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A LOW-NO_x BURNER FOR GAS-FIRED FIRETUBE BOILERS

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ABSTRACT

A field evaluation program has been conducted under sponsorship of the Gas Research Institute to evaluate the durability of the fiber burner in gas-fired firetube boilers. The fiber burner is a radiant surface burner that typically operates with NO_x emissions of 15 ppm, CO emissions of 20 ppm, and essentially no hydrocarbons. Under this program, four firetube boilers ranging in size from 245 kW (25 hp) to 980 kW (100 hp) were retrofit with the fiber burner and operated for up to 24 months. Tests of the burners installed at these sites show a one to two percentage point increase in efficiency, 80 percent reduction in NO_x, and up to 80 percent reduction in CO. In addition, the ability of the burner to allow increased boiler loads has been demonstrated, and flame noise has been virtually eliminated.

INTRODUCTION

The Pyrocore® fiber burner for firetube boiler applications has been evaluated in field testing and is rapidly approaching commercialization. Burner development and field evaluation have been supported over the previous 3 years by the Gas Research Institute. This paper describes the boiler performance results from these tests, continuing the earlier development of the burner concept reported at the 1983 International Gas Research Conference in London (1).

The Alzeta gas-fired ceramic fiber burner is a premixed, power burner that uses a radiant ceramic surface as the heat source rather than a conventional suspended flame. As shown in Figure 1, the burner consists of a porous layer of ceramic fibers through which premixed gaseous fuel and air are passed and ignited on the outer surface. The surface glows flamelessly and uniformly at about 1,270K (1,800°F). It operates at very low excess air and pressure drop, turns on and off instantly, is noiseless, and is not susceptible to thermal shock.

Major advantages of the burner are its very low NO_x emissions -- 15 ppm -- and the enhanced efficiency of the radiant section of the heat exchanger. The low NO_x level is due to the low combustion temperature which suppresses thermal NO_x formation. Enhanced radiation promotes greater heat transfer in the system's radiant section and results in lower stack gas temperatures. In firetube boilers, a one to two percentage point increase in boiler efficiency is typical.

The burner operates at a nominal heat release rate per unit area of burner surface of 315 kW/m^2 (100,000 Btu/hr-ft^2). Because the heat input is based on surface area, the burner is easily scalable. Burners ranging in size from 4.4 kW

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(15,000 Btu/hr) up to 290 kW (10^6 Btu/hr) are made using the same type of support structure and forming techniques. Also, the burner can be made in a variety of geometric shapes, notably flat plates and cylinders. This versatility makes the burner appropriate for a variety of industrial uses.

The advantages of the fiber burner in firetube boilers were first proven in laboratory tests of a 245-kW (25-hp) low-pressure steam boiler sponsored by the U.S. Environmental Protection Agency. A one-piece burner was constructed and operated for over 1,300 hours. During the test, NO_x emissions were reduced by 80 percent with CO and HC emissions of the same levels as those from the conventional burner. In addition, excess air levels were reduced, resulting in a 1- to 2-percent boiler efficiency increase. Overfiring to 120 percent of rated load was also found possible without detrimental effects to boiler tube weldments.

These advantages are important in firetube boilers where 40 percent of the gas used in the U.S. industrial sector is consumed. In small- and medium-sized boilers used for industrial process and space heating, gas is the preferred fuel. The ability of the fiber burner to enhance natural gas's low pollutant and noise emissions and allow more efficient production of steam are of wide interest in the industrial market.

In initial concept tests, the single-piece burner design and the inherent 2-to-1 turndown ratio of the burner surface firing rate limited the boiler low fire rate to 50 percent of capacity. In addition, due to its large size and tight spacing within the combustion chamber, the single-piece burner presented some problems in installation as a retrofit system. Therefore, a segmented burner was devised as the solution to size and turndown problems. These refinements provided the basis of the field evaluation phase of the program.

OBJECTIVES

The objective of the burner field evaluation was to implement the required design changes to the burner and demonstrate durability in field service. An assessment of user acceptance and analysis of burner cost versus benefits are being performed to accelerate commercialization. These objectives have been met by Alzeta and its subcontractor, York-Shipley, Incorporated, by retrofitting fiber burners in four industrial boilers at different sites and testing the system performance for varying periods at each site. Thermal and emissions performance goals are at least a 1-percent thermal efficiency increase and less than 20 ppm NO on the retrofit boilers, and retrofit performance has been compared to baseline performance as measured with the conventional gas burner in place. Satisfactory burner durability, as evidenced by no change in thermal or emissions performance over the test period, is an additional goal. The plan for achieving these goals and the field test results are discussed in the following two sections.

TEST PLAN

The project was organized into five technical tasks, including:

1. Site selection

2. Burner design and fabrication

3. Site preparation

4. Installation

5. Field testing

Field boiler tests were planned for four locations within the United States: (1) West Coast, near Alzeta, (2) York-Shipley boiler test bay in York, Pennsylvania, (3) an industrial site near York-Shipley, and (4) Eastern Ohio, a unique potential market area due to the prevalence of Ohio Special boiler designs. Selection criteria to be satisfied by each host site included: (1) normally gas-fired boiler, (2) size range from 245 to 980 kW, and (3) adequate room for burner retrofit. Columbia Gas Systems personnel, particularly from Columbia Gas of Pennsylvania, provided instrumentation and site information for the industrial site near York-Shipley in Pennsylvania, and East Ohio Gas Company located the site and provided instrumentation for the Eastern Ohio field test.

