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Project Summary

Combustion Modification Tests on a Subscale Cement Kiln for NO_x Reduction

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Field tests were conducted on a subscale rotary cement kiln to evaluate the effect of various combustion modifications on gaseous emissions. The test program was conducted with a research kiln donated by a cement company. The test unit was 8.2 m (27 ft) long and 0.38 m (15 in.) inside diameter and will produce 68 kg (150 lb) of clinker per hour. A coal burner was designed and built for the test program, and the kiln was reworked to incorporate heated secondary air and flue gas recirculation (FGR). The effect on NO emissions of FGR, diluted primary air, primary/secondary air ratio, burner tip velocity, and secondary air temperature were evaluated. The most effective combustion modification for coal firing was determined to be dilution of primary air with inert gas which reduced NO by nearly 40 percent when the primary-air oxygen concentration was reduced to 12 percent.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

KVB has reported on previous EPA-sponsored sub- and full-scale cement kiln combustion modification tests that evaluated the effects on NO_x emission of several types of modifications including air preheat, fuel injection velocity, and oxygen content of the primary combustion air stream. Tests in a combustion tunnel simulating kiln conditions showed dilution of the primary air stream with an inert gas, altered fuel injection velocity, and combustion air preheat to be most effective in lowering the NO emission level.

This report summarizes results of tests of a subscale rotary cement kiln firing natural gas and pulverized coal. The kiln was modified to incorporate flue gas recirculation (FGR) and combustion air preheat. A coal burner was fabricated and installed in the kiln. The FGR system was designed to inject flue gas into the secondary combustion air stream or into a tertiary air stream in the burner.

The overall objective of the contract, under which the work reported here was conducted, was to investigate advanced combustion modification concepts requiring relatively minor hardware modifications that could be used by operators and/or manufacturers of industrial process equipment to reduce NO_x emissions. Another objective was to investigate the feasibility of these modifications to be readily adopted by equipment manufacturers and operators.

The specific object of the test program reported here was to evaluate FGR, vitiated primary air, primary/secondary air ratio, temperature of combustion air, and coal-carrier air velocity as they affect emission of NO_x in a subscale rotary cement kiln provided by a major cement manufacturer. The test results were to be compared with previous laboratory-scale tests and recommendations formulated for tests at larger scale.

The initial phase of testing was conducted with natural gas fuel to define kiln operation over a range of operating variables; e.g., excess air, primary-to-secondary-air ratio, and combustion air preheat. When the performance of the kiln was documented with natural gas fuel, firing was changed to coal. Kiln NO emissions were evaluated as a function of combustion air temperature, primary air velocity, primary-to-secondary-air ratio, FGR rate, and primary (carrier) air oxygen content.

Previous Work

The present program is a follow-on study, intended to build on the results of an earlier program in a laboratory combustion tunnel. The objective of the earlier effort was to determine the effect of burner parameters on near-flame NO levels for both natural gas and coal fuels. This laboratory effort determined that combustion air preheat, fuel injection velocity, and oxygen content of the primary combustion air stream have first-order effects on NO levels. These parameters were then selected for implementation on the subscale kiln.

Program Approach

During the earlier program, several subscale test facilities were visited and evaluated. A test program was presented to the operators of these facilities, and estimates of test costs were received from each. The selected subscale kiln offered the most operational flexibility and opportunity for the maximum data at minimum cost.

Prior to the subscale tests, KVB conducted laboratory tests in a kiln-simulation furnace to define key parameters influencing NO formation in the near-burner region. The data gained from this program were used to design the subscale test plan.

A coal burner and feed system were built and installed at the test site, and the kiln was modified to incorporate combustion air preheat and flue gas recirculation. The initial portion of the test program was conducted firing natural gas to define kiln operation over a range of operating variables; e.g., excess air, primary-to-secondary-air ratio, and combustion air preheat.

When the performance of the kiln was documented with natural gas fuel, firing was changed to coal. Kiln NO emissions were evaluated as a function of combustion air temperature, primary air velocity, primary-to-secondary-air ratio, tertiary air injection FGR rate, and primary-air oxygen content.

Tables 1 and 2 summarize the significant results obtained from the test program for natural gas and coal firing, respectively.

