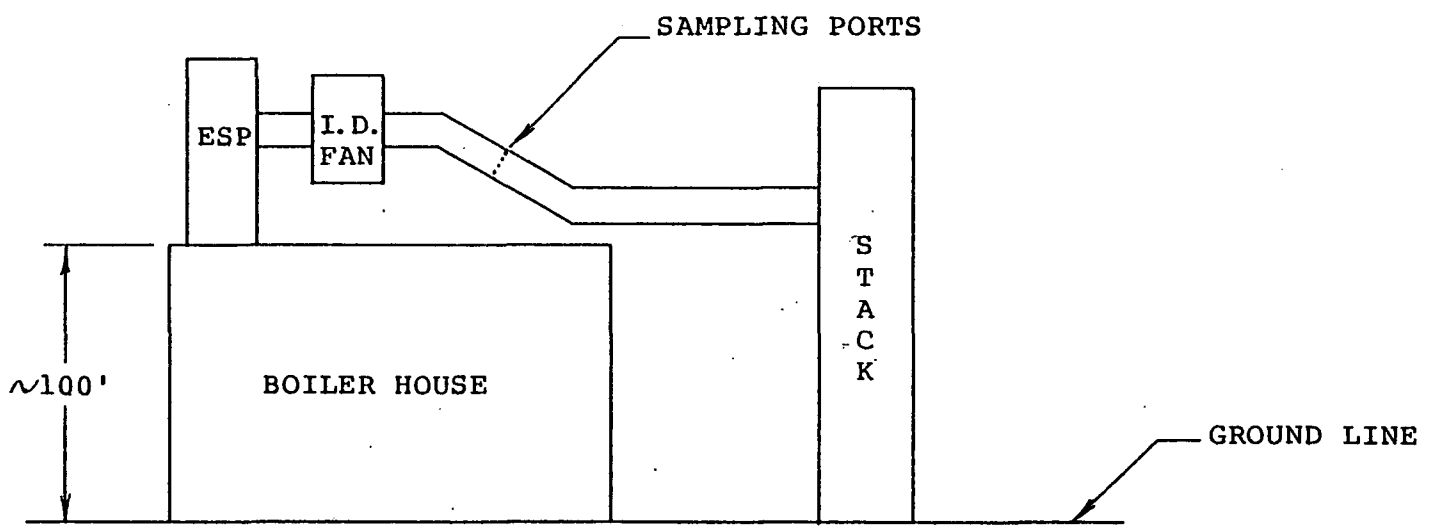
As-fired coal samples were collected at each of the eight feeders.

4.2 Modifications to Existing Facilities

Tennessee Eastman performed the modifications to the effluent duct system necessary to bypass the combustion air preheater. These modifications included: (1) installing a bypass duct around the preheater; (2) cutting into the existing duct before and after the preheater; (3) bypassing the preheater; (4) re-installing the preheater; and (5) disassembling the preheat bypass system. The EPA reimbursed Tennessee Eastman for the costs of these modifications.



TOP VIEW



ELEVATION VIEW

FIGURE 4-1. EFFLUENT SAMPLING LOCATION

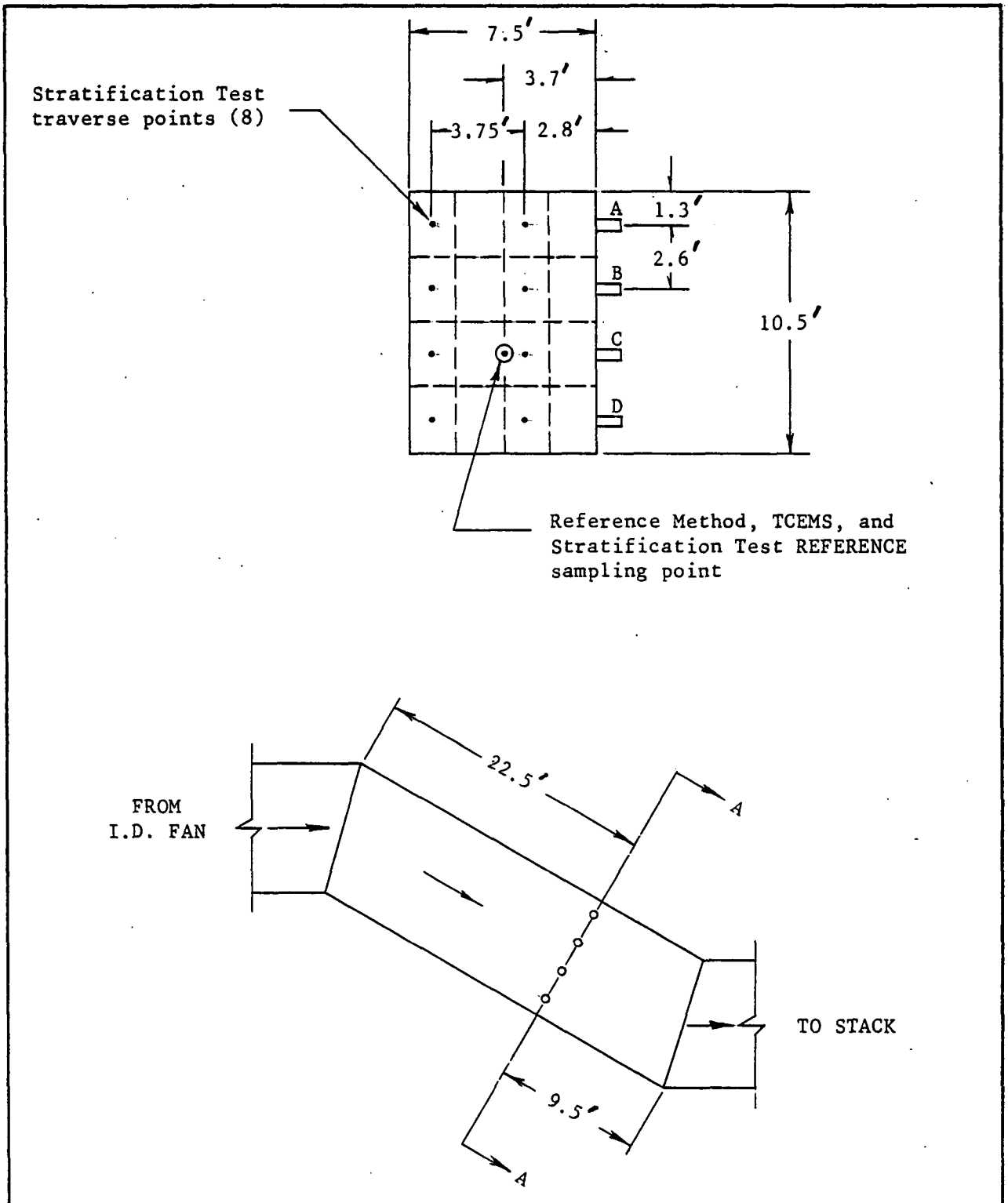


FIGURE 4-2. EFFLUENT SAMPLE PORT LOCATIONS

5.0 SAMPLING AND ANALYTICAL PROCEDURES

Sampling and analytical procedures employed in the NO_x testing of boiler Unit 24 are described and discussed in this section both for reference method and non-reference method testing, together with process monitoring procedures and the chain of custody of samples and data.

5.1 Reference Method Sampling Procedures

Reference method sampling procedures employed in the boiler Unit 24 testing included Method 3 (O_2), Method 7 (NO_x), and alternate Method 4 (H_2O). Appendix 7.3 of this document contains copies of all reference method procedures used. Integrated samples were collected during the 2-hour test runs for Method 3 and alternate Method 4. The Method 7 flask samples were obtained at 20-minute intervals for a total of six NO_x samples collected per run.

5.2 Non-Reference Method Sampling Procedures

Non-reference method sampling procedures included: (1) effluent stratification tests; (2) continuous instrumental monitoring of NO_x, O_2, and CO; and (3) coal sampling. Procedures employed during the test program are discussed in the following subsections, and copies of each protocol (except coal sampling, since this sampling and analysis was performed by Tennessee Eastman Company according to their standard procedures) are contained in Appendix 7.3 of this document.

5.2.1 Effluent Stratification Test

Effluent stratification testing was conducted at the reference method sampling location in order to evaluate the representativeness of the gas concentration measurements made at that location. The goal of this test was to establish that the reference method (and TCEMS) measurements of NO_x and O_2 concentrations at the sampling location were representative of the concentrations of these constituents in the total effluent stream.

The stratification test procedure involved the use of a transportable continuous emission monitoring system (TCEMS) composed of two monitors to measure concentrations of NO_x and O_2 in the effluent sampling ports. (See Section 4.0, Figure 4-2.) Differences in the concentrations of these gases were evaluated between a reference point (selected as the mid point of the

traverse line "C," located 3.69 feet from the duct wall) and each of the traverse sampling points. Differences of less than 10% are considered indicative of a non-stratified sampling location. (See Appendix 7.3 for the stratification test protocol.)

5.2.2 Continuous Monitoring

Boiler Unit 24 emissions of NO_x, O_2, and CO were continuously monitored through the use of the same TCEMS employed in the stratification test with the addition of a CO monitoring system, which was operated in accordance with the procedures of Reference Method 10 in order to obtain reliable CO emissions data.

Concentrations of NO_x (ppm - dry basis) in the effluent stream were measured utilizing a Beckman 951 NO/NO_x chemiluminescence analyzer. The measurement range used throughout the testing was 0-1000 ppm. A Teledyne 320P-4 O_2 analyzer was used in conjunction with the NO_x analyzer in order to compute NO_x emission rates in units of lb $NO_x/10^6$ Btu. A Beckman 864 CO NDIR analyzer was employed to continuously measure the levels of CO. The concentrations of NO_x, O_2, and CO were displayed on a strip chart recorder.

