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Research and Development

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Project Summary

Evaluation and Demonstration of Low NO_x Burner Systems for TEOR Steam Generators—Test Report: Preliminary Evaluation of Commercial Prototype Burner

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The report summarized here describes the preliminary testing of a 16 MW low-NO_x burner for thermally enhanced, oil recovery (TEOR) steam generators. These "steamers" are often required to burn low-grade fuels with minimum environmental impact.

The 16 MW commercial prototype burner described in this report was developed from scaling criteria generated in previous bench- and pilot-scale experiments supported by EPA. NO_x emissions can be reduced by staging the combustion process. The design of this burner is based on optimizing conditions of stoichiometry, temperature, residence time, and mixing so that NO_x emissions are minimized. The current design utilizes a separate, regeneratively cooled prechamber. Fuel and a portion of the combustion air enter the prechamber and burn under optimum fuel-rich conditions. Secondary air is injected at the prechamber exit into the furnace where combustion is completed.

The tests were conducted in an experimental test furnace which closely simulates the thermal environment of a watertube boiler. Firing a 0.74 percent nitrogen residual fuel oil with the optimum burner configuration produced 49 ppm of NO_x, 35 ppm of CO (corrected to 3 percent oxygen), and a Bacharach smoke number of 2 to 4. Flame conditions within the furnace were favorable, with no impingement on any of the test furnace surfaces. Although the geometry of the test furnace (L/D = 1.4) is different from TEOR steamers (L/D = 4) the flame characteristics appeared to be well suited for the intended applications.

This document summarizes the results of tests to determine the effects of first-stage parameters (swirl, throat geometry, stoichiometry) and second stage parameters (air injection geometry, excess air) on emissions and flame characteristics. Turndown was also investigated. Thermomechanical performance of the burner hardware and control system performance are also discussed.

The results of the preliminary evaluation demonstrated the ability of the burner to produce very low NO_x levels on a high-nitrogen heavy residual oil, with low smoke and CO emissions, and with a flame which appears to be compatible with field steam generators. The burner hardware has performed without serious mishap for the short duration of these tests. Final optimization and detailed evaluation of the burner hardware and control system will take place during the field evaluation.

This Project Summary was developed by EPA's Industrial Environmental Re-

search 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

Enhanced oil recovery processes are applied to oil field production in order to extract heavy, viscous crude oil and tar sands which cannot otherwise be produced. A significant fraction of total U.S. oil reserves require application of enhanced oil recovery in order to be realized. Thermally enhanced oil recovery (TEOR) involves injection of wet steam which is produced by combusting crude oil in oil field steam generators typically ranging in size from 7 to 15 MW capacity. More than 90 percent of all oil field steam generators in the United States are located in California, one-third (approximately 1000 units) of which are located in Kern County. Approximately one-third of the produced crude oil is consumed by steam generators, amounting to over 200,000 barrels of crude oil consumed per day at full capacity. The crude oils which are fired in these steam generators are typically high in nitrogen (-0.8 to 1.0 percent) and sulfur content. Uncontrolled emissions of NO_x and SO_x can therefore reach high levels and potentially worsen ambient air quality.

Local legislation regulating emissions of NO_x from oil field steam generators threatens to limit oil production unless NO_x control methods are applied. A ceiling on total NO_x emissions from all steam generators in Kern County has been established which limits total emissions to 1979 levels; thus new generators cannot be brought on line without reducing emissions from existing ones. New generators are required to have "best available control technology" (BACT) which may include low-NO_x burners, postflame NH_3 injection, or other postflame treatment methods. In addition, if ambient NO_2 level in Bakersfield exceeds a specified level, the total NO_x ceiling is lowered to the equivalent of 0.14 lb $NO_x/10^6$ Btu (60 mg/MJ) or 105 ppm NO, corrected to 3 percent oxygen if all steamers are in operation. Enhanced oil recovery operations are projected to expand through 1995. The level of NO_x control required to meet both growth and air quality goals has typically been difficult to achieve with available technology while maintaining acceptable CO and particulate emissions and practical flame conditions within the steamer.

