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CEMENT KILN NOx REDUCTION EXPERIENCE USING THE NOxOUT® PROCESS

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ABSTRACT

Urea-based Selective Non-Catalytic Reduction (SNCR) is a proven NOx control technology for many types of combustion systems. Cement kilns pose special challenges for the control of NOx emissions. The wide variety of mechanical designs, the process requirement for high combustion temperatures, diverse and changing fuels, NOx generation from multiple locations, and the variability of the NOx emission rates add to the complexity of the challenge.

There have been a number of demonstrations and commercial systems installed for NOx control using a Urea-SNCR process called NOxOUT®. The Urea-SNCR experience in kiln combustion devices includes various designs of long moving-grate kilns, long wet kilns, preheater, and preheater/precalciner kilns for cement production, and coke calcining kilns for petroleum processing. Valuable SNCR design and operation information has been obtained that allows NOx reduction in a cost-effective way, while maintaining efficient cement production.

This paper summarizes our NOx reduction experiences in kiln systems. Specific SNCR performance and the economics associated with two preheater/precalciner types of cement production systems are described.

INTRODUCTION

Fuel Tech, Inc. (FTI) has successfully commissioned over 250 commercial contracts that reduce NOx emissions from stationary sources in many parts of the world. FTI NOx control technologies have been primarily implemented using a Urea-based Selective Non-Catalytic Reduction (SNCR), called the NOxOUT® Process. While the SNCR experience in the cement industry has been relatively limited, FTI has conducted over ten (10) demonstrations in various types of cement kiln systems worldwide. The growing need for NOx reduction, and the increasing awareness of NOx control capability using the SNCR technology, resulted in a new commercial application involving two precalciner/preheater style cement kilns.

Cement production emits substantial quantities of NOx because of the characteristic flue gas flow and high temperatures required for clinkering. Consequently, there have been many methods evaluated to mitigate and manage these emissions. Around the world, regulatory requirements on NOx emissions have been proposed and implemented. For example, the German Clean Air Standards (TA Luft) of 1986 set the emission limit for cement works, with a provision for progressive updating. The regulatory requirements in 1994 were 800 mg/Nm^3 (ca. 400 ppm) @10% O_2 for retrofit kilns, and 500 mg/Nm^3 (ca. 250 ppm) @10% O_2 (all expressed as NO_2) for new systems. This was modified in 1996 to 0.8 g/Nm^3 for existing kilns and 0.5 g/Nm^3 for new kilns to change the effective decimal accuracy. Actual operations are significantly stricter than the emission limits indicate. This is because TA Luft specifies (in Section 2.1.5) short-term value which is based on the half-hour average value. Since cement manufacturing typically produces large fluctuations in the NOx concentrations, the average emission values have to be significantly lower than the emission limits.

In Taiwan, the New Suspension Heater (NSP) type of existing cement kiln is now required to meet a limit of 650 ppm (all referencing 10% O_2) standard; whereas, a 500 ppm standard is required for a Suspension Heater (SP) type of existing kiln. For the new cement kilns, the NOx standards vary (350, 400, to 450 ppm), depending on the stack height (75-85 m, 85-100 m, and $\geq$100 m respectively). These standards are now being tightened. Simultaneous to progressive updating, the Taiwan EPA instituted an emission control incentive program. The

NOx emission fee is reduced 50% when a control measure is implemented and operated at 25% below the emission standard. When a plant operates the NOx control system at 50% below the emission standard, the emission fee is reduced to 25%. The fee is further reduced to 12.5% when the plant operates the emission control at 70% NOx reduction relative to the standard. The owner/operator will benefit from the incentive two ways. First, the NOx emission fee is greatly reduced, and second, the payment is based on a lowered emission mass, rather than the untreated quantity.

In the U.S., the Ozone Transport Assessment Group (OTAG) consists of air quality representatives of thirty-seven (37) states, formed to achieve a consensus of NOx control strategy for all the states affected by ozone transport. The OTAG was formed following a modeled demonstration of non-attainment in the northeast, even with all sources shutdown. The State Implementation Plan (SIP) call issued on October 10, 1997 requires states to issue NOx reduction rules to minimize ozone transport and adapts the most stringent OTAG recommendations for stationary sources. The final rule of NOx SIP call issued on September 24, 1998 recommends that states reduce cement kiln NOx emissions by 30% from uncontrolled levels.

As a technology supplier, FTI has successfully demonstrated the NOxOUT® system's cost-performance on cement kilns in Germany, France, Korea, Taiwan, and the U.S. (Table I). However, the market's understanding of NOx-reducing system performance, cost, and application conditions is generally limited. A recent paper[1] describes the economics in a range of US$ 2,300-3,400 per metric ton (m.t.) of NOx removed for an ammonia-SNCR system installed on a preheater or precalciner kiln. The NOx reduction obtained by ammonia-SNCR ranges from 15 to 65% and averages 30%. It also states that the SNCR process may increase carbon monoxide, ammonia, and/or ammonium salts emissions as detached plumes. The combustion economics is reported to show a loss of 15% on average, with a range from 0 to 30%. This results from combustion modifications, such as installing Low NOx Burners (LNBs) with indirect firing, which has a reported cost from US$6,400 to 8,900/m.t. NOx removed. Secondary combustion by mid-kiln firing of fuel is reported to have a cost range from US$2,900 to 4,100 per m.t. NOx removed. Another paper[2] describes the SNCR cost between US$ 2,300-5,200/ton NOx removed with performance range of 15-75% NOx reduction. These reported costs are substantially higher than those typically associated with NOx control methods, by as much as a factor of 10. As will be described later in this paper, the NOxOUT™ process offers good NOx reduction with reasonable costs that are substantially lower than the previously reported economics.[1,2]

EFFECTIVE NOx CONTROL TECHNOLOGIES

NOx control technologies are generally classified as combustion modifications, selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR) and their combinations. Combustion modifications include LNBs, overfire air, mid-kiln firing of fuel, and staged combustion of various methods.

Combustion Modifications

While staging combustion, air or fuel, can be used to reduce the NOx emissions, the extent of low-NOx burner performance is limited because a high temperature zone (>1,450° C or 2,650° F) is required to sinter the clinker. Staging the combustion air while maintaining desirable oxygen level in the burner in a cement kiln can be extremely difficult, given the temperature sensitivity of NOx formation and the process requirement for high temperature. The increase of carbon monoxide (CO) levels, as the result of LNB, is unfavorable to the necessary oxidation of clinker components, whether it occurs in the high-temperature sintering or lower-temperature calcination sections. Some kiln operators have tried to use low NOx burners, and found them difficult to control. This is especially true when they are installed in the kiln, as opposed to the calciner section. There have been some successes in using low primary air burners for rotary kilns in Germany; however, the level of reduction was limited (to < 30%). Another abatement option may be a staged combustion for the precalciner section of the system. The staged combustion can reduce NOx to a lower level; however, this involves significant modifications of the precalciner system and the operation of the kiln. The bottom of the precalciner may be used as a reducing zone; whereas, the excess CO is oxidized in upper precalciner. The calcination and sintering properties may be negatively changed as a result. Certain

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acidic compounds may form a hard and corrosive scale on the bottom of the precalciner, especially in systems that use tires or combustible waste as supplemental fuels. There may be unexpected release of unwanted pollutants in various post-kiln sections as a result of system modification for staged combustion. Space limitation is also a consideration, as is more complex controls and operations.