Initially, the TCEMS was calibrated with certified gases having concentrations of NO_x, O_2, and CO that corresponded to the typical ranges encountered in the Boiler Unit 24 effluent. The calibration of the TCEMS was checked between each change in operating parameters by flowing the calibration gases to each monitor in order to quantify any calibration drift. (See Appendix 7.3 for the TCEMS operational protocol.)

The NO calibration gases used were NBS-traceable (Protocol No. 1); the O_2 gases were certified by triplicate reference method analysis. Each CO gas concentration was certified by the EPA's Quality Assurance Division Laboratory at Research Triangle Park. (See Appendix 7.5 for the certificates of analysis.)

5.2.3 Coal Sampling

Coal sample increments were collected from each of the eight feeders at 30-minute intervals by plant personnel during each emissions test run. Coal sampling was initiated 30 minutes prior to each test run and concluded at the end of the run, for a total sample time of 2-1/2 hours per run. The samples acquired during each test period were analyzed according to the protocol currently employed by the plant. In addition, the samples were split, and a portion of each sample

was turned over to the EMB in order to allow for subsequent additional analyses, should questions arise regarding the accuracy of the plant's results. The plant analysis data are included in Appendix 7.1, Table 7-3.

5.3 Process Monitoring Procedures

Process (boiler) operating parameters were monitored during the test program by ISB personnel. The procedures employed provided data to verify the status of boiler load and O_2, based on the monitoring of combustion air, fuel, and feedwater parameters. Existing plant data acquisition systems were employed to monitor the following parameters:

Parameter	Units
Steam Flow	lb/hr
Air Flow	percent
Steam Pressure	psig
Steam Temperature	^{o}F
Feed Water Temperature	^{o}F
Air Preheater Temperature	^{o}F
Opacity	% opacity
Boiler Oxygen	% oxygen

5.4 Sample/Data Chain of Custody

All on-site source data were acquired by EMB and ISB personnel. Entropy's off-site field representative took possession of all test (non-process) data and samples as they became available.

Following the completion of the on-site phase of the test program, the NO_x reference method samples and the remaining test data were taken to the Entropy home office, where the laboratory portion of the NO_x analyses was conducted. The ISB representative provided Entropy with copies of necessary process data, and both ISB and EMB personnel provided Entropy with notes on testing activities and observations. The final data reduction and compilation of the test results were performed by Entropy.

6.0 QUALITY ASSURANCE

Quality assurance (QA) procedures incorporating quality assessment and quality control are delineated in this section. QA activities associated with reference method testing are described, as well as those associated with non-reference method sampling.

6.1 Reference Method Sampling Quality Control

Quality control techniques employed by EMB and Entropy were designed to verify both the validity of sampling techniques and the calibration of analytical techniques. The following subsections describe the quality control activities employed in the reference method sampling and analysis.

6.1.1 EPA Method 3

Quality control of EPA Method 3 was assessed before and during its application in the field, employing two techniques.

The first technique was applied immediately before the analysis of field samples and entailed determinations of a known concentration of a CO_2 and O_2 mixture. The concentrations of the CO_2 and O_2 audit gases were selected to be consistent with concentrations ordinarily encountered within the effluent streams of industrial boilers. The cylinder concentrations of CO_2 and O_2 were established by Entropy personnel at the Entropy laboratory using triplicate reference method analysis.

An audit sample containing CO_2 and O_2 was analyzed prior to each series of Method 3 sampling runs performed. These analyses were conducted by the person who performed the analysis of the Method 3 field samples. The criteria for acceptable quality are results within 0.2% CO_2 and 0.2% O_2 of the established concentration values.

The second technique for assessing quality control was applied during the Orsat analyses of the individual field samples. The technique, termed the F_o technique, is based upon the stoichiometries associated with the combustion of specified fuel types. The F_o technique is a recommended procedure for assessing quality control and is contained in Method 3, 40 CFR, Part 60, a copy of which is contained in Appendix 7.3 of this document.

6.1.2 EPA Method 7

Quality control of the analysis phase of EPA Method 7 was assessed through the use of "Stationary Source Quality Assurance NO_x Reference Standards" provided by the U. S. EPA, (QAD). Immediately before analysis of the NO_x field samples, NO_x reference standards were determined in a "blind" fashion by the person responsible for the reference method analyses using the procedures prescribed by the QAD. The analysis phase of EPA Method 7 was considered to be in a state of quality control if results of the NO_x reference standards determinations were within 10% of the nominal NO_x mass value. Field samples were analyzed only after quality control had been established.

6.2 Non-Reference Method Sampling Quality Control

The quality control activities employed during the Boiler Unit 24 non-reference method tests are described in the following subsections.

6.2.1 TCEMS Sampling

Quality control of the TCEMS is based on the utilization of the proper operational protocol and the proper calibration gases. The operational protocol for the TCEMS was developed by the U. S. EPA Stationary Source Compliance Division for the performance of stratification, source emission, and relative accuracy tests. This protocol has been field tested and has been demonstrated to provide accurate, precise measurements of effluent gas concentrations ("Transportable Continuous Emission Monitoring System Operational Protocol: Instrumental Monitoring of SO_2, NO_x, CO_2, and O_2 Effluent Concentrations," EPA-340/1-83-016).

The utilization of certified gases in the calibration of the TCEMS employed in the testing program ensures an adequate level of quality control. As an additional quality control check, "blind" audit calibration gas injections were conducted for each of the individual TCEMS analyzers on two occasions using gases supplied by the QAD.

6.2.2 Coal Sampling

Quality control procedures employed by the plant in the coal analysis were not available at the time of the preparation of this test report.

6.3 Assessment of Sample Representativeness

The representativeness of effluent gas samples collected through reference method and TCEMS testing were evaluated in the performance of the stratification test. Fuel sampling techniques employed by the plant to ensure representative coal samples were not available at the time of the preparation of this test report.

7.0 APPENDICES

7.1 RESULTS AND CALCULATIONS

EQUATIONS

Calculation of dry-basis fuel factor (F_d) - dscf/10^6 Btu

$$F_d = \frac{10^6 (3.64\%H + 1.53\%C + 0.57\%S + 0.14\%N - 0.46\%O)}{\text{Gross Calorific Value (GCV)}}$$

Calculation of fuel factor, F_o, using Orsat data for validation

$$F_o = \frac{20.9 - \%O_{2d}}{\%CO_{2d}}$$

Calculation of fuel factor, F_o, using ultimate analysis results from coal samples

$$F_o = \frac{0.209\ F_d}{F_c}$$

where: F_d determined from above equation

$$F_c = \frac{10^6 (0.321\%C)}{GCV}$$

Calculation of NO_x emission rate (E_{NO_x}) - lb NO_x/10^6 Btu

$$E_{NO_x} = (ppm_d NO_x)(1.194 \times 10^{-7})\ F_d \left[\frac{20.9}{20.9 - \%O_{2_d}}\right]$$

Calculate stack concentration of CO using measured concentrations indicated by NDIR analyzer and accounting for volume fraction of CO_2 in sample removed by ascarite

$$CO_{stack} = CO_{NDIR}\left(1 - \frac{\%CO_{2_d}}{100}\right)$$

$\%CO_{2_d}$ as measured with Orsat

(Equations cont.)

Calculate the algebraic mean difference of the data set as follows:

$$MD = 1/n \sum_{i}^{n} D_i$$

where: n = number of data points

D_i = sample run (i) difference ($CEMS_i - TCEMS_i$)

Calculate the 95% (two-sided) confidence interval (CI) as follows:

$$CI_{95} = \frac{t_{.975}}{n\sqrt{n-1}} \sqrt{n(\Sigma D_i^2) - (\Sigma D_i)^2}$$

where:

n^a	$t_{.975}$
3	4.303
4	3.182
5	2.776
6	2.571
7	2.447
8	2.365
9	2.306

[a]The values in this table are already corrected for n-1 degree of freedom. Use n equal to the number of individual values.

Calculate the relative accuracy (RA) of the data set as:

$$RA = \frac{[|MD| + CI]}{AVG} \times 100$$

where: AVG = average Reference Method value for all sample runs

EXAMPLE REFERENCE METHOD 7 NITROGEN OXIDES TEST CALCULATIONS NO. 1-3

(Equations cont.)

INITIAL ABSOLUTE PRESSURE IN FLASK

$Pa(i) = Pbar(i) + Pg(i)$ $\quad Pa(i) = 29.02 + (-27.90) = 1.12$ in. Hg.

FINAL ABSOLUTE PRESSURE IN FLASK

$Pa(f) = Pbar(f) + Pg(f)$ $\quad Pa(f) = 29.04 + (-5.30) = 23.74$ in. Hg.

VOLUME OF DRY GAS SAMPLED AT STANDARD CONDITIONS*

$$Vsc = 17.64 * (Vf-Va) * ((Pa(f) / (ts(f) + 460)) - (Pa(i) / (ts(i) + 460))$$

$$Vsc = 17.64 * (2,087 - 25.0) * \left(\left(\frac{23.74}{74 + 460}\right) - \left(\frac{1.12}{107 + 460}\right)\right) = 1,545.2 \text{ ml}$$

PARTS PER MILLION, DRY BY VOLUME

$$ppmd = \frac{24.056 * m * 0.001}{Vsc * Mol.\ Wt.} * 1,000,000$$

$$ppmd = \frac{24.056 * 946.8 * 0.001}{1,545.2 * 46} * 1,000,000 = 320.4 \text{ ppmd}$$

POUNDS PER MILLION BTU

$$Lb/MMBtu = \frac{ppmd * Mol.\ Wt.}{385.3 * 10E6} * FAC * \frac{20.9}{20.9 - 02\%}$$

$$Lb/MMBtu = \frac{320.4 * 46}{385.3 * 10E6} * 9,876 * \frac{20.9}{20.9 - 8.0\%} = 0.612 \text{ Lb/MMBtu}$$

WHERE:

(i) = Initial

(f) = Final

Pbar(i) = Barometric Pressure, in. Hg.