This program addresses the need for advanced NO_x control technology for oilfield steam generators, and concerns the development of a full-scale burner system, for which the concept is based on fundamental studies. The burner will be retrofittable to existing steam generators and will produce acceptable emissions of CO and particulate while maintaining a flame form compatible with the steamer design. The emission goals for NO_x are to achieve less than 85 ppm NO_x at 3 percent excess oxygen.

The major elements of this program are:

1. Conceptual design development—to verify and refine design scaling criteria developed under previous EPA contracts in order to develop hardware designs.

2. Detailed burner design and construction—to produce a commercial-grade full-scale burner suitable for retrofit on an existing steam generator.

3. Burner optimization and evaluation—to minimize pollutant emissions in a field-operating TEOR steam generator firing high-nitrogen crude oil, and evaluate performance over an extended period of time.

The report summarized in this document is the second of three project reports. The first two elements of the program are discussed in the related "Design Phase Report." This current report documents the initial series of full-scale (16 MW) burner tests conducted in EER's Medium Tunnel test furnace. The final phases of the program—field retrofit and testing—are currently in progress and will be covered in the final report.

The objectives of these tests were to:

- Cure the refractory contained in the first-stage chamber of the burner under controlled conditions.

- Evaluate control system operation/response and establish input/output factors.

- Establish the impact of burner settings on emissions and flame shape.

- Evaluate overall mechanical and thermal performance.

These preliminary tests were conducted in an experimental test furnace (EER's Medium Tunnel), which simulates the thermal environment of a watertube boiler, so that risk to field equipment would be minimized.

Burner Design

The design of the commercial prototype burner, discussed in the related "Design Phase Report," is based on an optimized two-stage combustion system. The burner concept, shown in Figure 1, utilizes a physically separate primary combustion zone which operates with approximately 60 percent of theoretical combustion air. The first-stage chamber is constructed of high-temperature refractory supported within a hollow stainless steel shell. The primary combustion air is preheated as it passes through the hollow shell, simultaneously cooling the shells. This "regenerative" concept permits the refractory lining to be thinner, minimizing heatup and cooldown time, while increasing the temperatures in the fuel vaporization zone.

Fuel and the preheated primary air are injected into the first stage and burn under optimally fuel-rich conditions. This maximizes the conversion of fuel nitrogen to N_2. The gas temperature in the first stage is maintained as high as possible in order to maximize the rate of reduced nitrogen species decay to N_2, which makes the most efficient use of available residence time within the first-stage chamber.

The primary combustion products leave the first-stage chamber and mix with the secondary air, injected through radial and axial ports located at the first-stage exit, to complete combustion within the furnace. Second-stage mixing is controlled to minimize conversion of reduced nitrogen species to NO and to minimize thermal NO formation, while producing an acceptable flame shape.

The operation of the burner is supervised by a hybrid pneumatic-electronic control system. Conventional relay logic and pneumatic control signal processing are integrated with a programmable controller and instrumentation subsystem. The system is designed to provide *parallel pneumatic positioning of fuel and* air valves with a closed-loop metering trim control which maintains the burner at optimum conditions for NO_x, smoke, and CO emissions. The system was designed to interface easily with the existing host field steam generator.

Emissions Performance

The optimum emissions performance of the commercial prototype burner is shown in Figure 2. These data were