SCR

The SCR process is probably the least suitable method for cement or coke calcining kilns. Because of the high dust load, there is an unacceptable potential of particulate fouling and poisoning of the catalyst, notably by various alkaline or acidic salts, and metals in the flue gas.

SNCR

Generally, cement-making kilns, burning coal, produce a NOx baseline between 200-1,000 ppm (@ 6% O_2). A higher NOx baseline makes the SNCR reactions more kinetically effective. SNCR performance depends on the availability of chemical injection points in locations where the temperature and residence times are both favorable for the SNCR reactions. Kiln systems are generally more complex designs for NOx reduction, because of the possibility of multiple treatment locations such as the kiln, preheater, and calciner. The exit section of the kiln and the bottom of the suspension preheater are frequently proposed injection locations for SNCR reagent. The confined space in the injection zone allows efficient contact between the chemical reagent and the flue gas. This results in higher reagent utilization and lower operating cost. In units with no preheaters, it may be feasible to inject the chemical reagent into the rotating kiln at a point where the gas temperature is in the effective temperature window (850-1,150 °C or 1,600-2,100 °F). While FTI uses a stabilized Urea solution for most of these applications, FTI is also evaluating dry dust or pellet injection methods[3] for direct injection into the kilns.

The Urea and Ammonia-based Selective Non-Catalytic Reduction processes have shown effective NOx reduction ability in various types of cement kilns. Experience indicates that the optimum cost-performance level for each kiln may vary widely depending on its specific characteristics. Depending on the fuel and firing conditions, NOx reduction may even change significantly for the same kiln. When suitable temperature, residence time, and NOx baselines can be found, one can generally expect a 40% or greater NOx reduction with the New Suspension Preheater (NSP) and Suspension Preheater (SP) types of systems.

In the Urea reaction with NO, one mole of Urea reacts with two moles of NO to complete the reaction to nitrogen, carbon dioxide and water. Normalized Stoichiometric Ratio (NSR) is used to express the reagent feed rate relative to the reaction stoichiometry. The NSR takes into account of the 2:1 mole ratio of the NO:Urea reaction as the "normalized" ratio. If 50% of the Urea reacts to reduce NO to nitrogen, reduction of 100% NOx occurs at an NSR =2; 80% Reduction at NSR = 1.6; 50% Reduction at NSR = 1.0, etc. SNCR performance improves with increased turbulence or mixing, residence time, and more favorable temperature conditions. A higher NOx baseline generally leads to a higher percentage of NOx reduction.

While both Ammonia and Urea can be used for reagents in cement plants; the health hazards, handling, storage, and government reporting requirements, potential for leakage, and flammability issues associated with ammonia solutions make it generally less desirable than Urea. Anhydrous ammonia imposes an additional explosion danger and is generally not proposed for this type of environment.

SPECIAL CONSIDERATIONS FOR REDUCING NOx IN CEMENT KILNS

Characteristics of NOx in Cement Plants

The NOx reduction systems for cement kilns require special consideration. While "*Thermal NOx*" formed by the combustion air will constitute the majority of NOx emissions, NOx is generated at multiple locations in the precalciner and preheater in addition to the kiln when the system is equipped with them. The "*Fuel NOx and Prompt NOx*" formed by the nitrogen in the fuel provides relatively lower concentrations of NOx; however, the raw mix may also contain nitrogen and/or ammonia which can result in additional NOx emissions. Much of the NOx emissions may come from the precalciner, which may be designed to burn up to 60% of the fuel input, to achieve 80-90% calcination. Higher heat input and a higher degree of calcination in the precalciner will increase the NOx emission from the precalciner relative to the kiln. The NOx removal from the calciner section is therefore much more important in this design. A preheater, burning 5-20% of the fuel, and providing up to 20% calcination, may also emit NOx. However, the quantity will be relatively small compared to the kiln. The heat transfer properties of the raw mix will also influence NOx formation. The nitrogen content of the raw mix may vary, and the variability in gas-solids heat transfer may create local hot spots that magnify NOx generation. The raw mix tends to absorb heat until it can no longer hold it, resulting in a gas release burst. While CO and O_2 content may be monitored and controlled at the exit of the kiln, in the calciner, and in the preheater, it is not uncommon to observe serious CO spikes associated with calcination. The raw mix may also contain unpredictable levels of ammonia, sulfur, and chloride compounds, which then generate their respective emissions.

Design Considerations

Fuel Tech's process evaluation includes the use of Chemical Kinetic Modeling (CKM) and Computational Fluid Dynamic (CFD) Modeling[4-6] with data input from the specific combustion system of interest. CKM and CFD are tools that were developed to predict and guide field SNCR implementation and performance. The FTI CKM uses 31 species in 93 reactions. Among other uses, the CKM is routinely used to analyze the impact of NOx baseline, temperature, residence time, and reagent and CO concentrations on NOx reduction performance. The CFD model employs extensive combustion system information such as configuration, fuel properties, and heat input to compute the resulting fluid dynamics and the impact of reagent injection at various locations. A combustion system is typically divided into 50,000 to 500,000 cells and the CFD model individually computes energy, mass, and momentum balance of each cell with or without the presence of NOx-control reagent.

In performing the process design for a NOx reducing system in a cement plant, it is important to include consideration of the following parameters:

- NOx Baseline Range and Frequency
- Required Controlled NOx Level
- Flue Gas Flow(s)
- Temperature at Injection(s)
- Residence Time
- CO Levels
- O_2 Levels
- Kiln:Caliner Heat Input Ratio
- Kiln Load and Production Rate (e.g., Over-Capacity)

Some of the parameters (e.g., NOx baseline) may show high fluctuations. Therefore, the information needs to not only be accurate, but it must also show the range and frequency of such variations. The temperature information across the equipment is critical, as is the heat-input ratio of the kiln: calciner. It is also important to include the control parameters for clinker quality control (such as CO, O_2 and temperature), and the type of cement produced in the design of the NOx reduction system. This will prevent any potential interference with the two control methods. The heat transfer property of raw mix in the flue gas should also be analyzed to understand heat absorption and heat release. The possibility of continued combustion of coal at the SNCR injection point and its impact on NOx reduction must be assessed as well.

UREA-SNCR NOxOUT® CASE HISTORY IN PRECALCINER/PREHEATER CEMENT KILN SYSTEMS

FTI has conducted a number of demonstrations and commercial projects[7-9] in preheater/precalciner types of cement systems. The designs have included New Suspension Preheater/Precalciner (NSP), Reinforced Suspension Preheater/Precalciner (RSP), and Suspension Preheater/Precalciner (SP) types. The fuels used included coal, and coal in combination with No. 6 heavy fuel oil, waste oil, and/or tire chips. The clinker capacity of these kilns has ranged from approximately 1,000 m.t. to 3,200 m.t. per day. This paper describes a commercial Urea-SNCR application involving two preheater/precalciner style cement kiln systems (Table II).

A. NOx Baseline

The NOx baselines for both kiln systems (A and B) were very erratic. For example (Figure 1):

- The "Daily Average", based on 24 hourly average values is 419 ppm, (with a maximum of 464 ppm = 11% higher than the average; and a minimum of 359 ppm = –14% of the average. The span of the already averaged hourly values in a day is a high 25%. Within an hour, the maximum to minimum NOx Ratio was as high as 2.4 (418 ppm /177 ppm).

- For consecutive hourly average values, the hourly average could increase as much as 70%, and could decrease as much as –25% compared to the previous value.

