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Project Summary

Design Report: Low-NO_x Burners for Package Boilers

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A low-NO_x burner was designed for residual oil-fired industrial boilers including boilers cofiring nitrated wastes. The design employs deep staging to achieve NO_x levels lower than conventional low-NO_x approaches while maintaining an environment favorable to high waste destruction efficiency. A cylindrical shell precombustor chamber fired substoichiometrically is to be retrofitted to the burner opening of the boiler. Remaining combustion air would be added through retrofit sidefire wall air ports. The design is based on fabrication from lightweight refractory block modules covered with a Saffil™ fiber veneer. This design allows quick thermal response necessary for industrial boiler applications which is not possible with heavy castable or brick refractory. Design dimensions and materials specifications are made for the thermal input capacity range of 15-59 MW[a]. Annular spool section modules are installed to fire higher loads in the range of 15-29 MW, and a geometric scale-up is used for larger capacities. Construction and field evaluation of the burner has not been performed.

This Project Summary was developed by EPA's Air and Energy Engineering 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).

[a] Readers more familiar with nonmetric units may use the conversion factors at the back.

Introduction

The low-NO_x burner design reported here was motivated by two regulatory needs for more effective NO_x emission reduction. The primary need is for additional emission reduction for new industrial boilers firing high nitrogen residual oil. This requirement derives from Section III of the Clean Air Act, which directs that New Source Performance Standards (NSPS) be periodically reviewed and tightened as new technology is developed. The current standard for residual-oil-fired industrial package boilers constructed after July 6, 1984, was set at 172 ng/J on an NO_2 basis that corresponds to about 330 ppm. This emission standard requires a fairly low degree of emission reduction from uncontrolled levels because of a lack of demonstrated technology applicable to package boilers without introducing operational problems. The current burner design effort was initiated in part to support EPA in the next series of revisions of the NSPS so that additional emission reduction technology would be available.

The second need addressed by the burner arises from the requirements of the Resource Conservation and Recovery Act (RCRA) for disposal technologies such as thermal destruction as alternatives to land disposal. Where the waste has high heat content, cofiring of the waste in industrial boilers is a practical means of destruction while recovering fuel credits from the heating value. If the waste has high nitrogen content, however, the NO_x emissions from cofiring may be unacceptably high unless additional steps are taken for NO_x reduction. Approximately 114 RCRA Appendix VIII compounds and 30 F and K category listings contain significant nitrogen in the form of nitriles, amines, nitrobenzene, and cyanides. Thermal destruction of these wastes currently presents a challenge to simultaneously satisfy the intent of both the Clean Air Act and RCRA. The current burner design is intended to offer waste generators a thermal destruction option which is high in destruction efficiency but low in NO_x emissions in order to treat nitrated wastes.

Approach

The design goals set for the low-NO_x burner were:

- Fuels:
  - High nitrogen residual oil
  - Nitrated waste cofired with residual oil
  - Natural gas or distillate oil for light-off
- NO_x emissions:
  - 100-125 ppm with residual oil
  - 200-300 ppm with nitrated waste cofiring
- Carbon monoxide: <35 ppm
- Smoke emissions: <4 Bacharach
- Capacity: 15-59 MW thermal input
- Turndown: >5:1
- Destruction efficiency with waste cofiring: > 99.99%

The concept for the burner was derived from an earlier EPA-sponsored program in which a deep-staging prototype burner was designed and tested for an enhanced oil recovery (EOR) steam generator firing crude oil. With this concept, low conversion of fuel nitrogen compounds to NO_x is achieved by creating a hot, fuel-rich first stage with relatively long residence time. The high temperatures and long residence time serve to drive the kinetics of fuel nitrogen intermediary species toward recombination to N_2 rather than oxidation to NO.

The earlier EOR burner used a regenerative design for the precombustor in which the refractory was cooled by the incoming combustion air. The precombustor was fabricated from heavy refractory bricks. The NO_x performance for this prototype burner was 65 ppm.

Although the earlier design was appropriate for the EOR steamer, several changes were needed for the more demanding industrial boiler application. The high density refractory in the EOR burner required a long thermal response time to keep thermal stresses within acceptable limits. A faster response was needed for the industrial boiler for rapid start-up, shut down, and load following. For the boiler burner design, this was approached by using a nonregenerative design with a lightweight insulating refractory. This design also gave a better capacity turndown potential than the regenerable design.