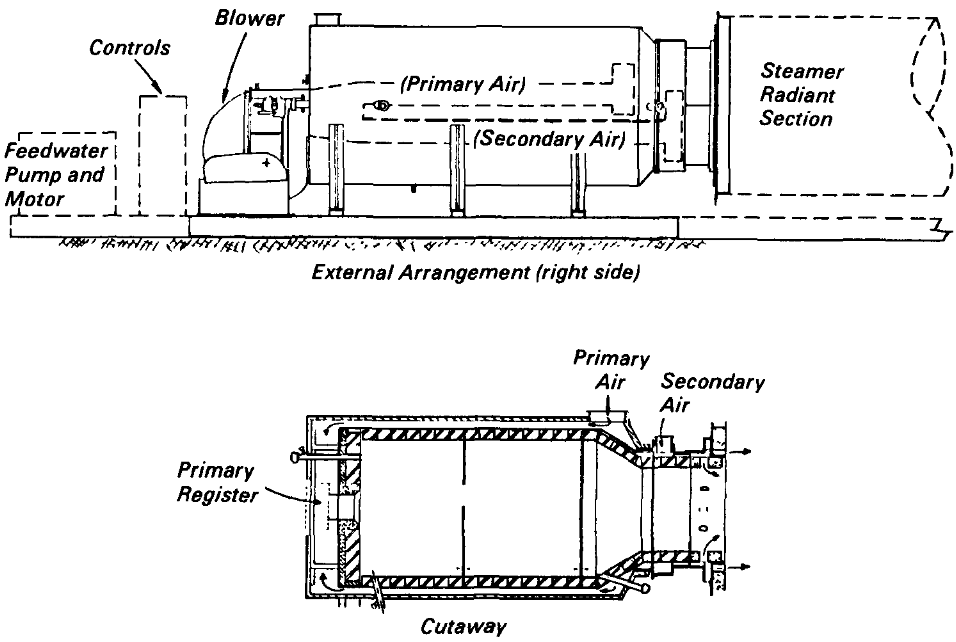

Figure 1. *TEOR steamer low-NO_x burner, regeneratively cooled concept.*

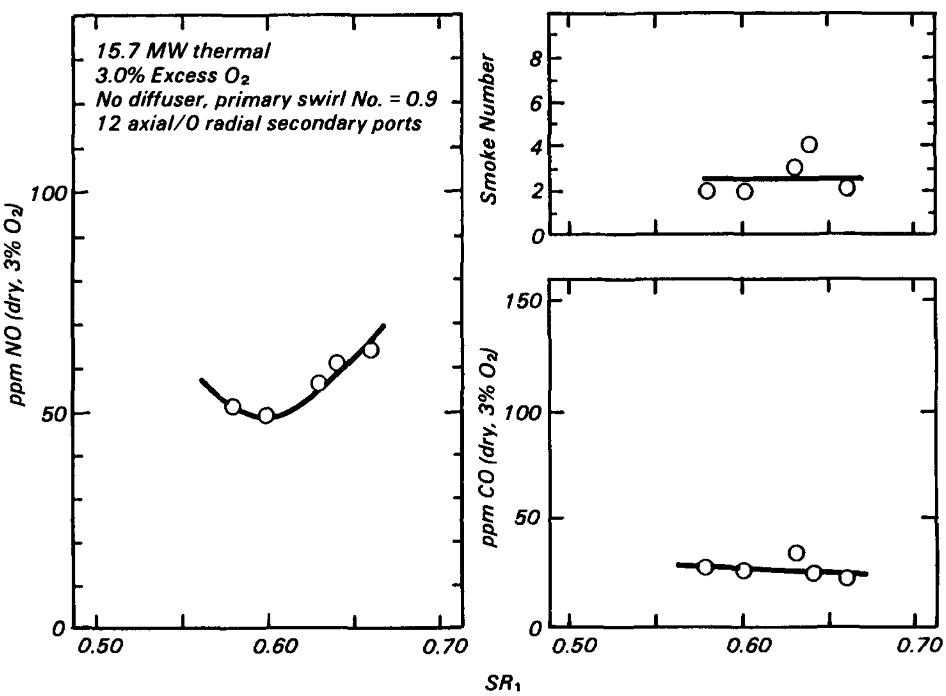

Figure 2. *Optimum full-load emissions performance of the commercial prototype burner (medium tunnel test furnace).*

obtained from a residual fuel oil derived from California crude oil, containing 0.74 percent fuel nitrogen. Minimum NO_x emissions were 49 ppm, corrected to 3 percent oxygen, and were obtained at a first-stage stoichiometric ratio (SR_1) of 0.60. Overall excess oxygen was 3 percent for these data. CO emissions were 35 ppm and Bacharach smoke number ranged from 2 to 4. Smoke and CO were generally insensitive to SR_1 near the minimum NO_x condition.