- The highest to lowest ratio for the NOx baseline for one day is 3.5 (627 ppm/177 ppm).

- On a day with stable production, at full capacity, the NOx baseline became much more stable. Other than two points (1st and last hour), the hourly maximum/minimum NOx ratios were ≤ 1.2. The Daily Average of the hourly average was 427 ppm. The highest span between the maximum and minimum value within an hour was 13% (+6% and –7%). The hourly average changed only ≤10% from one hour to the next.

In real-time monitoring of the NOx level, the SNCR process does not have an untreated NOx baseline that can be compared to the controlled NOx at the same time. Since NOx can be formed and treated at multiple locations, it is overwhelmingly difficult to compute a true NOx baseline. The knowledge that the NOx baseline is constantly changing adds to the difficulty. Consequently, the most convincing performance result may come from statistical analysis of a pool of data (e.g., > 10 average points), rather than simple data points. The accuracy of the statistics is subject to the limitation of the span and fluctuation of the NOx baseline. A before-and-after "cause-effect" type of test can also be meaningful. Because of the high variability in NOx baseline, it is advisable to compare NOx reductions after a baseline of no less than 24 hours and preferably, ≥ 48 hours, followed by the SNCR performance monitoring using the same period of time.

B. Impact of CO and Temperature on NOx Reduction

In addition to NOx baseline, temperature and CO conditions vary as well. This further challenges the effectiveness of the process design and data analysis of a NOx reduction system. The analysis by the CKM model shows:

- A combination of high CO (e.g., ≥ 250 ppm) and low temperature (e.g., ≤ 800 °C) may make the NOx reduction performance erratic and unpredictable.
- NOx reduction vs. the required reagent feed rate (as expressed as NSR or Normalized Stoichiometric Ratio) follows a predictable pattern when there is limited CO (e.g., 10-250 ppm) at 850 °C (Figure 2).

- Temperature at injection of 850-900 °C or higher is preferred over 800 °C in reducing NOx (Figure 3).

The schematics of the two commercial kiln systems, named A and B are shown in Figures 4 and 5. Due to significant historical modifications of the original design, Kiln B represents one of the most complex existing kiln systems among cement plants. Not only is the flue gas split into K (kiln, 40% of flow)- and C (calciner, 60% of flow)-side, the split flue gas re-combines after the calciner and splits again into two flue gas flows prior to reaching the stack. Use of the CFD model (Figures 6 and 7) helped identify the locations suitable for injection zones prior to field commissioning. The CFD model also tracks the trajectories of injected reagent in terms of their streamlines and evaporation rates in the system, followed by a computation of reagent reaction with NOx and the resulting NOx reduction.

C. NOx Reduction Performance

The commissioning data for Kiln A is depicted in Figure 8. Based on a total of 20 data points, 50% NOx reduction from a wide range of NOx baselines (≥ 400 ppm) was achieved with an NSR < 1.43. This was achieved by using only one zone of injectors. This performance was provided even with a NOx baseline which was substantially lower (400 ppm+) than the one used for the process design and performance guarantee (480 ppm).

The coal feed control for Kilns A and B is based on thermocouple readouts at the Cyclone 4 exit. Initially the perceived temperature was lowered, and the coal feed increased by the injection of reagent adjacent to the thermocouple. This was corrected and the problem was solved. As the Table below indicates, there was practically no change in coal feed with, or without Urea-SNCR, in operation.

A switch to petroleum coke and other types of coal did not appear to affect the SNCR operations. Conversely, the SNCR operation did not appear to affect the cement production or the clinker quality produced. Raw mix does appear to have some impact on heat transfer and the resulting temperature evident by corresponding CO spikes. Low NOx baselines (e.g., < 300 ppm) may introduce limitations on the SNCR reaction kinetics to achieve > 45% NOx reduction, especially when the temperature is also low.

The final acceptance test for Kiln A was completed with 24 hours of NOx baseline measurements, followed by 24 hours of Urea-SNCR measurements. The results are tabulated below:

TEST	**BEFORE: SNCR**		
	NOx (ppm)	Coal (m.t./hr)	Cement Production (m.t./hr)
Test I	412	10	90.25
Test II	389	9.66	91.03
TEST	**AFTER: UREA-SNCR**		
	NOx (ppm)	Coal (m.t./hr)	Cement Production (m.t./hr)
Test I	203	9.77	90.48
Test II	185	9.8	90.36

It took longer to optimize the performance of Kiln B, and the results obtained are very encouraging, considering the complexity of the system. After normalizing the flue gas flow to 100%, the NOx reduction obtained on the K-side is between 30 to 60%, at an NSR of 1. On the C-side, the NOx reduction is between 20-60%, at an NSR of 1 (Figure 9). The large fluctuation in the NOx baseline did result in large fluctuation in the controlled NOx.

The final acceptance test for Kiln B was accomplished with 24-hours of NOx baseline measurements, followed by 24 hours of Urea-SNCR. The results are listed below:

BEFORE : SNCR		
NOx (ppm)	Coal (ton/hr)	Cement Production (m.t./hr)
525	16.99	137.6
AFTER: UREA-SNCR		
NOx (ppm)	Coal (ton/hr)	Cement Production (m.t./hr)
283.5	16.97	137.6

Ammonia slip, as measured at the stack (referencing 10% O_2) is undetectable for both Kilns A and B. No negative impact on cement production or other emissions (e.g., CO, SO_2, dust, plume or opacity) were noted.

To summarize, the actual performance suppresses the designed performance despite the adverse factor of NOx baseline. This comparison is listed below:

Guaranteed vs. Actual Performance:

	KILN A	**KILN B**
Design NOx Baseline ppm	~~480 ppm~~	~~590 ppm~~
Actual NOx Baseline ppm	389, 412 ppm	525 ppm
Design % NOx Reduction	~~50 %~~	~~45 %~~
Actual % NOx Reduction	> 50%	46 %
Design Controlled NOx ppm	~~240 ppm~~	~~325 ppm~~
Actual Controlled NOx ppm	185, 203 ppm	284 ppm
Design NSR	~~1.43~~	~~1.29~~
Actual NSR	1.30	1.27
% O_2	10 %	10 %

D. Economics

An optimized SNCR system allows operation with minimum reagent feed (or NSR), and maximum reagent utilization. Due to high flue gas volume and NOx emissions, a properly designed and operated NOx reduction system for Cement plants will provide significant savings in operating cost, relative to the initial investment for process design and control systems. The increase of equipment and design cost relative to annual savings in operating cost is small. Therefore, it is important to seek the most appropriate process design with full consideration of the available injection zones to take advantage of the operating cost savings.

The economics of the NOxOUT® Process is calculated by totaling the cost contribution of the following categories:

- Urea Reagent and Specialty Additive Cost
- Power Cost
- Maintenance Cost
- Manpower Cost
- Urea Preparation and Transport Cost: Water and Solutionizing Steam Cost
- Depreciation of Equipment Cost

In the case of 50% NOx reduction on Kiln A, it is estimated that the annual levelized cost is below US$ 0.75/ton of clinker produced, even after accounting for all the costs. A calculation based on just operating cost, using the local reagent price and equipment depreciation (10 years), results in a Urea-SNCR cost which averages US$500 per ton of NOx removed for Kiln A, and US$600 per ton of NOx removed for Kiln B. The corresponding cost increases relative to the cost of cement production generally varies from 0.5 to 2.5%, depending on the degree of NOx reduction and the complexity of the system.

