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Project Summary

Emissions from Refinery Process Heaters Equipped with Low-NO_x Burners

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This report summarizes results of an investigation of the performance of commercial low-NO_x burners in refinery process heaters. Refineries in Southern and Central California were surveyed to determine the number of low-NO_x burner installations existing or planned. Ten process heaters, equipped with low-NO_x burners, were tested to measure gaseous emissions, particulates, and efficiences over a normal range of operating conditions. The as-found NO_x emission increased from 58 to 245 ng/J as the fuel-bound nitrogen increased from 0 to 0.81 percent. The NO_x concentrations were strongly influenced by excess air levels in most cases. Reducing excess air to about 3-4 percent reduced NO_x to 34-200 ng/J, depending on fuel nitrogen. Comparisons of present emissions data with past field test data for refinery heaters equipped with standard burners showed that for mechanical-draft gas-fired heaters, low-NO_x burners may reduce the NO_x emission factor by 32-77 percent below the mean emission factor for standard burners. Three heaters (one firing gas, another firing distillate oil, and the third firing residual oil) were selected as suitable candidates for 30-day continuous monitoring of gaseous emissions.

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

Approximately 6000 refinery process heaters are in operation in the United States (Ref. 1). Of these, about 5400 have natural draft burners; the remainder have forced or balanced draft burners. Both types emit a total of about 121.5 Gg/y (134,000 tons/y) of NO_x, making process heaters one of the largest industrial emitters of this pollutant.

Several field test programs have been conducted to characterize NO_x emissions from process heaters over a wide range of operating conditions. However, all the previous field test work was conducted on heaters equipped with conventional burners. Only recently have refinery heater burner manufacturers begun to market low-NO_x burners for the petroleum industry, and new commercial installations are somewhat sparse.

It was the purpose of this program to (1) locate refineries in Southern California which have installed or ordered low-NO_x burners, (2) test nine gas- or oil-fired process heaters in which low-NO_x burners have been installed (NO_x and other gaseous emissions were to be measured over a normal range of operating conditions), and (3) assess the potential for long term (30-day) tests of the heaters with the goal of finding three suitable sites—one firing gas, a second firing distillate oil, and the third firing residual oil.

Southern California was selected for the heater survey because of its strict NO_x emission regulations; hence, a high likelihood of finding installations with low-NO_x burners. Results of the survey are summarized in Table 1. At least 29 heaters were found with low-NO_x burners installed or planned for installation. Heaters which were tested in this program were assigned the site numbers shown in Table 1.

Results of the tests conducted at these 10 sites are reported here. (Site 10 was added to the required nine because it was near Sites 6 through 9 and the refinery was willing to allow it to be tested.)

Summary of Program Results and Comparison with Past Results

This program required that baseline tests be conducted for nine refinery process heaters equipped with low-NO_x burners. Tests were completed on 10 process heaters, since one extra could be tested for minimal additional cost.

At each test site, the gaseous emissions and stack gas temperature were measured. Samples of fuel were taken and submitted to an independent laboratory for analysis. Unit operational data such as flow rate, pressure, and temperature were recorded periodically. After testing the unit in the as-found condition, burner registers and/or stack dampers were adjusted to determine the effect of excess oxygen on unit operation, gaseous emissions, and heater efficiency.

The heaters tested included four natural draft and six mechanical draft units firing gas, distillate, and residual oils. Four of the mechanical draft units had preheated combustion air.

Emission Test Methods and Instrumentation

All emission measurement instrumentation was carried in a 2.4 x 12.8 m (8 x 42 ft) mobile laboratory trailer. Th trailer was used at all test sites. Gaseou species were measured with analyzer in the trailer. The emission measure ment instrumentation used is listed i Table 2.

Results

Figure 1 shows NO_x emissions as function of stack oxygen for the 1 process heaters tested. These data shov that for all heaters, lowering the oxyge resulted in lower NO_x emissions. Th gas-fired heaters had lower NO_x emis sions than did the distillate-oil-fire heater, and the residual-oil-fired heater had the highest NO_x emissions. Th gas-fired heaters with combustion ai preheat had higher NO_x emissions tha gas-fired heaters with ambient combus tion air. The points at which significan CO emissions or visible smoke occurre are marked in the figure as "CO limits."

