United States
Environmental Protection
Agency

Research and Development

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/S8-83-017 June 1983

EPA

# Project Summary

# Guidelines for the Reduction of Emissions and Efficiency Improvement for Refinery Process Heaters

R. J. Tidona

**The manual contains guidelines for the operation, adjustment, and modification of refinery process heaters to achieve reduced emissions and increased efficiency. Combustion fundamentals are summarized and test data obtained on this contract from previous subscale and full-scale process heaters are reviewed. All of the results cited pertain to natural draft, vertically fired heaters; however, many of the combustion modification techniques discussed in the manual are also expected to be applicable to forced-draft and horizontally fired heaters. Recommended procedures for adjusting combustion on process heaters are given. The most promising combustion modification to reduce refinery heater emissions and improve efficiency -- staged combustion air lances -- is discussed in detail. Information appropriate to the design, operation, and maintenance of a staged combustion air lance system for a process heater is presented. Cost effectiveness estimates for such a system are also given. It is expected that, through the proper use of a staged combustion air system and the heater adjustment procedures described in the manual, the fuel costs for a typical refinery heater will be reduced by about 4 - 5 percent and the $NO_x$ emissions may be reduced to 50-33 percent of baseline levels.**

***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).***

## Summary and Objectives

These guidelines should assist manufacturers and operators of natural draft process heaters in the petroleum refining industry in achieving maximum efficiency with minimum pollutant emission. The means for achieving such optimized heater performance have been investigated over a period of several years through an exhaustive field test program encompassing both sub- and pilot-scale heater tests. These methods include operating variable optimization (e.g., amount of excess air and air distribution and mixing patterns) applied either alone or in combination with hardware modifications such as staged combustion air lances, altered fuel injection geometry, low-$NO_x$ burners, flue gas recirculation, and steam injection.

The guidelines focus on the use of operating variable changes and the implementation of the most promising of the hardware modifications investigated for process heaters -- staged combustion air lances. Combustion adjustments combined with the staged combustion modification have been successfully applied to a natural draft process heater for 30 days. Their application resulted in significant increases in the thermal efficiency of the heater and $NO_x$ emission reductions of 60 percent or more.

Methods for measuring emissions, optimizing excess air level, and establishing the proper burner register settings are discussed. Also covered are suggested procedures for monitoring heater performance once the unit has been properly adjusted. These topics should be of particular interest to heater operators.

The design, operation, and maintenance of a staged combustion air system which uses stainless steel pipes (or "lances") to introduce combustion air downstream of the burner injection plane, as well as the costs and cost effectiveness of this system, are also discussed. This information should be of interest to both manufacturers and operators.

The guidelines include those for combustion modifications which apply to new or existing natural draft heaters. The test results described are given for a vertical cylindrical firebox; however, the combustion modifications are expected to be applicable to vertical rectangular and horizontally fired heaters as well.

Although the tests were conducted on a crude oil heater, the modifications and adjustments discussed are expected to be applicable to other heater types (e.g., cracking heaters or reformer heaters) since the process tube wall temperature distribution does not appear to be significantly altered by these changes in heater operation. In addition, the use of burner adjustments and staged combustion air is not limited, in principle, to natural draft heaters. Mechanically drafted units, both with and without combustion air preheat, are expected to lend themselves well to such modifications based on previous experience with industrial and utility boilers. In a particular example, staged air lances applied to a mechanically drafted industrial boiler resulted in a $NO_x$ emission reduction of 42 percent (while increasing the unit's thermal efficiency by 0.5-1 percent) (Ref. 1).

## Process Heater Test Program

Tests were conducted on a natural-draft, vertical cylindrical crude heater containing six John Zink burners, capable of combined fuel firing. 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 fuel types. In these tests, hardware was not modified to affect combustion. For some tests firing refinery gas, steam was injected through the oil-atomizing system, and its effect on $NO_x$ emissions assessed.

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, including 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. At the completion of the long-term test a permanent system was designed. This system was intended to be suitable for a typical furnace of the same type as that tested in this program.

Table 1 summarizes significant results of the test program. A detailed final report covering the research activities at this heater is being published by EPA (Ref. 2).

The cost effectiveness, 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 oxygen. The cost effectiveness is shown in Table 2 for three heater sizes.

The values for lowered excess air (LEA) and for staged combustion air (SCA) plus LEA modification on the largest heater are negative, indicating a cost savings in addition to a $NO_x$ reduction. This is a desirable situation; however, one must realize that a modification which saves money yet produces only a small $NO_x$ reduction will have a large negative cost effectiveness ratio. This may not be the most desirable modification if the level of $NO_x$ reduction is lower than is necessary to achieve compliance with regulations or to offset future emissions from plant expansions.

