Cement Kilns

SUMMARY

The U.S. cement industry uses the nation's 213 cement kilns to produce about 81 million tons of cement a year. Nearly all NO, emissions from cement manufacturing are the result of the high process temperatures out of these kilns.

Among the states, California, Texas, Pennsylvania, Michigan, Missouri and Alabama are the top cement producers. All of these states have capacities greater than 4 million tons.

There are four basic kiln types which together emit an estimated 118,000 to 146,000 tons of NO,, annually. Emission factors, on average, range from 3.4-9.7 lbs NO_C/ton of product, depending on the type of kiln and site-specific factors.

A number of NO, control strategies are available, with reduction efficiencies ranging from 20-90 percent. At a typical kiln, these controls can achieve NO,, reductions of hundreds of tons a year, compared to uncontrolled levels.

EPA estimates of cost effectiveness ($/ton of NO_X removed) range from $830-$1330 for low NO,, burners, to $450-$610 for mid-kiln firing, to $790-$930 for urea-based SNCR, to $3140-$4870 for SCR.

DESCRIPTION OF SOURCE

Cement kilns are used by the cement industry in the production of cement. Portland cement, used in almost all construction applications, is the industry's primary product. Essentially all of the NO, emissions associated with cement manufacturing are generated in the kilns because of high process temperatures.

To make cement, raw materials such as limestone, cement rock, sand, iron ore, clay and shale are crushed, blended and fed into a kiln. These materials are then heated in the kiln to temperatures above 2900°F to initiate a chemical reaction (called "fusion") that produces cement "clinker," a round, marble-sized, glass-hard material. The clinker is then cooled, mixed with gypsum and ground to produce cement.

Nearly all cement clinker is produced in large rotary kiln systems. The rotary kiln is a refractory brick-lined cylindrical steel shell equipped with an electrical drive to turn it at 1-3 rpm, through which hot combustion gases flow countercurrently to the feed materials. The kiln can be fired with coal, oil, natural gas, waste or a combination of these fuels. Currently, most cement plants (over 75 percent) are coal-fired.

There are four types of kilns in use - long wet kilns, long dry kilns, kilns with a preheater and kilns with a precalciner. The long wet and dry kilns and most preheater kilns have only one fuel combustion zone, whereas the newer precalciner kilns and preheater kilns with a riser duct have two fuel combustion zones.

In a wet kiln, the ground raw materials are suspended in water to form a slurry. In a dry kiln, the raw materials are dried to a powder. Newer U.S. cement plants normally use the dry process because of its lower energy requirement.

Because the typical operating temperatures of these kilns differ, the NO_x formation mechanisms also differ among these kiln types. In a primary combustion zone at the hot end of a kiln, the high temperatures lead to predominantly thermal NO,, formation. In the secondary combustion zone, however, lower gas-phase temperatures suppress thermal NO_x formation. Energy efficiency is also important in reducing NO_x emissions; for example, a high thermal efficiency means less heat and fuel are consumed and, therefore, less NO_x is produced.

EMISSIONS PER UNIT OUTPUT

Average emission factors for the four different types of cement kilns discussed above are identified in *Table 1*. As shown, emission factors (lb/ton of clinker) range from 3.4 for precalciner kilns to 9.7 for long wet kilns.

Both EPA's draft ACT document and the *Air Pollution Engineering Manual* from the Air & Waste Management Association, however, caution that due to the diversity of cement plant design and operation, NO,, emission factors should be viewed as encompassing a wide range.

NATIONAL EMISSIONS ESTIMATE

In its *National Air Pollutant Emission Trends, 1900-1992,* published in 1993, EPA's estimate of annual NO, emissions from cement manufacturing is 118,000 tons.

According to EPA's AIRS Executive database, 1993 NO, emissions from 98 "hydraulic cement plants" totaled 146,203 tons. EPA's AIRS Facility Subsystem breaks out the total emissions from dry process cement kilns (78,975 tons per year) and wet process cement kilns (46,025 tons per year) for a total of 125,000 tons of *NO,* per year.

Therefore, total NO_x emissions appear to range between approximately 118,000 and 146,200 tons per year.

GEOGRAPHIC DISTRIBUTION OF SOURCES AND EMISSIONS

Recent data show a total of 213 cement kilns at approximately 100 plants in the U.S., producing about 81 million tons of Portland cement a year. The industry's annual clinker capacity has steadily declined from the 1973 peak of 414 kilns with a capacity of 91 million tons. (Clinker production is being exported).