	NOx REDUCT.	CAPITAL COST, US$	ANNUAL OPERATING COST, US$	ANNUAL LEVELIZED COST/TON NO x REMOVED, US$
Kiln A	50%	500,000 - 750,000	200,000-250,000	400-600
Kiln B	45%	500,000 - 750,000	800,000-1,000,000	400-800

The Urea-SNCR cost numbers are reasonable, because generally a NOx control cost between US$1,000 and 2,000 per ton NOx of removed is considered cost-effective. These costs are even on the lower-end of the Urea-SNCR costs experienced in commercial SNCR applications for electric utilities and other industries.

CONCLUSIONS

Urea-SNCR is an effective technology to reduce NOx emissions produced by cement production systems. The SNCR design is flexible and will accommodate the many complications present in this process. They include a wide variety of mechanical designs, the high combustion temperatures that the process requires, diverse and changing fuels, NOx generation from multiple locations, and the variability of the NOx emission rates. Consequently, positive experiences have come from successful demonstrations and commercial commissioning of the NOxOUT® systems in long moving-grate kilns, long wet kilns, preheater, and preheater/precalciner kilns for cement production, as well as coke calcining kilns for petroleum processing. The annual, levelized Urea-SNCR system cost for reducing NOx by 45-50% for two preheater/precalciner cement kiln systems are US$500 and US$700 per ton of NOx removed. This cost is also reasonable when compared to NOx reducing technologies in general, and to Urea-SNCR costs experienced in electric utilities and other industries.

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TABLE I. Notable Field and Design Experience With the NOxOUT® Urea-SNCR Process.

A. Field Experiences

KILN SYSTEM SUPPLIER	TYPE	FUEL	CLINKER CAPACITY
Fuller	Preheater/Precalciner NSP	Coal/Gas	2,400 tpd
KVS - Svedala	Coke Calcining System	Petroleum Coke	Coke Processing
Allis Mineral-Fuller	Rotary Kiln	Paper Sludge	100,000 lb/hr Flue Gas Flow
Lepol - Polysius	Moving Grate Kiln	Lignite Coal	840, 1,272 mtpd
FCB - Holderbank	Rotary Long Kiln -Wet Process	Coal/Oil	1,500 mtpd
Polysius - Holderbank	Preheater/Precalciner	Coal/Auto Oil/Tire Chips	4,500 mtpd
MIAG - Holderbank	Preheater/Precalciner	Coal/#6 Oil	950 tpd
Lepol	Long Kiln – Dry Process	Coal	1,000 mtpd
Polysius	Preheater/Precalciner NSP	Coal	2,400 mtpd
KHD Humboldt Wedag	Preheater/Precalciner	Coal/Tires	1,400 mtpd
Onoda	Preheater/Precalciner RSP	Coal	2,200 mtpd
FLS	Preheater/Precalciner NSP	Coal	3,200 mtpd

B. Design Experiences

KILN SYSTEM SUPPLIER	TYPE	FUEL	CLINKER CAPACITY
KHD – Humboldt Wedag (2 Units)	Preheater/Precalciner NSP	Coal	2,400, 3,500 mtpd
KRUPP (2 Units)	Preheater/Precalciner	Coal	3,200, 1,300 mtpd
Polysius-Krupp	Preheater/Precalciner NSP	Coal/Tires	270 mmBTU/hr

Table II. Dry Preheater/Precalciner Application Specifics Used in Urea-SNCR Process Design.

A. General Characterization

	Type	Production (MT/hr)	Diameter x Length (m)	Burners	Fuel Ratio
No. 3	RSP	91.67	4∅x63.5	General	55%:45%
No. 5	NSP	133.33	4.55∅x68	General	37%:63%

B. Specific Data of Kilns

	No. 3 Kiln	**No. 5 Kiln**
1. Heat Input to Kiln (Kcal/hr)	4.48 x 10^7	4.34 x 10^7
2. Heat Input to Calciner (Kcal/hr)	3.6 x 10^7	6.47 x 10^7
3. Temp of Combustion, Air to Calciner (°C)	543-620	766
4. O_2 and CO in the Flue Gas, Exiting the Kiln Before Entering the Calciner (%)	O_2: 2.3% CO: 0.06%	O_2: 6.5% CO: 0.01%
5. Flue Gas Flowrate at Kiln Exit (Nm^3/min)	790.4	725
6. Flue Gas Flowrate at the Calciner Exit (Nm^3/min)	618.9	1302
7. NOx at the Exit of Raw Mill ESP (ppm Corrected to 10% O_2)	479.5	No. 1 593 No. 2 585
8. Gas Flowrate at Exit of Raw Mill ESP (Nm^3/min)	3,400	No. 1 3,510 No. 2 4,130
9. O_2 at Exit of Raw Mill ESP (%)	12.2	No. 1 10.3 No. 2 10.7

Figure 1. One-Day NOx Baseline in Cement Plant.