Pbar(f) = Barometric Pressure, in. Hg.

Pg(i) = Evacuated Flask Pressure, in. Hg.

Pg(f) = Gauge Pressure, in. Hg.

Pa(i) = Absolute Pressure, in. Hg.

Pa(f) = Absolute Pressure, in. Hg.

ts(i) = Temperature, Degrees F.

ts(f) = Temperature, Degrees F

FAC = F-Factor, DSCF/MMBTU @ 0% O2

m = Mass Absorbed, micrograms

%O2 = Percent Oxygen, By Vol. Dry

ppmd = Concent., PPM Dry by Vol.

Va = Volume of Absorbing Sol.

Lb/MMBtu = Concent., Lbs/Million Btu

Vf = Volume of Flask, ml.

Vsc = Volume Sampled, Dry Std.* ml.

* 68 Degrees F -- 29.92 inches Hg.

TABLE 7-1.

CONTINUOUS EMISSION MONITORING RESULTS
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24
Kingsport, Tennessee

TEST 1 6/6/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1235-1240	308	8.0	27	0.59
1240-1245	314	8.0	28	0.60
1245-1250	317	7.9	27	0.60
1250-1255	317	7.9	27	0.60
1255-1260	315	8.0	28	0.60
1300-1305	316	8.0	30	0.60
1305-1310	313	8.0	30	0.60
1310-1315	316	7.9	27	0.60
1315-1320	318	7.9	26	0.60
1320-1325	316	7.9	26	0.60
1325-1330	314	7.9	26	0.60
1330-1335	313	7.9	27	0.59
1335-1340	317	7.8	27	0.60
1340-1345	310	7.9	30	0.59
1345-1350	316	7.9	30	0.60
1350-1355	321	7.8	29	0.60
1355-1360	323	7.7	30	0.60
1400-1405	322	7.8	30	0.61
1405-1410	320	7.8	30	0.60
1410-1415	320	7.8	32	0.60
1415-1420	319	8.0	34	0.60
1420-1425	320	7.9	32	0.61
1425-1430	321	7.9	32	0.61
1430-1435	324	7.9	32	0.61
AVG.	317	7.9	29	0.60
Range (High-Low)	(300-330)	(7.3-8.6)	(26-41)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO	
	Mid	Low	High	Mid	Mid	Low
	1.7%	0.7%	-1.0%	0%	-0.8%	-0.8%

F-Factor calculated based on fuel analysis = 9876 $dscf/10^6$ Btu

TABLE 7-1 (continued).

TEST 2 6/6/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1650-1655	333	10.0	59	0.76
1655-1700	333	10.1	59	0.77
1700-1705	329	10.1	61	0.76
1705-1710	329	10.2	61	0.76
1710-1715	325	10.1	65	0.75
1715-1720	325	10.1	65	0.75
1720-1725	325	10.1	66	0.75
1725-1730	328	10.1	68	0.76
1730-1735	333	10.1	65	0.77
1735-1740	332	10.1	65	0.77
1740-1745	334	10.0	64	0.76
1745-1750	333	10.0	66	0.76
1750-1755	331	10.0	66	0.76
1755-1760	331	10.1	65	0.76
1800-1805	326	10.1	65	0.75
1805-1810	324	10.0	68	0.74
1810-1815	318	10.1	81	0.73
1815-1820	317	10.1	79	0.73
1820-1825	316	10.1	74	0.73
1825-1830	315	10.1	76	0.73
1830-1835	307	10.2	85	0.71
1835-1840	300	10.1	97	0.69
1840-1845	297	10.1	101	0.68
1845-1850	299	10.2	98	0.70
AVG.	323	10.1	72	0.74
Range (High-Low)	(292-339)	(9.6-10.6)	(57-106)	

Calibration Drift (relative to analyzer span)	NO_x Mid	O_2 High	CO Low
	0.7%	1.0%	-0.6%

F-Factor calculated based on fuel analysis = 9967 dscf/10^6 Btu

TABLE 7-1 (continued).

TEST 3 6/7/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1015-1020	219	10.0	31	0.49
1020-1025	217	9.9	33	0.48
1025-1030	214	9.9	35	0.48
1030-1035	216	9.9	37	0.48
1035-1040	234	10.0	32	0.53
1040-1045	242	10.2	31	0.56
1045-1050	241	10.0	29	0.54
1050-1055	230	9.9	27	0.51
1055-1060	225	9.8	27	0.50
1100-1105	229	9.6	26	0.50
1105-1110	226	9.8	25	0.50
1110-1115	221	9.8	26	0.49
1115-1120	219	9.8	26	0.48
1120-1125	218	9.8	27	0.48
1125-1130	218	9.8	27	0.48
1130-1135	219	9.8	27	0.48
1135-1140	220	9.8	27	0.49
1140-1145	219	9.9	27	0.49
1145-1150	219	9.9	27	0.49
1150-1155	220	9.9	28	0.49
1155-1160	220	9.9	28	0.49
1200-1205	220	10.0	27	0.50
1205-1210	219	10.0	27	0.49
1210-1215	218	10.0	27	0.49
AVG.	223	9.9	29	0.50
Range (High-Low)	(214-244)	(9.3-10.6)	(25-41)	
Calibration Drift (relative to analyzer span)	NO_x Mid 1.0%	O_2 High -0.8%	CO Mid -0.2%	

F-Factor calculated based on fuel analysis = 9849 $dscf/10^6$ Btu

TABLE 7-1 (continued).

TEST 4 6/7/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1430-1435	230	11.4	49	0.59
1435-1440	233	11.4	53	0.60
1440-1445	233	11.3	56	0.59
1445-1450	233	11.4	53	0.60
1450-1455	232	11.5	49	0.60
1455-1460	232	11.4	46	0.59
1500-1505	235	11.5	47	0.61
1505-1510	228	11.4	44	0.58
1510-1515	228	11.4	44	0.58
1515-1520	232	11.3	47	0.59
1520-1525	230	11.4	46	0.59
1525-1530	229	11.4	46	0.59
1530-1535	229	11.4	46	0.59
1535-1540	231	11.4	47	0.59
1540-1545	237	11.4	49	0.61
1545-1550	237	11.4	50	0.61
1550-1555	234	11.4	51	0.60
1555-1560	235	11.4	50	0.60
1600-1605	236	11.5	52	0.61
1605-1610	234	11.5	53	0.61
1610-1615	233	11.4	54	0.60
1615-1620	233	11.4	56	0.60
1620-1625	233	11.5	56	0.60
1625-1630	233	11.5	57	0.60
AVG.	233	11.4	50	0.60
Range (High-Low)	(225-242)	(11.0-11.8)	(41-59)	
Calibration Drift (relative to analyzer span)	NO_x Mid 0.7%	O_2 High -0.8%	CO Mid -0.2%	

F-Factor calculated based on fuel analysis = 9749 $dscf/10^6$ Btu

TABLE 7-1 (continued).

TEST 5 6/11/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1345-1350	338	8.1	59	0.65
1350-1355	338	8.2	63	0.65
1355-1360	335	8.3	69	0.65
1400-1405	335	8.2	63	0.65
1405-1410	337	8.2	73	0.65
1410-1415	336	8.2	80	0.65
1415-1420	334	8.2	85	0.64
1420-1425	332	8.2	96	0.64
1425-1430	330	8.3	124	0.64
1430-1435	332	8.2	201	0.64
1435-1440	342	8.3	66	0.66
1440-1445	342	8.2	63	0.66
1445-1450	346	8.2	59	0.67
1450-1455	347	8.2	56	0.67
1455-1460	344	8.2	56	0.66
1500-1505	335	8.2	99	0.65
1505-1510	337	8.2	103	0.65
1510-1515	335	8.2	changed ascarite	0.65
1515-1520	332	8.2	136	0.64
1520-1525	333	8.2	126	0.64
1525-1530	333	8.1	129	0.64
1530-1535	331	8.2	135	0.64
1535-1540	329	8.2	180	0.63
1540-1545	347	8.3	98	0.67
AVG.	337	8.2	96	0.65
Range (High-Low)	(326-357)	(7.9-8.6)	(47-289)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO	
	Mid	Low	High	Mid	Mid	Low
	0.4%	0.2%	-0.4%	0%	-0.2%	-0.2%

F-Factor calculated based on fuel analysis = 9811 dscf/10^6 Btu

TABLE 7-1 (continued).

TEST 6 6/12/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
0955-1000	272	8.1	70	0.53
1000-1005	268	7.9	59	0.51
1005-1010	266	7.9	57	0.51
1010-1015	268	7.9	64	0.51
1015-1020	264	8.0	63	0.51
1020-1025	272	8.2	55	0.53
1025-1030	264	8.3	62	0.52
1030-1035	260	8.3	59	0.51
1035-1040	265	8.3	48	0.52
1040-1045	269	8.4	74	0.53
1045-1050	266	8.3	100	0.52
1050-1055	269	8.3	77	0.53
1055-1060	282	8.2	74	0.55
1100-1105	289	8.3	47	0.57
1105-1110	294	8.3	40	0.58
1110-1115	297	8.2	36	0.58
1115-1120	298	8.1	35	0.58
1120-1125	288	8.3	39	0.57
1125-1130	283	8.5	42	0.57
1130-1135	286	8.4	65	0.57
1135-1140	286	8.2	91	0.56
1140-1145	291	8.3	75	0.57
1145-1150	294	8.4	62	0.58
1150-1155	295	8.4	56	0.58
AVG.	279	8.2	60	0.55
Range (High-Low)	(257-310)	(7.3-9.2)	(34-146)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO
	Mid	Low	High	Mid	Low
	0.4%	0.2%	-0.4%	0%	-0.2%

F-Factor calculated based on fuel analysis = 9926 $dscf/10^6$ Btu

TABLE 7-1 (continued).