All test sites were selected during the first 8 months of the project. The locations and boiler uses are listed in Table 1. All units are normally gas fired; sites 2, 3, and 4 also maintain capabilities for backup oil firing. Tests have been conducted at each of the sites. In addition, burner testing has been ongoing in the Alzeta laboratory to evaluate system design concepts developed during the project.

Since each field boiler had unique demands for process steam, burner data were obtained under various operating conditions and load schedules. At each site, data were taken on the boiler in the as-found condition and following optimization of burner O_2 levels for the conventional burner, and additional data were obtained at periodic intervals of the test duration of the fiber burner. Data generally included the input gas and/or feedwater rates, appropriate temperatures and pressures, and stack O_2 and CO levels. NO_x measurements were also made at Sites 3 and 4 as well as at the Alzeta lab. CO_2 and hydrocarbon emissions have been monitored at Alzeta.

BURNER DESIGN AND LABORATORY TESTING

Most firetube boiler installations have insufficient room at the burner and backwall ends of the boiler for insertion of a single-piece burner. These space limitations and the handling difficulties or larger burners required that the fiber burner be segmented. The shorter burner sections are thus sequentially inserted into the firetube until the burner is assembled to its total length.

Since burner segmenting represented a significant departure from one-piece burner design (requiring interfaces between burner sections), a prototype 245-kW segmented burner was designed and tested at Alzeta to evaluate the performance and durability of the concept prior to design of the field units.

Testing the burner allowed refinements to be made prior to construction of the burners for the 392-kW, two 588-kW, and 980-kW test sites. A second 245-kW burner of similar design to these units was also constructed and tested at Alzeta.

Initial testing of the prototype showed the need for a higher pressure combustion air blower to overcome pressure drop through the burner flow passages. The refined second design reduced burner pressure drop, allowing use of blowers similar in size to those used on conventional burners of the same firing rate. The 245-kW version of the field test burner is shown in Figure 2.

Testing of the laboratory 245-kW burner included performance measurements over ranges of excess air and boiler load, investigation of obtaining lower boiler loads by staging the operation of the burner segments, and durability evaluation to 500 hours of operation. Since more complete data could be obtained in laboratory testing, these results are described below.

NO, CO, and HC emissions for firing of one to four burner segments were obtained over a boiler load range of 12 to 125 percent. The four-segment data are shown in Figure 3. The data show:

- NO increases with load (i.e., burner surface temperature)
- HC was generally below 20 ppm
- CO was also below 20 ppm, except at low loads for the 1, 2, and 3 segment firing where surface firing rates approach the low capabilities of the burner material.

The resulting boiler efficiency is shown as a function of load in Figure 4, reaching 88 percent efficiency at 12 percent load.

Tests were also conducted to evaluate compatibility of the burner with existing control systems. On/off, high/low, and full modulation burner controls have all been qualified in the laboratory and were subsequently implemented in the field installation.

The successful emissions and efficiency performance of the laboratory burner provided confidence in the four-segment field site burner design. The listed program goals were left to be evaluated during the field tests described next.

FIELD INSTALLATION AND TEST RESULTS

At each of the four burner field sites initial preparations were made to the system to provide the necessary instrumentation and to determine available equipment and gas pressure. These activities allowed characterization of emissions and efficiency of each boiler with the conventional burner in place. Following retrofit of the burner, comparative emissions and efficiency measurements were made to evaluate the fiber burner effects on system operation. Each retrofit presented some unique demands and results, and the activities at each of the sites are described below in the order in which installations were performed.

York-Shipley Boiler Test Bay

The York-Shipley test bay is used for checkout of each assembled boiler prior to shipment. The test area contains utilities and available instrumentation for testing of newly manufactured boilers. The 588-kW (60-hp) boiler used in this project was new off the assembly line, set up with a modulating control system, and equipped with the required instrumentation.

The 588-kW boiler exhibited similar CO emissions to those of the 245 kW-boiler (both with conventional burners) at Alzeta. In general, 10 percent excess air represents the lower operating limit to maintain CO emissions below 20 ppm.

The 588-kW fiber burner was designed to accept the existing blower and burner controls. Required changes to the system included installation of a new pilot, switchover of flame controls from infrared to ultraviolet sensing,and removal of the boiler target ring. Additional viewports were also added to the boiler rear door. Completion of the retrofit required approximately 8 hours.

Following installation, tests were run under similar conditions to those for the conventional burner. Only limited CO data were obtained due to unavailability of instrumentation at York-Shipley. A comparison of boiler efficiency with the two burners is shown in Figure 5. Fiber burner data are shown primarily at 10 and 20 percent excess air. The fiber burner results in about a 0.5-percent increase in efficiency over that of the relatively efficient new conventional burner-equipped system. Figure 5 also shows the results of varying segment operation, reaching loads as low as 20 percent of rating.

Following installation in April 1983, the York-Shipley boiler was operated during two shifts per day, 5 days per week to accumulate test hours. At approximately 1,000 hours of operation in September 1983, significant reductions in maximum achievable load were encountered. Inspection of the burner flow passages showed large amounts of dust ingested from the test bay atmosphere. As maximum load approached 39 percent, the burner was removed from the boiler and returned to Alzeta. Combustion air filters for the blower were subsequently implemented as standard burner equipment at other test sites.