Gas-fired heaters with ambient combustion air showed NO_x emissions a 40-50 ng/J (80-100 ppm at 3 percent

Table 1. *Heater Low NO_x Burner Test Site Survey*

Location	Site No.	Air Quality Control Region	No. Heaters	Heat Input Rate MW	10^6 Btu/Hr	Burners	Operational	Fuel	Comments
A	2	31	1	4.7	~ 16	1	Yes	LO-S resid	Natural Draft
B	-	31	1	16.4	56	8	Yes	6 Gas, 2 Oil	Old heater; leaks above firebox
C	-	24	-	-	-	-	-	-	
D	-	24	-	-	-	-	-	-	
E	-	24	1	7.5	25.7	4	Dec. 80-Jan. 81	Gas	Natural Draft
F	-	31	11	-	-	-	-	-	
G/1	6, 7, 8, 9	30	4	93.8[a]	320	32	Sept. 80	Gas	Preheat, Balanced Draft
G/2	10	30	1	8.8	30	1	Sept. 80	Gas	Ambient, Forced Draft
H	-	24	1	7.7	26.4	8	Jan. 81	-	
I	-	31	1	10.3	35	3	March 81	#6 Oil	Natural Draft
J/1	-	24	1	-	-	-	Jan. 81	Gas	Natural Draft
J/2	-	24	1	-	-	-	Jan. 81	Gas	Natural Draft
K	1	24	1	6.1-6.7	21-23	3	Yes	Gas	Forced Draft
L/1	4	31	1	6.7	22.9	3	Yes	#5 Oil, gas	Natural Draft
L/2	3	31	1	11.7	39.9	12	Yes	#5 Oil, gas	Natural Draft
M	5	31	1	11.7	40	10	Yes	#6 +RG	Natural Draft
N	-	24	-	-	-	-	-	-	
O/1	-	30	1	21.4	73	-	Yes	Gas	Natural Draft
O/2	-	30	1	6.4	22	-	Yes	Gas	Natural Draft
P	-	31	-	-	-	-	-	-	

[a]*Total for four heaters.*

O_2, dry*) in the as-found condition. By lowering the excess oxygen to a CO limit or to the minimum acceptable condition as determined by the plant, NO_x emissions were reduced to about 25 ng/J (50 ppm). Heaters with preheated combustion air showed as-found NO_x emissions as 58-76 ng/J (115-150 ppm).

Lowering excess oxygen resulted in NO_x reduction to 25-43 ng/J (50-85 ppm).

As-found NO emissions from a natural-draft distillate-oil-fired process heater were 92-117 ng/J (168-212 ppm) and were reduced to approximately 58 ng/J (105 ppm) by lowering excess air to the single burner.

Emissions in the as-found condition were considerably higher for the three units firing residual oil. All were natural draft units, and two were found to be emitting 207-281 ng/J (370-500 ppm) of NO. The unit at Site 5 fired 15-20 percent refinery gas simultaneously with residual oil. This unit was found to be emitting 194-205 ng/J (350-370 ppm) of NO and was the only unit firing residual oil which showed a significant tendency toward reduced emissions when excess air levels were lowered. At reduced excess air settings, this unit produced about 166 ng/J (300 ppm) of NO.

Table 3 is a summary of gaseous emissions and efficiency for each site tested. Emissions at as-found conditions and at optimum low-NO_x conditions (i.e., lowest NO_x emission without adverse effects on flame stability or unit efficiency) are compared in this table. At most sites, significant reductions in NO_x emission below as-found levels could be achieved along with small increases or, at worst, no change, in efficiency. With respect to flame stability, product flows and temperatures, and emissions of CO and unburned hydrocarbons, unit operations at the optimum low-NO_x conditions were generally unchanged from the as-found conditions.