An additional change was required in the size of the unit. The EOR NO_x design goal was 65 ppm which necessitated a precombustor nearly as long as the radiant section of the steamer. In the current design, the goal of 100-125 ppm allows a shorter combustor to be built, since the combustor length is needed primarily to provide residence time for the fuel nitrogen compounds to recombine to N_2 prior to introduction of stage air. The necessary length was also reduced by introducing stage air from the side of the boiler rather than at the interface of the precombustor and the boiler. This allows additional residence time in the boiler prior to staging for nitrogen reactions to occur.

Changes in the prior design were also needed in the sophistication of the control system as well as safety measures for rapid shutdown.

Burner Design

The general burner design is shown in Figure 1 for a nominal 15 MW heat input capacity. For higher capacities, up to 29 MW, additional spools can be inserted to give added combustor volume. The burner diameter of 2.1 m was selected to adapt to the firing wall of package industrial boilers, and to give gas velocities in the precombustor typical of commercial operation with lightweight refractory.

The combustor length was selected to give a predicted boiler exit NO_x level of 85 ppm (corrected to 3% oxygen). This target gives a margin of safety in achieving the design goal of 100 ppm. NO_x as a function of precombustor length was predicted using test data from the prior EPA burner development for the EOR steamer, and fuel nitrogen kinetic calculations.

For the precombustor stoichiometry of 0.7 and temperature of 1540°C, interpolations and extrapolations of the EOR burner test data showed a reduction in total fixed nitrogen concentrations at the exit of the precombustor to a level of 112 ppm, (at 0% oxygen) for a precombustor residence time of 400 msec. A further reduction in total fixed nitrogen to 85 ppm is predicted for the cooling zone between the exit of the precombustor and the injection of second stage air at the stage air ports. The completion of combustion in the second stage is predicted to yield 60 ppm NO_x (corrected to 3% oxygen) from the fuel nitrogen species, and 25 ppm thermal NO_x for a total flue gas concentration of 85 ppm at 3% oxygen. For these NO_x design predictions, the internal combustor length needed was 2.7 m for the 15 MW capacity.

The throat diameter at the transition from the precombustor to the boiler was set at 0.9 m for the 15 MW design to maintain exit velocities below 35 m/s. This is the desired velocity at full load to allow flame shaping and capacity turndown similar to conventional register burners.

The location of the stage air ports to be retrofitted to the boiler sidewalls was selected as the farthest upstream point at which the fuel nitrogen kinetics are effectively frozen and no additional reduction would accrue from longer exposure. For the nominal 15 MW design, this length was 2.1 m from the front wall. This gives a second stage residence time of about 620 msec. Calculations of CO and smoke burnout show that, for this residence time and the design temperatures, the CO is effectively burned out, and the soot is burned to below the particulate emission standards.

The burner to be fired at the front end of the precombustor is a standard commercial register burner with adjustable louver blades. This burner offers capabilities for flame shaping and provides high turndown ratios. Fuel atomizers and jets are specified for residual oil, waste fuel, natural gas, and (if needed) distillate oil for light-off. Steam atomization is specified for both the waste and residual oil.

The insulating refractory configuration for the precombustor is shown in Figure 2. Section I is Pyro-Bloc® H with a maximum design limit of 1340°C. Section II is Unifelt® XT, a Saffil veneer with a maximum design temperature of 1650°C and a recommended continuous use temperature of 1570°C. Section III is a Unikote™ S coating with a use limit of 1650°C. This coating is partly to give structural rigidity prior to curing and hardening of the insulating blocks.

The front and rear end plates of the precombustor use a more complex structure to accommodate the burner throats and the need for greater thermal conduction away from the wall. The throat is fabricated from castable refractory that has sufficient strength to be self-supported. The castable will also be anchored by studs welded to the front plate and to the boiler front wall tubes. A lightweight castable refractory is placed behind the castable plastic refractory in the front plate assembly. This provides