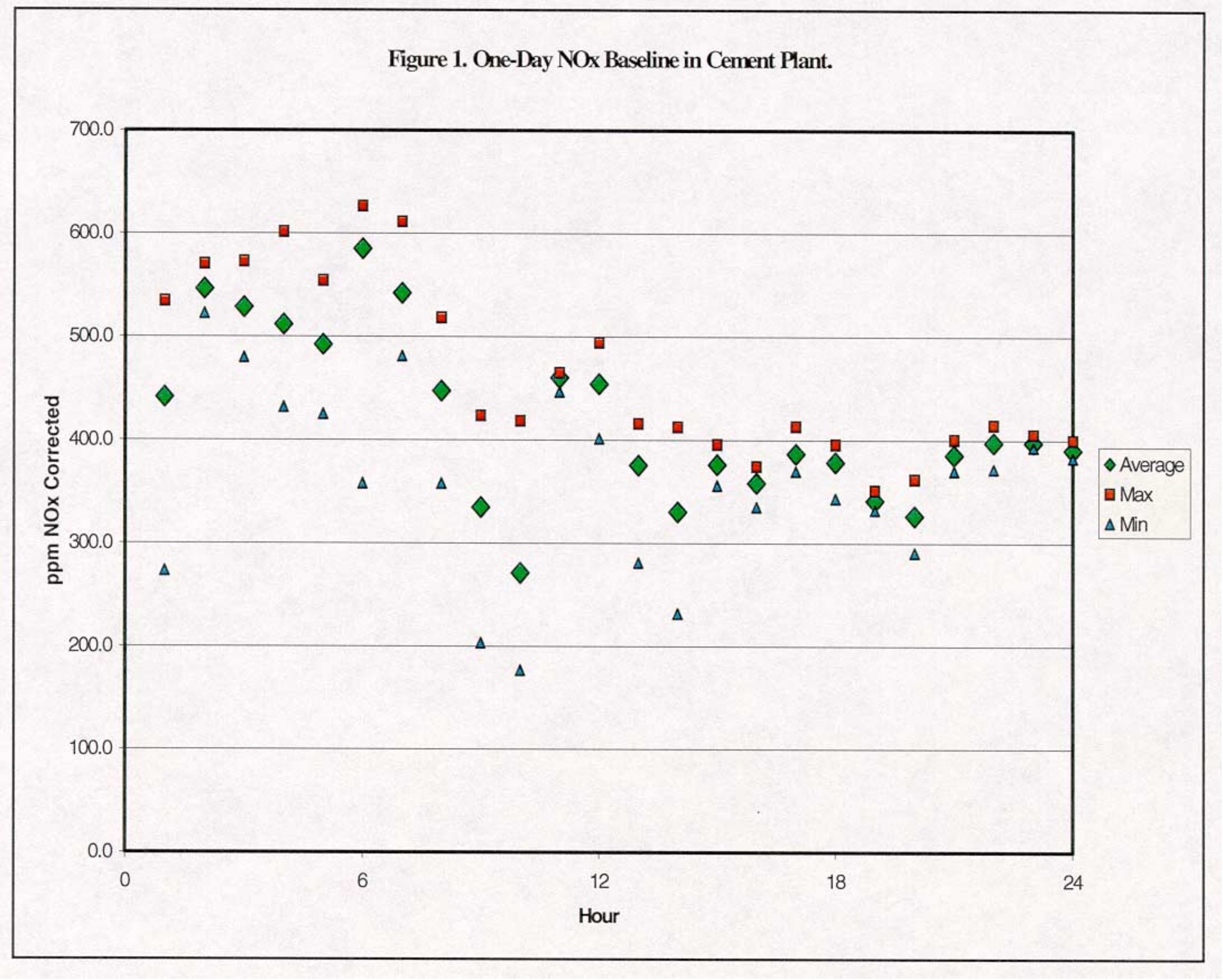


Figure 2. Chemical Kinetic Modeling (CKM) Results for Cement Plant Situation - NOx Reduction as a Function of Urea Normalized Stoichiometric Ratio (NSR) at 850 °C and 10 ppm CO (Based on an Assumption of 100% Efficiency).

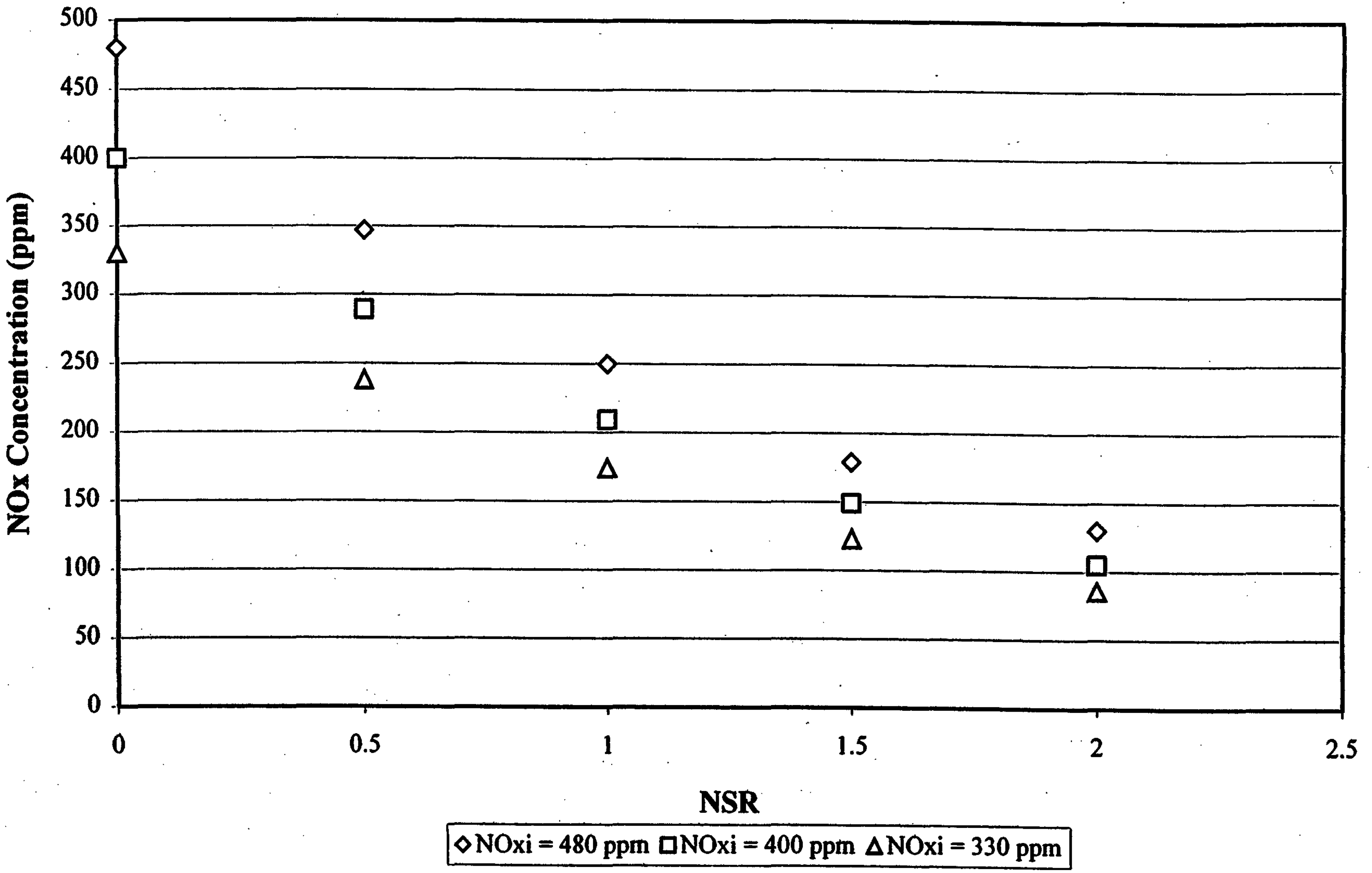


Figure 3. Chemical Kinetic Modeling (CKM) Results for Cement Plant Situation - NOx Reduction as a Function of Urea Normalized Stoichiometric Ratio (NSR) at 900 °C and 250 ppm CO (Based on an Assumption of 100% Efficiency).