Vandenberg Air Force Base

The 392-kW (40-hp) test boiler at Vandenberg AFB is located in a dining room facility, providing low-pressure steam for cooking and cleaning. The boiler is in service with low load factors over much of the year and with a seasonally higher demand during the summer months to support ROTC activities. The boiler operates in an on/off mode (fixed firing rate) to maintain steam pressure of 10 to 13 psig, cycling several times each hour. This site therefore represented a good opportunity to test the burner's durability in cyclic operation.

Site preparation included installation of a gas meter at the boiler inlet to determine firing rate and to record total gas usage. With the conventional burner, the system was found to be operating at 62 percent of rated load. This operating condition was fixed by the blower air shutter which was frozen in a partially open position. Efficiency was measured as 81 percent with the fixed 55 percent excess air. The somewhat lower efficiency than had been achieved in prior 245-kW and 588-kW boiler testing is probably a result of the age of the unit (installed in 1966). CO emissions were relatively high at 240 ppm (corrected to 0 percent O_2).

Installation of the fiber burner was complicated by the age of the boiler, requiring modifications to the refractory and freeing of rusted and seized components. Retrofit was completed within 8 hours, and the burner was easily interfaced with the on/off control system.

Tests of the fiber burner produced a boiler efficiency increase at approximately 2 percent, comparable to prior 245 kW and 588 kW results. Excess air was set at approximately 15 percent, and CO ranged from 4 to 37 ppm (at 0 percent O_2).

The system has performed well for over 2 years, accumulating nearly 3,800 hours of use through the first 2 years of operation. Also, the burner has achieved approximately 60,000 cycles. Tests will continue through the 1985 summer use period.

Peter Paul Cadbury

The three boilers in the Peter Paul Cadbury plant in York, Pennsylvania supply process steam for the production of York Peppermint Patties and steam for space heating. Burner installation in July 1983, occurred during a period of low demand and directly followed a scheduled annual boiler inspection. Since total steam demand reaches available capacity during peak usage, overfire capabilities were of interest at the site. The fiber burner allowed 20-percent additional capacity while maintaining internal boiler gas-side temperatures at acceptable levels. The conventional burner was controlled by a high/low firing combination.

Site preparation was supported by Columbia Gas System Service Companies through the loan of two gas meters for the retrofit No. 2 588-kW (60-hp) boiler and its companion No. 1 boiler. A NO_x meter was also loaned during initial testing of the fiber burner. The No. 2 boiler was fitted with a feedwater meter by Alzeta.

The boiler was tested with the conventional burner both prior to and following the annual inspection. Prior to inspection, the boiler was found to be operating rich over most of the load range. Data was taken between the low and high points of 35 and 100 percent of rated load by manual movement of the modulating linkage. Since operation was rich, CO emissions always exceeded 2,000 ppm. Adjustments to the fuel-air ratio were also made at each load to provide data at 20 percent excess air. At the adjusted conditions, CO ranged from 85 to 400 ppm (at 0 percent O_2). The boiler efficiency was 83 percent at full load and about 2 percent less efficient that the new York-Shipley boiler.

Fiber burner installation at Peter Paul was somewhat more complex than at previous sites. Since the maximum achievable load on the York-Shipley boiler had been 98 percent, a higher pressure blower was required at Peter Paul to achieve overfire with the fiber burner. In addition, Peter Paul is located in an older area of the Columbia Gas system where available gas pressure is limited to 7 to 10 in. w.c. — marginal for achieving the desired load. For these reasons, a sealed blower was installed for simultaneously compressing the mixed gas and air. Significant control wiring modifications were also required.

The data obtained for the Peter Paul boiler with the fiber burner have shown 0.5- to 1-percent increases in efficiency over that of the conventional burner. Significant reductions in CO were achieved from conventional burner levels of 85 to 400 ppm. With the fiber burner, CO ranged from 5 to 40 ppm over the rated load range. Limited measurements of NO_x varied from 8 to 20 ppm for the fiber burner.

In February 1984, following 7 months of operation, damage to the burner occurred in an incident apparently related to gas pressure fluctuations. Since a lower pressure drop, 2 to 1 modulation burner design was now available, a second burner was installed at Peter Paul in July, 1984. This burner ran successfully until January, 1985, when an incident very similar to the February, 1984 one occurred, again damaging the burner. A replacement burner and an improved control system were installed in April, 1985.

Hall Chemical Company

Hall Chemical Company in Wickliffe, Ohio, uses process steam in the manufacture of various metallic salts. The 980-kW (100-hp) Ohio Special boiler is an overfired 686-kW (70-hp) design, eliminating the need for a licensed operator under Ohio regulation. The burner operates in a high/low mode with the set point selected manually by plant personnel. Four other boilers exist at the plant. The site was prepared with the installation of gas and feedwater meters by East Ohio Gas Company personnel. East Ohio Gas has also supported data taking and arranged for NO_x measurements to be made by an independent contractor.

In an initial visit to Hall, data taken on the conventional burner showed the two load points to be 39 and 81 percent of rated load. Data were taken between these settings and up to 90 percent load (limited by maximum blower air shutter opening) by manual movement of the linkage. Prior to fiber burner installation, additional data at selected values of excess air were taken. The latter data are reported in comparison to fiber burner results. CO emissions were 40 to 110 ppm, and NO_x emissions were approximately 75 ppm at these adjusted conditions.

Fiber burner installation utilized the same blower and control system as for the conventional burner. Again, flame controls were modified to accept an ultraviolet flame sensor. Retrofit was completed within 8 hours. The Hall boiler and two sections of the fiber burner are shown in Figure 6.