Conclusions

The following conclusions were made from the field tests and the analyses of the data:

- The subscale tests corroborated laboratory combustion tunnel test results. Combustion tunnel tests indicated that reducing the coal carrier air oxygen content was a promising method of NO reduction, and the subscale tests verified this. Figure 1 compares the data taken during the laboratory program with those from the subscale kiln tests. The data trends are similar: the kiln was more sensitive to carrier-gas oxygen content probably due to higher secondary air preheat temperature.
- The subscale kiln tests showed that NO emissions are quite sensitive to kiln operating O_2 level. Figure 2 shows the effect of kiln oxygen level on NO emissions for 1100°F (593°C) secondary air temperature. This figure shows that a 1-percent reduction in O_2 level results in a NO reduction of about 63 ppm.
- Flue gas recirculation (FGR) was found to be more effective with gas firing than with coal firing. Gas firing reduced NO by about 20 percent from the baseline condition at a FGR rate of 34 percent. Coal firing reduced NO by only 7 percent from the baseline with 21 percent FGR.
- Diluting coal carrier air with an inert gas reduced NO by about 30 percent from baseline conditions. Diluting the primary air (coal carrier gas) was found to be the most effective combustion modification.
- Further evaluation of the dilution of coal carrier air in larger scale kilns should provide valuable information.

Table 1. Summary of Test Results: Gas Firing - Subscale Cement Kiln[a]

Test Series[b]		SA Temp		% Primary Air	% FGR	Fuel MW	Firing Rate (10^6 Btu/hr)	Kiln Exit O_2 (%, dry)	NO (ppmv, @ 3% O_2, dry)	CO_2 (%, dry)	Maximum % NO Reduction from Baseline
		°F	K								
PA/SA Variation (20/80)	Baseline	1100	867	19.1	0	0.21	(0.70)	2.0	640	11.2	
		900	756						600		
		600	589						400		64.4
		300	422						243		
		Amb.							228		
PA/SA Variation (33/67)	Baseline	1200	922	33.0	0	0.21	(0.70)	2.0	300	11.5	
		600	589						194		
		300	422						180		43.3
		Amb.							170		
SA Temp. Variation	Baseline	1000	811	14.6	0	0.19	(0.64)	2.0	404	14.2	
		900	756						419		
		800	700						364		47.5
		700	644						350		
		Amb.							212		
FGR	Baseline	1168	904	28.0	0	0.19	(0.64)	2.0	340	15.8	
					21.6				163		
					28.6				135		70.6
					32.6				110		
					33.8				100		

[a]All CO data for the nominal O_2's listed are less than 200 ppmv.
[b]PA = Primary Air; SA = Secondary Air; FGR = Flue Gas Recirculation.

Table 2. Summary of Test Results: Coal Firing - Subscale Cement Kiln

Date (1982)	SA Temp.[a]		PA Velocity[a]		% PA	Avg. O_2 (%)	Avg. CO (ppm)	Avg. NO (ppm corrected to 3% O_2, dry)	CO_2 (%)	Comments
	°F	(K)	fpm	(m/s)						
7/27	1099	(866)	3338	(17)	28.4	3.5	25	753	16.4	Evaluate the effect of SA temperature on NO emissions; PA = constant O_2 = constant.
7/27	1003	(816)	3338	(17)	27.9	3.7	35	794	15.4	
8/04	1145	(892)	3338	(17)	29.4	3.8	559	826	14.6	
7/29	1167	(904)	3232	(16.4)	25.8	3.6	125	848	15.4	
8/12	1162	(901)	2950	(15)	21.0	3.7	148	806	15.5	Velocity variation; varied primary air flow. SA ΔP was relatively constant.
8/12	1158	(899)	2504	(12.7)	19.3	3.6	396	643	17.8	
8/12	1166	(903)	2285	(11.6)	17.1	4.1	303	708	15.3	
8/12	1169	(905)	2128	(10.8)	16.2	5.3	963	773	15.5	
8/12	1161	(900)	2504	(12.7)	9.3	4.3	293	711	17.6	PA/SA variation tests. Varied PA flow and SA flow at constant O_2.
8/11	1187	(915)	2915	(14.8)	22.2	3.6	608	775	15.1	
7/29	1167	(904)	3232	(16.4)	25.4	3.6	136	822	15.8	
8/04	1153	(896)	3268	(16.6)	29.8	4.1	268	848	14.6	
8/04	1130	(883)	3440	(17.5)	30.1	5.4	452	847	13.8	Baseline for series to evaluate FGR, 0% FGR
8/04	1144	(891)	3390	(17.2)	29.7	5.0	79	836	16.4	19% FGR[a]
8/04	1160	(900)	3440	(17.5)	30.1	5.6	167	788	13.7	21% FGR
8/10	1140	(889)	3120	(15.8)	22.5	2.9	481	727	15.3	Baseline for PA dilution tests } High PA Velocity
8/10	1160	(900)	2890	(21.7)	21.7	3.7	104	700	13.5	18% O_2 in PA
8/10	1140	(889)	3120	(15.8)	22.5	2.3	550	613	16.2	12% O_2 in PA
8/12	1160	(900)	2500	(12.7)	19.3	5.0	188	771	17.5	Baseline for PA dilution tests } Low PA Velocity
8/12	1160	(894)	2500	(12.7)	18.4	4.0	87	635	17.9	15% O_2 in PA
8/12	1160	(900)	2500	(12.7)	19.7	3.8	440	544	17.6	12% O_2 in PA

