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Project Summary

Refinery Process Heater NOx Reductions Using Staged Combustion Air Lances

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Results of full scale tests to evaluate combustion modifications for emission control and efficiency enhancement on petroleum process heaters are summarized. Test objectives were to determine NO_x emission reductions, thermal efficiency changes, long-term performance, and cost of a staged combustion air modification (the most promising combustion modification in pilot scale tests). The test unit was a vertical, cylindrical, natural-draft crude-oil heater; test fuels were natural gas, refinery gas, and a combination of No. 6 oil and refinery gas. The unit had a 16 MW heat input capacity and was capable of a throughput of 108 m^3/h of crude oil. Firing refinery gas at normal excess air levels (4 percent stack O_2) at 10.4 MW heat input during a long-term test, the staged air modification lowered NO_x emissions by 60 percent below a baseline of 66 ng/J while increasing thermal efficiency slightly. At 2 percent stack O_2, the NO_x reduction reached 71 percent and heater thermal efficiency was increased by about 3 percent of the baseline thermal efficiency. For the combined refinery gas/No. 6 oil fuel at normal excess air and the same heat input rate, the NO_x reduction with the application of staged air was 34 percent below a baseline of 115 ng/J. At 2 percent stack O_2, this improved to 53 percent. Thermal efficiency increases at these conditions were nominally the same as observed for the refinery gas fuel. Long-term (30-day) evaluation of the staged air system revealed no special operating difficulties or process constraints: the system appeared to suffer no significant degradation. The cost of the modification was determined based on a permanent system.

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 and Summary

This final report is one of four final reports covering the pilot- and full-scale tests of combustion modification technology for reduction of NO_x emissions and to enhance thermal efficiency on industrial process equipment.

The activities summarized herein include field evaluations of several modification techniques applied to a natural-draft crude-oil heater. Test efforts focused on developing a new method of staged combustion which can be retrofitted on a wide variety of process heaters and can achieve NO_x reductions of over 50 percent from baseline, along with modest efficiency increases.

The modifications discussed in this report had previously been applied to a pilot-scale natural-draft heater as a part of this program in a series of tests aimed at determining the most promising techniques for full scale application. Emphasis was placed on developing modifications which required relatively minor hardware changes which could be made easily on a wide range of existing process heater types.

During earlier testing of full scale process heaters under EPA Contract 68-02-2144, operating variables such as excess air and load were adjusted to lower NO_x emissions. No hardware changes to the units were made during those tests, however.

Objectives and Scope

The objective of this program was to research combustion modification concepts requiring relatively minor hardware modifications that could be used by operators and/or manufacturers of selected industrial process equipment to reduce emissions and to improve thermal efficiency. The effort was to be performed for equipment in which the modifications would be most widely applicable and of the most significance in mitigating the impact of stationary source emissions on the environment. The objective was to assess the feasibility of these modifications to the extent that they could be readily adopted by the fuel burning equipment manufacturers. The path to this objective included concept definition, economic and technical assessment, subscale performance evaluation tests, cost/benefit analysis, full scale equipment modification or retrofit, full scale performance evaluation tests, and preparation of final reports and instructional guidelines.

Past Work

The present program is a follow-on study, building on the results of the program reported in Reference 1. The objective of that earlier effort was to investigate the effectiveness and applicability of combustion modifications involving only operating variable changes as means of improvement in thermal efficiency and for emissions control in industrial and combustion equipment. In that project (EPA Contract 68-02-2144), various kinds of industrial equipment for energy consumption and emissions were surveyed. Existing data were collected, and equipment manufacturers, operators, and associations were contacted. Industries were defined for which emissions reduction or efficiency increase through combustion improvement would be of significance on a national basis. These industries were petroleum refining, minerals, paper, and metals. The characteristics of specific combustion equipment of most importance in those industries were defined within the limitations of available data. These characteristics were used as guides in selecting test units that would be most nearly representative of the total population.

The program scope provided for tests on 22 industrial combustion devices representing kilns, process furnaces, boilers, stationary engines, and gas turbines in industrial use. Emissions measured included NO, NO_2, SO_2, SO_3, CO, CO_2, O_2, gaseous hydrocarbons, and (where possible) particulates, particle size distribution, smoke number, and opacity. Combustion modifications evaluated, where possible, included lowered excess air, staged combustion, reduced air preheat, and burner register adjustment. No hardware modifications were attempted, however. All experiments involved only operating changes.

In general, results indicate that combustion modifications may be applied to industrial combustion equipment, but reductions achievable can vary significantly for different types of devices. Reductions in NO^x of up to 69 percent were observed, but on many devices, reductions were less than 10 percent.