Figure 2 is a plot of the effect of fuel-bound nitrogen content on the NO_x emission factor. The three circles plotted in this figure represent data from the oil-fired units tested. Site 2 burned 100 percent No. 2 oil; Sites 3 and 4, No. 6 oil (both units burned fuel having the same composition); Site 5, a combination of 80 percent No. 6 oil (by heat input rate) and 20 percent refinery gas. The "zero

*All emission concentrations given as ppm are corrected to 3 percent O_2, dry basis.

Table 2. *Emission Measurement Instrumentation*

Species	*Manufacturer*	*Measurement Method*	*Model No.*
Hydrocarbon	*Beckman Instruments*	*Flame Ionization*	*402*
Carbon Monoxide	*Beckman Instruments*	*IR Spectrometer*	*865*
Oxygen	*Teledyne*	*Polarographic*	*326A*
Carbon Dioxide	*Beckman Instruments*	*IR Spectrometer*	*864*
Nitrogen Oxides	*Thermo Electron Co.*	*Chemiluminescent*	*10A*
Particulates	*Joy Manufacturing Co.*	*EPA Method 5 Train*	*EPA*
Sulfur Dioxide	*DuPont Instruments*	*UV Spectrometer*	*400*

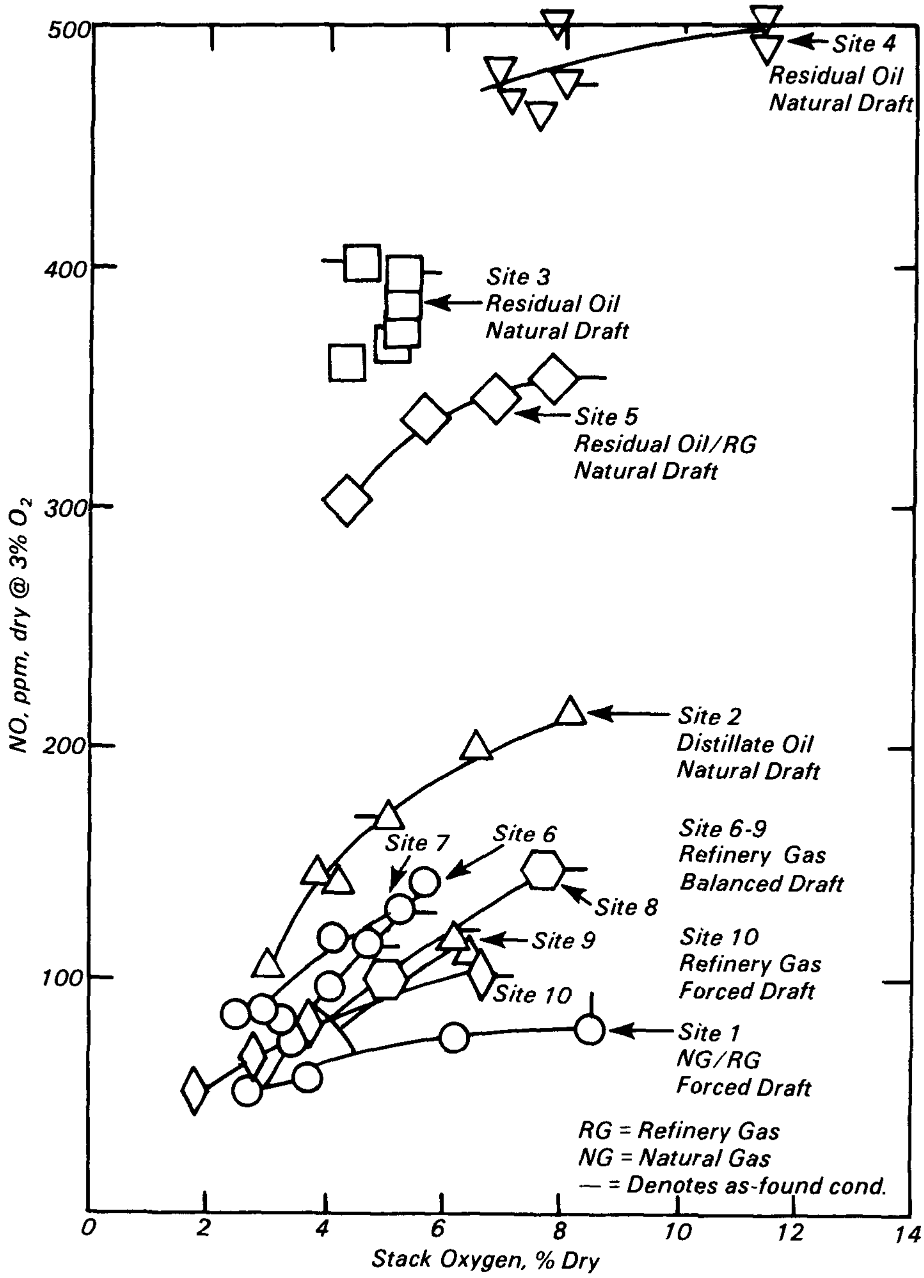

Figure 1. *NO_x emissions as a function of stack oxygen for low-NO_x burners in process heaters.*