[a]SA = Secondary Air; PA = Primary Air; FGR = Flue Gas Recirculation.

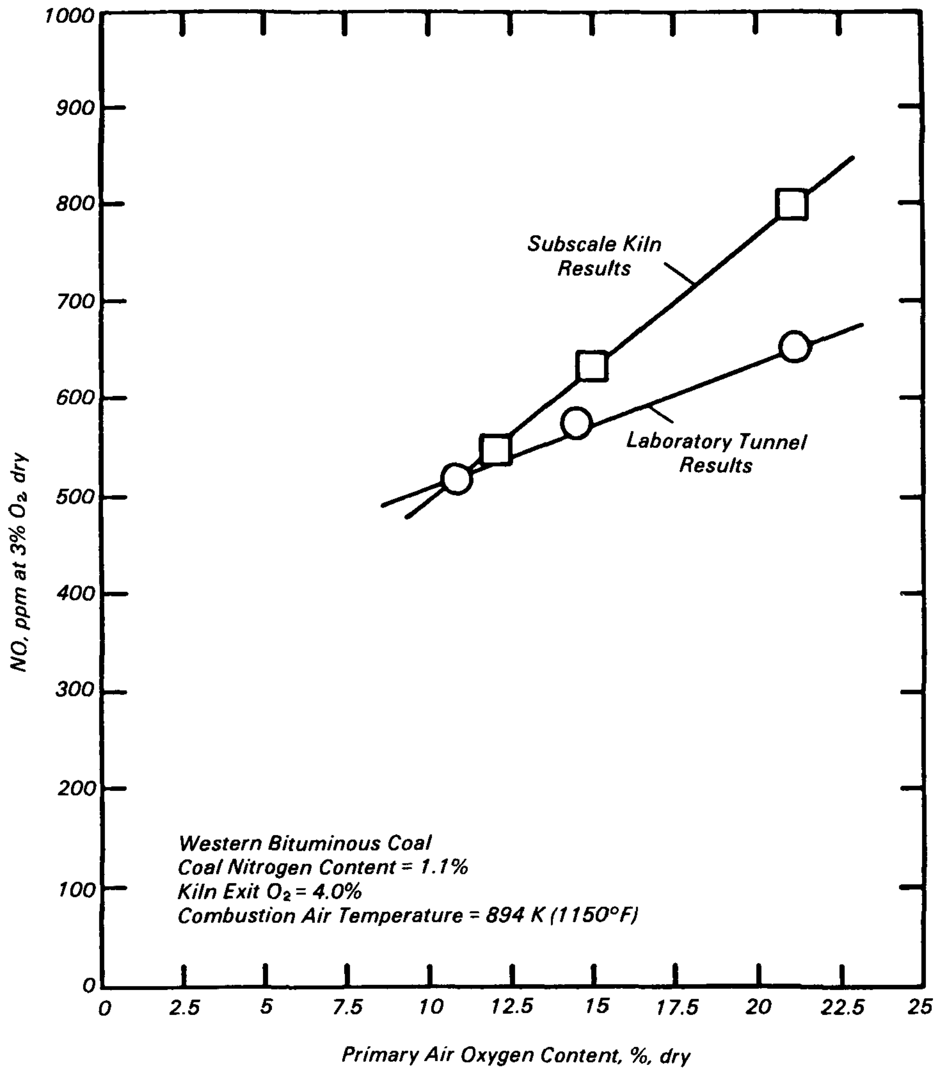

Figure 1. *Effect of primary-air oxygen content on NO emissions.*

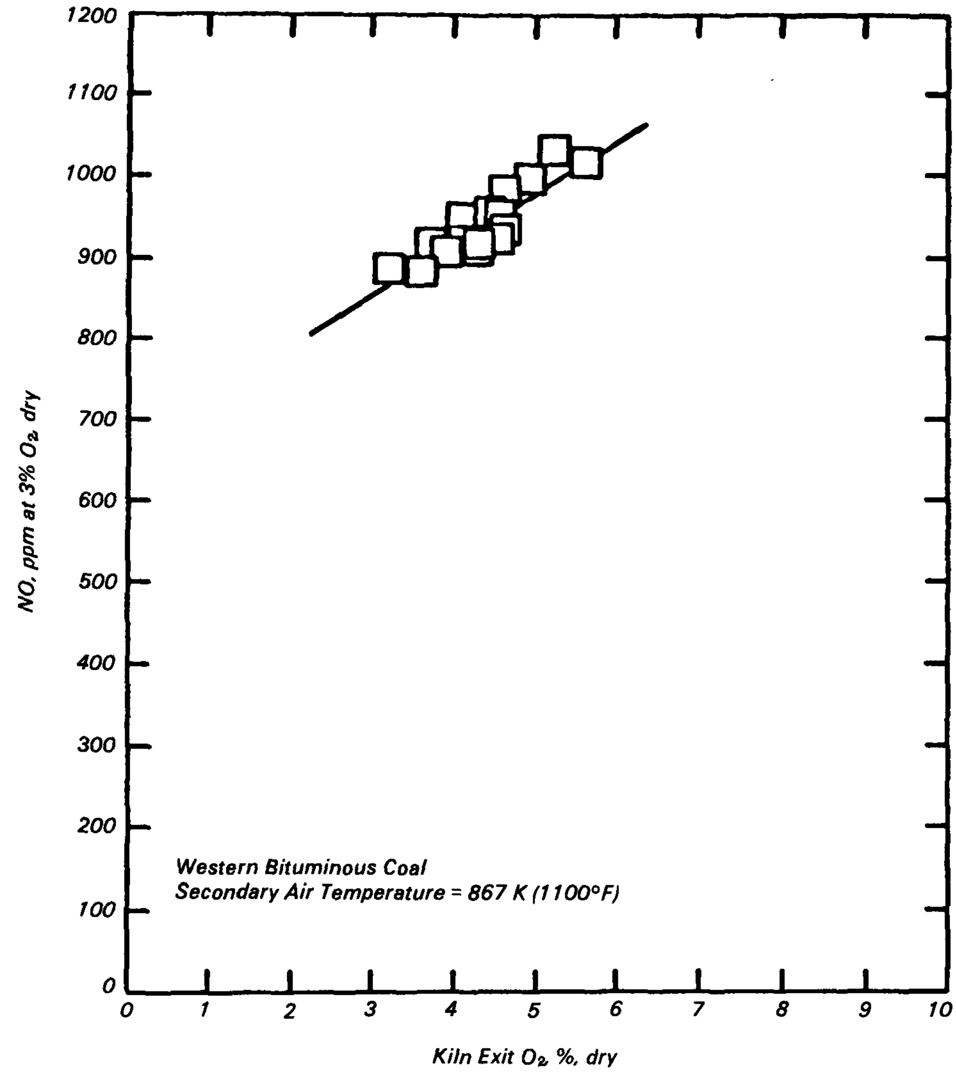

Figure 2. *Effect of kiln oxygen level on NO emissions.*

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The complete report, entitled "Combustion Modification Tests on a Subscale Cement Kiln for NO_x Reduction," (Order No. PB 84-223 502; Cost: $10.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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