KOOGLER & ASSOCIATES
ENVIRONMENTAL SERVICES
4014 NW THIRTEENTH STREET
GAINESVILLE, FLORIDA 32609
352/377-5822 ▪ FAX/377-7158

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JAN 12 2005
BUREAU OF AIR REGULATION

187-04-16
January 10, 2005

Mr. Jim Pennington
Florida Department of Environmental Protection
Office of the Bureau Chief, Administrator
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Subject: ***Florida Rock Industries, Thompson S. Baker Cement Plant***
Permit: 0010087-011-AC
Request Extension of Time to Report on SNCR Testing

Dear Mr. Pennington:

The purpose of this letter is to request an extension of 45 days to submit a written report of SNCR testing allowed by permit No. 0010087-011-AC. The extension will allow for needed time to gather and analyze all data sources used to monitor this testing. If you have questions, please contact Henry Gotsch (352) 472-4722, John Koogler or me (352) 377-5822.

Very truly yours,

KOOGLER & ASSOCIATES

Max Lee, Ph.D., P.E.

Cc: Henry Gotsch, FRI
John Koogler, KA

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ENVIRONMENTAL SERVICES
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GAINESVILLE, FLORIDA 32609
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KA 187-04-16
February 2, 2005

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BUREAU OF AIR REGULATION

Mr. Jim Pennington
FDEP - Tallahassee
Twin Towers Office Bldg.
2600 Blair Stone Road, MS 5500
Tallahassee, FL 32399-2400

Subject: ***Florida Rock Industries Inc.***
Thompson S. Baker Cement Plant
Facility ID: 0010087
SNCR Test Report

Dear Jim:

In accordance with the authorization granted by Permit 0010087-001-AC, Florida Rock Industries, Inc. (FRI) conducted tests at their Thompson S. Baker Cement Plant in Newberry, Florida during the period December 6-11, 2004 to evaluate the Selective Non-Catalytic Reduction (SNCR) process for reducing the emission rate of NOx from that plant. In accordance with an amendment to the above referenced permit dated January 26, 2005, we are submitting three copies of the enclosed report (prior to February 4, 2005) describing the results of the tests.

In summary, ammonia was injected into the calciner of the cement plant at various rates and the NOx reduction in the stack gas from the kiln/raw mill was determined for each injection rate. The ammonia injection rates, expressed as a molar ratio of ammonia to uncontrolled NOx, ranged from approximately 0.1-1.0. NOx control efficiencies over this range of injections ranged from approximately 7-82 percent. Another phase of the SCNR test was to establish a set stack gas NOx concentration and to maintain this concentration by varying the ammonia injection rate. This part of the test demonstrated (at least for a 16-hour period) that a relatively constant stack gas NOx concentration could be maintained by varying the injection rate of ammonia.

During the SNCR tests, concentrations of unreacted ammonia (ammonia slip) and carbon monoxide were monitored in the kiln/raw mill stack. It was observed that for the 6-day test period, little of no ammonia slip occurred with the raw mill operating. However, when the raw mill was offline, ammonia concentrations in the stack gas peaked at approximately 40 ppm. With carbon monoxide, there was a trend toward higher CO emissions during periods when ammonia was injected. This is consistent with previous observations as discussed in the enclosed report.

Finally, the report addresses the estimated cost of reducing NOx from a range of uncontrolled emission rates to a range of controlled emission rates. It should be noted that these costs apply only to the FRI Thompson S. Baker plant. The cost of control ranges from approximately 0.25-0.95 dollars per ton of clinker depending upon the initial uncontrolled NOx emission rate and the targeted controlled NOx emission rate.

We appreciate the Department's interest and cooperation in these tests. If there are questions related to the information reported herein, please contact me at 352-377-5822 or jkoogler@kooglerassociates.com.

Very truly yours,

KOOGLER & ASSOCIATES

John B. Koogler, Ph.D., P.E.

JBK/lt

Enclosure

cc: Trina Vielhauer
Gary Sauer
Chris Horner
Henry Gotsch
Mark Terry
Segundo Fernandez

SELECTIVE NON-CATALYTIC REDUCTION TEST REPORT

FLORIDA ROCK INDUSTRIES, INC.
Thompson S. Baker Cement Plant

Facility ID: 0010087
Newberry, Florida

Test Date: December 6-11, 2004
Report Date: February 2, 2005

187-04-16

KOOGLER & ASSOCIATES
ENVIRONMENTAL SERVICES

SELECTIVE NON-CATALYTIC REDUCTION TEST REPORT

FLORIDA ROCK INDUSTRIES, INC.
Thompson S. Baker Cement Plant

RECEIVED
FEB 03 2005
BUREAU OF AIR REGULATION

Facility ID: 0010087
Newberry, Florida

Test Date: December 6-11, 2004
Report Date: February 2, 2005

Koogler & Associates, Inc.
4014 N.W. 13th Street
Gainesville, Florida 32609
(352) 377-5822

187-04-16

ENVIRONMENTAL SERVICES

To the best of my knowledge, all test data and plant operating data are true and correct and the conclusions presented herein are representative of the data reported.

John B. Koogler, Ph.D., P.E.

State of Florida
Registration No. 12925

2/2/05
Date

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Appendix

1.0 INTRODUCTION

Florida Rock Industries, Inc. (FRI) operates the Thompson S. Baker Portland cement plant on CR 235, approximately 3.5 miles north of the city center of Newberry, Florida. The plant is a modern preheater/precalciner Portland cement plant designed by the Polysius Corporation. The plant has a permitted clinker production rate of 2650 tons per day and currently operates under FDEP Permit 0010087-009-AV.

On November 8, 2004 the Florida Department of Environmental Protection (FDEP) issued Air Construction Permit 0010087-011-AC to FRI authorizing tests to assess the viability of Selective Non-Catalytic Reduction (SNCR) for the control of NOx emissions from the cement kiln. These tests were conducted during the period December 6-11, 2004. The Polysius Corporation designed the tests, supplied the equipment for the injection of ammonia and provided personnel to operate the equipment. Additionally, Polysius monitored and reported the ammonia injection rates and the stack gas concentrations of NO and oxygen. FRI personnel were responsible for operating the plant, reporting plant operating data and operating continuous emissions monitors for NOx, SO2, total hydrocarbons, and stack gas flow located in the kiln/raw mill stack. Koogler and Associates, Inc. was the engineer of record for the tests and monitored ammonia and carbon monoxide in the kiln/raw mill stack.

The purpose of the testing was to evaluate the effectiveness of SNCR for NOx reduction. The ammonia used for the tests was a 10 percent (by weight) ammonia/water solution. This solution was injected into the calciner just before the Stage I cyclone (the bottom cyclone) of the preheater. This injection point was selected by Polysius based on experience at other plants. Ammonia was injected at various rates defined by the molar ratio of ammonia to uncontrolled NOx (NO + NO_2) measured in the kiln/raw mill stack. The NOx reductions measured in the kiln/raw mill stack are reported as a function of these molar ratios. The ammonia injection tests were conducted with and without the firing of whole-tire derived fuel at the kiln inlet. The tests demonstrated NOx reduction efficiencies in the range of 6-82 percent with molar ratios in the range of 0.1-1.0.

Additionally, ammonia was injected at varying rates for approximately a 16-hour period to maintain a set stack gas NOx concentration of about 130 ppm (v/v); equivalent to about 1.8 pounds of NOx per ton of clinker. This test demonstrated that a relatively constant NOx stack gas concentration can be maintained with an SNCR system by varying the injection rate of ammonia.

Finally, this report includes a cost estimate for the operation of an SNCR system at the FRI Thompson S. Baker Cement Plant based on the results of this test program.

2.0 THE SNCR PROCESS

The bases of the SNCR process are reactions between ammonia (NH_3) and NO and ammonia and NO_2. In these reactions, the NO and NO_2 are chemically reduced to elemental nitrogen. The governing reactions are as follows:

$$2\ NO + 2\ NH_3 + \tfrac{1}{2}\ O_2 \rightarrow 2\ N_2 + 3\ H_2O$$

$$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$$

These reactions take place without the aid of a catalyst and are highly temperature dependent. With the injection of aqua ammonia (an ammonia/water solution), the optimum reaction temperature is approximately 950°C (1750°F). For urea injection, the optimum temperature is in the range of 1000°C (1830°F). For temperatures significantly below these optimum temperatures, some of the ammonia is unreacted and ends up in the raw materials or as ammonia in the stack gas. At temperatures significantly above the temperatures, the ammonia will react with oxygen, increasing the concentrations of NO and NO_2 (referred to as collectively herein as NOx).