Figure 7 shows conventional and fiber burner boiler efficiencies. Boiler efficiency was taken at three values of excess air for the conventional burner firing over its possible load range. Loads above 80 percent with the conventional burner were obtained only intermittently, as an instability developed in the flame at that load. Fiber burner data were taken primarily at 10 and 20 percent excess air at high and low loads, showing a nominal 1 percent increase in efficiency. CO and NO_x emissions were reduced by the fiber burner to 35 ppm and 15 ppm, respectively.

Three different burners were operated at Hall Chemical for 3,450, 2,500, and 1,500 hours, respectively. The first burner was operated with unfiltered combustion air and eventually became subject to severe load reduction capability, as was experienced at York-Shipley. The latter two burners both experienced a manufacturing inconsistency that resulted in shortened life of the fiber layer; this problem has now been solved.

CONCLUSIONS

A summary of the retrofit results to date at the four field test sites and the Alzeta laboratory is shown in Table 2, including the approximate number of operating hours. Improvements in efficiency of about 1 percent have been typical, meeting the goal of the program. Reductions in CO have been most significant in older boilers, and NO_x reductions to below 20 ppm were consistently achieved. In addition to the verification of these performance parameters, acceptable durability of burner design features and materials has been demonstrated and compatibility with a variety of existing ultraviolet-based control systems has been shown. User interest in the quiet operation, low emissions, and ability to overfire standard boilers by 20 percent above rated capacity has been high.

Calculations show that for each percentage point increase in boiler efficiency (typical for current installations) per 980 kW (100 hp), the gas savings are approximately $1,100 per year. At current projected production costs for burners of 980-kW size, payback would occur in 2 to 3 years. These early estimates show potential for commercialization of the burner concept.

The field test results indicate the need for longer duration operation and material evaluation to achieve the 5- to 10-year burner lifetime required in most industrial uses. Extension to larger boilers represents the next logical step. These systems will require more complex controls and the potential for distillate oil firing as an alternate fuel. These activities are proceeding as the burner approaches commercialization.

REFERENCES

1. R. Schreiber, W. Krill, J. Kesselring, R. Vogt, and M. Lukasiewicz. Industrial Applications of the Radiant Ceramic Fiber Burner, Alzeta Corporation, Mountain View, CA: IGRC/D06-83, 1983 International Gas Research Conference, June 13-16, 1983.