## Combustion Adjustments to Process Heaters

To establish the optimum operating conditions on a natural draft process heater (e.g., excess air level, air register settings, and stack damper position), one should be able to accurately measure stack oxygen, $NO_x$ and CO concentrations, stack temperature, tube skin temperatures, and furnace draft (preferably at a minimum of three elevations in the heater--at the firebox, the convection section inlet or bridgewall, and the stack). These measurements allow the operator to maximize heater efficiency by reducing the excess air (*stack oxygen*) to the minimum amount which can be maintained without causing combustibles (*CO*) to appear in the stack gases. Reducing the excess air will generally affect the ***stack gas temperature***, as well. A change in stack gas temperature also affect heater thermal efficiency and, therefore, is an important parameter to be measured so that the efficiency improvement may be quantified.

Lowering the excess air to this minimum value also lowers $NO_x$ emissions since it reduces the amount of atmospheric nitrogen contacting the flame. Mea-

***Table 1.*** *Summary of Results of Combustion Modification Tests on a Process Heater*

| Heat Input MW | Fuel Type | Baseline $NO_x$ ng/J | Baseline $NO_x$ ppm dry at 3% $O_2$ | $NO_x$ Reduc. from Baseline % | Change in Fuel Cons. % | Combustion Modification |
|---|---|---|---|---|---|---|
| 10.4 | Ref. gas[a] | 66 | 125 | 60 | −0.2 | SCA[b,c] |
| 10.4 | Ref. gas | 66 | 125 | 71 | −4.8 | SCA + LEA[c,d] |
| 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] *Ref. gas = Refinery gas.*
[b] *SCA = Staged Combustion Air.*
[c] *Based on results of a 30-day test.*
[d] *LEA = Lowered Excess Air.*

suring the *$NO_x$ concentration* ($NO_x$= NO + $NO_2$ concentrations) is thus important to quantify the amount of emission reduction obtained by adjusting the heater.

Also important in a natural draft heater when making air adjustments is the ***draft profile.*** The heater should be maintained at a negative pressure throughout to avoid both flashback at the burners and the escape of toxic and flammable combustion gases to the surroundings through cracks, ports, etc.

The operating condition which results in the lowest stack oxygen level and stack temperature (without affecting the heater feed rate and while maintaining negative pressures throughout the heater) must also result in radiant section tube skin temperatures which are well within the limitations of the tube materials and/or the process constraints. Significant local increases in tube skin temperatures could cause coking of the process fluid or tube failure. It is thus essential that ***tube skin temperatures***, especially in the vicinity of the flame, be monitored throughout any adjustment procedure. Changes in flame appearance can indicate changes in the tube temperatures caused by a combustion adjustment.

Once the condition is reached at which stack $O_2$, $NO_x$, and stack temperature have been optimized with respect to CO emissions, heater draft profile, and tube skin temperatures, the proper operating condition has been reached for that particular heater feed rate. It then remains to determine the optimum operating conditions at several other feed rates covering the normal operating range of the heater.

The $NO_x$ emissions resulting from a heater at various stack oxygen levels at varying process rates are shown in Figure 1 for gas firing. These data were collected from the test site discussed earlier. Although baseline $NO_x$ emissions are higher for oil fuels, the general shapes of the curves are similar for both oil and gas fuels. These characteristic curves should be developed for each individual heater in order to compare results each time the unit is adjusted. Ideally, for constant fuel and feed composition, each time the heater is returned to the same set of operating conditions (i.e., fuel and feed flow rates, feed inlet and outlet temperatures and pressures, fuel temperature and pressure, stack oxygen, register settings and furnace draft, and combustion air temperature and humidity), the same $NO_x$ emissions will result. Naturally, it is never possible to duplicate a set of operating conditions *exactly*; however, a discrepancy of more than about 5 percent in $NO_x$ concentration when attempting to reproduce a past test condition usually indicates that some operating parameter has not been set correctly.

The guidelines contain recommendations for stack sampling instruments and techniques useful in implementing a program such as that just described. In addition, helpful tips on conducting spot-checks on combustion efficiency and periodic comprehensive performance evaluations are also offered.

## Staged Combustion Air Modification

The principle of staged combustion is not new. It has been used as a $NO_x$ reduction technique on utility and industrial boilers and steam generators for several years. The recent interest in applying $NO_x$ reduction technology (which permits safe reliable operation at minimum additional cost) to other industrial combustion devices motivated the design of a staged air system applicable to many refinery process heaters. Process heaters, as well as several other industrial devices, had been determined to contribute significantly to nationwide $NO_x$ emissions in addition to consuming large amounts of energy in the form of fossil fuels.