The actual reaction between ammonia and NOx first involves the reaction of ammonia with OH^* radicals to produce the NH_2^* radical and water. The NH_2^*

then reacts with NOx to produce the elemental nitrogen and water as shown in the above equations.

Because of this intermediate reaction, another factor to take into consideration is the presence of carbon monoxide (CO) in the gas stream into which the ammonia is injected. The oxidation of CO to CO_2 involves the same OH^* radicals that react with ammonia to produce the NH_2^* radical. Thus, if CO is present, there are competing reactions between the CO and NH_3 for the OH^* radicals and both the oxidation of CO and the creation of NH_2^* radicals suffer.

For SNCR to be effective, therefore, there must be enough residence time in the precalciner between the injection of tertiary combustion air and the injection of ammonia for the CO to be substantially oxidized. Considering these factors, Polysius has found that the most favorable point of ammonia injection at this Multi-Stage Combustion (MSC) plant is just prior to the Stage I cyclone of the preheater.

Polysius has found that because of the aforementioned competing reactions between CO and NH_3 for OH^* radicals, the presence of unoxidized carbon monoxide at the point of ammonia injection will result in an increase in carbon monoxide emissions. Polysius has reported (*Latest Developments in NOx Reduction Technology in the Cement Industry*, R. M. Erpelding, Polysius A.G.-

Germany, Cement Plant Environmental Handbook, 2003) that at a molar ratio of ammonia to NOx of 0.8, CO emissions will increase in the range of 0.3-1.0 pounds per ton of clinker. At a molar ratio of 1.0, the CO increase will be in the range of 0.5-1.5 pounds per ton of clinker.

3.0 SNCR TEST EQUIPMENT

Polysius supplied the equipment necessary for injecting the aqua ammonia. For the test at FRI, a 10 percent (by weight) ammonia in water solution was delivered by tank truck. The specific gravity of the solution was 0.9582.

The Polysius equipment consisted of three components; a control panel, the pump station and the injectors. The aqua ammonia was delivered from the tank truck through a 20 stage centrifugal pump and a series of controllers to the injectors at a pressure in the range of 150-220 psig (10-15 bars). Four injector nozzles were placed at 90 degrees to one another in the wall of a circular cross section of the precalciner just upstream of the Stage I cyclone of the preheater. Each injector nozzle created a flat fan-shaped distribution with an aperture angle of 60 degrees. The flat, thin spray of aqua ammonia maximized the interface between the reagent and the gas stream, optimizing the reaction between ammonia and NOx. One to four nozzles were used during the test period depending upon the ammonia injection rate.

The entire system was controlled with a control panel designed to maintain a constant ammonia injection rate or to vary the ammonia injection rate in order to maintain a constant stack gas NOx concentration.

The Polysius controller recorded NO in the stack gas (ppm, dry), stack gas oxygen (volume percent, dry), kiln feed (tons per hour provided by FRI), stack gas flow (from the FRI continuous monitoring system), and the ammonia injection rate, and other operating variables.

4.0 MONITORING

Ammonia injection at varying set molar ratios and ammonia injection at a variable rate to maintain a set stack gas NOx concentration was conducted during the period 0800 hours on December 9, 2004 and 2400 hours on December 10, 2004. During this period of time, there were two periods of disruption in kiln feed (See Figure 1). Ammonia injection tests were not conducted during these periods.

During the periods of testing, the kiln feed rate ranged from 165-175 tons per hour and averaged approximately 170 tons per hour (approximately 102 tph of clinker). During this period of time, the kiln and calciner were both fired with coal. Testing was conducted for about a one hour period between 0800-0900 hours on December 9 while whole-tire derived fuel was fired at the kiln inlet and again between 1400-2400 hours on December 10, 2004 with the firing of tire derived fuel. The tire firing rate typically averages about one ton per hour and provides about seven percent of the total heat input to the pyroprocessing system.

FRI was responsible for monitoring the kiln feed rate, the fuel firing rates, clinker production rate, and stack gas parameters including NOx, SO_2, total hydrocarbons, flow rate and temperature. The stack gas monitoring was conducted with continuous monitors permanently installed in the FRI kiln/raw mill stack. These monitors have been previously certified in accordance with the requirements of 40 CFR 60, Appendices B and F. The FRI NOx data were used for the analyses presented herein.

Polysius was responsible for the ammonia injection and the monitoring of parameters associated with this injection. These parameters included the ammonia injection rate and stack gas concentration of NO, O_2, and CO. The NO, O_2, and CO were measured on a dry basis in a bypass stream from the Koogler and Associates monitors.

Koogler and Associates was responsible as the engineer of record for the testing and monitored ammonia and CO in the stack. The ammonia was monitored continually in accordance with the general procedures of EPA Method 320 (the FTIR method) and CO was measured in accordance with the general procedures of EPA Method 10. Both methods are described in 40 CFR 60, Appendix A. The CO monitored in accordance with Method 10 was used for the analyses reported herein.

The extractive stack gas monitoring (NH_3 and CO) and the continuous in-stack gas monitoring were conducted in the 112-inch diameter, 241-foot high kiln/raw mill stack. The sampling ports are located 15.7 diameters downstream from the point where gases enter the stack and 5.4 diameters below the top of the stack.

5.0 DESCRIPTION OF TESTS

The purpose of the SNCR tests was two fold. First, the NOx (expressed as NO_2) control efficiency was determined as a function of the molar ratio of ammonia to uncontrolled NOx and secondly, a test was conducted with variable ammonia/NOx molar ratios to see if a set stack gas NOx concentration could be maintained.

In both cases, the ammonia was injected into the calciner just prior to the Stage I cyclone of the preheater. At this point, the average temperature during the test period was 862°C (1580°F) and the average pressure was -15 millibars (approximately -6 in. H_2O).

For the NOx reduction tests, ammonia was introduced for discrete periods of time ranging from approximately 30-60 minutes. During each injection period, the ammonia injection rate was held constant at a predetermined NH_3/NOx molar ratio. The molar ratios ranged from approximately 0.1-1.0. Tests were conducted with whole-tire derived fuel fired at the inlet of the kiln and again with no whole-tire derived fuel being used.

Before and after each ammonia injection period, the uncontrolled NOx (expressed as NO_2) concentrations were measured in the stack gas. The uncontrolled NOx emission rate for each NH_3 injection period (expressed as pound per ton of clinker) was calculated as the average of the uncontrolled NOx emission rates before and after each injection period. From these data, the NOx reduction for each test period was calculated as:

$$\text{NOx Reduction (\%)} = (\text{NOx}_{\text{uncontrolled}} - \text{NOx}_{\text{controlled}}) \times 100 / \text{NOx}_{\text{uncontrolled}}$$

The molar ratio of ammonia to NOx was calculated as the molar injection rate of ammonia (moles per hour) divided by the uncontrolled NOx emission rate (moles per hour). The molar injection rate of ammonia was based on a 10 percent (by weight) solution of ammonia in water. The specific gravity of this solution was 0.9582. The molar injection rate of ammonia is expressed as moles of NH_3 per hour.

6.0 TEST RESULTS

The results derived from the SNCR testing at FRI are divided into three sections; NOx control as a function of ammonia injection rate, factors associated with carbon monoxide and ammonia emissions and the estimated cost of operating an SNCR system at FRI.

6.1 NOx Control Efficiency

The control of NOx from the kiln/raw mill stack is defined as a function of the uncontrolled emissions and the controlled emissions as defined in Section 5.0. The uncontrolled emissions are based on NOx data collected immediately before and immediately following periods of ammonia injection. During the time periods used for determining uncontrolled NOx emissions, no ammonia was being injected. The controlled emissions were measured and calculated based on data collected during each period of ammonia injection.

The controlled and uncontrolled NOx emissions, expressed both as pounds per ton of clinker and pound-moles (of NO_2) per hour for each period of ammonia injection are summarized in Table 1. One set of data was collected while tire derived fuel was fired at the kiln inlet and the second set of data was collected with no tire derived fuel being burned.

The ammonia injection rate was varied from approximately 75-600 liters per hour during the NOx control efficiency test period. Ammonia was injected at six discrete flow rates while tire derived fuel was being used and six discrete flow rates when no tire derived fuel was being used. The time periods of ammonia injection typically ranged from 30-60 minutes.

The injection rates of ammonia were calculated in terms of moles per hour based on the injection rate of the ten percent aqua ammonia solution (liters per hour), a solution specific gravity of 0.9582 and the molecular weight of ammonia (NH_3; m.w. = 17.

The molar ratio of ammonia to NOx was calculated for each period based on the ammonia injection rate (moles per hour) and the uncontrolled NOx emission rate (moles per hour). The data summarized in Table 1 show that the molar ratios for the two test periods combined ranged from approximately 0.1-1.0.