Table 3. *Optimum Low-NO_x and As-Found Gaseous Emissions and Efficiencies at 10 Heaters Equipped with Low-NO_x Burners*

			As-Found					Optimum Low-NO_x					
Site	Heater[a] Config.	Test Nos. (A.F.;Low-NO_x)	NO (ng/J)	NO (ppm)	O_2 (%)	CO (ppm)[b]	Htr. Eff. (%)	NO (ng/J)	NO (ppm)	O_2 (%)	CO (ppm)[b]	Htr. Eff. (%)	%NO Reduction
1	121	1-13; 1-24	39.0	77	6.2	0	79.9	24.0	48	3.0	20	83.0	38.5
2	211	2/1-1e;2/1-3a	92.4	168	5.1	11	64.0	80.4	145	4.0	11	64.0	13.0
3	311	3-1;3-3	222.0	396	5.2	11	63.4	203.0	361	4.3	11	64.5	8.5
4	311	4-1; 4-4	268.0	477	8.1	0	67.9	264.0	471	7.1	0	68.6	1.5
5	411	5-3;5-6	194.0	352	7.7	11	--	167.0	303	4.4	22	--	13.9
6	132	6/5-3;6/5-1	57.9	114	4.8	11	69.8	38.1	75	3.5	11	71.3	34.2
7	132	7/1-1;7/2-2	65.8	130	5.3	11	68.0	35.4	70	2.3	33	68.5	46.2
8	132	8/1-1;8/1-3	74.9	148	7.7	14	65.4	41.0	81	3.8	15	69.2	45.3
9	132	9/1-1; 9/1-3	60.2	119	8.4	0	66.4	32.9	65	3.3	10	68.8	45.3
10	121	10/1-1; 10/1-4	51.6	102	6.7	13	73.1	32.9	65	2.8	10	74.4	36.2

[a]*Heater configuration designations are:*

1st Digit Fuel Burned	2nd Digit Draft Type	3rd Digit Air Temp.
1 = gas	1 = natural	1 = ambient
2 = dist. oil	2 = forced	2 = preheater
3 = residual oil	3 = balanced	
4 = combined oil & gas		