TEST 7 6/12/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1340-1345	326	9.3	37	0.68
1345-1350	327	9.3	38	0.68
1350-1355	327	9.3	38	0.68
1355-1360	325	9.3	38	0.68
1400-1405	323	9.3	38	0.67
1405-1410	324	9.2	39	0.67
1410-1415	331	9.2	38	0.69
1415-1420	333	9.3	39	0.70
1420-1425	338	9.2	39	0.70
1425-1430	338	9.3	39	0.71
1430-1435	339	9.2	40	0.70
1435-1440	336	9.3	40	0.70
1440-1445	327	9.2	40	0.68
1445-1450	322	9.3	41	0.67
1450-1455	323	9.3	42	0.67
1455-1460	335	9.3	41	0.70
1500-1505	337	9.3	40	0.70
1505-1510	336	9.2	40	0.70
1510-1515	332	9.3	42	0.69
1515-1520	327	9.3	43	0.68
1520-1525	326	9.3	43	0.68
1525-1530	327	9.4	45	0.69
1530-1535	329	9.3	45	0.69
1535-1540	332	9.3	45	0.69
AVG.	330	9.3	40	0.69
Range (High-Low)	(320-343)	(8.9-9.7)	(36-46)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO	
	Mid	Low	High	Mid	Mid	Low
	-0.6%	0.3%	0.4%	0%	0.8%	1.0%

F-Factor calculated based on fuel analysis = 9707 dscf/10^6 Btu

TABLE 7-1 (continued).

TEST 8 6/13/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
0930-0935	203	10.1	42	0.46
0935-0940	203	10.0	42	0.46
0940-0945	202	10.1	42	0.46
0945-0950	199	10.1	42	0.45
0950-0955	199	10.1	42	0.45
0955-0960	200	10.1	42	0.45
1000-1005	204	10.0	43	0.46
1005-1010	205	10.0	43	0.46
1010-1015	202	10.0	43	0.45
1015-1020	201	10.0	43	0.45
1020-1025	203	9.9	43	0.45
1025-1030	207	9.8	43	0.46
1030-1035	210	9.7	43	0.46
1035-1040	211	9.8	43	0.46
1040-1045	213	9.9	43	0.47
1045-1050	215	10.0	43	0.48
1050-1055	216	10.0	44	0.48
1055-1060	217	10.0	44	0.49
1100-1105	216	10.1	43	0.49
1105-1110	214	10.1	42	0.48
1110-1115	214	10.0	42	0.48
1115-1120	214	10.0	42	0.48
1120-1125	214	10.1	42	0.48
1125-1130	214	10.1	41	0.48
AVG.	208	10.0	43	0.47
Range (High-Low)	(194-219)	(9.2-10.7)	(41-46)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO	
	Mid	Low	High	Mid	Mid	Low
	-0.1%	0%	0%	0%	0.2%	0.2%

F-Factor calculated based on fuel analysis = 9801 dscf/10^6 Btu

TABLE 7-1 (continued).

TEST 9 6/13/84

Time	NO_x Conc. (ppm_d)	O_2 Conc. ($\%_d$)	CO Conc. (ppm_d)	E_{NO_x} Rate (lb $NO_x/10^6$ Btu)
1240-1245	233	11.7	62	0.62
1245-1250	235	11.7	60	0.63
1250-1255	229	11.9	68	0.62
1255-1260	237	11.9	68	0.64
1300-1305	238	12.1	69	0.66
1305-1310	240	12.0	77	0.66
1310-1315	237	12.1	78	0.66
1315-1320	236	12.1	77	0.66
1320-1325	238	12.0	71	0.65
1325-1330	240	12.0	73	0.66
1330-1335	239	12.0	71	0.66
1335-1340	240	12.0	66	0.66
1340-1345	237	12.1	72	0.66
1345-1350	240	12.1	72	0.67
1350-1355	251	12.0	58	0.69
1355-1360	250	11.9	54	0.68
1400-1405	247	11.8	53	0.66
1405-1410	243	11.6	49	0.64
1410-1415	244	11.5	44	0.64
1415-1420	238	11.2	41	0.60
1420-1425	232	11.1	43	0.58
1425-1430	226	11.2	45	0.57
1430-1435	222	11.2	50	0.56
1435-1440	218	11.2	54	0.55
AVG.	237	11.8	61	0.64
Range (High-Low)	(215-264)	(10.7-12.7)	(39-90)	

Calibration Drift (relative to analyzer span)	NO_x		O_2		CO	
	Mid	Low	High	Mid	Mid	Low
	-0.1%	0%	-0.8%	0%	-0.8%	-0.6%

F-Factor calculated based on fuel analysis = 9810 $dscf/10^6$ Btu

TABLE 7-2.

ACCUPACY DETERMINATION (NO_x , O_2 , SYSTEM)

Source and Location Tennessee Eastman Co., Kingsport, Tenn., Unit #24

Monitor Reference Method vs. Beckman 951 NOx / Teledyne 320P-4 O_2

Test No.	TIME	REFERENCE METHOD			MONITOR			DIFFERENCE		
		NO_x (ppm_d)	O_2 ($\%_d$)	SYSTEM lb/MMBtu	NO_x (ppm_d)	O_2 ($\%_d$)	SYSTEM lb/MMBtu	NO_x (ppm_d)	O_2 ($\%_d$)	SYSTEM lb/MMB
1	6/6/84 1235-1435	307	~~12.8~~ *	~~0.93~~ *	317	~~7.4~~	~~0.60~~	10	—	—
2	6/6/84 1650-1850	334	9.9	0.76	323	10.1	0.74	-11	0.2	-0.02
3	6/7/84 1015-1215	222	9.9	0.50	223	9.9	0.50	1	0	0
4	6/7/84 1430-1630	214	12.2	0.60	233	11.4	0.60	19	-0.8	0
5	6/11/84 1345-1545	331	8.7	0.66	337	8.2	0.65	6	-0.5	-0.0
6	6/12/84 0955-1155	291	8.9	0.60	279	8.2	0.55	-12	-0.7	-0.05
7	6/12/84 1340-1540	328	9.4	0.69	330	9.3	0.69	2	-0.1	0
8										
9										
10										
11										
12										
Mean ref. method test value		290	9.7	0.60				Mean Difference	2.1	-0.32	-0.015

95% Confidence intervals = ± 10.2 ppm NO_x, = ± 0.43 % O_2, = ± 0.021 lb/MMBt

Accuracies = $\frac{\text{Mean difference (absolute value)} + 95\% \text{ confidence interval}}{\text{Mean reference method value}} \times 100$ =

4.2 % NO_x, = 7.7 % O_2, = 5.7 % SYSTEM

* Orsat bag leak, therefore only six run comparison for O_2 and system

TABLE 7-3.

FUEL SAMPLING RESULTS
Tennessee Eastman Company
Kingsport Facility: Boiler Unit 24

Test Run No.	% Moisture	% Ash (dry)	% Sulfur (dry)	% Carbon (dry)	% Hydrogen (dry)	% Nitrogen (dry)	% Oxygen (dry)	GCV (Btu/lb)	Calculated F-Factor (dscf/10^6 Btu)
1	4.40	11.11	0.83	75.41	4.76	1.40	6.49	13203	9876
2	5.10	12.72	0.87	74.73	4.47	1.42	5.79	12906	9967
3	6.30	11.91	0.96	73.46	4.63	1.50	7.54	12847	9849
4	6.40	11.64	0.84	74.26	4.62	1.41	7.23	13107	9749
5	2.05	9.01	0.72	77.69	4.83	1.45	6.30	13674	9811
6	4.15	8.60	0.88	77.82	4.90	1.65	6.15	13581	9926
7	3.75	8.16	0.87	77.18	4.95	1.74	7.10	13761	9707
8	3.55	11.41	0.79	74.42	4.59	1.62	7.17	13055	9801
9	3.35	9.62	0.86	75.87	4.70	1.81	7.14	13318	9810
								AVG.	9833

STRATIFICATION DATA SHEET

Source and Location Tennessee Eastman, Boiler #24, ESP Outlet (No Preheat)

June 7, 1984

Sample Point	Reference Probe			Traverse Probe			Ave. Ref. Probe			Temporal Change			Normalized Trav.			
		NO_x (ppm)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)		NO_x (%)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)	
		235	11.7													
C2					241	11.8		240	11.4	0	-0.4	-1.7	0.65	242	12.0	0.4/0.8
		244	11.5													
		244	11.5													
C4					245	11.7		243	11.5	0	0.8	-2.5	0.65	243	12.0	1.2/0.8
		242	11.5													
		242	11.5													
D2					235	11.9		242	11.5	0	0.4	-2.5	0.64	234	12.2	-2.9/2.5
		242	11.5													
		242	11.5													
D4					235	11.7		239	11.6	0	-0.8	-1.7	0.62	237	11.9	-1.7/0
		235	11.6													
		235	11.6													
B2					236	11.6		233	11.7	-1.6	-3.3	-0.8	0.63	244	11.7	1.2/1.7
		230	11.8													

Rt

7.1-16

STRATIFICATION DATA SHEET

Source and Location Tennessee Eastman, Boiler #24, ESP Outlet (No Preheat)

Sample Point	Reference Probe			Traverse Probe			Ave. Ref. Probe			Temporal Change			Normalized Trav.			
		NO_x (ppm)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)		NO_x (%)	CO_2/O_2 (%)		NO_x (ppm)	CO_2/O_2 (%)	
		230	11.8													
B4					232	11.6		229	11.9	-1.4	-5.0	0.8	0.62	244	11.5	1.2/3.4
		227	11.9													
		227	11.9													
A2					229	11.7										
A4																
													0.635	241	11.9	

Ended test prematurely due to storm @ conclusion of sampling traverse point A2.