The NOx control efficiencies range from about seven percent with a molar ratio of 0.09 (with no tire derived fuel) to about 82 percent with a molar ratio of 1.04 (with no tire derived fuel). The control efficiencies with tire derived fuel ranged from about 34-68 percent with molar ratios ranging from 0.12-0.64. The control efficiency data are also shown in graphical form in Figure 2.

It will be noted from the data presented in Figure 2 that the apparent NOx control efficiency is greater when tires are used as a supplemental fuel than when tires are not used. This is particularly true at the lower molar ratios; i.e., between 0.1 and 0.6. At molar ratios of 0.6 and above, the control efficiencies tend to converge.

The difference in control efficiencies with and without tire derived fuel is not readily explained. Looking at the data in Table 1, it will be noted that in general, the uncontrolled NOx emissions during tests without tire derived fuel were greater than the uncontrolled NOx emissions when tire derived fuel was being burned. This would indicate a higher oxygen level at the kiln exit (resulting in higher uncontrolled NOx emissions) when no tire derived fuel was used. This higher oxygen level and the fact that oxygen was not consumed by the combustion of tire derived fuel, would have a tendency to lower CO levels in the calciner and result in a more efficient reaction between ammonia and NOx (See Section 2.0). The control efficiency data are contrary to this.

The data presented in Figures 3 and 4 are the time dependent NOx emission rates, carbon monoxide emission rates, and ammonia injection rates for the SNCR tests when tire derived fuel was being burned (Figure 3a-3c) and when no tire derived fuel was being burned (Figure 4). These data confirm that when the highest uncontrolled NOx emissions occurred (the lower molar ratio injections with no tire derived fuel), the CO emissions were lowest (approximately 10 pound-moles per hour). As the uncontrolled NOx emissions decreased (again with no tire derived) the CO emissions increased to approximately 20 pound-moles per hour. This higher CO emissions rate was typical of most of the ammonia injection periods when tire derived fuel was fired (Figures 3a-3c). Again, the lower levels of CO would indicate the reaction between ammonia and NOx should be more efficient. As stated previously, the data in Figure 2 do not support this.

For purposes of evaluating the effectiveness of SNCR for NOx control under the variable conditions of this cement plant, it is probably best to use the relationship between ammonia injection and NOx control represented by the combined data set shown in Figure 2.

The molar injection of ammonia (pound-moles per hour) is compared with the reduction in NOx in the stack gas (pound-moles per hour) in Figure 5. Again, these data show an apparent greater reduction when tire derived fuel was being burned than when tire derived fuel was not being burned. Again, it is probably best to use the combined data set to represent the functioning of SNCR at this cement plant.

These data show that stack gas NOx is reduced by approximately 0.8 pound-moles with the injection of 1.0 pound-mole of ammonia. The data further show that this relationship is linear over the injection rates tested (molar ratios between 0.1 and 1.0). This indicates an ammonia utilization efficiency of about 80 percent.

The other part of the NOx control efficiency tests was to set a stack gas NOx concentration and to maintain this concentration over an extended period of time by varying the ammonia injection rate. This was done for an approximate 16-hour period between 1800 hours on December 9 and 1000 hours on December 10, 2004. The ammonia injection rate (liters per hour) and the stack gas NOx concentration (ppm) for this period of time are presented in Figure 6. These data show (for the limited period of this test) that it is possible to maintain a relatively constant NOx emission rate by varying the ammonia injection rate.

For the period, the stack gas NOx concentration averaged approximately 130 ppm (equivalent to an NOx emission rate of 1.80 pounds per ton of clinker). The ammonia injection rate for the period ranged from approximately 200-400 liters per hour (equivalent to molar ratios of NH_3/NOx of 0.35-0.70).

6.2 Carbon Monoxide and Ammonia Emissions

Carbon monoxide and ammonia concentrations were measured in the kiln/raw mill stack during the SNCR test period in accordance with the general procedures of EPA Methods 10 and 320, respectively.

6.2.1 Carbon Monoxide Emissions

The carbon monoxide emissions (pound-mole per hour) are presented graphically in Figures 3 and 4 for periods when tire derived fuel was fired and periods when no tire derived fuel was fired. During the period when tire derived fuel was fired (Figure 3a-c) the CO emissions were generally quite variable and no trend between ammonia injection and CO emissions is discernible. During the period when no tire derived fuel was fired (Figure 4) the CO emissions were more stable; especially during the first part of the test period. From these data, a trend of increased CO emissions is observed when ammonia was injected. This is consistent with previous Polysius observations and the reactions between ammonia, CO, and NOx discussed in Section 2.0.

Until more experience is gathered defining the relationship between CO emissions and the injection of ammonia, FRI is comfortable with the CO emission limit proposed in the Air Construction Permit Application for Line No. 2 of 3.6 pounds of CO per ton of clinker.

6.2.2 Ammonia Emissions

The continuous monitoring of ammonia in the kiln/raw mill stack demonstrated that during most periods of time when the raw mill was operating, very little to no ammonia was observed in the stack gas. When the raw mill was not operating, however, the ammonia concentration in the stack gas peaked at approximately 40 ppm (v/v) (See Figure 7a-7b).

This indicates that the unreacted ammonia is absorbed in the raw materials in the raw mill and recirculated until such time that the raw mill shuts down. With the raw mill down, some of the absorbed ammonia is purged from the system.

Due to the limited period of time over which the SNCR tests were conducted at FRI (six days), no definitive conclusion can be reached regarding long-term ammonia emissions during the operation of an SNCR system.

It appears that long term, an ammonia equilibrium would be reached in the plant and that some ammonia slip may occur even with the raw mill running. The majority of the unreacted ammonia would more than likely still be purged during periods when the raw mill is not operating. The long-term effect of ammonia emissions can only be determined with the continuous operation of an SNCR system.

6.3 SNCR Cost Estimate

The SNCR system is relatively easy to install and operate compared with other add-on NOx control systems. Additionally, the operational costs (reagent, variable operating cost, and capital return) are relatively low compared with other systems and the SNCR system offers considerable operating flexibility.

In general, an SNCR system would include:

- an ammonia storage tank,
- a redundant pumping system,
- a control system,
- a set of injectors, and
- the necessary piping.

The system can be installed in a relatively short period of time with minimal plant downtime.

Based on data provided by Polysius and others, the basic fixed costs associated with an SNCR system for the FRI plant are approximately 0.20 dollars per ton of clinker.

The operating cost can vary considerably depending on the source of ammonia and the ammonia injection rate. For purposes of this report, the ammonia considered was a 10 percent aqua ammonia solution at a delivered cost of $145 per ton of solution ($1,450 per ton of ammonia).

The cost data developed from data collected during the SNCR test period at FRI are presented in Figure 8. These data show the costs of an SNCR system (operating cost plus capital recovery) to reduce NOx emissions from a range of uncontrolled emission rates to a range of targeted controlled emission rates. For example, to reduce NOx emissions from 3.5 pounds per ton of clinker (uncontrolled) to 2.0 pounds per ton of clinker (controlled), the cost would be about 0.60 dollars per ton of clinker.

7.0 CONCLUSION

The six-day SNCR test at FRI demonstrated the apparent feasibility of SNCR for controlling NOx emissions from the FRI cement plant. NOx emissions were reduced between 7 and 82 percent with ammonia injected at molar ratios between 0.1 and 1.0. Limited testing also demonstrated that a relatively constant NOx level can be maintained in the kiln/raw mill stack gas by varying the ammonia injection rate.

Factors that could not be totally evaluated because of the short duration of the tests include the long-term ammonia equilibrium in the kiln/raw mill system and the effect of this equilibrium on ammonia emissions both during periods with the raw mill operating and with the raw mill not operating. Other factors that could not be fully evaluated are the long-term effect of ammonia on overall plant operations and the product quality and the effect of operating an SNCR system while using tire derived fuel.

The tests did demonstrate that SNCR is effective for controlling NOx emissions during normal plant operations. Because of the temperature dependency of the reactions associated with SNCR, it is apparent that SNCR will not be effective during plant startups and during periods of plant upset. There will also be periods of downtime for the SNCR system. During periods of startup, plant malfunction and SNCR system downtime, NOx emissions can be controlled using best operating practices and Multi-Stage Combustion.