As a part of the present combustion modification program, a pilot-scale natural-draft process heater firing natural gas, No. 2 oil, No. 6 oil, and shale oil was tested. These test results were reported in Reference 2.

Several combustion modifications, most of which involved minor hardware changes, were evaluated during these tests. They included: low-NO_x burners, staged combustion air through floor lances, staged combustion air through a central cylinder, steam injection, flue gas recirculation, altered fuel injection geometry, and lowered excess air.

The results of the pilot scale tests are summarized below.

1. For a subscale natural draft process heater, baseline NO_x levels for two standard burners were 54.6 - 67.0 ng/J, firing natural gas. One standard burner emitted 150 ng/J (firing No. 6 oil) and 63 ng/J (firing No. 2 oil).
2. Two low-NO_x burner designs had baseline NO_x emissions of 47.1 - 53.0 ng/J, firing natural gas. Thus, the mean NO_x emission level from these burners was about 18 percent lower than the mean value for the two standard burners. Firing No. 6 oil, one low-NO_x burner design produced 149 ng/J, a reduction of 7 percent below the standard burner. The reduction of NO_x due to the low-NO_x burner when firing No. 2 oil was only 2 percent below the standard burner baseline.
3. Combustion modification techniques were effective in reducing NO_x emissions on a subscale process heater firing either natural gas or No. 6 oil. Staged combustion air through lances in the heater floor and coupled wi lowered excess air was the mo effective technique, followed by fl gas recirculation at either normal reduced excess air. When proper adjusted and under reduced exce air conditions, a low-NO_x (tertiary design) burner also effectively lo ered NO_x emissions firing both natur gas and No. 6 oil fuel. Lower excess air alone (without other mo fications) did not effectively reduc the NO_x concentration when firir No. 6 oil.
4. Modifications which worked well firir gas fuel (but which were not trie firing oil because of time or te equipment limitations) included stage combustion air using a central cyli der above the primary air zone, stea injection, and altered fuel injectic geometry. Each modification reduce NO_x emissions by more than 3 percent below baseline, and som may be applicable to oil firing as we as to gas firing.
5. Staged combustion air through flo lances reduced the NO_x at a norm operating excess air level by 4 percent below baseline (54.6 ng/ firing natural gas fuel. At lowered O levels, the reduction was as much a 67 percent (natural gas fuel). A normal O_2 conditions, the NO_x reduc tion firing No. 6 oil was 35 percer below baseline (160 ng/J); at re duced O_2, the reduction reached 5 percent.
6. Staged air through floor lances wa also the most cost-effective techniqu based on the data available. Cost were predicted to be roughly $700 Mg of NO_x reduction for small heate (2.9 MW and below) firing gas, an only $30/Mg of NO_x reduction fc large heaters (147 MW and above firing oil. Cost calculations did nc include annual fuel costs or saving due to the combustion modification because of the unrealistic efficienc changes that were observed on th small-scale heater.

Present Test Program Approacl

Following the work just discussed, location was sought which would perm the application of combustion modifica tions and, in particular, the installation c staged combustion air lances, on a fu scale operating process heater. A natura draft, vertical, cylindrical crude-oil heate was found containing six combination fuel John Zink burners of the same desig as those previously tested at the pilot scale facility.

Initial tests were conducted to determine heater performance over a range of operating variables such as excess air, load, and air register settings for various fuels. The tests were similar to the previous full scale tests mentioned earlier in that no hardware modifications were made to effect combustion modifications.

Once the performance of the heater was documented over its normal range of operating parameters, staged combustion air was implemented. A prototype system, constructed largely of polyvinyl chloride pipe, fittings, and valves with 24 stainless steel lances (4 per burner) was built. The system was designed to provide maximum flexibility and flow control for minimum cost. The heater was then reevaluated over the same ranges of operating parameters. During testing of the staged air system, several additional parameters were varied: burner stoichiometric ratios, staged air insertion height, and staged air lance orientation. An optimum low-NO_x operating condition was defined as the configuration at which the lowest NO_x concentrations were obtained while still permitting stable heater operation without a significant increase in CO emissions. This condition was defined for gaseous fuel and for a 50/50 mixture of No. 6 oil and gas.

A 30-day test was then conducted with the staged air system in continuous operation firing refinery gas at the optimum low-NO_x condition. System performance and durability were evaluated as well as the ability to maintain steady heater operation at the low-NO_x condition. After the long-term test, a permanent system was designed, suitable for a typical furnace of the same type tested in this program.