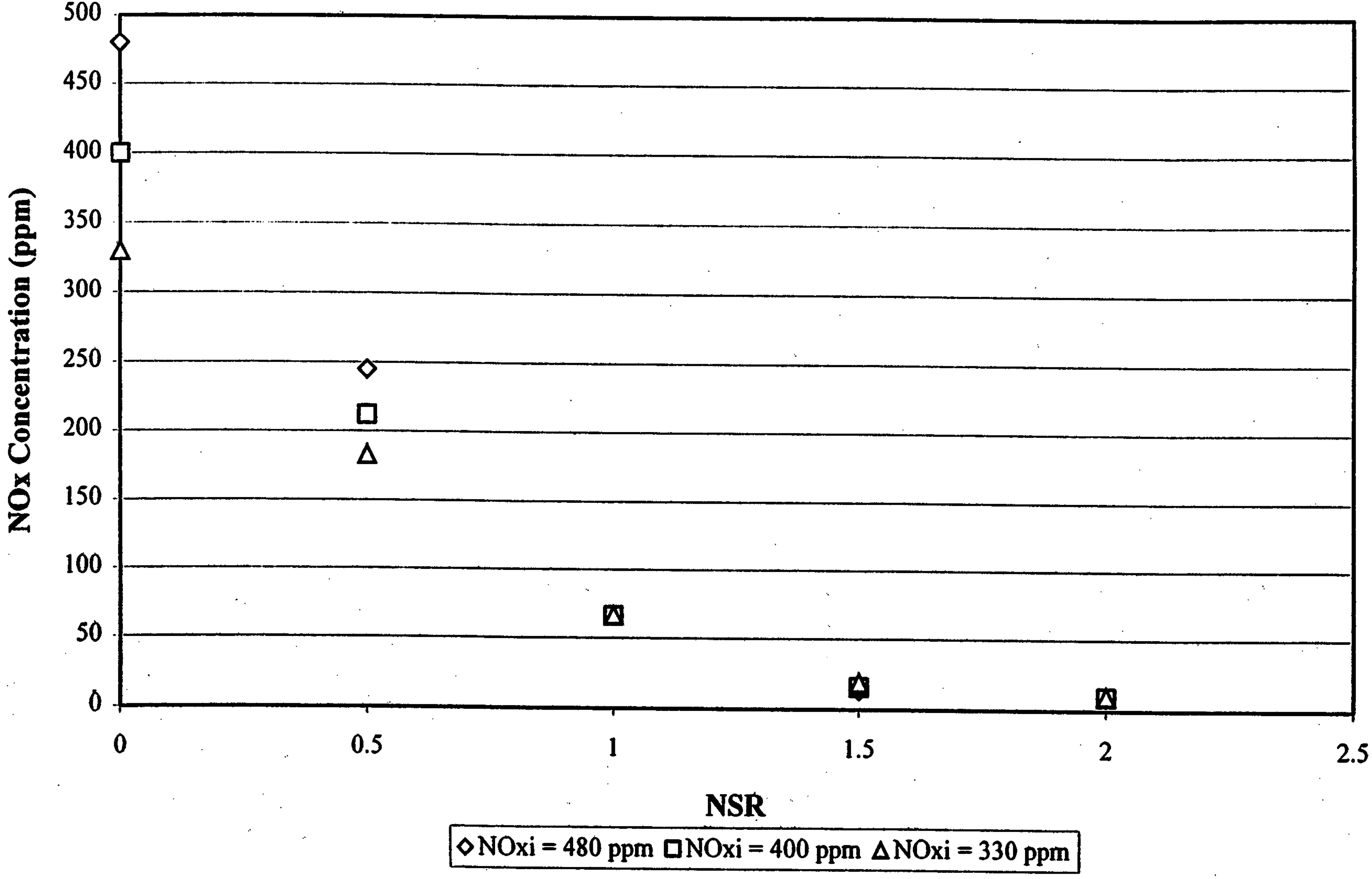


Figure 4. Dry Cement Preheater/Precalciner System - Kiln A.

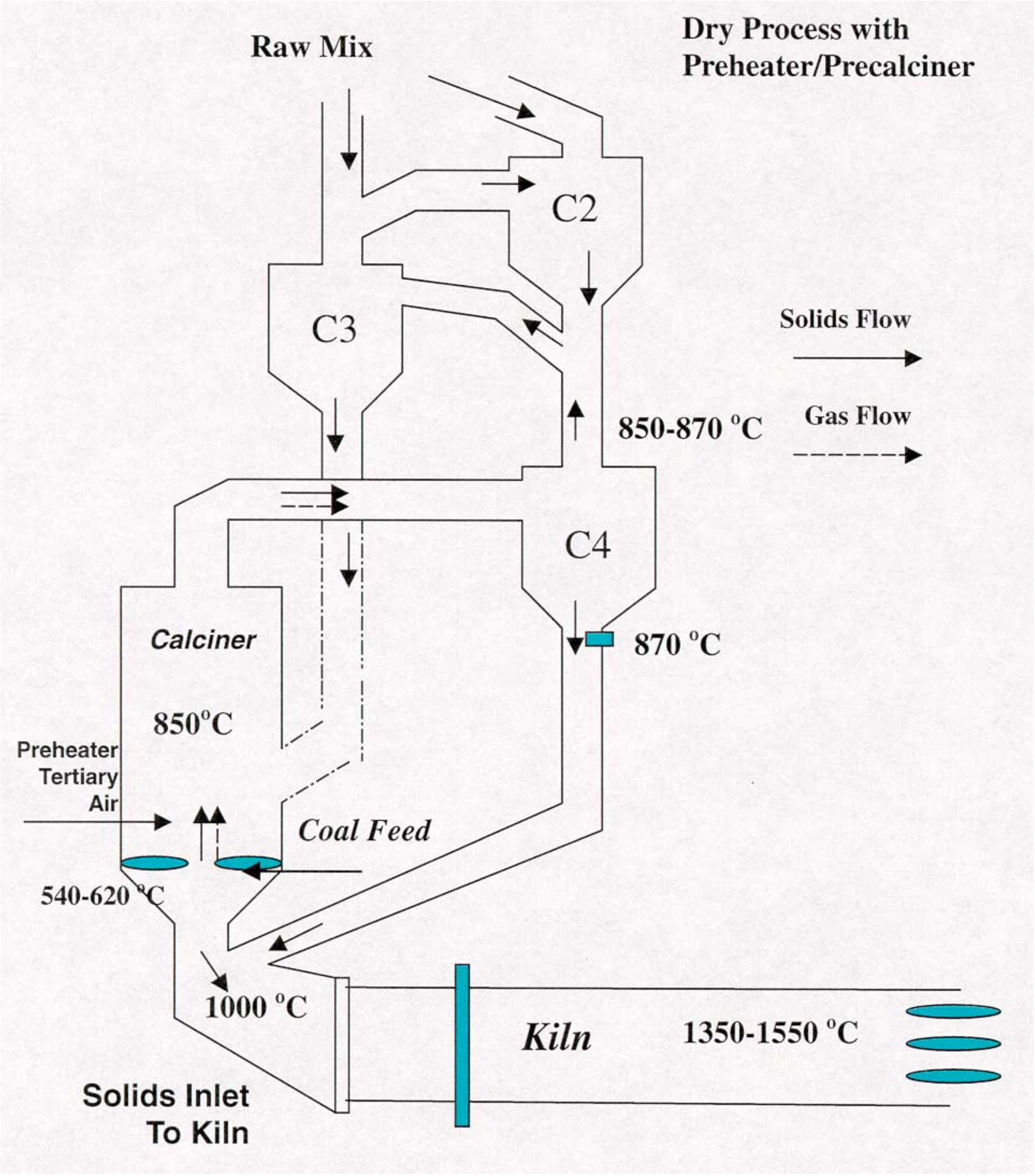


Figure 5. Dry Cement Preheater/Precalciner System 33- Kiln B.