STAPPA/ALAPCO Recommendation

® Agencies should consider requiring combustion controls on cement kilns, which can reduce uncontrolled emissions by up to 40 percent. Technologies for post-combustion controls - SNCR - are being demonstrated in the United States and could achieve NO_x reductions up to 70 percent for certain cement kiln processes.

Table 2 profiles the clinker-producing capacity in the U.S. by state. California, Texas, Pennsylvania, Michigan, Missouri, and Alabama all have clinker capacities greater than 4 million tons.

Table 3 details the number of cement plants by state and their emissions. Similar to the data in *Table 2,* EPA's AIRS Executive data show concentrations of cement plants in Alabama, Florida, Illinois, Indiana, Iowa, Missouri, New York, Pennsylvania, South Carolina and Texas.

AVAILABLE CONTROL STRATEGIES

Combustion and post-combustion controls are available for controlling NO_x emissions from cement kilns.

Combustion Controls. Process control approaches, which provide optimum kiln operating conditions, thereby increasing energy efficiency and productivity, minimize NO, emissions. Such approaches, however, are generally considered necessary for proper kiln operation and are usually viewed as setting baseline NO, emissions, not as NO,, control techniques *per se.*

Some kiln operators, however, do rely on process monitoring and control to meet NO_x emission permit levels. Such process controls include less intense "lazy" flames in the kiln burning zone, increased fuel input in the flash calciner furnace, preheating the raw feed, using raw feed additives and recycling cement dust.

Limited data exist on the use of low NO_x burners in cement kilns, although staging of combustion air is a possible NO,, reduction technique in precalciner kilns. In the first stage, fuel combustion occurs in a high-temperature, fuel-rich environment. Fuel combustion is completed in the fuel-lean, low temperature environment of the second stage. By controlling the available oxygen and temperature, low NO_x burners can reduce NO_x formation in the flame zone. Although low NO_x burners are used in some European cement kilns, very few have been installed in U.S. cement kilns.

Secondary combustion of fuel ("mid-kiln" firing) is available for long dry and wet kilns to achieve NO_x reductions of 20-40 percent, although this technology has not been applied extensively. Secondary fuel combustion is, however, inherently present in all precalciner kilns and preheater kilns with riser duct firing; such kilns produce less NO_x than long dry kilns.

Experimental studies also show that changing the primary kiln fuel from natural gas to coal can reduce the flame temperatures, resulting in significantly lower thermal NO_x emissions. A number of cement kilns have switched from gas to coal; currently over 75 percent of the primary fuel cement kilns bum coal.

Post-Combustion Controls. In early 1994, an SNCR vendor announced the first demonstration of urea-based SNCR on a U.S. cement kiln/calciner process. The objective was to reduce NO,, emissions below 422 pph; test results indicated that reductions well below this level were achieved.

EPA's draft ACT document for cement manufacturing concludes that SNCR is not applicable to long wet and dry kilns due to difficulties involved in continuous injection of reducing agents. For preheater and precalciner kilns, however, potential SNCR NO,, removal efficiencies are reported at 30-70 percent.

There are no reported installations of SCR in U.S. cement kilns, although application of this technology is theoretically possible and tests in the late 1970s showed removal efficiencies of 75-98 percent. The presence of alkalies and lime in the exhaust gases of cement plants, however, is an issue to be addressed. SCR would have to be installed after particulate collection, and flue gas reheating would be necessary to increase the flue gas temperatures to the appropriate SCR operating level.

Table 4 identifies the NO,, reduction potentials of these controls.

POTENTIAL NATIONAL EMISSIONS REDUCTION

NO_x emissions can be reduced by hundreds of tons a year at individual facilities by retrofitting available control technologies. Since data is not available on the extent to which these controls are already installed on U.S. cement kilns, it is not possible to quantify the national emissions reduction potential. It would seem likely, however, that widespread retrofit of NO_x controls would reduce NO,, emissions from cement kilns by tens of thousands of tons a year.

COSTS AND COST EFFECTIVENESS

One SNCR vendor estimates that the capital cost (including equipment, engineering, installation, license fee, service contract, start-up, optimization and training) of applying the technology to a cement kiln, based on a demonstration in late 1993, would be a consistent $0.08 per ton on a 15-year life, 85-percent average plant capacity of 100 tons/hr normal output.