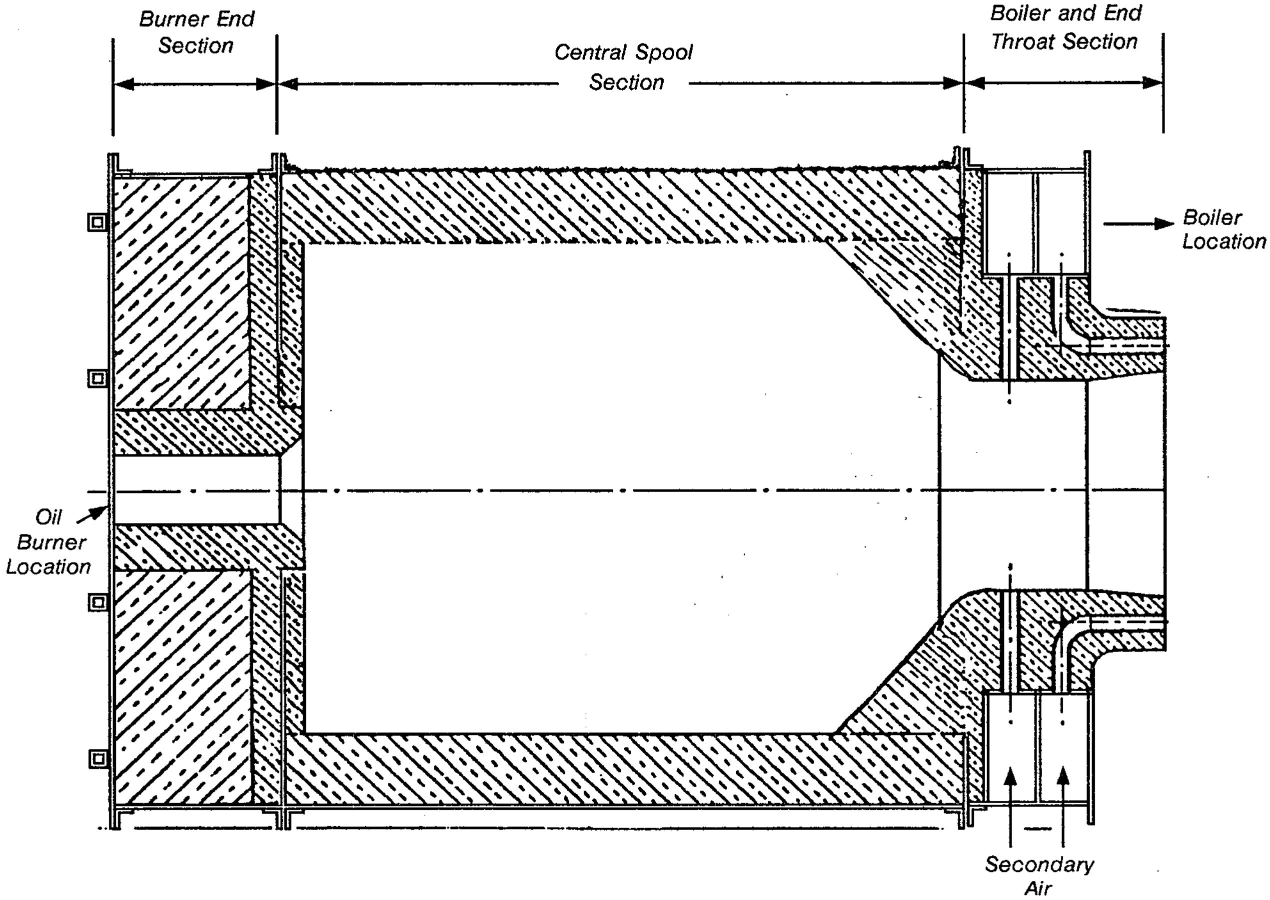

Figure 1. The combustor section.

thermal insulation while the castable refractory and the studs conduct heat away from the localized hot spots on the front face.

Conclusions

The initial objective of this project was to design, fabricate, install, and evaluate the EPA low-NO_x heavy oil burner for an industrial package boiler in the 59-74 MW thermal input range. Early in the project, this objective was revised in two ways. The capacity range for the burner was lowered and broadened because (1) almost no industrial boilers in the 59-74 MW range were firing residual oil to serve as a demonstration, and (2) most operators who could use the burner for low-NO_x firing of nitrated waste had boilers in the 15-29 MW thermal input range. The design range was accordingly changed to 15-59 MW.

The second revision of the objective was to adapt the design to the industrial boiler application with the more stringent requirements for faster thermal response.

In addressing these objectives, the design development effort in the current project led to selection of the lightweight refractory precombustor/burner design with boiler sidefire air. Although this burner was not fabricated and evaluated in the field, the following conclusions on the design are based on the process engineering analyses done as part of the design development.

Emissions Performance

The estimated performance of the design based on previous test results and kinetic estimates is 85 ppm at 3% oxygen. The emission goal selected for this program was 100-125 ppm, so the final design should give sufficient margin to meet the emission performance demands of the intended market.

Burner Performance

The use of the lightweight refractory should allow thermal response during start-up, shutdown, and load swings comparable to conventional burners and should not constrain industrial boiler applications. The burner is smaller, much lighter, and cheaper than the earlier EPA oil burner design. The control logic during start-up is more complex due to the two-stage operation, but not out of line with new boilers with advanced low-NO_x systems.