STRATIFICATION DATA SHEET

Source and Location Tennessee Eastman, Boiler #24, ESP Outlet (With Preheat)

June 11, 1984

Sample Point	Reference Probe			Traverse Probe			Ave. Ref. Probe			Temporal Change			Normalized Trav.		
	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (%)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)
	0.63	324	8.3												
C2				0.63	328	8.2	0.63	324	8.2	1.6	0	1.2	0% 0.62	0.9 328	0 8.1
	0.62	324	8.1												
	0.62	324	8.1												
C1				0.63	328	8.0	0.63	325	8.1	1.6	0.3	0	0% 0.62	0.6 327	-1.2 8.0
	0.63	326	8.2												
	0.63	326	8.2												
D2				0.62	325	8.2	0.63	329	8.3	1.6	1.5	2.5	-1.6% 0.61	-1.5 320	-1.2 8.0
	0.64	332	8.3												
	0.64	332	8.3												
D1				0.64	331	8.3	0.64	331	8.3	3.2	2.2	2.5	0% 0.62	-0.3 324	0 8.1
	0.64	330	8.4												
	0.64	330	8.4												
B2				0.64	334	8.1	0.63	329	8.3	1.6	1.5	2.5	1.6% 0.63	1.2 329	-2.5 7.9
	0.63	328	8.1												

Re

STRATIFICATION DATA SHEET

Source and Location Tennessee Eastman, Boiler #24, ESP Outlet (With Preheat)

June 11, 1984

Sample Point	Reference Probe			Traverse Probe			Ave. Ref. Probe			Temporal Change			Normalized Trav.		
	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (%)	CO_2/O_2 (%)	E_{NO_x} (lbs/10^6 Btu)	NO_x (ppm)	CO_2/O_2 (%)
	0.63	328	8.1												
R1				0.64	328	8.3	0.64	331	8.2	3.2	2.2	1.2	0.62 (0?)	321 (1.2)	8.2 (1.2)
	0.65	333	8.3												
	0.65	333	8.3												
A2				0.64	335	8.1	0.65	331	8.4	4.8	2.2	3.7	0.61 (-1.6%)	328 (0.9)	7.8 (-3.7)
	0.65	330	8.5												
	0.65	330	8.5												
A4				0.66	335	8.5	0.65	334	8.3	4.8	3.1	2.5	0.63 (1.6%)	325 (0)	8.3 (2.5)
	0.64	338	8.1												