Several burner configurations were tested to determine the optimum settings for emissions and second-stage flame characteristics. The tests included variation of both first- and second-stage parameters. First-stage input parameters which were varied included stoichiometry, air register setting (swirl), oil gun setback, atomizer spray angle, and stabilizer. Second-stage input parameters included excess air, secondary air distribution through the radial and axial ports, and number of secondary air ports. First-stage parameters which significantly affected NO_x emissions were stoichiometry and stabilizer geometry. NO_x emissions reached a minimum as SR_1 was decreased below stoichiometric. The bench- and pilot-scale development had shown that this is due to a minimum in total fixed nitrogen species formation (HCN, NH_3, NO) in the first stage. Figure 3 shows the effect of stabilizer geometry on NO_x emissions at full load. Two configurations were tested: with and without a conical diffuser at the tip of the oil gun. NO_x emissions were lower without the diffuser. This was attributed to an improvement in the mixing characteristics in the first stage without the diffuser due to the increased swirl level required to stabilize the flame. Pilot-scale results had indicated that, when the primary air had too little swirl, first stage mixing was poor, resulting in large external recirculation zones which produce backmixing and poor residence time distribution. Backmixing (stirring) is undesirable in the first-stage since it produces a less favorable distribution of radical species in the early part of the first-stage flame and because a broader distribution of residence times is produced. Both effects can result in increased NO_x emissions.

Smoke and CO emissions were also much lower without the diffuser, which appeared to be due to decreased second-stage flame length. High smoke and CO emissions were generally associated with a portion of the second-stage flame extending into the exhaust duct of the test furnace. The test furnace is much shorter than the TEOR steamer (see dashed lines in Figure 4), so this condition is not likely to occur in an actual TEOR steamer.

Second-stage air injection geometry was found to affect both emissions and flame shape. Secondary air was selectively injected through sets of axial or radial injection ports. Radial air injection produced high NO_x emissions. As secondary air was shifted from the radial ports to the axial ports, NO_x emissions decreased sharply; however, smoke and CO emis-