The cost, based on the permanent system design, of the staged combustion modification was evaluated for the gaseous fuel and for the combination fuel, and also at two levels of stack O_2.

Table 1 summarizes significant results obtained during the full scale test program.

Table 1. Summary of Results of Combustion Modification Tests on a Full-Scale Process Heater

Heat Input MW	Fuel Type	Baseline NO_x ng/J	Baseline NO_x ppm dry at 3% O_2	NO_x Reduction from Baseline %	Change in Fuel Consumption, %	Combustion Modification
10.4	Ref. gas	66	125	60	−0.2	SCA[a]
10.4	Ref. gas	66	125	71	−4.8	SCA + LEA[b]
9.0	Ref. gas	54	105	15	−2.8	LEA
13.7	Ref. gas	61	120	2.5	+2.2	Steam inj.
13.2	No. 6 oil + ref. gas	114	212	34	−0.6	SCA
13.1	No. 6 oil + ref. gas	115	214	53	−4.8	SCA + LEA
13.1	No. 6 oil + ref. gas	115	214	28	−3.0	LEA

[a]SCA = Staged Combustion Air
[b]LEA = Lowered Excess Air.

Conclusions and Recommendations

The following conclusions may be drawn from the field testing and analyses performed on this project.

- Lowered excess air and staged combustion air reduced NO_x emissions on a natural-draft, vertical, cylindrical process heater firing refinery gas or combined No. 6 oil and refinery gas.
- Steam injection did not effectively reduce NO_x emission firing refinery gas.
- In a long-term test, combined staged combustion air and lowered excess air reduced NO_x emissions by 71 percent below a baseline of 66 ng/J firing refinery gas, while decreasing fuel consumption by nearly 5 percent.
- Some form of automatic stack O_2 control is necessary to maintain the desired low stack O_2 content which produced optimum low NO_x operation.
- Without any such automatic system, the staged air system (operated at normal overall excess air levels when firing refinery gas in a long-term test) reduced NO_x emissions by 60 percent below the 66 ng/J value while decreasing fuel consumption by about 0.2 percent.
- The staged combustion air system can function effectively and continuously with little operator attention and little lance deterioration over a 30-day period.
- The staged combustion air system is expected to be applicable to most types of refinery heaters, whether forced draft or natural draft and whether vertical or horizontal. The cost effectiveness is likely to be site specific, however.
- Firebox temperatures at or below about 1200 K (1700°F) do not appear to be important in determining NO_x emissions.
- Pilot scale predictions for NO_x reductions on a natural draft process heater with staged combustion air are expected to be valid for 100 percent No. 6 oil firing in a full scale heater.
- The cost of staged combustion air on a natural draft process heater applied at normal stack O_2 is calculated as $2636/Mg NO_x reduction for a 16.1 MW heater, decreasing to $1934/Mg at 147 MW heat input.
- The cost of staged combustion air combined with lowered excess air on a natural draft process heater applied at 2 percent stack O_2 is calculated as $1089/Mg for a 16.1 MW unit. The cost becomes negative for a 147 MW unit, indicating a savings associated with the combined modifications.

Possible areas for future test work involving combustion modifications for NO_x control on process heaters include:

1. Evaluating staged air for a natural-draft air-injection system, to eliminate the cost of installing and operating a blower.
2. Using slower air velocities in a staged air system to reduce the pressure requirements of the blower, thereby lowering costs. Larger diameter air lances could perhaps be combined with a lower pressure blower than that used in the present tests.
3. Coupling the staged air system with some type of automatic stack O_2 control system, to achieve optimum heater performance with respect to NO_x and CO emission levels, as well as heater thermal efficiency.
4. Testing the staged air system, firing 100 percent No. 6 oil fuel.
5. Applying staged combustion lances to forced draft units both with and without air preheat, to assess NO_x reduction potentials and cost effectiveness. Presumably, a special staged air blower would not be required on such units, thus reducing costs (al-

though interfacing with an existing air supply system—particularly for preheated units—might be more costly than modifying a relatively simple natural draft heater).

References

1. Hunter S. C. et al., "Application of Combustion Modifications to Industrial Combustion Equipment," EPA-600/7-79-015a (NTIS No. PB 294 214, January 1979.
2. Hunter, S. C. et al., "Application of Advanced Combustion Modifications to Industrial Process Equipment: Subscale Test Results," EPA-600/7-82-021 (NTIS No. PB82-239310), April 1982.

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The complete report, entitled "Refinery Process Heater NO_x Reductions Using Staged Combustion Air Lances," (Order No. PB 83-193 946; Cost: $20.50, subject to change) will be available only from:

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