[b]*Dry, corrected to 3%O_2.*

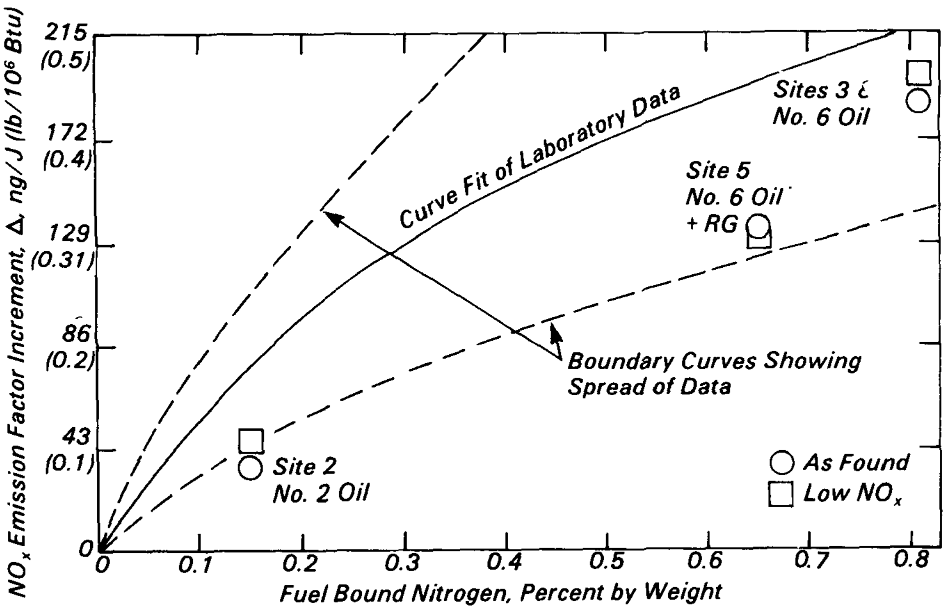

Figure 2. *Fuel-bound nitrogen effect on NO_x emission factor.*

level" or base NO_x emission factor for gaseous fuel (containing no fuel-bound nitrogen) was computed by taking the average as-found NO_x emission factor for all sites firing gas fuel only. This value was 58 ng/J. The increase, Δ, in emission factor for No. 2 oil was 34 ng/J (as found). For No. 6/gas fuel, the increase over the gas fuel emission factor was 136 ng/J (as found). For No. 6 oil, Δ was 187 ng/J (as found).

Comparing these points to the curve fit of previous laboratory data (Figure 2), shows that in all cases the emissions from low-NO_x burners fall below that curve. It is interesting to note that operation at the optimum low-NO_x mode (represented by squares in Figure 2) did not significantly alter the fuel-bound nitrogen conversion to NO_x. Also, except for Site 2, in the as-found condition all points plotted in Figure 2 fall within the boundary curves for the laboratory data. The effect of fuel nitrogen on NO_x emissions is thus responsible for the large differences in emissions between gas- and oil-fired heaters shown in Figure 1.

Table 4 summarizes NO emissions from the heater configurations studied over the tested range of operating variables. The values reported in parentheses are ppm corrected to 3 percent O_2, dry. (NO_2 emissions were not included due to lack of data at some sites. The data available from Sites 6-10, however, show that the NO_2 emissions average only 3.6 percent of the total NO_x emissions.)

Past Results - Comparison to Present

Reference 2 summarizes past NO_x emissions data on refinery process heaters firing oil and gas. These data are presented in Table 5. Unfortunately, the paucity of baseline data from oil-fired process heaters with standard burners makes it difficult to compare them with present low-NO_x burner data. Mechanically drafted heaters with low-NO_x burners firing gas, however, appear to have significantly lower NO_x emissions relative to the standard burners. Tables 4 and 5 reveal that low-NO_x burners produced NO_x emissions (neglecting NO_2) which were 32-77 percent less than the average emission factor for all standard burners on mechanical-draft gas-fired heaters. The variations in NO_x emissions from low-NO_x burners were due to operating differences between units (e.g., excess air level and air register settings). It is important to note that there is no NO_x data available on any of the units tested for operation with standard burners. Thus, NO_x emissions with and without low-NO_x burners cannot be compared directly for any heater. Because of a lack of availability, no natural-draft gas-firing low-NO_x burners were tested; hence, they cannot be compared with their standard counterparts.