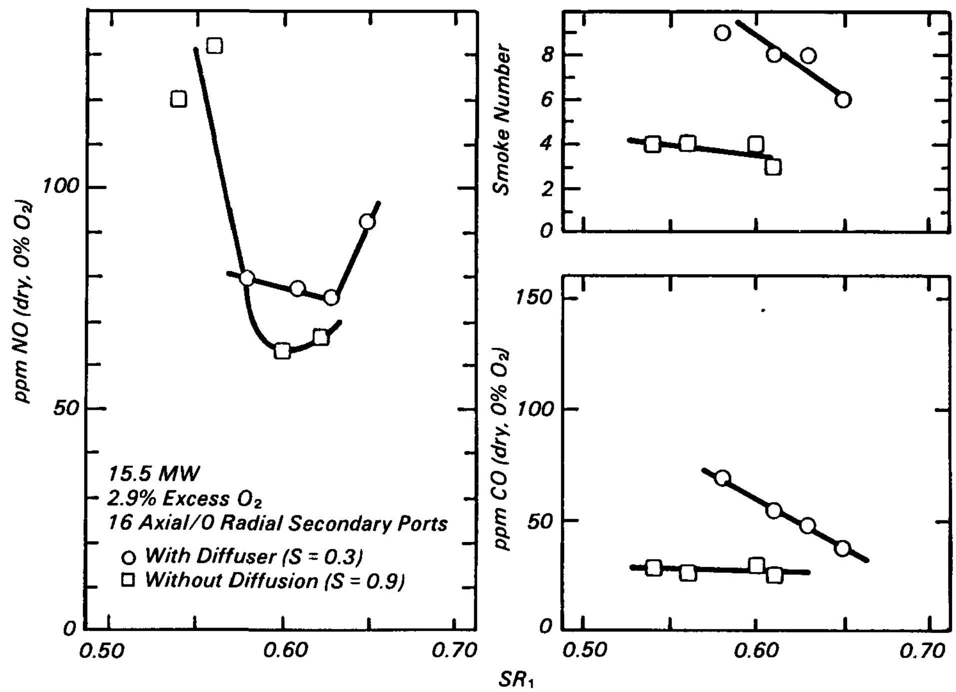

Figure 3. *Effect of primary configuration on emissions.*

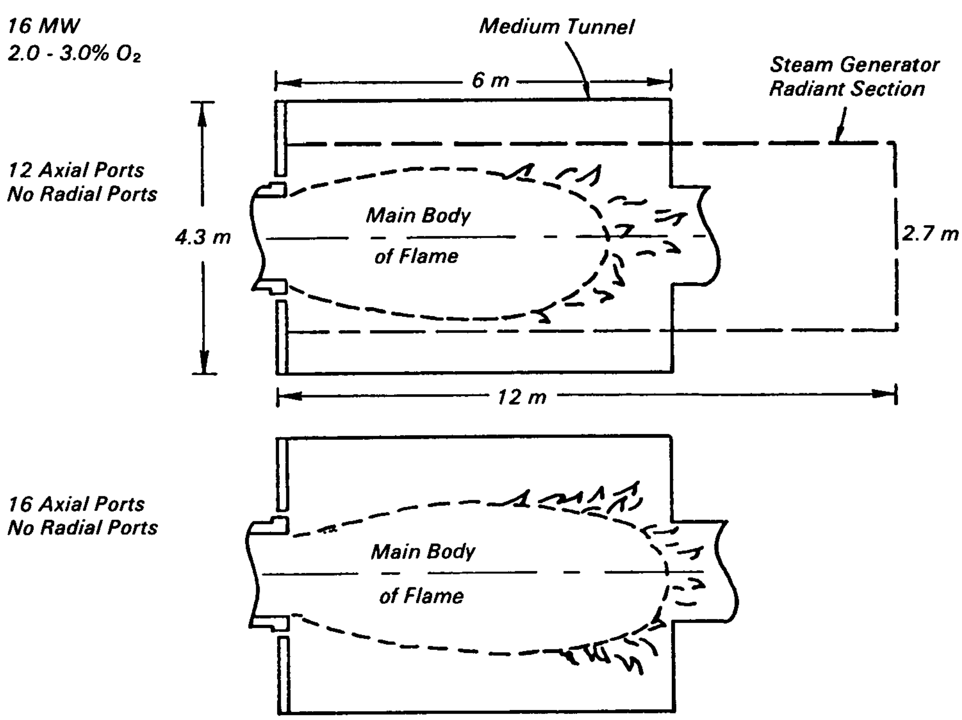

Figure 4. *Comparison of flame length observed in the MT for the 12 and 16 axial ports (16 MW, 2.0-3.0% O_2).*

sions increased. The high smoke and CO emissions were associated with the long flame produced with no radial air injection and with the primary diffuser in place.

Variation of the number of axial ports (hence velocity) without radial air injection showed that moderate variation of flame length is possible without strongly affecting emissions. Figure 4 compares flame shape for 12 and 16 axial ports, corresponding to secondary air injection velocities of 50 and 35 m/s, respectively, at the minimum NO_x condition. A decrease in flame length of approximately 1 meter was observed when the number of axial ports was decreased from 16 to 12 (thereby increasing velocity), while minimum NO_x emissions decreased slightly from 54 ppm to 48 ppm, corrected to 3 percent O_2. Based on these results, final optimization of second-stage mixing with respect to flame shape should be possible in the field without significantly compromising emissions performance.

Hardware Performance

Excess oxygen in the second stage was also varied under one test condition: results showed that NO_x emissions were relatively insensitive to O_2 level.

Hardware performance was generally excellent, except for minor shakedown problems. Inspection of the refractory lining after the test revealed no signs of significant damage. A portion of the lining appeared to have shifted slightly due to thermal expansion; however, this was not considered serious. Overall appearance of the lining was excellent.

Thermal performance of the first-stage chamber was well within the calculated design performance. Temperature of the stainless steel shells was well below the design point maximum at normal full-load conditions. Transient thermal performance of the lining during a long-term sudden shutdown was not determined.

Control system operation during light-off and shutdown sequences was satisfactory. Full control system characterization was not achieved; however, a brief test of the programmable controller trim loop showed that SR_1 and excess O_2 could be closely maintained over a narrow range of load near full load. Final setup and optimization will take place in the field.

Conclusions

The results of the preliminary evaluation are encouraging and suggest that the program emission goals will be easily achieved in the field. Characteristics of the flame produced by the commercial prototype burner in the medium tunnel furnace are very good and should easily fit within the confines of the field steam generator radiant section.

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The complete report, entitled "Evaluation and Demonstration of Low NO_x Burner Systems for TEOR Steam Generators—Test Report: Preliminary Evaluation of Commercial Prototype Burner," (Order No. PB 84-128 727; Cost: $10.00, subject to change) will be available only from:
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