Table 1. Summary of NOx Control Efficiency Data

Test Condition	Uncontrolled NOx (as NO2)		Controlled NOx (as NO2)		NH3 as NH3	Molar Ratio (NH3/NOx)	NOx Reduction (%)
	(lb/ton Cl)	(lb-mol/hr)	(lb/ton cl)	(lb-mol/hr)	(lb-mol/hr)		lb/ton Cl basis
With Tires	3.10	6.83	2.05	4.63	0.84	0.12	33.9
	2.86	6.03	1.76	3.76	1.14	0.19	38.5
	3.17	7.02	2.07	4.62	1.78	0.25	34.7
	3.20	7.08	1.96	4.34	2.42	0.34	38.8
	3.28	7.34	1.52	3.43	3.73	0.51	53.7
	3.32	7.47	1.06	2.36	4.75	0.64	68.1
Without Tires	4.46	9.54	4.17	9.01	0.88	0.09	6.5
	4.21	9.00	3.46	7.88	1.85	0.21	17.8
	3.74	8.01	2.64	6.09	2.78	0.35	29.4
	3.59	7.68	1.90	4.10	3.64	0.47	47.1
	3.55	7.63	0.87	1.84	6.10	0.80	75.5
	3.17	6.91	0.58	1.26	7.19	1.04	81.7