Conclusions and Recommendations for Future Testing

The following conclusions may be drawn from the study:

1. The effectiveness of low-NOx burners depends on operating techniques, especially excess air level and air register settings.
2. By changing excess air and air register settings, NO_x emissions were reduced at every site with improved overall heater performance.
3. Commercially available low-NO_x burners may reduce the NO_x emission factor by 32-77 percent below the *average* emission factor for standard burners on mechanical-draft gas-fired heaters, depending on operating techniques.
4. Because of the lack of a good data base for oil-fired heaters with standard burners, a *meaningful* comparison of the performance of low-NO_x oil-fired burners versus

Table 4. *NO Emissions from Process Heaters with Low-NO_x Burners (1)*

	Fuel Type			
Unit Type	*Gas (Ref. or NG)*	*Distillate Oil*	*Residual Oil + Gas*	*Residual Oil*
Natural Draft	—	*58-117 $\frac{ng}{J}$ (105-212 ppm)*	*167-202 $\frac{ng}{J}$[a] (303-366 ppm)*	*207-284 $\frac{ng}{J}$ (369-506 ppm)*
Forced Draft, Ambient Air	*26-52 $\frac{ng}{J}$ (51-102 ppm)*	—	—	—
Balanced Draft, Air Preheat	*25-75 $\frac{ng}{J}$ (50-148 ppm)*	—	—	—

[a]Ratio of heat input from oil to heat input from gas ≃ 83/17.

Table 5. *Mean NO_x Emissions from Process Heaters with Standard Burners*

	Fuel Type			
Unit Type	*Gas (Ref. or NG)*	*Distillate Oil*	*Residual Oil + Gas*	*Residual Oil*
Natural	*60.6 $\frac{ng}{J}$ (25 tests)*	—	—	—
Mechanical	*111 $\frac{ng}{J}$ (6 tests)*	—	*89.6 $\frac{ng}{J}$[a] (5 tests)*	*138 $\frac{ng}{J}$ (3 tests)*
Not Reported (Bay Area A.P.C.D.)	*70.0 $\frac{ng}{J}$ (64 tests)*	—	—	—
Not Reported (AP-42)	*95 $\frac{ng}{J}$ (8 tests)*	*198 $\frac{ng}{J}$ (4 tests) - oil - firing only; type unspecified*		

[a]Ratio of heat input from oil to heat input from gas ≃ 60/40.

standard oil-fired burners cannot be made at this time.

5. It is recommended that further testing include mechanical-draft oil-fired heaters with and without air preheat and equipped with low-NO_x burners as well as natural-draft gas-fired heaters equipped with low-NO_x burners.
6. Existing data on heaters with standard burners have a number of gaps (see Table 5); further testing is required on standard burners firing distillate oil (both natural- and mechanical-draft) and standard burners firing residual oil (natural-draft) for a more valid comparison with low-NO_x burners.
7. Each test site in the program was evaluated as to its potential for a 30-day test. Considerations included:

   - Fuel type fired.
   - Ability to fire this fuel independently of other fuels.
   - Availability of the heater and the desired fuel for 30-40 days.

   Based on these considerations, the following sites are proposed as desirable for 30-day tests:

   - Site 1 - gas-fired, forced-draft
   - Site 2 - distillate-oil-fired, natural-draft.
   - Site 4 - residual-oil-fired, natural-draft.

Although Sites 6 through 10 are all gas-fired mechanical-draft heaters, they are not desirable sites for a 30-day test because they are still experiencing start-up problems; i.e., availability problems. Site 5, firing a combination of gas and oil, does not satisfy the fuel specificity requirement. Sites 3 and 4 are both residual-oil-fired natural-draft heaters, but Site 4 is a vertical cylindrical heater similar to the other recommended sites. Because of this similarity in design, Site 4 is the better choice.

The influence of heater design on NO_x emission between the three candidate sites will thus be minimal. Since none of the residual oil tests provided low NO_x levels, it may be desirable to try to find a site which can achieve lowr NO_x levels.

References

1. Hunter, S. C. et al., "Application of Advanced Combustion Modifications to Industrial Process Equipment: Subscale Test Results," USEPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC (Draft No. IERL-RTP-1271).
2. Hunter, S. C. and Cherry, S. S., *NO_x Emission from Petroleum Industry Operations,* API Publication No. 4311, American Petroleum Institute, Washington, DC, October 1979.

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The complete report, entitled "Emissions from Refinery Process Heaters Equipped with Low-NO_x Burners," (Order No. PB 82-231 838; Cost: $16.50, subject to change) will be available only from:

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