This SNCR vendor also estimated the operating costs, which are a direct function of the firing rate in the kiln necessary to process the raw material mix. Raw material variations change the firing rate and NO_x levels are either below the permit level, where no chemical is required, or above, where the chemical rate will be needed to lower the NO_x emissions to below the permit level. To maintain NO,, emissions at 400 lb/hr, the operating cost of the SNCR system on the subject kiln was estimated at $0.14 per ton.

As shown in *Table 5,* EPA's 1994 draft ACT document estimates the total capital costs and cost effectiveness of several control technologies for eight model plants. As indicated, cost effectiveness ($/ton of NO,, removed) ranges from $830-$1330 for low NO_x burners, to $450-$610 for mid-kiln firing, to $790-$930 for urea-based SNCR, to $3140-$4870 for SCR. For each kiln type, the cost effectiveness of each control strategy varies inversely with kiln capacity.

In 1991, the SCAQMD estimated the cost effectiveness of using SCR to reduce cement kiln NO_x emissions by 85 percent to be $1300/ton of NO_x reduced.

FEDERAL RULEMAKING AND/OR GUIDANCE DOCUMENTS

EPA is developing an ACT document entitled, *Control of NO, Emissions from Cement Manufacturing.* The first draft is dated February 1993 and final drafts of some chapters were available as of March 1994.

For further information on the ACT, contact Bill Neuffer, U.S. Environmental Protection Agency, Emissions Standards Division (MD-13), Research Triangle Park, NC 27711 (telephone 919/541-5435).

STATE AND LOCAL CONTROL EFFORTS

The South Coast Air Quality Management District (Rule 1112) requires affected cement kilns to limit NO,, emissions to 11.6 lb/ton of clinker produced (24-hour average) and 6.4 lb/ton of clinker produced (30-day average). A higher emission limit is provided for kilns using energy recovery.

REFERENCES

1. Sun, W.H., Nalco Fuel Tech. October 28, 1993. *NO,. OUT Process Demonstration on a Cement Kilnl Calciner, Ash Grove Cement Seattle Plant.*

2. U.S. Environmental Protection Agency. October 1993. *National Air Pollutant Emission Trends, 1900-1992.*

3. U.S. Environmental Protection Agency. February 1993 and March 1994 (update). *Alternative Control Techniques Document - Control of NO, Emissions from Cement Manufacturing (Draft).*

4. California Air Resources Board. August 7, 1992. *Sources and Control of Oxides of Nitrogen Emissions.*

5. Air & Waste Management Association. 1992. *Air Pollution Engineering Manual.*

6. South Coast Air Quality Management District. July 1991. *Final Air Quality Management Plan.* Revision.

7. U.S. Environmental Protection Agency. July 1993. *AIRS Facility Subsystem.*

8. U.S. Environmental Protection Agency. January 28, 1994. *AIRS Executive.*

Table 1

Uncontrolled NO$_x$ Emission Factors for Different Kiln TypesI

Cement Kiln Type	Heat Input Requirement (MMBtu/ton of clinker)	NO$_x$ Emission Rate (lb/ton of clinker)
Long Wet Kiln	6.0	9.7
Long Dry Kiln	4.5	8.6
Preheater Kiln	3.8	5.9
Precalciner Kiln	3.3	3.4

'Source: EPA, draft ACT March 1994.

Table 2

United States Clinker Capacities By State, Rank[1]

State	Clinker (10^3 tons)
California	10,390
Texas	8,590
Pennsylvania	6,640
Michigan	4,900
Missouri	4,680
Alabama	4,260
Florida	3,360
New York	3,100
Indiana	2,830
Iowa	2,810
Illinois	2,590
South Carolina	2,580
Kansas	1,890
Oklahoma	1,890
Maryland	1,860
Colorado	1,800
Arizona	1,770
Ohio	1,700
Georgia	1,380
Arkansas	1,310
Virginia	1,120
Tennessee	1,050
Nebraska	960
Utah	930
West Virginia	820
South Dakota	770
Kentucky	720
Montana	590
Mississippi	500
Oregon	500
New Mexico	490
Washington	470
Wyoming	460
Maine	460
Nevada	420
Hawaii	260
Idaho	210
Total	81,060

Source: EPA, March 1994.

[1] *1990 Data.*

There are no clinker-producing plants in the following jurisdictions: Alaska, Connecticut, Delaware, District of Columbia, Louisiana, Massachusetts, Minnesota, New Hampshire, New Jersey, North Carolina, North Dakota, Rhode Island, Vermont, Wisconsin.