Figure 1

Kiln Operating Rate During SNCR Tests

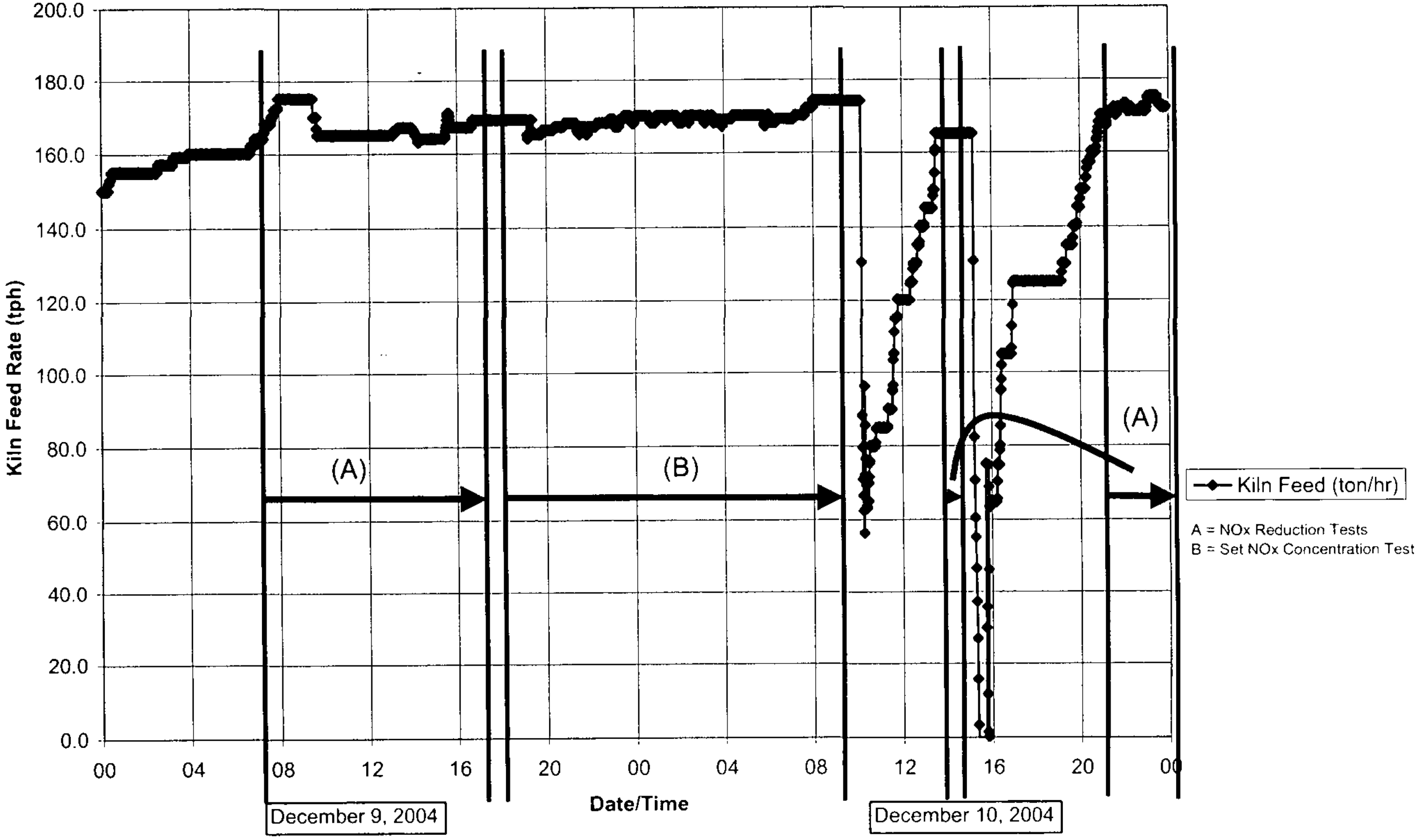


Figure 2

NOx Control Efficiency as a Function of NH3/NOx Molar Ratio

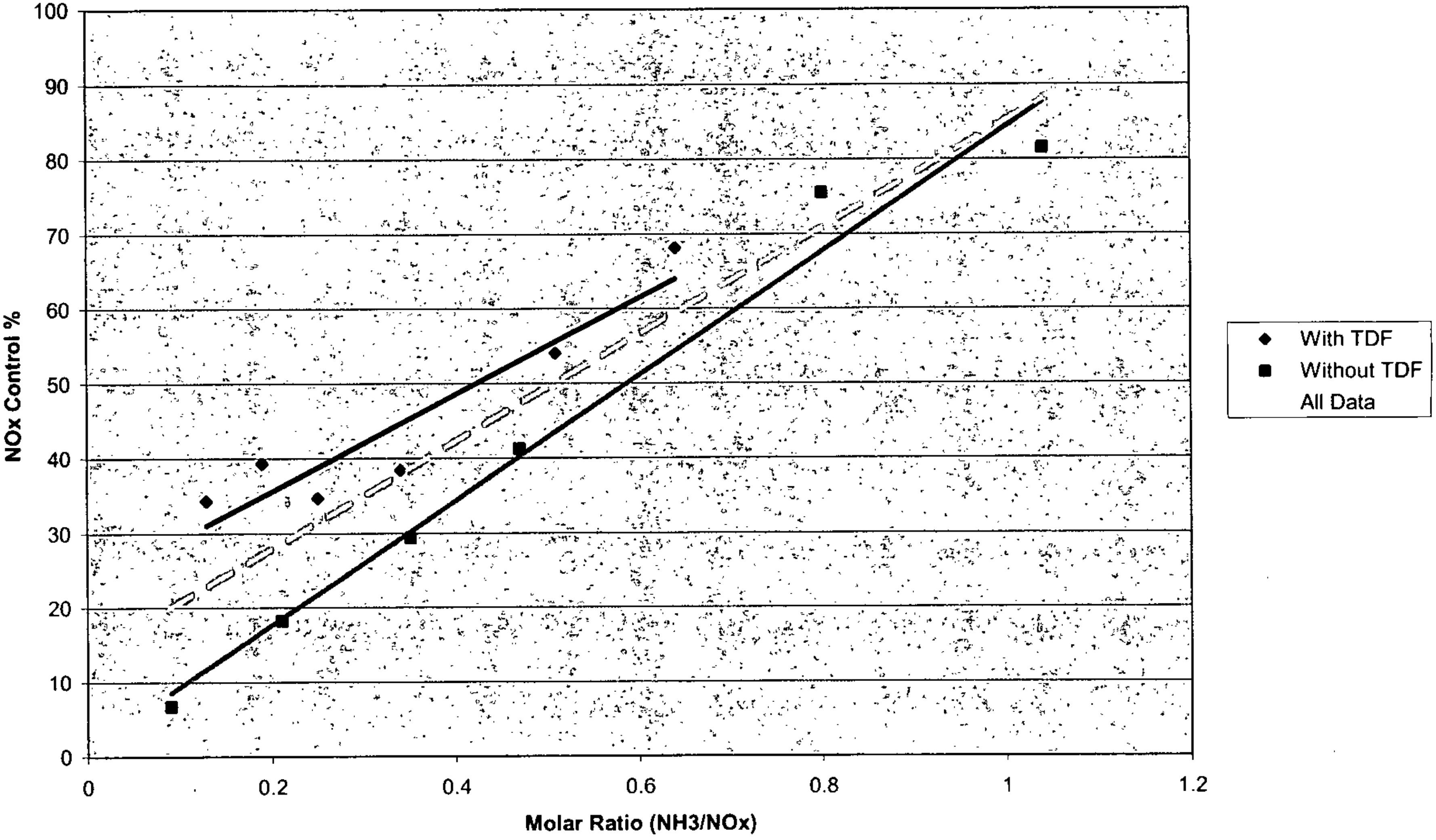
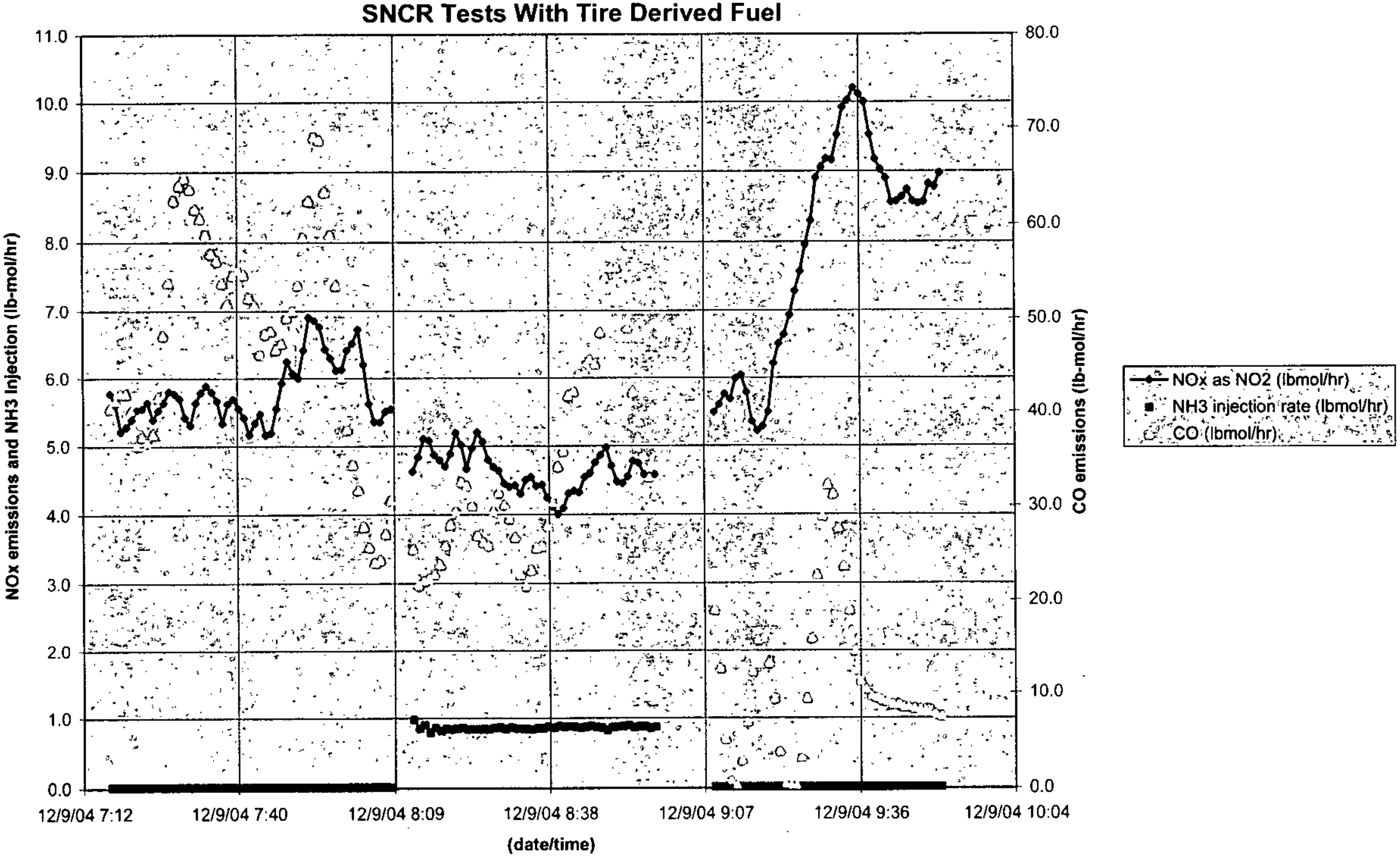


Figure 3a



SNCR Tests With Tire Derived Fuel
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
NOx emissions and NH3 Injection (lb-mol/hr)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
CO emissions (lb-mol/hr)
12/9/04 7:12
12/9/04 7:40
12/9/04 8:09
12/9/04 8:38
12/9/04 9:07
12/9/04 9:36
12/9/04 10:04
(date/time)
NOx as NO2 (lbmol/hr)
NH3 injection rate (lbmol/hr)
CO (lbmol/hr)

Figure 3b

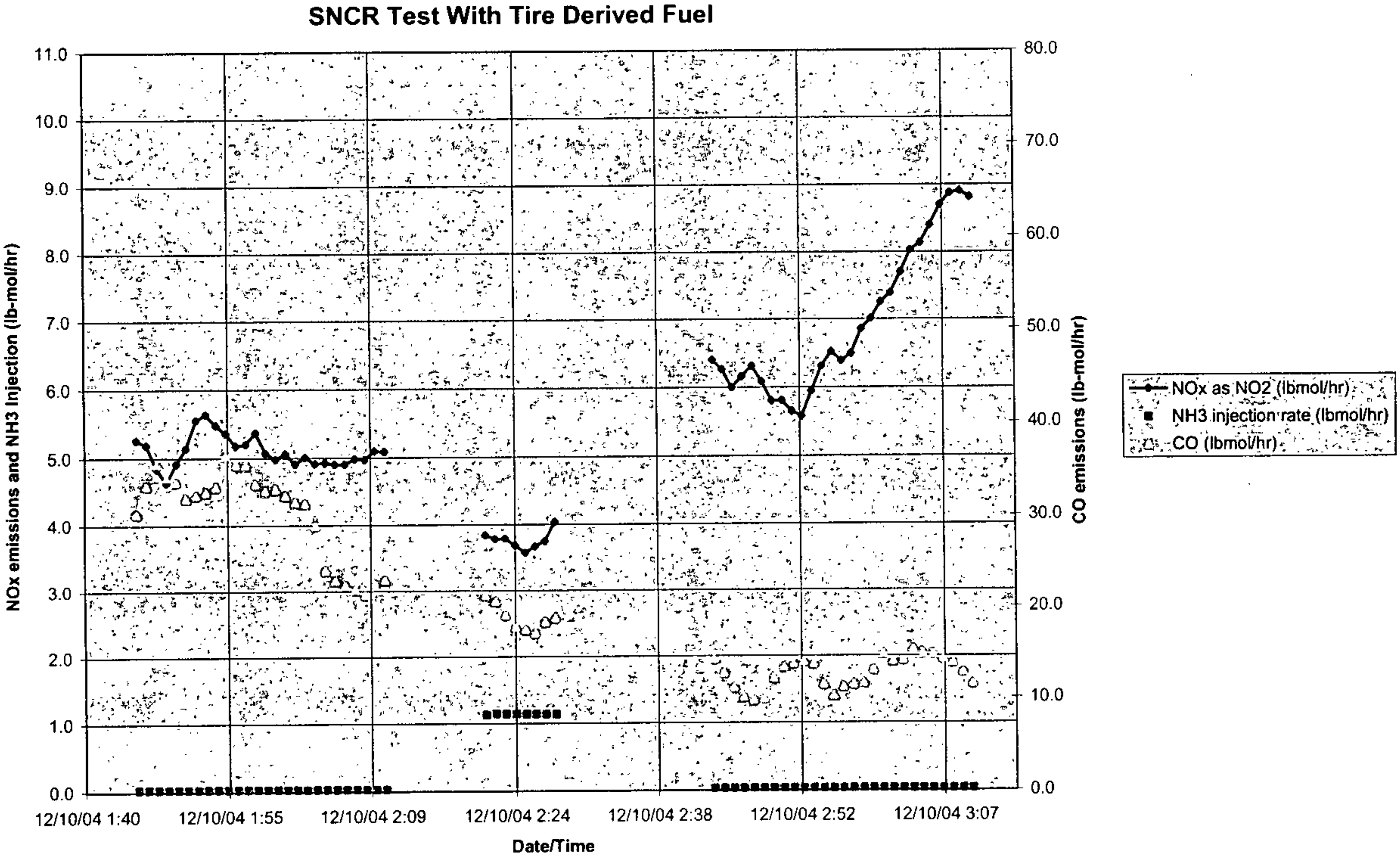

SNCR Test With Tire Derived Fuel
NOx emissions and NH3 Injection (lb-mol/hr)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
CO emissions (lb-mol/hr)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
12/10/04 1:40
12/10/04 1:55
12/10/04 2:09
12/10/04 2:24
12/10/04 2:38
12/10/04 2:52
12/10/04 3:07
Date/Time
NOx as NO2 (lbmol/hr)
NH3 injection rate (lbmol/hr)
CO (lbmol/hr)