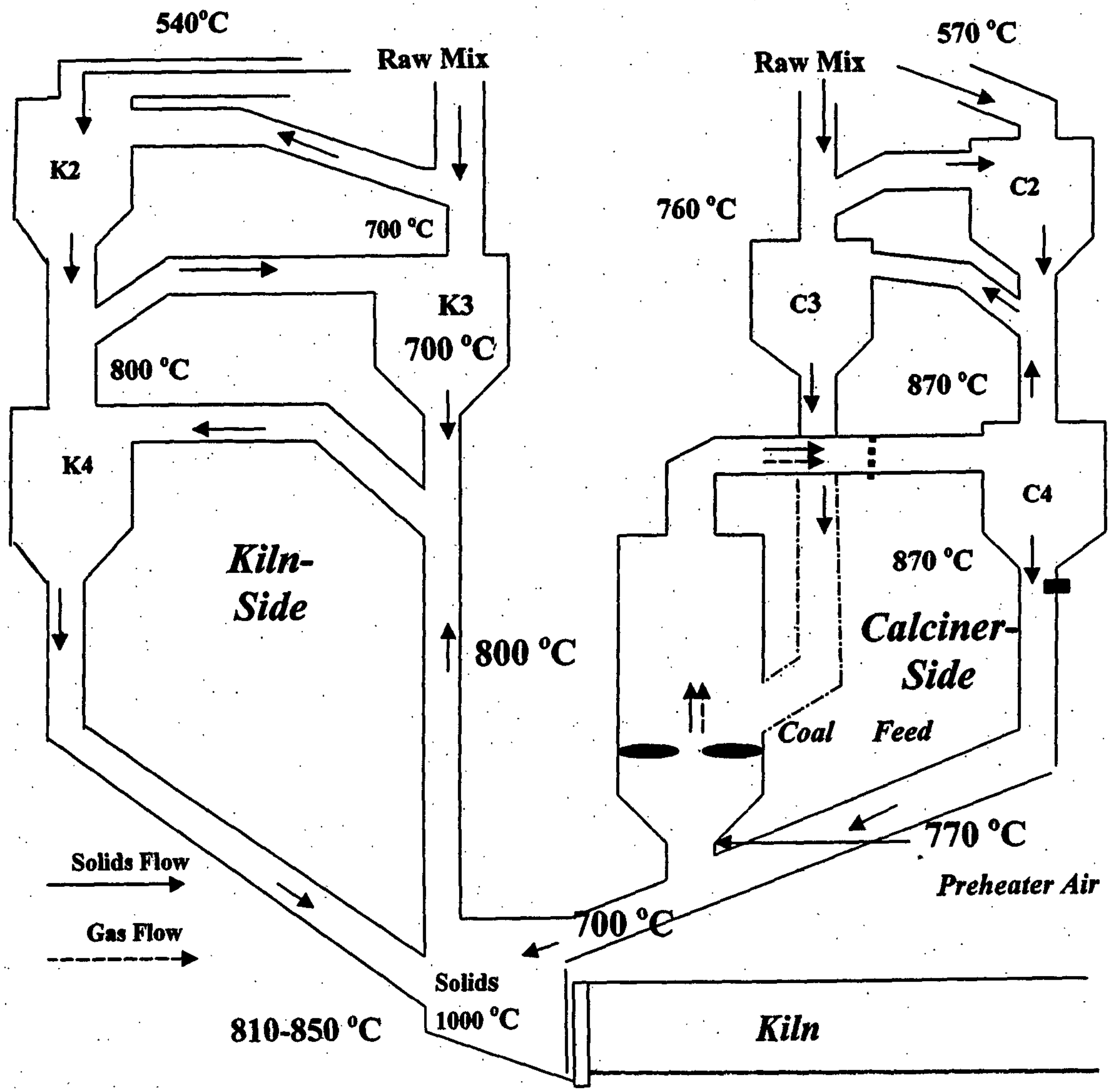


Figure 6. Temperature Profile in Precalciner Computed by Computational Fluid Dynamic (CFD) Modeling.

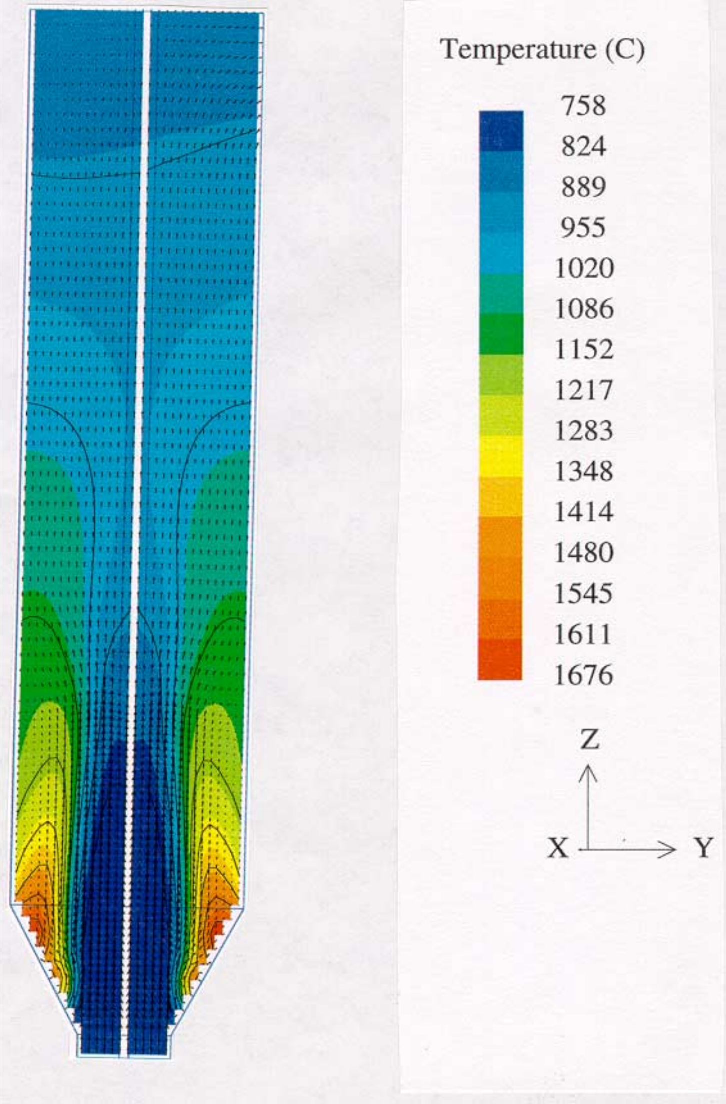


Figure 7. Calciner-Side of Urea Reagent Distribution with Six Injectors in One Zone - Computed by Computational Fluid Dynamic (CFD) Modeling.

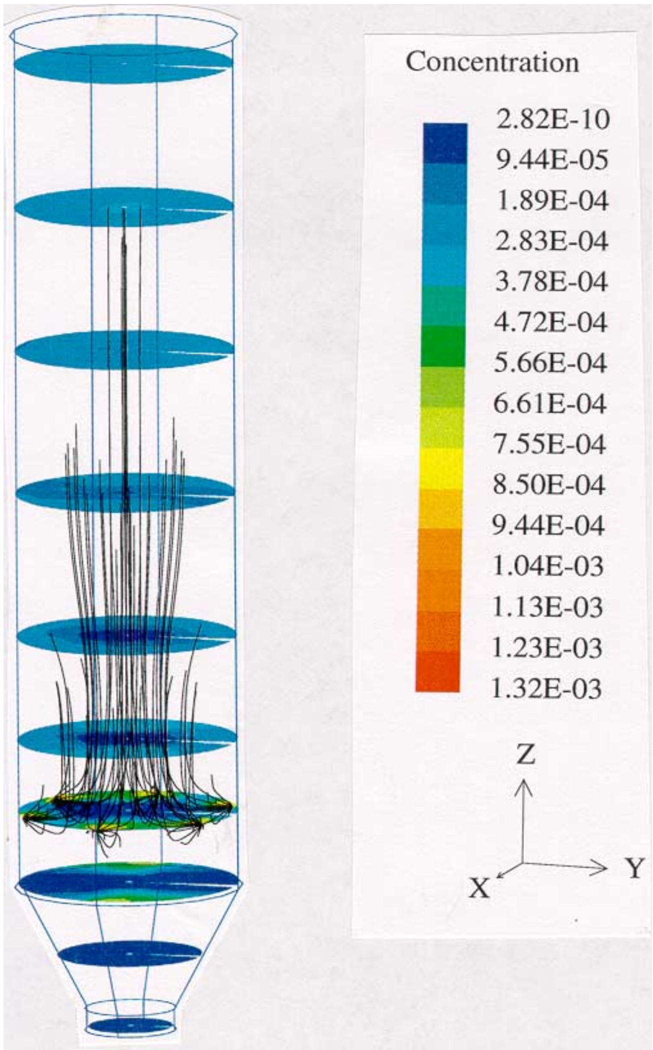


Figure 8. NOx Reduction Performance vs. Reagent Flow (Expressed as NSR) on Kiln A.