Market Niche

The burner addresses a need for both high nitrogen residual oil firing and cofiring of nitrated wastes. Conventional low-NO_x burners for high-capacity package boilers firing high nitrogen residual oil cannot lower emissions below the 250-350 ppm range without causing flame impingement, combustible emissions, or instabilities. With waste cofiring, the unique hot first stage used in the burner design offers simultaneous high waste destruction efficiency and low-NO_x emissions. This burner avoids the problem with other burners where measures

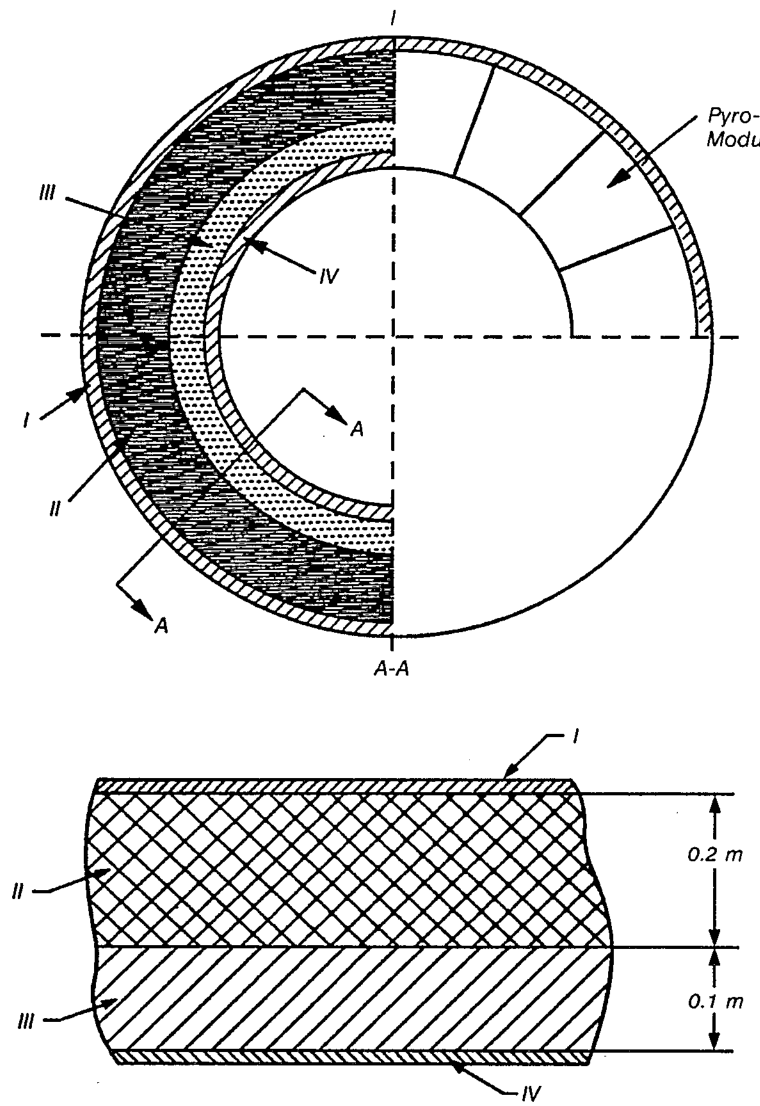

Figure 2. *Combustor cross section, Pyro-Bloc Plus module arrangement.*

taken to lower NO_x are counterproductive for high waste thermal destruction.

Reliability

The present design uses lightweight refractory to improve thermal response and reduce failure risk from thermal shock. The design increases the risk, however, of mechanical failure and overtemperature.

Scale-Up

Burner design data are given over a 4:1 capacity range. The general configuration, stoichiometric ratios, residence times, and temperatures all remain nearly identical across that range, however. Therefore, there is not expected to be significant performance variations with scale-up.

Developmental Status

Although the burner concept is derived from the earlier EPA oil burner, many differences in materials and configuration were made to address the industrial boiler market. Thus, the first prototype field evaluation will have a larger component of shakedown and confirmatory testing than that for a simple hardware scale-up..

Nonmetric Equivalents

Readers more familiar with nonmetric units may use the following conversion factors:

Metric	Multiplied by	Yields Nonmetric
°C	9/5°C + 32	°F
cm	0.391	in.
m	3.281	ft.
MW	3.414	10^6 Btu/hr
ng/J	0.0023	lb/10^6 Btu
Pa	0.0040	in. H_2O
tonne	1.102	ton

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The complete report, entitled "Design Report: Low-NO_x Burners for Package Boilers," (Order No. PB 90-159 898/AS; Cost: $23.00, subject to change) will be available only from:

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

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