Figure 3c

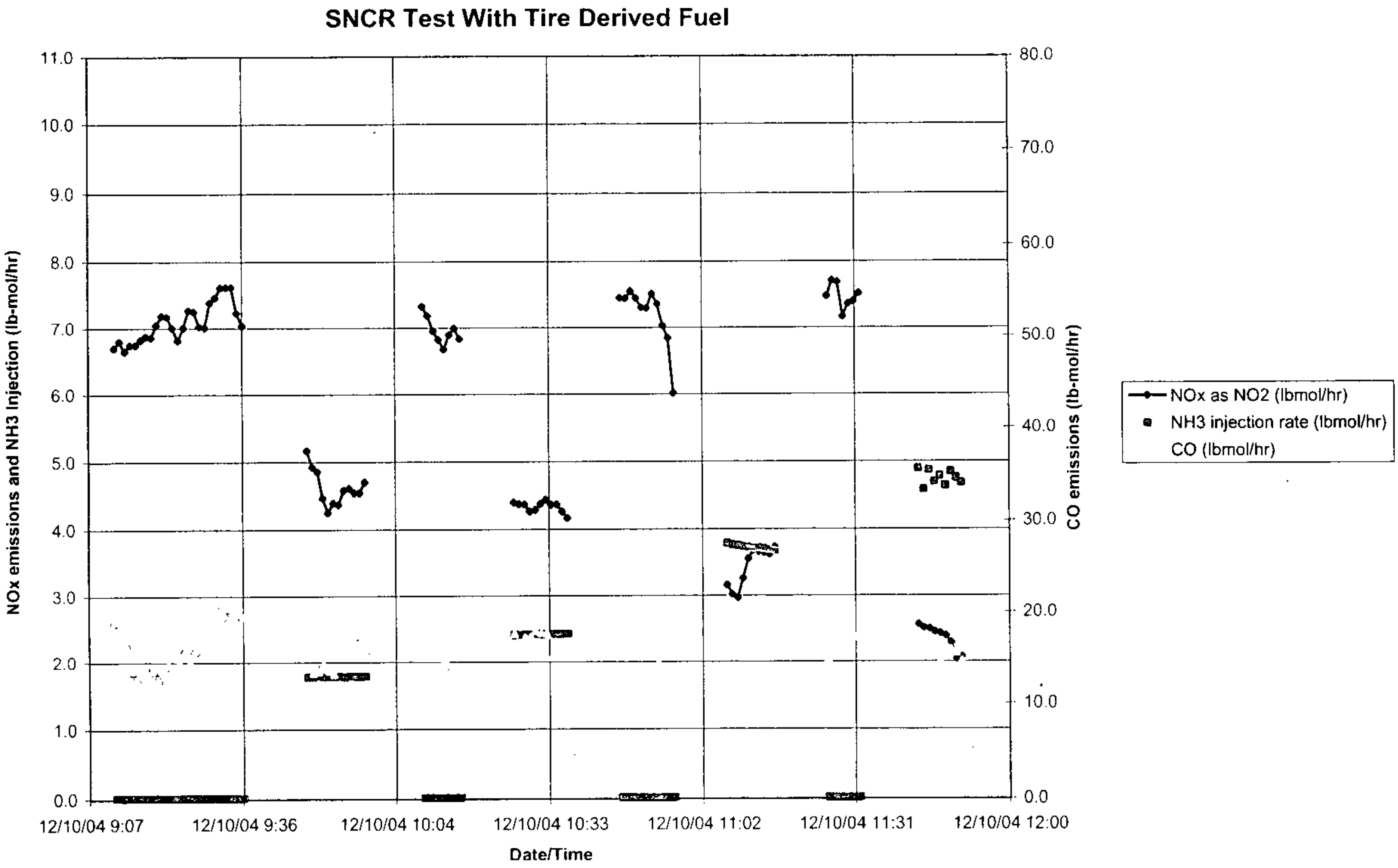

SNCR Test With Tire Derived Fuel
NOx emissions and NH3 Injection (lb-mol/hr)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
CO emissions (lb-mol/hr)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
12/10/04 9:07
12/10/04 9:36
12/10/04 10:04
12/10/04 10:33
12/10/04 11:02
12/10/04 11:31
12/10/04 12:00
Date/Time
NOx as NO2 (lbmol/hr)
NH3 injection rate (lbmol/hr)
CO (lbmol/hr)

Figure 4

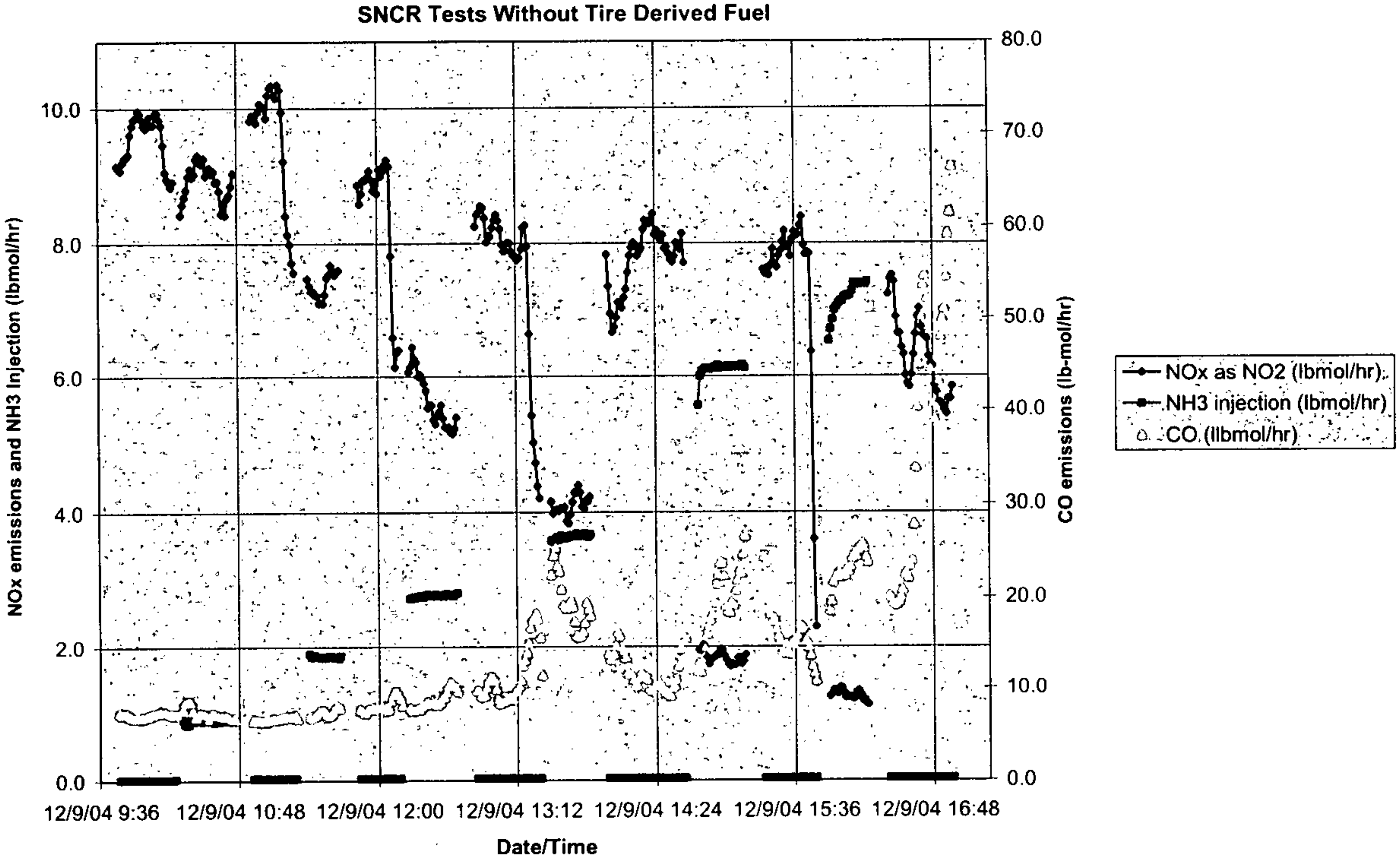

SNCR Tests Without Tire Derived Fuel
NOx emissions and NH3 Injection (lbmol/hr)
10.0
8.0
6.0
4.0
2.0
0.0
CO emissions (lb-mol/hr)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
12/9/04 9:36
12/9/04 10:48
12/9/04 12:00
12/9/04 13:12
12/9/04 14:24
12/9/04 15:36
12/9/04 16:48
Date/Time
NOx as NO2 (lbmol/hr)
NH3 injection (lbmol/hr)
CO (llbmol/hr)