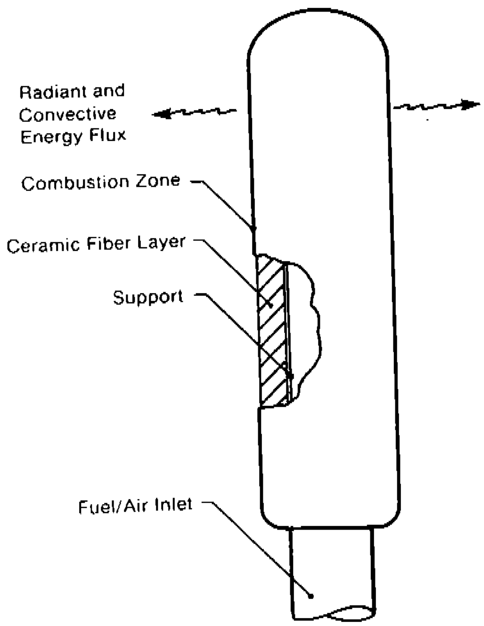

Figure 1. Ceramic Fiber Burner

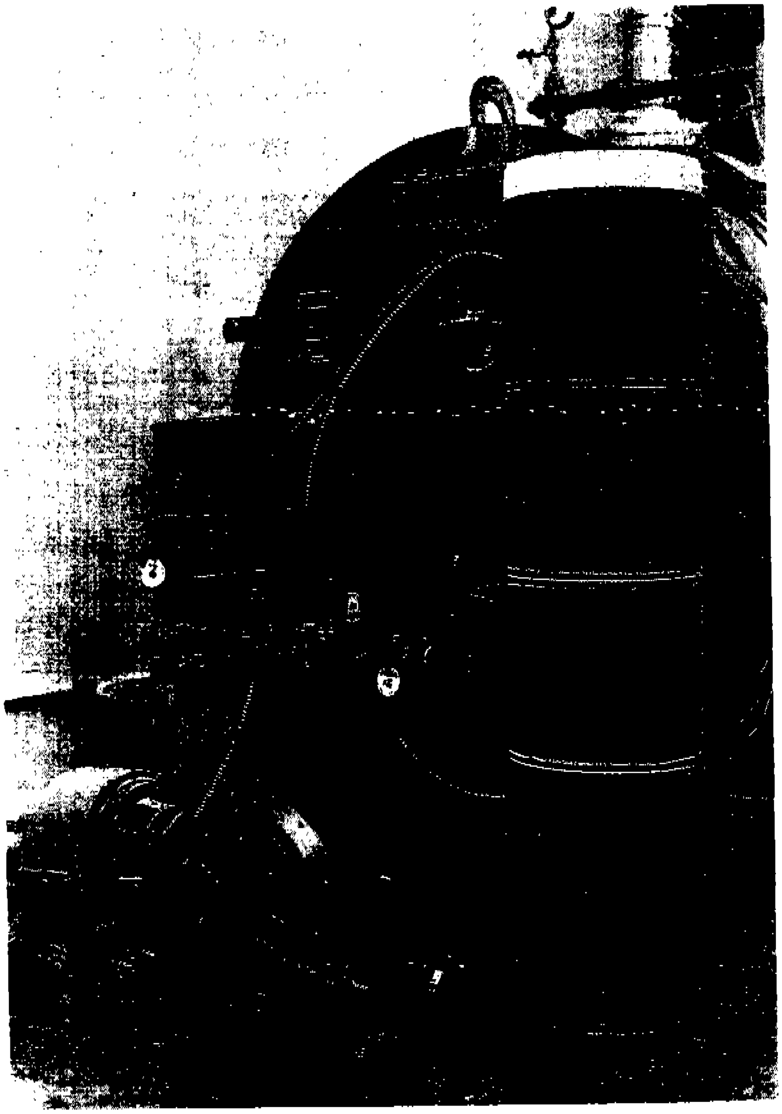

Figure 2. Four-Segment 245-kW Fiber Burner

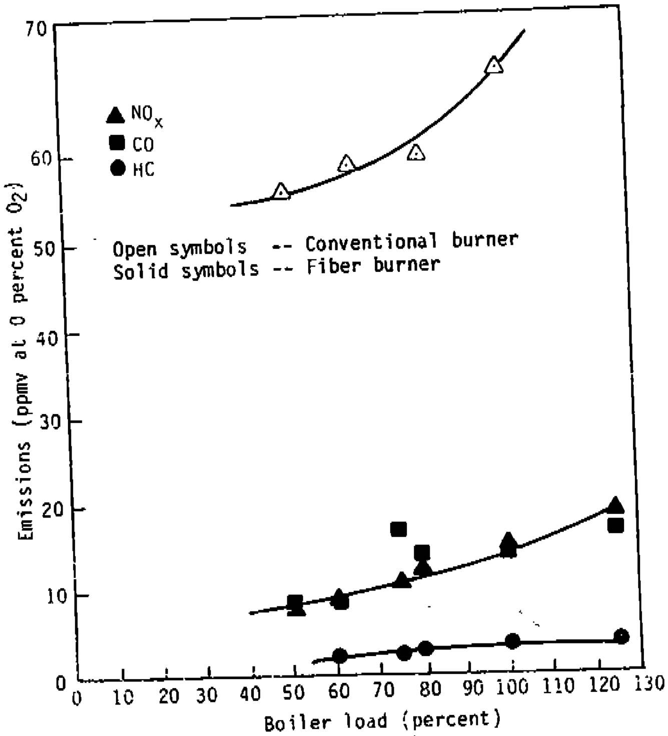

Figure 3. Four-Segment 245-kW Burner Emissions

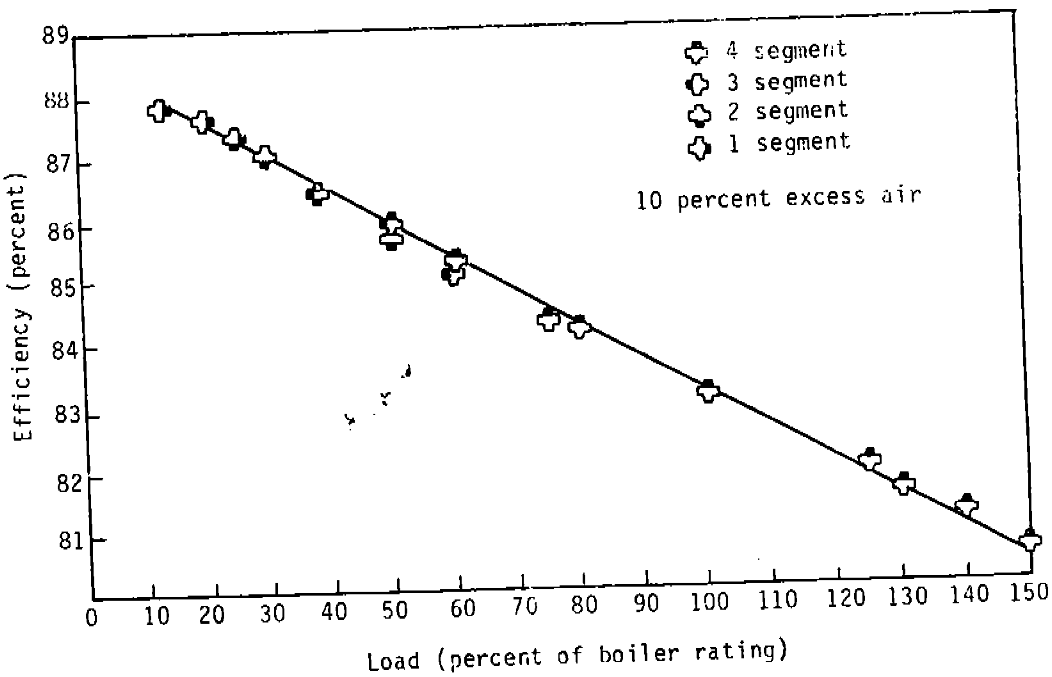

Figure 4. 245-kW Boiler Efficiency With Four-Segment Fiber

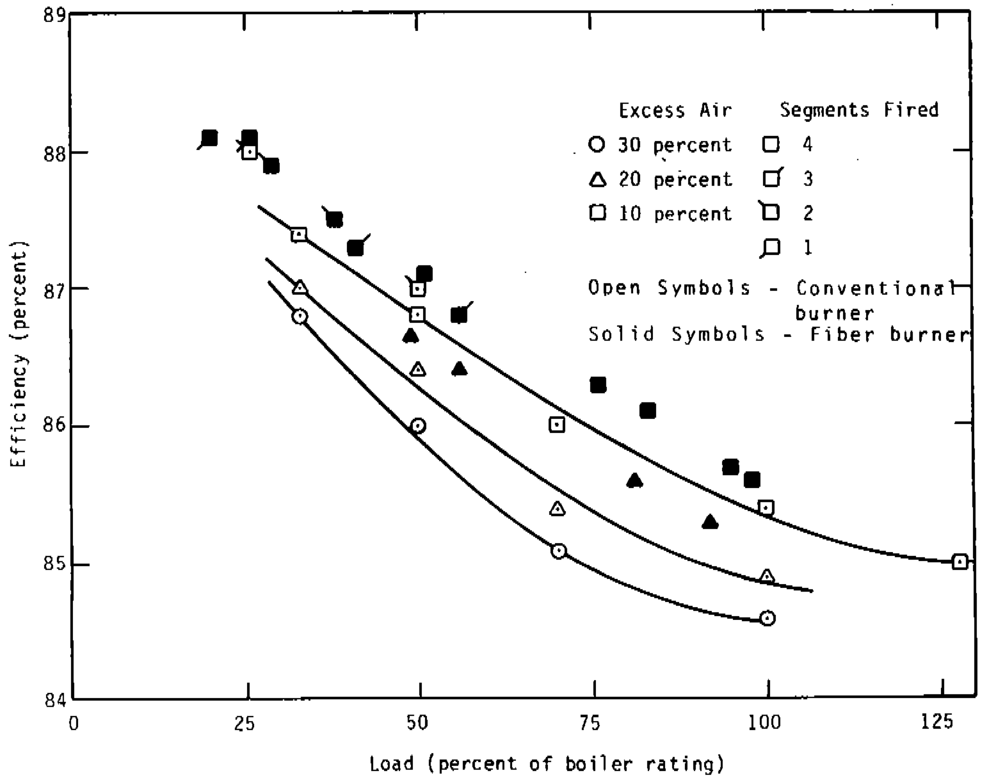

Figure 5. York-Shipley 588-kW Boiler Efficiency with Fiber Burner

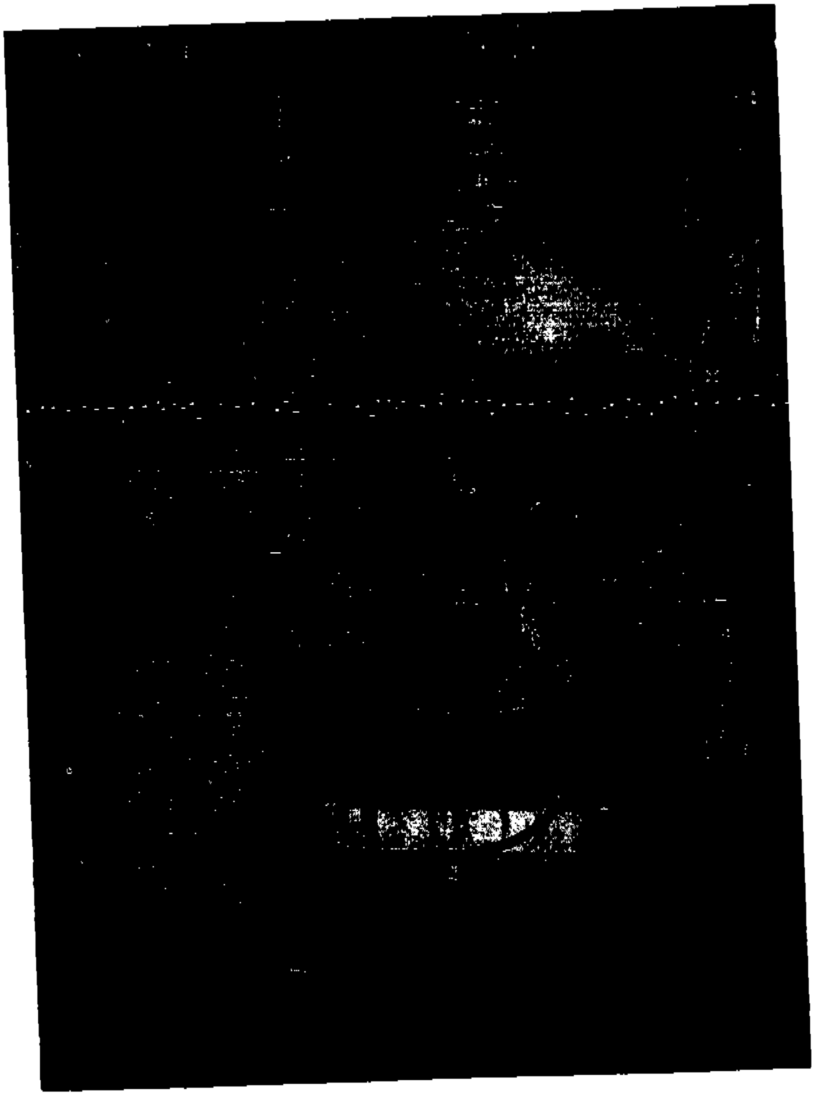

Figure 6. Hall Chemical Company 980-kW Ohio Special and Fiber Burner

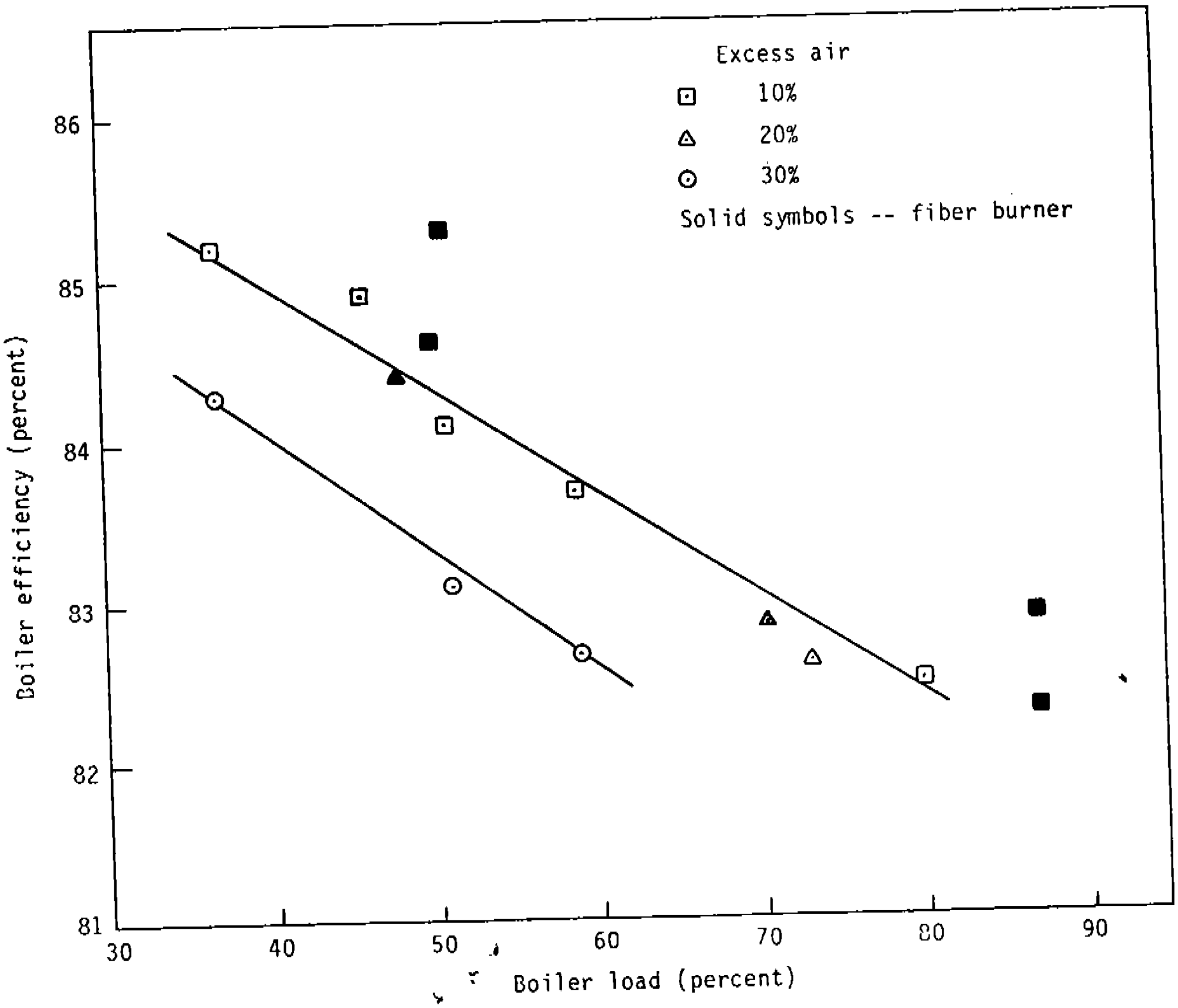

Figure 7. 980-kW Ohio Special Boiler Efficiency Comparison