A staged combustion air lance system flow schematic is presented in Figure 2. Basically, the system provides combustion air downstream of the fuel injection plane of each burner by means of a forced draft blower. The air is injected into the firebox through pipes or "lances" which penetrate either the floor of a vertically fired unit or the walls of a horizontally fired unit. The introduction of air downstream of the burners permits fuel-rich operation

***Table 2.*** *Cost Effectiveness (\$/Mg) of Combustion Modifications Applied to Three Natural Draft Process Heater Sizes*

| | Heater Size | | |
|---|---|---|---|
| *Modification[a]* | *16.1 MW* | *29.3 MW* | *147 MW* |
| *SCA at 4% $O_2$* | *2636* | *2362* | *1934* |
| *SCA + LEA* | *1089* | *700* | *(40)[b]* |
| *LEA Firing Gas* | *(5843)* | *(6853)* | *(4813)* |
| *LEA Firing Oil and Gas* | *(1459)* | *(1712)* | *(2189)* |

*[a]SCA = Staged Combustion Air, LEA = Lowered Excess Air.*
*[b] ( ) = savings.*

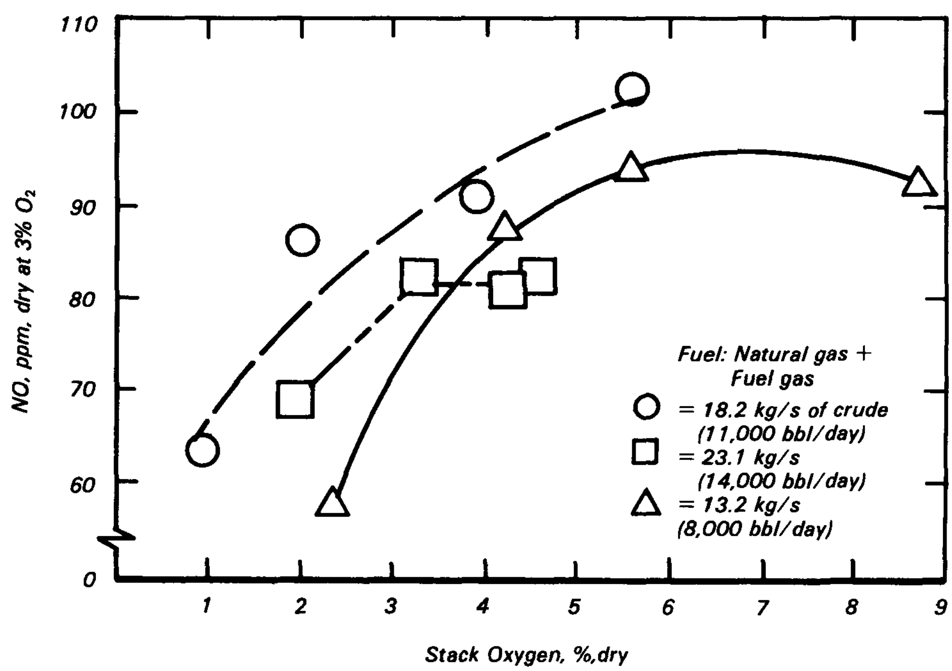


***Figure 1.*** *NO emissions at three different loads as a function of stack oxygen for a natural draft process heater firing a natural gas/refinery gas mixture.*

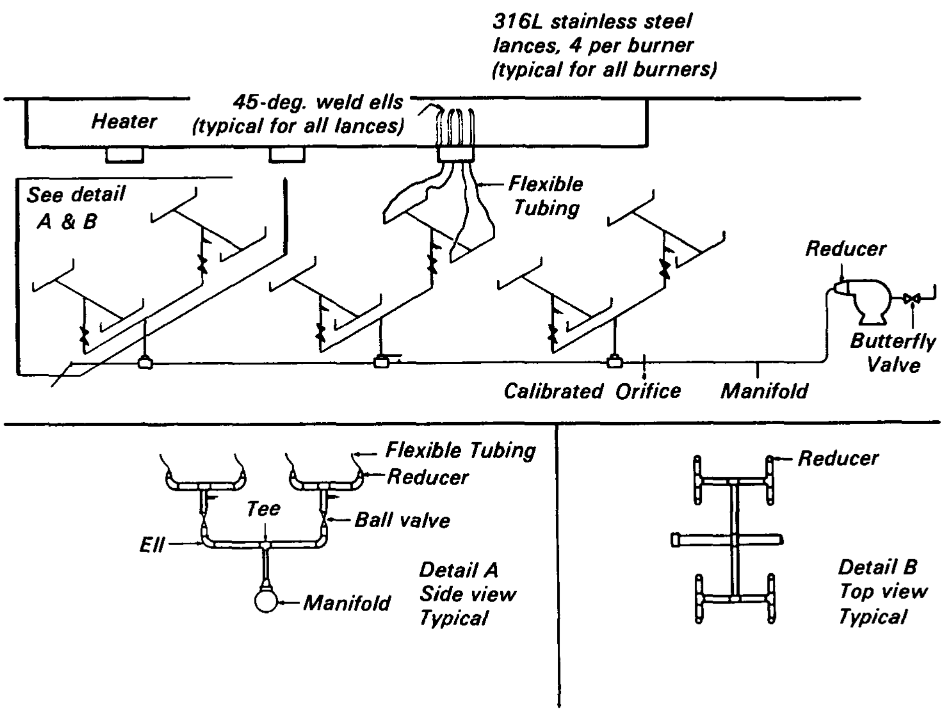


*Figure 2. Flow schematic of staged combustion air system for a natural draft process heater.*