Table 3

Cement Plant NO_x Emissions

State	Plants	Tons/Year	Percent of Total Stationary Source Emissions
Alabama	6	7,000	2.1%
Arkansas	1	500	0.5%
California	1	3,700	8.1%
Colorado	3	4,200	3.6%
Florida	4	7,100	2.1%
Georgia	2	2,000	0.7%
Hawaii	1	600	1.8%
Idaho	1	2,200	17.8%
Illinois	4	4,500	0.8%
Indiana	3	7,600	1.4%
Iowa	4	5,200	5.1%
Kansas	4	2,100	1.0%
Kentucky	1	1,200	0.4%
Louisiana	1	200	<0.1
Maine	1	400	1.2%
Maryland	2	3,600	2.5%
Michigan	1	2,200	15.1%
Mississippi	1	600	0.7%
Missouri	5	9,100	2.8%
Montana	2	1,700	2.8%
Nebraska	1	1,400	1.7%
Nevada	1	500	0.8%
New Mexico	1	400	0.3%
New York	4	17,400	7.0%
Ohio	3	2,300	0.3%
Oklahoma	3	2,900	1.5%
Oregon	1	300	2.9%
Pennsylvania	9	7,800	1.3%
South Carolina	3	6,200	4.4%
South Dakota	1	2,100	12.4%
Tennessee	2	3,000	0.9%
Texas	13	26,600	2.7%
Utah	3	3,700	4.3%
Virginia	1	1,400	0.9%
Washington	2	2,100	3.8%
West Virginia	1	1,000	0.3%
Wyoming	1	1,300	1.0%
Total	98	146,100	

Source: EPA, AIRS Executive, January 28, 1994.

Table 4

NO_x Reduction Effectiveness of Available Controls[1]

NO_x Control Technology	Achievable NOx Emissions Reductions (%)
Process Modifications	<25
Staged Combustion (Precalciner Kilns)	29-46
Low NO_x Burners	20-30
Mid-Kiln Firing (Long Kilns) with LNB	20-40
SNCR	30-70
SCR	80-90

'Source: EPA, draft ACT March 1994.

Table 5

Capital Costs and Cost Effectiveness of NOx Control Technologies

	Kiln Type	Kiln Capacity (tons/clinker/hr)	Capital Costs (103$)	NOx Removed (tons/yr)	Cost Effectiveness ($/ton NOx removed)
Low N0x Burner	Long wet	30	1,640	290	1,130
	Long wet	50	2,180	480	880
	Long dry	25	1,270	210	1,270
	Long dry	40	1,640	340	970
	Preheater	40	1,490	230	1,330
	Preheater	70	2,040	410	970
	Precalciner	100	1,720	340	1,010
	Precalciner	150	2,170	510	830
Mid-Kiln Firing	Long wet	30	718	590	550
	Long wet	50	748	480	450
	Long dry	25	708	210	610
	Long dry	40	728	340	470
	Preheater	40	N/A	N/A	N/A
	Preheater	70	N/A	N/A	N/A
	Precalciner	100	N/A	N/A	N/A
	Precalciner	150	N/A	N/A	N/A
SNCR Urea-Based	Long wet	30	N/A	N/A	N/A
	Long wet	50	N/A	N/A	N/A
	Long dry	25	N/A	N/A	N/A
	Long dry	40	N/A	N/A	N/A
	Preheater	40	671	470	930
	Preheater	70	927	825	790
	Precalciner	100	969	680	880
	Precalciner	150	1,240	1,020	800
SNCR Ammonia-Based	Long wet	30	N/A	N/A	N/A
	Long wet	50	N/A	N/A	N/A
	Long dry	25	N/A	N/A	N/A
	Long dry	40	N/A	N/A	N/A
	Preheater	40	1,340	470	1,100
	Preheater	70	1,850	925	910
	Precalciner	100	1,650	680	980
	Precalciner	150	2,110	1,020	880
SCR	Long wet	30	12.8*	930	3,600
	Long wet	50	17.4*	1,550	3,140
	Long dry	25	9.87*	690	3,630
	Long dry	40	13.11*	1,100	3,170
	Preheater	40	12.0*	750	4,120
	Preheater	70	16.8*	1,320	3,490
	Precalciner	100	19.3*	1,090	4,870
	Precalciner	150	24.6*	1,630	4,400

* 106$

Source.' EPA, draft ACT March 1994.