Table 1

SELECTED BURNER TEST SITES

Site	Boiler	Boiler Use
1. York-Shipley test bay York, PA	588-kW high-pressure steam	Test bay setup. 2:1 burner modulation.
2. Vandenberg Air Force Base Lompoc, CA	392-kW low-pressure steam	Mess hall cooking and cleaning. Cycles on and off at full load (no burner modulation).
3. Peter Paul Cadbury York, PA	588-kW high-pressure steam	Process steam. 2:1 burner modulation.
4. The Hall Chemical Co. Wickliffe, OH	980-kW Ohio Special high-pressure steam	Process steam. Set up for high/low firing. Extra capacity available.

Table 2

FIELD TEST FIRETUBE BOILER COMPARISON*

Site	Boiler Size (kW)	Burner Type	Excess Air (%)	CO (ppm)	NO (ppm)	HC (ppm)	Boiler Eff. (%)	Hours of Operation
Alzeta Laboratory	245	Conventional	16	11	57	0	82.8	NA
		Fiber	10	10	10	10	83.3	500**
York-Shipley Boiler Test Bay York, PA	588	Conventional	15	10	--	--	85.0	NA
		Fiber	10	10	--	--	85.8	2,000
Vandenberg AFB California	392	Conventional	55	240	--	--	81.0	NA
		Fiber	10	0	--	--	82.3	3,800
Peter Paul Cadbury York, PA	588	Conventional	20	400	--	--	83.2	NA
		Fiber	7	35	20	--	84.0	3,450
								2,500
Hall Chemical Company Wickliffe, OH	980 Ohio Special	Conventional	7	1,000	80	--	82.7	NA
		Fiber	13	35	18	--	83.7	3,450
								2,500
								1,500

*All results at high fire conditions, emissions corrected to 0% O_2.
**On segmented burner.