Figure 5
NOx Reduction and Ammonia Injection

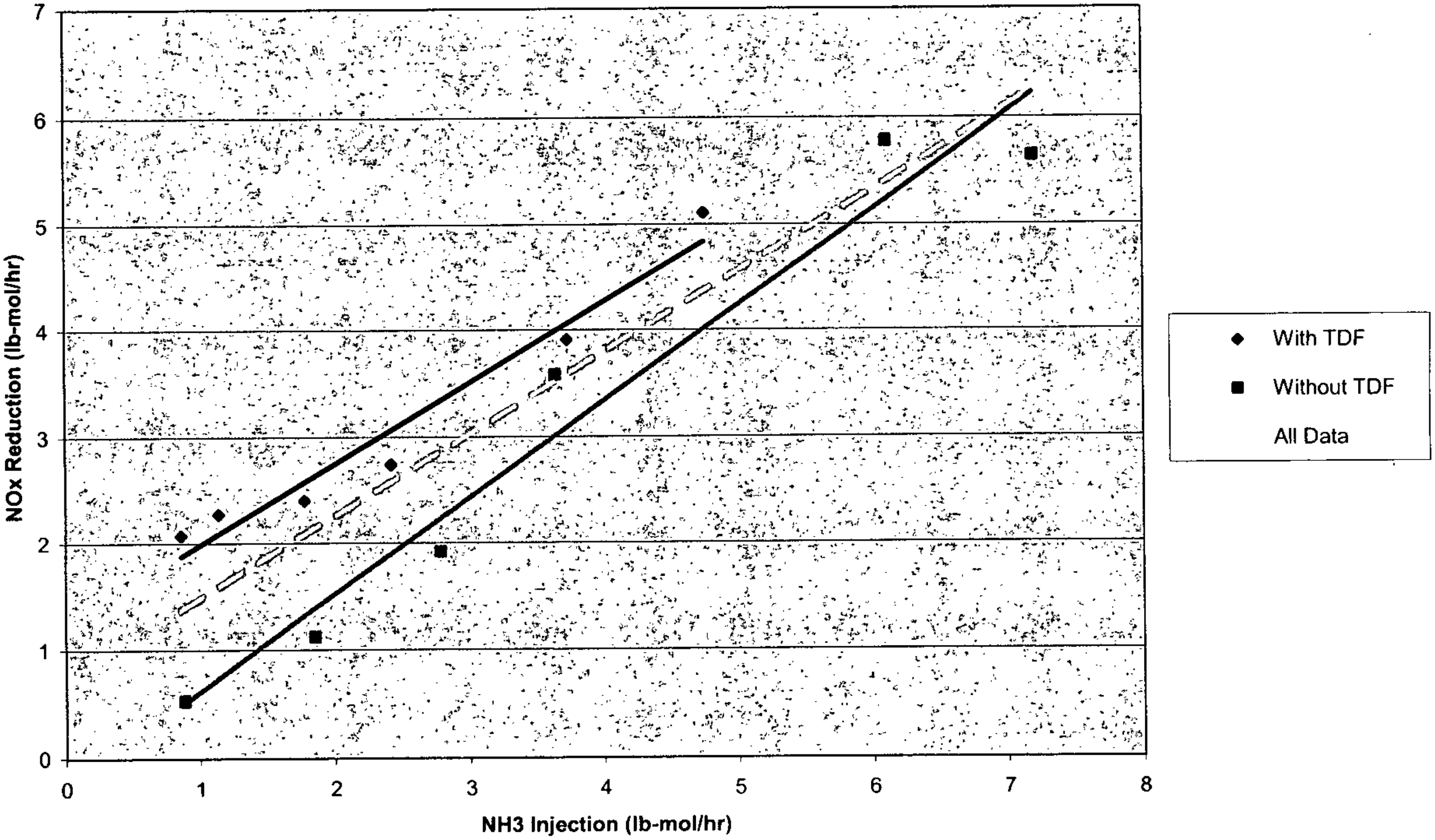


Figure 6

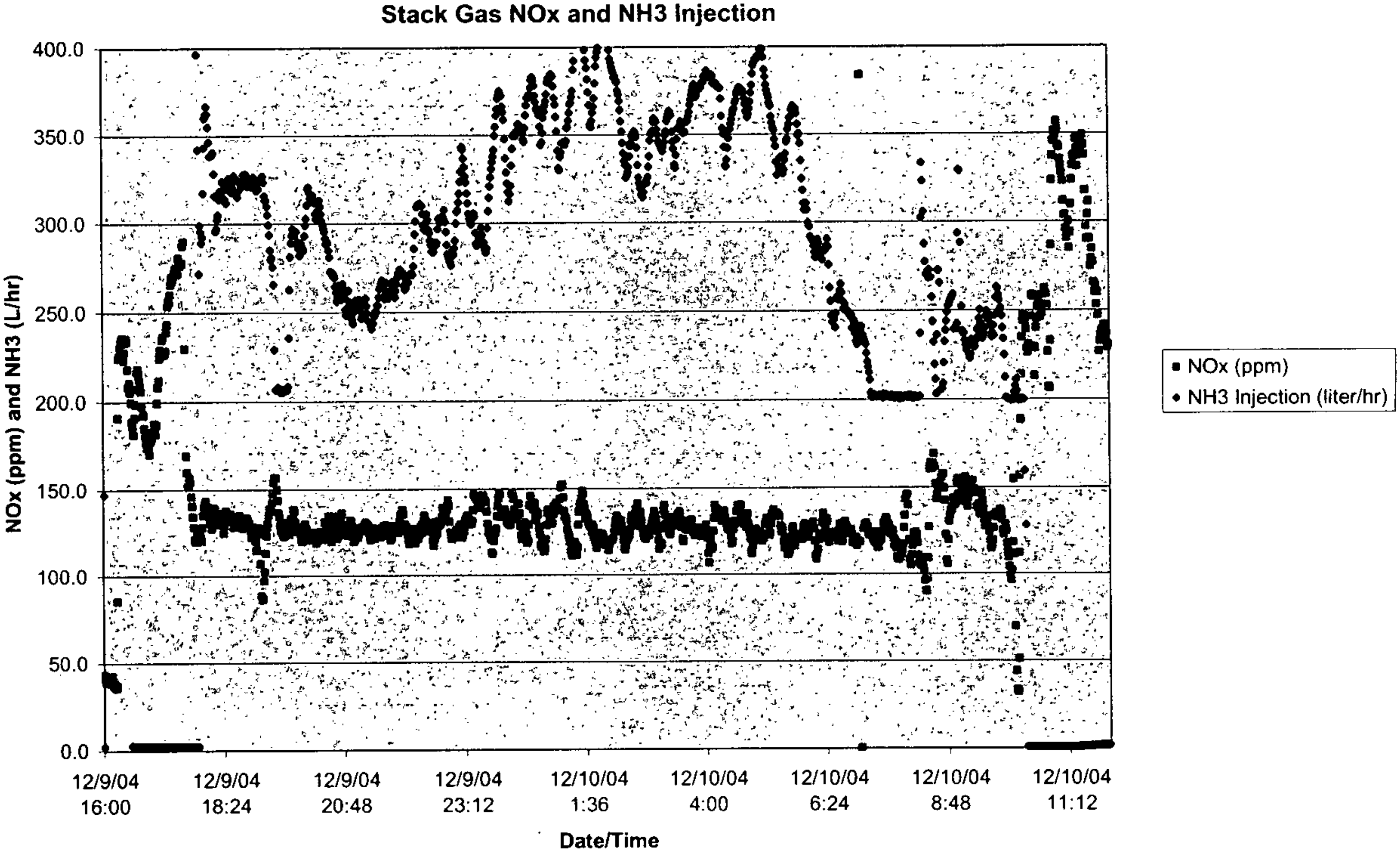

Stack Gas NOx and NH3 Injection
NOx (ppm) and NH3 (L/hr)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
12/9/04 16:00
12/9/04 18:24
12/9/04 20:48
12/9/04 23:12
12/10/04 1:36
12/10/04 4:00
12/10/04 6:24
12/10/04 8:48
12/10/04 11:12
Date/Time
■ NOx (ppm)
◆ NH3 Injection (liter/hr)