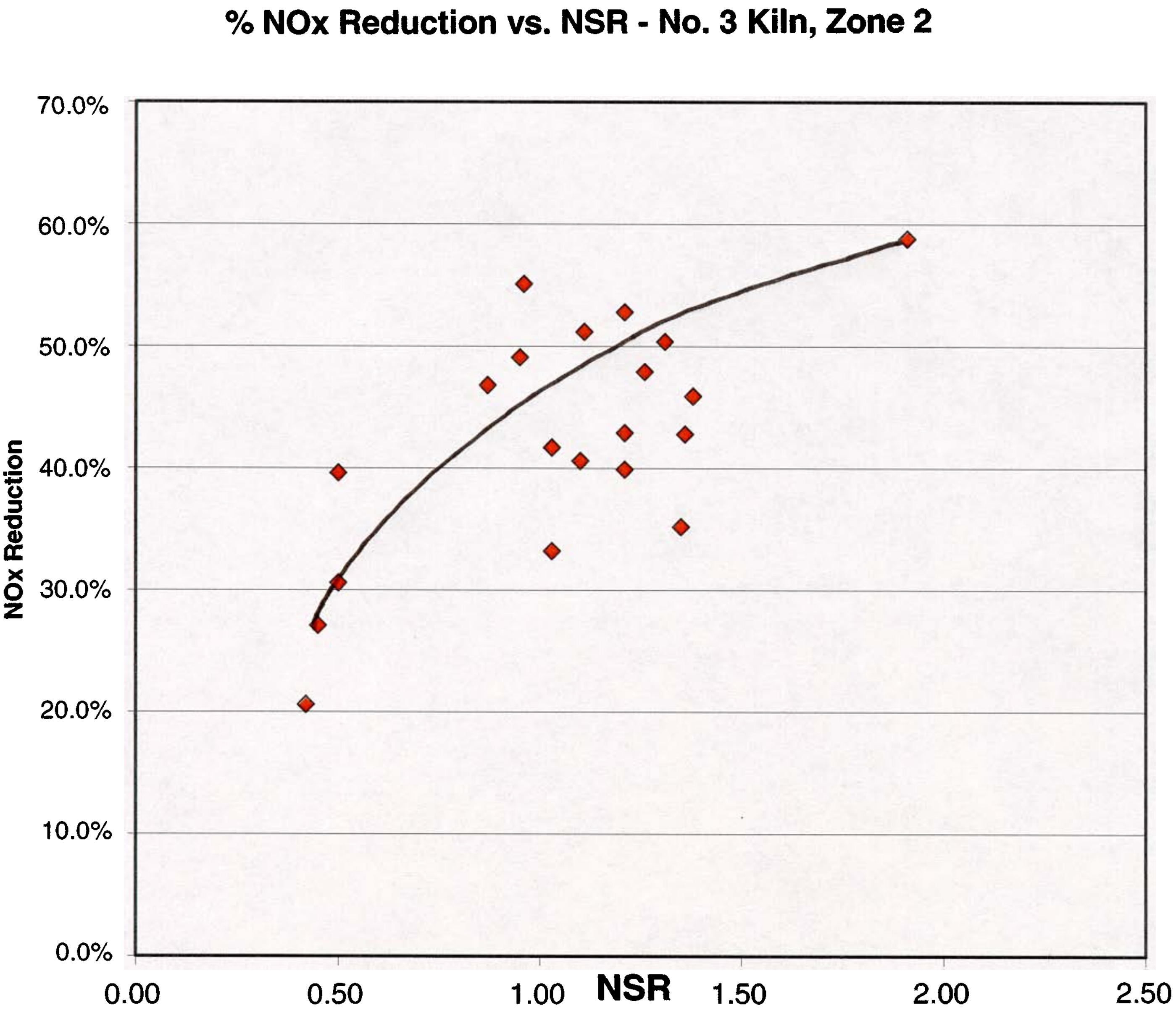
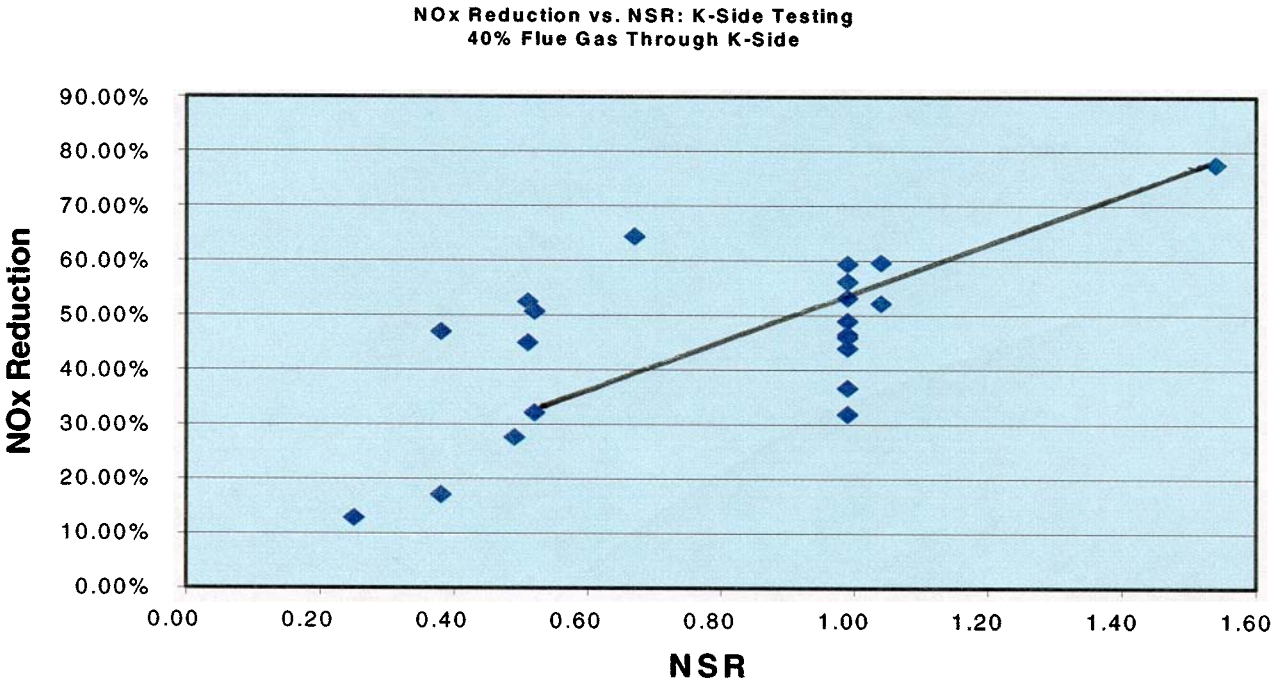


Figure 9. NOx Reduction Performance vs. Reagent Flow (Expressed as NSR) on Kiln B.

A. Kiln-Side Injection



B. Calciner-Side Injection