Avg 0.62/325/8.1

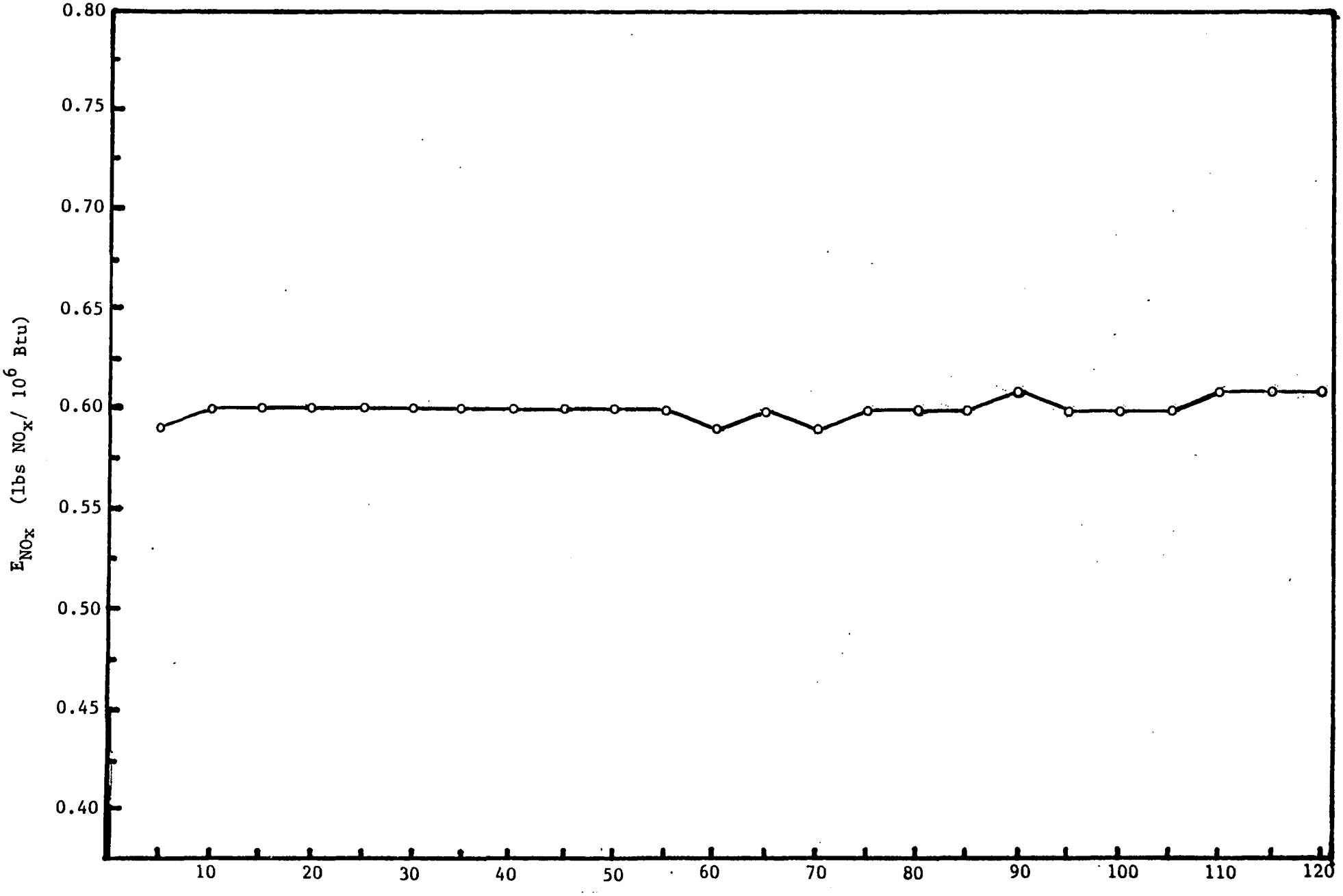


FIGURE 7-1. RUN NO. 1 NO_x EMISSIONS

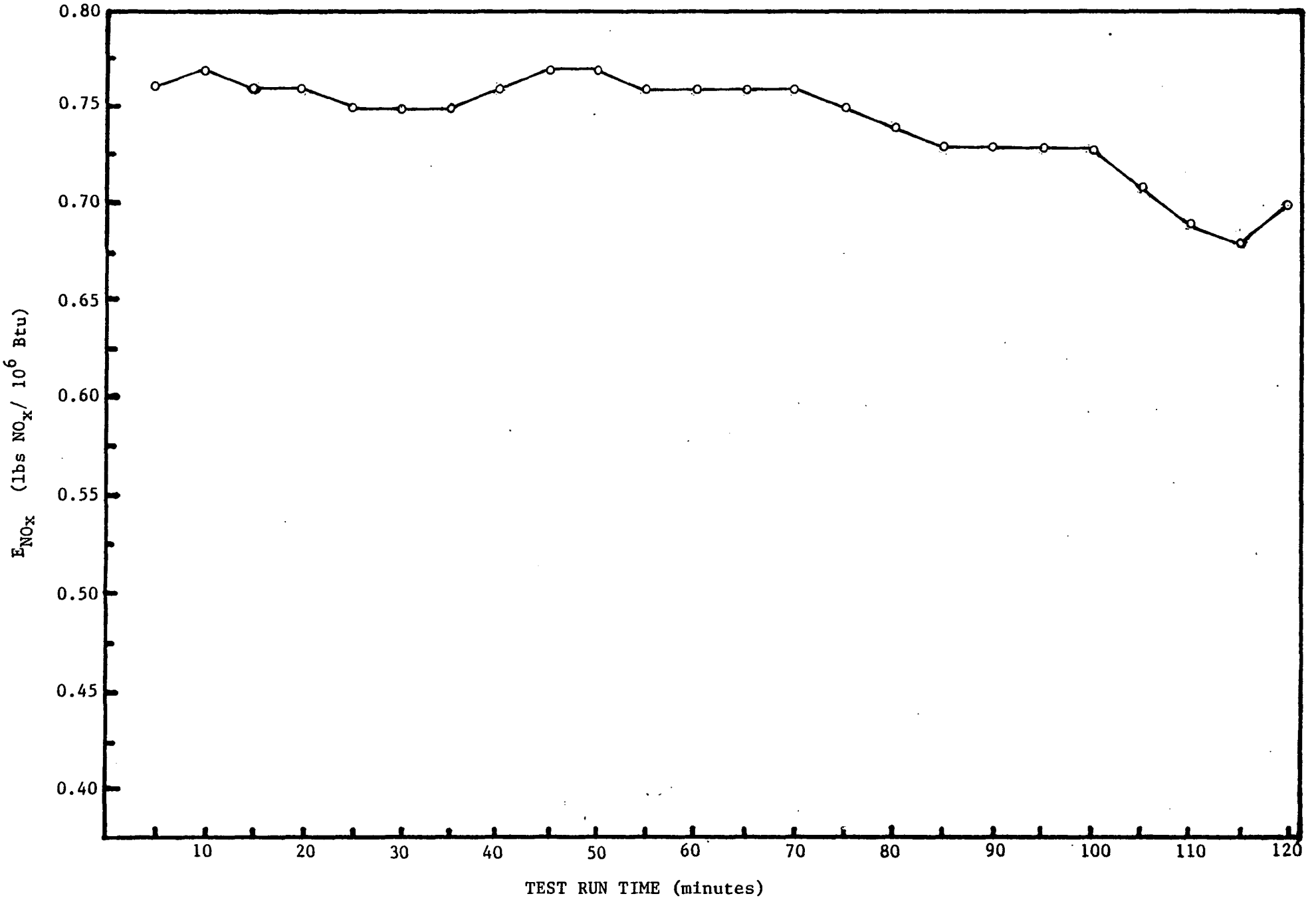


FIGURE 7-2. RUN NO. 2 NO_x EMISSIONS

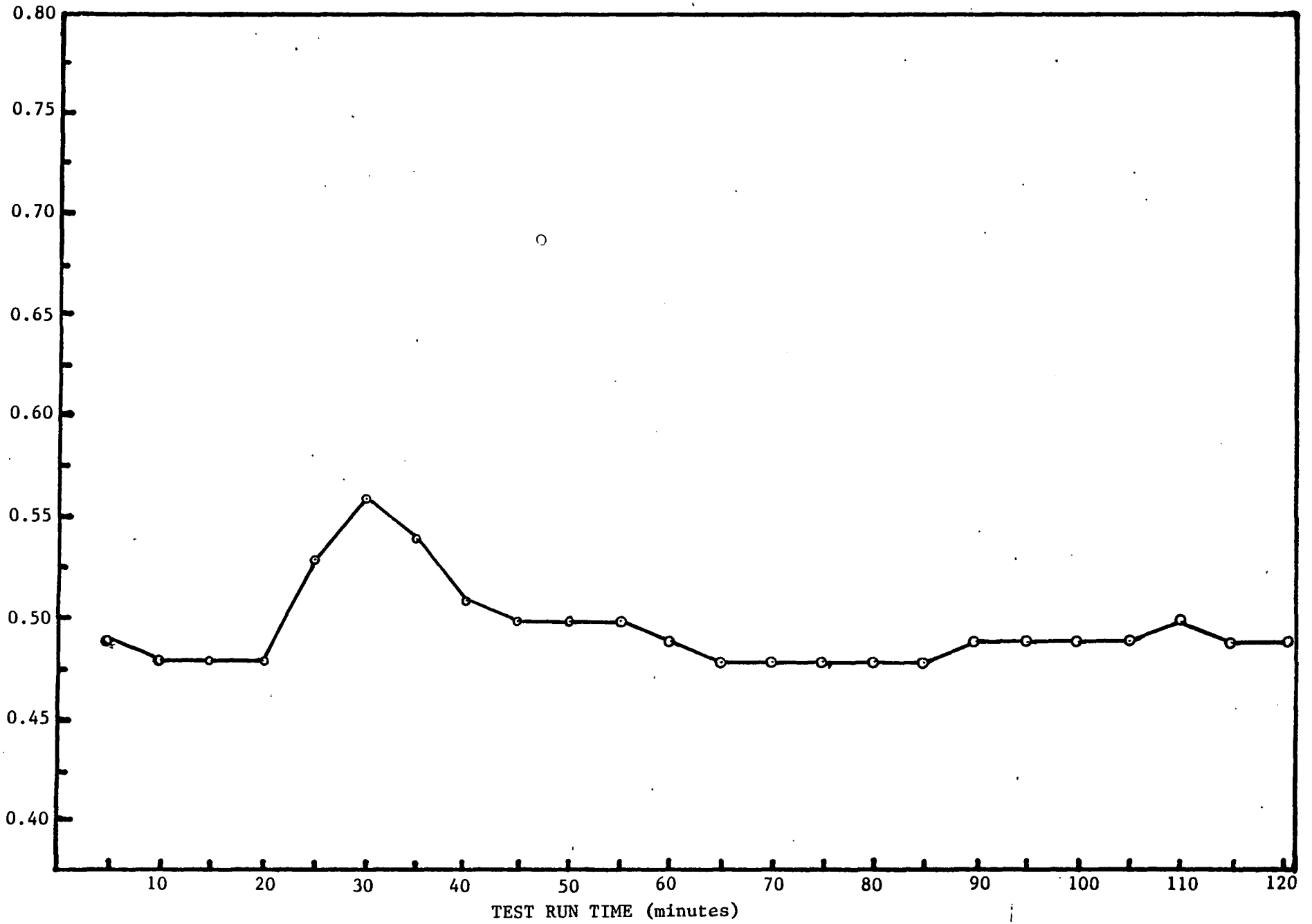


FIGURE 7-3. RUN NO. 3 NO_x EMISSIONS