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Proceedings
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Proceedings: 1985 Symposium on Stationary Combustion NO_x Control

Volume 2: Industrial Processes, Fundamental Studies, and Slagging Combustors

Prepared by
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Mountain View, California

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Ref 4

SOURCE CATEGORY: Natural Gas
EXCLUSION CRITERIA CHECKLIST

REFERENCE A Low-NO_x Burner For Gas-Fired Firetube Boilers
J.P. Kesselring and W.V. Krill, Alzeta Corp.

CRITERIA	YES	NO
1. Test series averages are reported in units that can be converted to the selected reporting units?	✓	
2. Test series respresent compatible test methods?		
3. In tests in which emission control devices were used, the control devices are fully specified?	✓	
4. Is the source process clearly identified and described?	✓	
5. Is it clear whether or not the emissions were controlled (or not controlled)?	✓	

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Date 5/6/92

INDICATE WHETHER ANSWER IS YES OR NO WITH AN "X" IN APPROPRIATE BOX.

IF ALL ANSWERS ARE "YES" PROCEED TO METHODOLOGY/DETAIL CRITERIA CHECKLIST.

SOURCE CATEGORY: Natural Gas

METHODOLOGY/DETAIL CRITERIA CHECKLIST

REFERENCE Low NO_x Burner - ALZETA

CRITERIA	YES	NO	COMMENTS
1. Is the manner in which the source was operated well documented in the report?		✓	
Was the source operating within typical parameters during the test?			Insufficient info to judge
2. Did sampling procedures deviate from standard methods?			
If so, were the deviations well documented?			
Were the deviations appropriate?			
Comment on how any alterations in sampling procedure may have influenced the results.			
3. Were there wide variations in the results?	✓		CO data
If yes, can the variations be adequately explained by information in the report?		✓	
If the variations are not well explained, should the data be considered of poor quality?	✓		CO data - poor quality NO_x data - OK
4. Do the test reports contain original raw data sheets?		✓	
Are the nomenclature and equations used equivalent to those specified by the EPA?	✓		
Comment on the consistency amd completeness of the results.			Consistent but not complete - only summary results

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INDICATE WHETHER ANSWER IS YES OR NO WITH AN "X" IN APPROPRIATE BOX. FILL IN COMMENTS.

IF ,BASED ON ABOVE ANSWERS, IT IS DETERMINED THAT SOURCE REPORTS PROVIDE ADEQUATE DETAIL AND DEMONSTRATE A SOUND METHODOLOGY, PROCEED TO RATING THE DATA IN THE RATING CRITERIA CHECKLIST.

SOURCE CATEGORY: Natural Gas

RATING CRITERIA CHECKLIST

REFERENCE Low NO_x Burner - ALZETA

RATING	CRITERIA	YES	NO
A	Tests performed by a sound methodology and reported in enough detail for adequate validation?		✓
B	Tests were performed by a generally sound methodology, but not enough detail for adequate validation?	✓	
C	Were tests based on untested or new methodology that lacks significant amount of background data?		✓
D	Were tests based on generally unacceptable methods, but may provide order-of-magnitude values for the source?		✓

All data are CEM data

COMMENTS Recommend B Rating for this data - Generally sound methodology (CEMs) but not sufficient information to validate methodology

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Date 5/6

BASED ON ANSWERS TO ABOVE, AND COMMENTS, ASSIGN A RANK TO THIS LITERATURE SOURCE:

B	RANK ASSIGNED TO EMISSION SOURCE DATA

Commercial

ALZETA Paper: 1985 EPRI NOx Symposium

Pipetube

Conventional Burner Emissions

Uncontrolled

Site	Heat Input (MM Btu/hr)	Boiler Size, kW	Burner Type	CO (ppm @ 0% O2)	NOx (ppm @ 0% O2)	HC (ppm @ 0% O2)	CO EF, lb/MMBtu	CO EF, lb/MM ft3	NOx EF, lb/MMBtu	NOx EF, lb/MM ft3	HC EF, lb/MMBtu	HC EF, lb/MM ft3
Alzeta	0.84	245	Conv.	11	57	0	.007	7.5	.061	64.0	—	0.0
York Shipley	2.01	588	Conv.	15	10		.010	10.2	.012	11.2	—	0.0
Vandenburg AFB	1.34	392	Conv.	240			0.156	164.0	—	0.0		0.0
Peter Paul	2.01	588	Conv.	400			.260	273.3	—	0.0		0.0
Hall Chemical	3.35	980	Conv.	1000	80		.650	683.1	.086	89.8		0.0
						Averages	.217	227.6	.052	55.0	-	0.0

Exclude as non-representative

Fiber Burner Emissions

LNB

Site	Heat Input (MM Btu/hr)	Boiler Size	Burner Type	CO (ppm @ 0% O2)	NOx (ppm @ 0% O2)	HC (ppm @ 0% O2)	CO EF, lb/MMBtu	CO EF, lb/MM ft3	NOx EF, lb/MMBtu	NOx EF, lb/MM ft3	HC EF, lb/MMBtu	HC EF, lb/MM ft3
Alzeta	0.84	245	Fiber	10	10	10	.006	6.8	.011	11.2	.007	7.3
York Shipley	2.01	588	Fiber	10			.006	6.8	—	0.0	—	0.0
Vandenburg AFB	1.34	392	Fiber	0			—	0.0	—	0.0	—	0.0
Peter Paul	2.01	588	Fiber	35	20		.023	23.9	.021	22.4		0.0
Hall Chemical	3.35	980	Fiber	35	18		.023	23.9	.019	20.2		0.0
					Averages		.014	15.4	.017	18.0	.007	7.3

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