Figure 7a

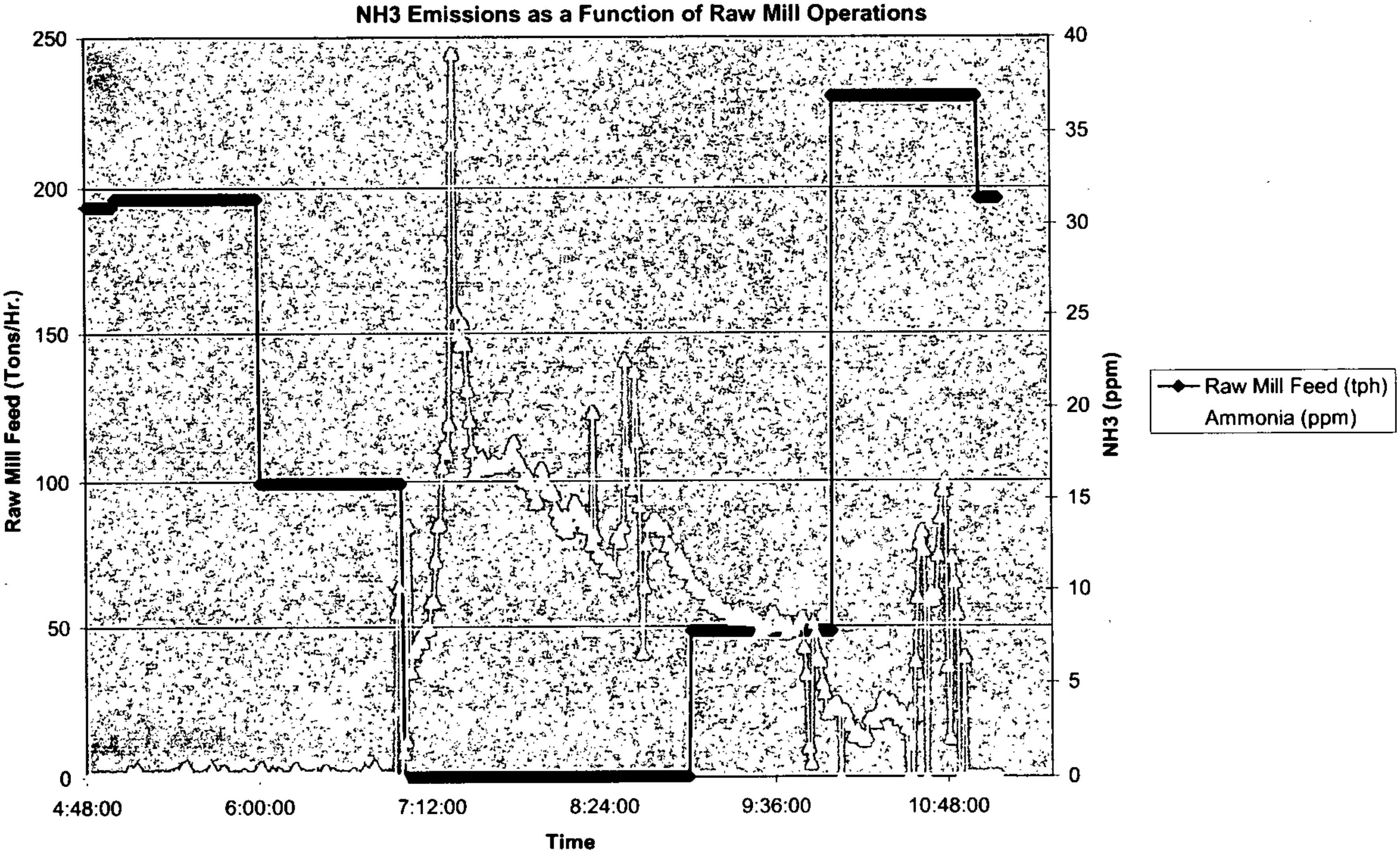

NH3 Emissions as a Function of Raw Mill Operations
Raw Mill Feed (Tons/Hr.)
250
200
150
100
50
0
NH3 (ppm)
40
35
30
25
20
15
10
5
0
4:48:00
6:00:00
7:12:00
8:24:00
9:36:00
10:48:00
Time
Raw Mill Feed (tph)
Ammonia (ppm)

Figure 7b

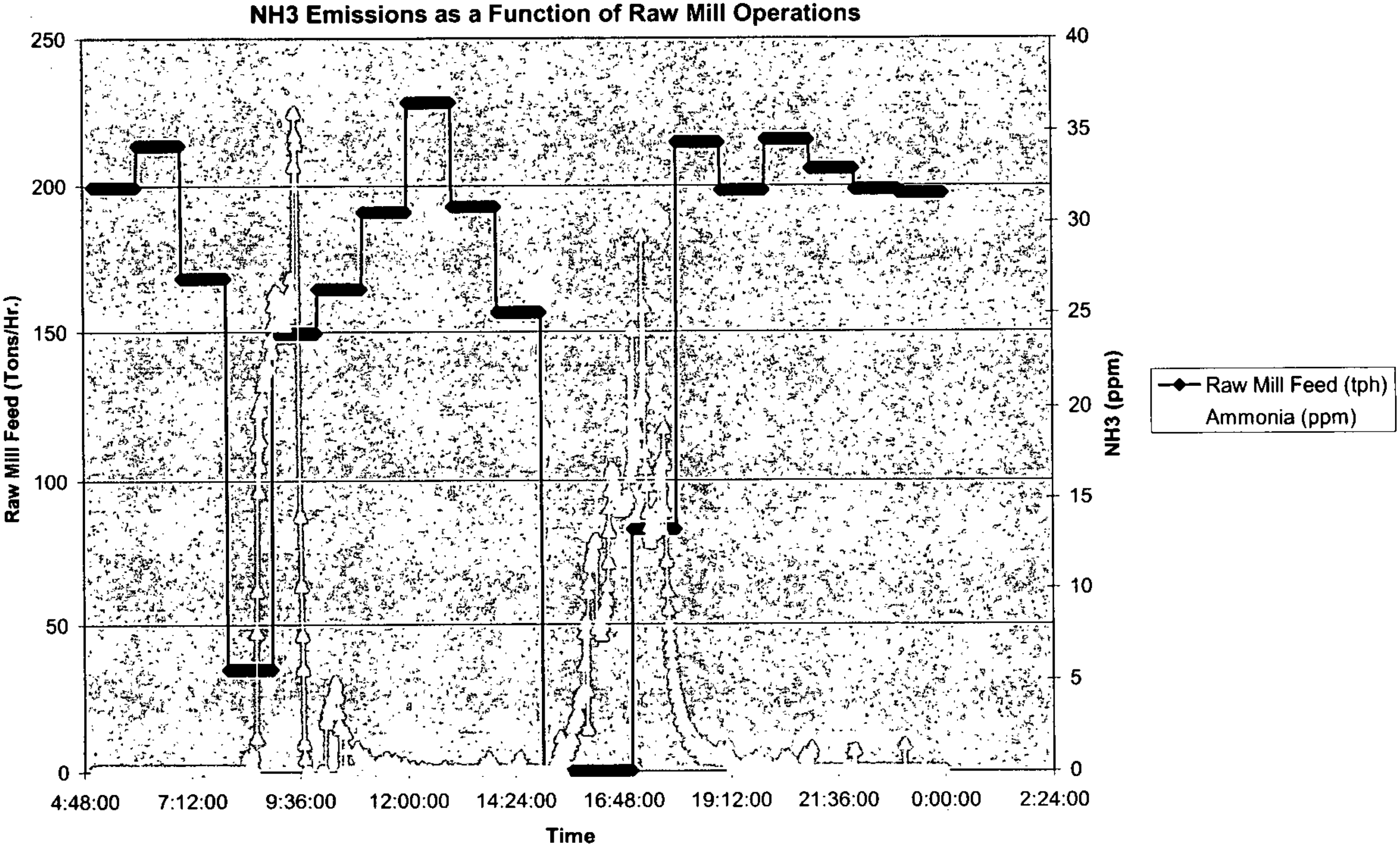

NH3 Emissions as a Function of Raw Mill Operations
Raw Mill Feed (Tons/Hr.)
250
200
150
100
50
0
NH3 (ppm)
40
35
30
25
20
15
10
5
0
4:48:00
7:12:00
9:36:00
12:00:00
14:24:00
16:48:00
19:12:00
21:36:00
0:00:00
2:24:00
Time
Raw Mill Feed (tph)
Ammonia (ppm)

Figure 8
Cost Per Ton of Clinker to Reduce NOx from an Uncontrolled Emission Rate to a Target Rate