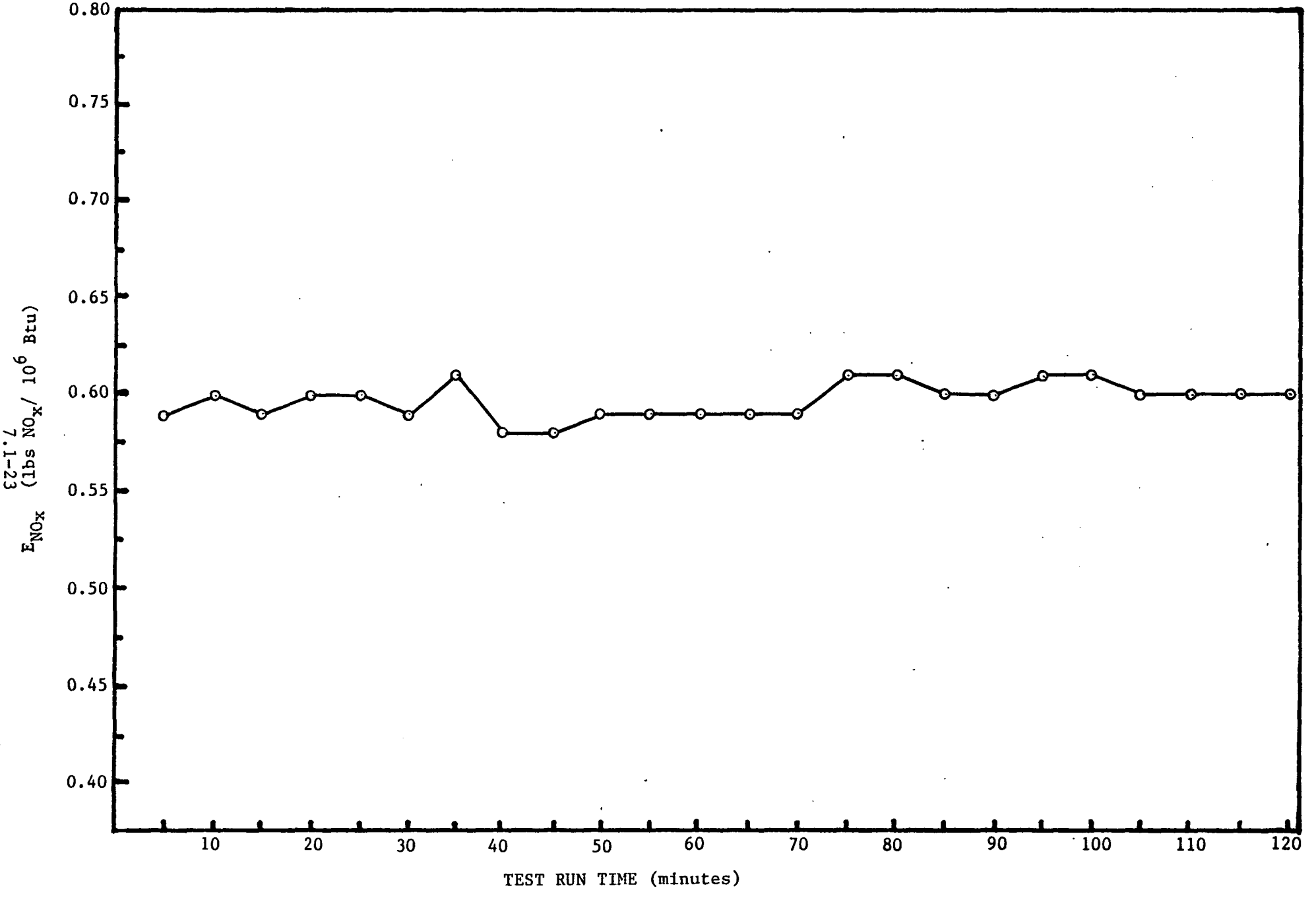


FIGURE 7-4. RUN NO. 4 NO EMISSIONS

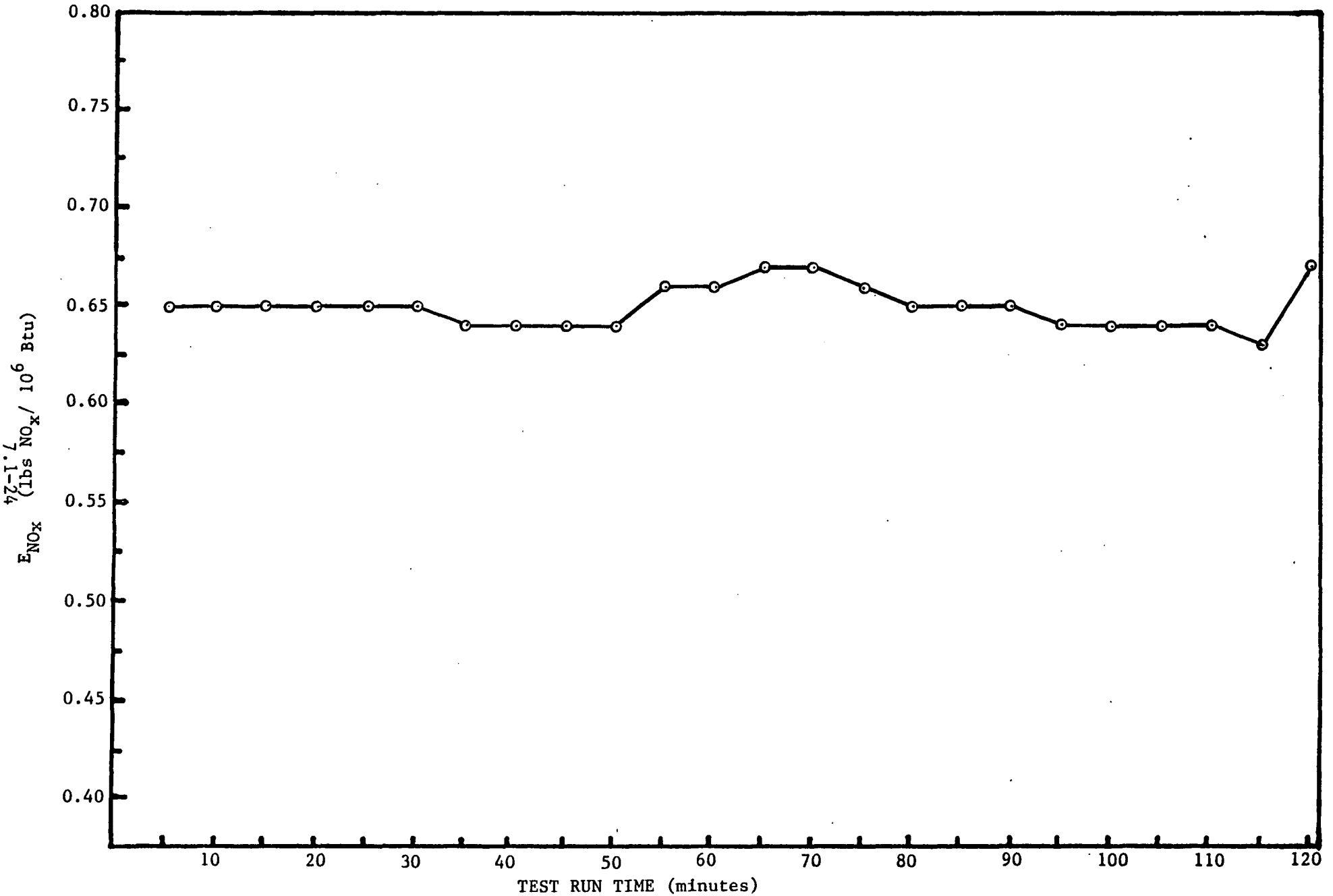


FIGURE 7-5. RUN NO. 5 NO_x EMISSIONS

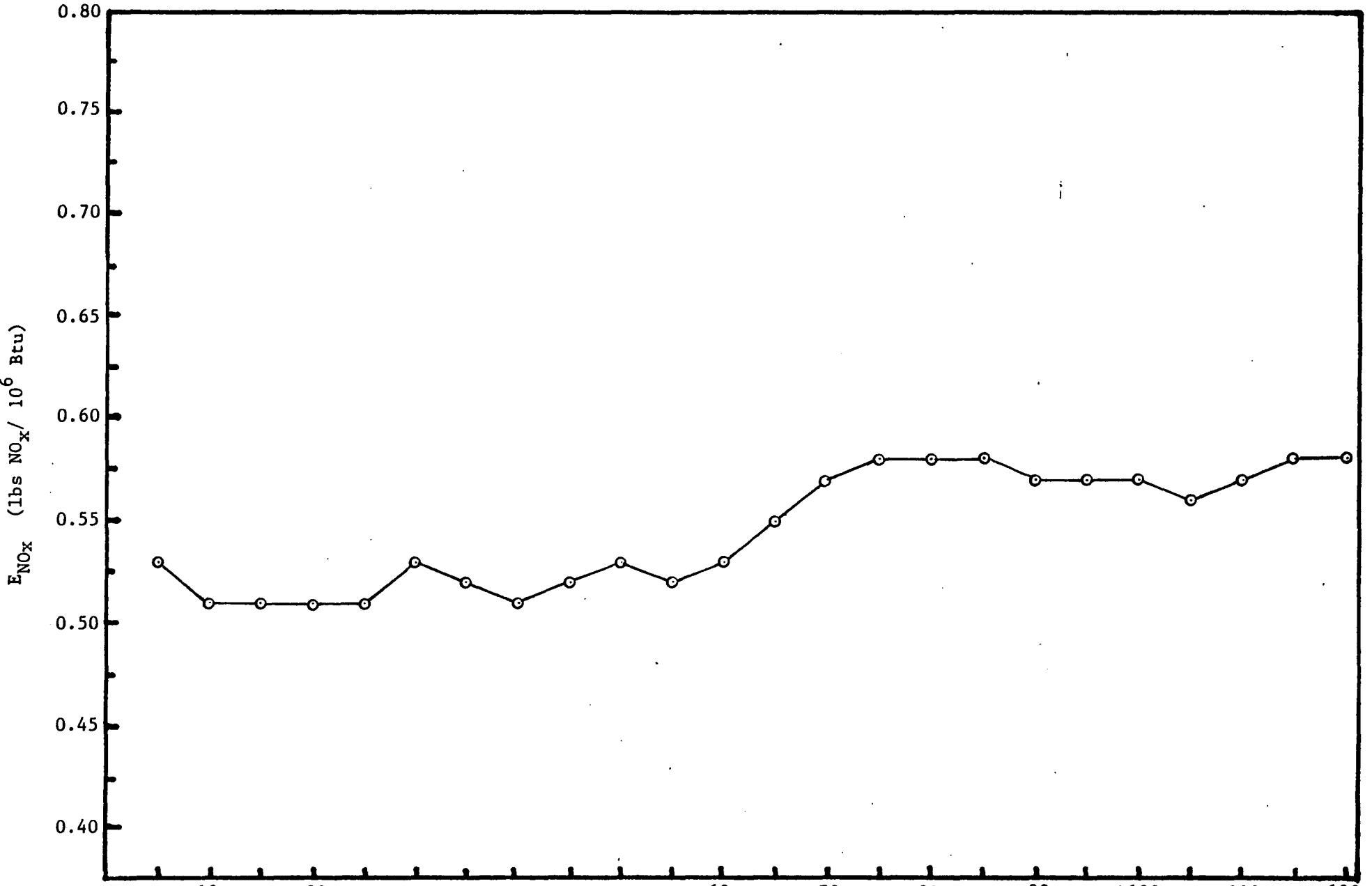


FIGURE 7-6. RUN NO. 6 NO_x EMISSIONS