at the burners with as little as 60 percent of the theoretical air required for complete combustion. The amount of combustion air injected through the staged air lances is enough to provide the remainder of the theoretical air requirement plus the amount of excess air necessary to eliminate combustibles in the flue gas and provide a good flame.

The system was designed for a vertical cylindrical heater with six natural draft John Zink DBA-22 burners. The heater had a maximum thermal input capability of 16 MW (55 x $10^6$ Btu/hr). The staged air system had the capability of controlling the air flow to each burner by means of ball valves, and the lance height above the furnace floor was adjustable. These features although desirable, are not necessary in a working system. They were used to allow flexibility so that firing conditions could be optimized in the prototype system.

Provision should be made in the design of the system to vary the lance height above the furnace floor. During the system checkout testing, the firing conditions can be optimized for each specific heater design and operating condition. After the optimum configuration has been determined, the system can be hard plumbed, if desired.

The height of the staged air lance tips was 1.2 m (4 ft) above the plane of the burner gas tips. This height was found to give the best $NO_x$ reductions for both gas- and gas/oil-firing.

## Applicability of the Staged Combustion Air Modification

The combustion modification technique of staged combustion air has been assessed on a vertically fired natural draft process heater for 30 days firing refinery gas. The modification has been applied for short-term tests (up to 12 hours) on that unit when firing No. 6 oil and refinery gas in approximately equal proportions by heat input.

Ultimately, it is expected that this modification could be applied to virtually any type of process heater; however, the fan requirement, the $NO_x$ reduction potential, and the efficiency implications are all likely to be site-specific because of the wide variety of heater designs currently in use. Temperature and pressure/draft profiles may differ significantly from those measured at the prototype site and may have significant effects on the $NO_x$ reduction potential and efficiency impact of staged combustion air.

For heaters which are mechanically drafted, this combustion modification technique may prove to be very cost effective since a separate staged-air fan would probably not be required. The initial design and installation of a staged air system would likely be more complex for that type heater, however, than they were for the natural draft unit.

A horizontally fired heater would probably require that lances be horizontal in the firebox. In that case lance skin temperatures would become more critical since they may be high enough to cause the lances to droop. Some vertically fired heaters may be more easily modified by means of horizontal lances, also, due to ground clearance limitations (the distance between the heater floor and the ground limits the staged air lance height above the burner). In that instance the modification is similar to overfire air or "$NO_x$ ports" which are already in use on many industrial and utility boilers.

It is expected that staged combustion air will be applicable to all process heaters regardless of fuel, although optimum lance placement and orientation may be different when burning 100 percent No. 6 oil fuel from the configuration used for refinery gas fuel and the gas/oil mixture.

When key parameters are different from those of the test unit (e.g., fuel type, pressures, temperatures, air velocities, and mixing patterns), this staged combustion air system performance may differ from the test unit performance with regard to $NO_x$ emission reductions and efficiency impact.

Also note that the test unit was a crude oil heater, typically one of the most flexible in a refinery in terms of tolerating changes in temperature and heat flux distributions. Other units (e.g., reforming heaters and vacuum heaters) often have process fluids of more than a single phase or at a higher temperature regime where the process fluid flow may be seriously affected by variations from a design heat flux distribution. These process limitations should be studied before attempting to apply the staged air modification to a process heater used for any such complex application.

## References

1. Carter, W. A., H.J. Buening, and S.C. Hunter, "Emission Reduction on Two Industrial Boilers with Major Combustion Modifications," EPA-600/7-78-099a (NTIS PB 283109), June 1978.
2. Tidona, R. J., W.A. Carter, and H.J. Buening, "Refinery Process Heater $NO_x$ Reductions Using Staged Combustion Air Lances," EPA-600/7-83-022, March 1983.

*R. J. Tidona is with KVB, Inc., Irvine, CA 92714.*
***Robert E. Hall*** *is the EPA Project Officer (see below).*
*The complete report, entitled "Guidelines for the Reduction of Emissions and Efficiency Improvement for Refinery Process Heaters," (Order No. PB 83-206 995; Cost: $11.50, subject to change) will be available only from:*

*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*

*The EPA Project Officer can be contacted at:*

*Industrial Environmental Research Laboratory*
*U.S. Environmental Protection Agency*
*Research Triangle Park, NC 27711*

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604