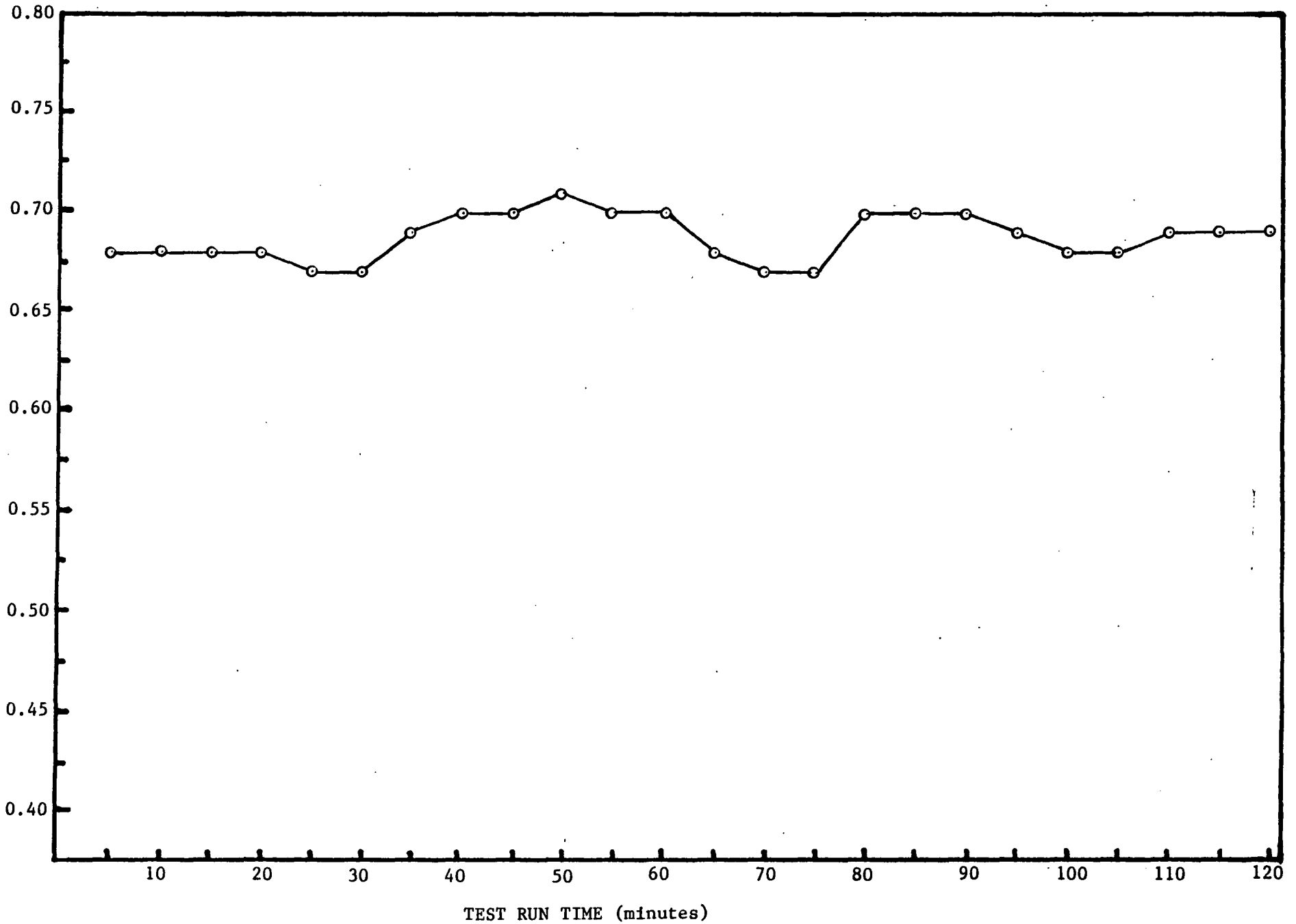


FIGURE 7-7. RUN NO. 7 NO_x EMISSIONS

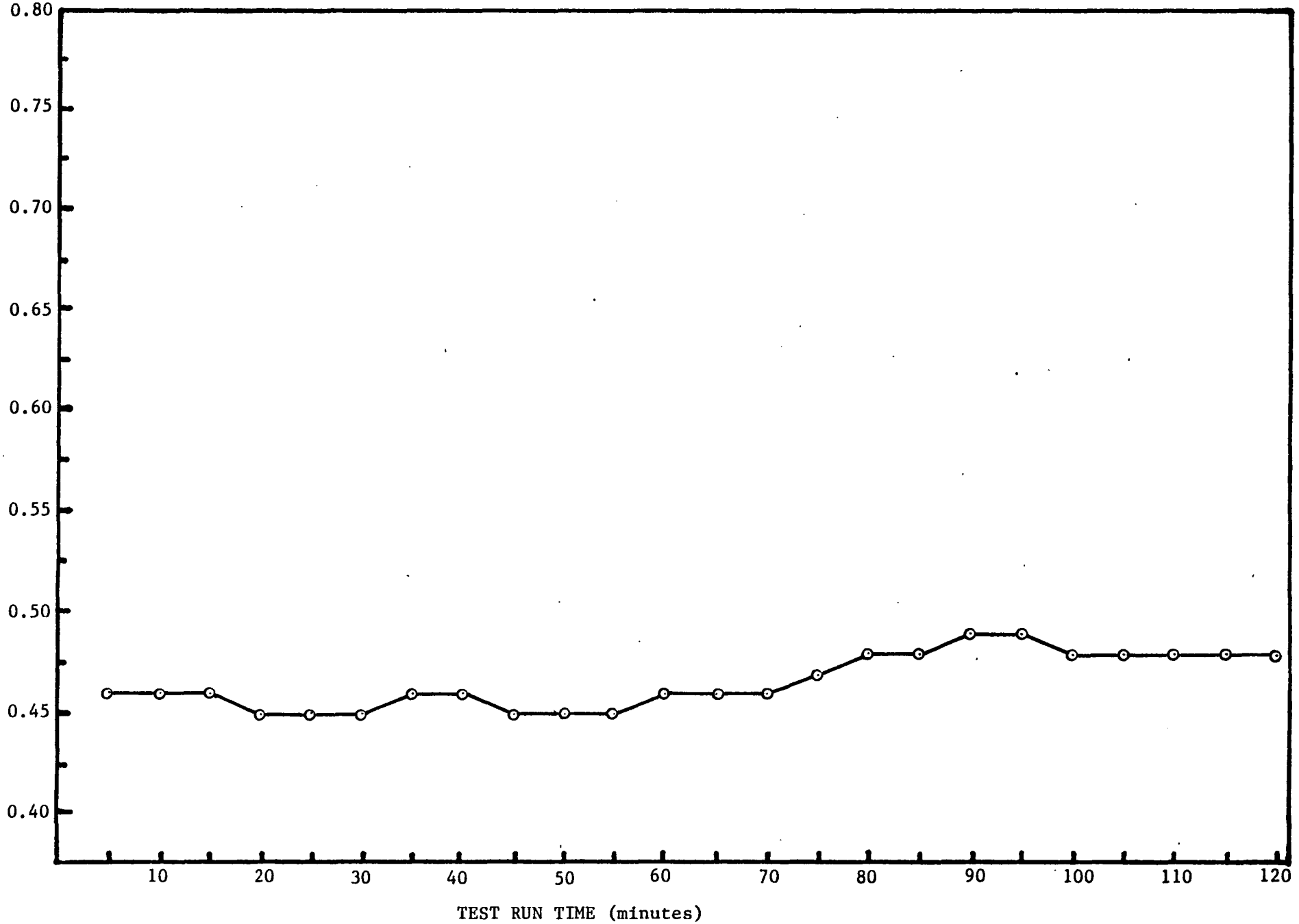


FIGURE 7-8. RUN NO. 8 NO_x EMISSIONS

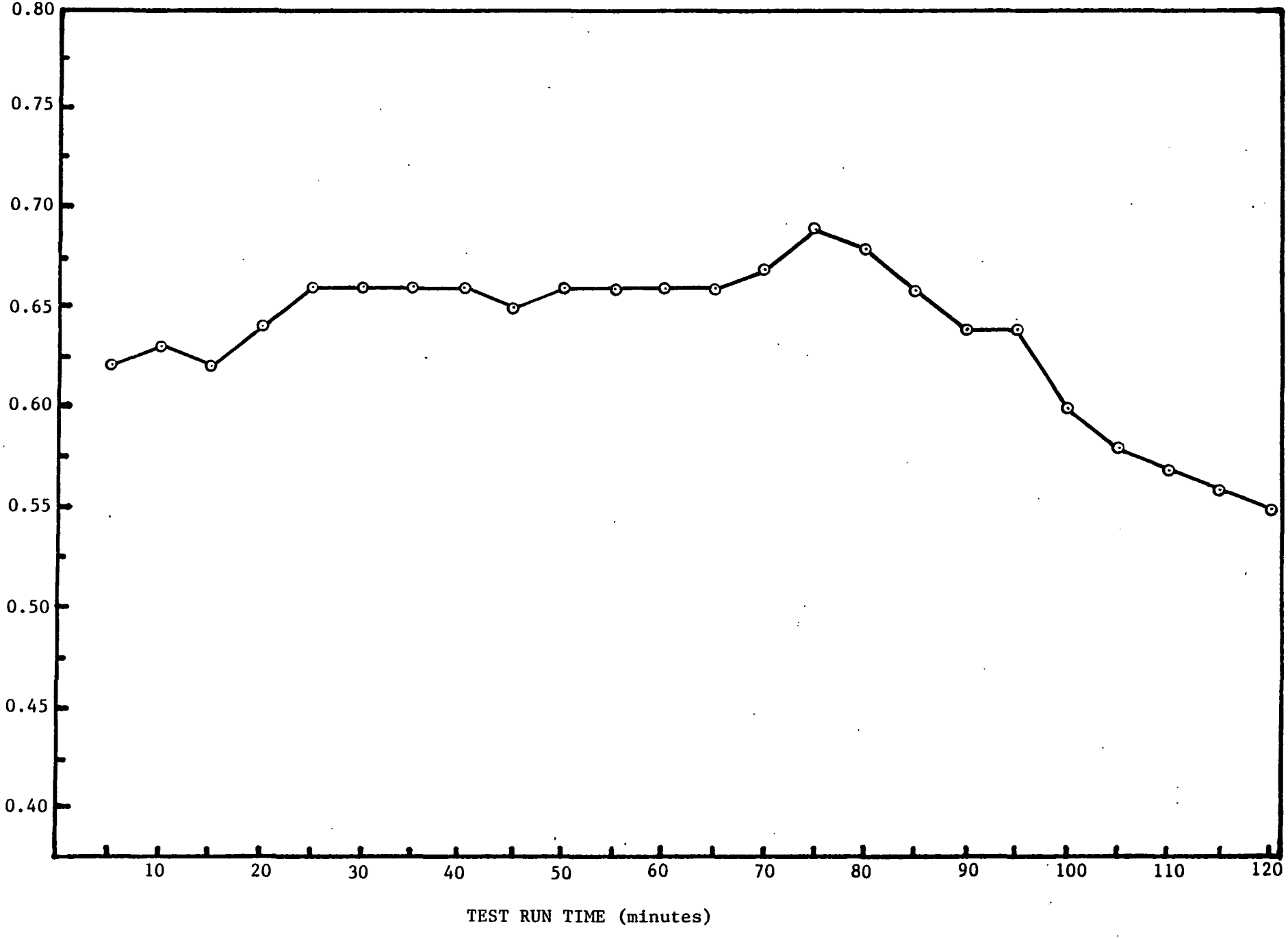


FIGURE 7-9. RUN NO. 9 NO_x EMISSIONS