GRI-92/0165 PB92 193176

SELECTIVE AND ENHANCED RADIATION FROM POROUS MATRIX BURNERS

Annual Report
(October 1990 - September 1991)

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631

SELECTIVE AND ENHANCED RADIATION FROM POROUS MATRIX BURNERS

ANNUAL REPORT

(October 1990-September 1991)

Prepared By

Robert M. Kendall and John D. Sullivan

Alzeta Corporation
2343 Calle del Mundo
Santa Clara, CA 95054

Alzeta Report No. 91-7049-170

For

Gas Research Institute

Contract No. 5089-260-1817

GRI Project Manager
Dr. Kevin Krist
Inorganic Chemistry, Physical Sciences Department

March 1992

This report was prepared by Alzeta Corporation as an account of work sponsored by Gas Research Institute ("GRI"). Neither GRI, members of GRI, nor any person acting on behalf of either:

a. Makes any warranty or representation, express or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe privately owned rights; or

b. Assumes any liability with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. GRI-92/0165	2.	3. Recipient's Accession No.
4. Title and Subtitle Selective and Enhanced Radiation From Porous Surface Burners			5. Report Date March 1992 6.
7. Author(s) R.M. Kendall and J.D. Sullivan			8. Performing Organization Rept. No. 91-7049-170
9. Performing Organization Name and Address Alzeta Corporation 2343 Calle Del Mundo Santa Clara, CA 95054			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) 5089-260-1817 (G)
12. Sponsoring Organization Name and Address Gas Research Institute 8600 West Bryn Mawr Avenue Chicago, IL 60631			13. Type of Report & Period Covered Annual Report Oct 1990 to Sept 1991 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Rare earth oxide materials previously identified to produce highly selective radiant emissions when used in ceramic mantles have been incorporated into large porous surface radiant burner structures. Results to date have been promising, as spectral selectivity has been demonstrated using ytterbia fibers cast over a porous matrix of more conventional ceramic fibers. Concept feasibility was demonstrated during the first year and improved durability is currently being investigated. High emissivity materials are being added to broad band radiant burners to increase radiant flux and improve thermal efficiency of radiant burners.

17. Document Analysis a. Descriptors

Gas burners, infrared heating,

b. Identifiers/Open-Ended Terms

Infrared burners

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) Restricted	21. No. of Pages
	20. Security Class (This Page) Restricted	22. Price

(See ANSI-Z39.18) See *Instructions on Reverse* OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

Title:	Selective and Enhanced Radiation From Porous Surface Burners
Contractor:	Alzeta Corporation
Principal Investigators:	R.M. Kendall and J.D. Sullivan
Annual Report:	Oct 1990 to Sept 1991
Contract:	5089-260-1817

Objectives: The objective of this contract is to enhance the thermal performance of porous surface radiant burners through the use of improved ceramic materials. Previously identified rare earth oxides that exhibit selective radiant emissions in the near infrared will be incorporated into fiber matrix burners. High-temperature high-emissivity fibers will also be identified and used to improve radiant burner performance.

Technical Perspective: There is a perception in the paper and glass industries that high frequency thermal radiation can provide significant process benefits over longer wavelength radiant energy. This has been the basis for the sales of high-temperature quartz lamp emitters for selected applications, since competing "high-temperature" gas radiant burners do not exist. If the claimed benefits of high frequency radiators are real, then the gas industry must provide a viable gas-fired alternative in order to compete in these markets. The goals of the proposed program are to develop and demonstrate these viable alternatives and to identify applications where process benefits truly exist.

Results: During the second year of this project, significant improvements in the durability of ytterbia fiber selective emitters were demonstrated. Spectral selectivity approaching that of ytterbia fiber mantles was demonstrated during the first year of the contract, but burners showed signs of significant degradation after less than 10 hours of operation. We have now demonstrated burners that have operated for 500 hours and show little evidence of aging. Selective emitter work will continue to focus on ytterbia fiber burners through the duration of this contract. Modeling and tests were performed to quantify the relationship between material emissivity, surface emittance, and thermal performance. Burner surface emittance was controlled by varying the content of a high emissivity material in the burner pad. Results were compared to the PROF (PRemixed One-dimensional Flame) code. Predicted trends of increasing radiant exitance and decreasing burner surface temperature as surface emittance is increased were observed experimentally. High temperature and high emissivity broadband (gray body) fibers have been identified and tested. The high emissivity fibers do not appear to increase the surface emittance of new burners when compared with the standard Pyrocore ceramic fiber burner. Testing performed this year indicates the performance benefits resulting from the use of high emissivity fibers may become more apparent as the burner ages.

Technical Approach: Previously identified ceramic fiber selective emitters will be incorporated into porous surface radiant burners with the goal of demonstrating high spectral selectivity and durability comparable to that of existing radiant burners. In addition, high emissivity and high temperature broadband emitters will also be identified and tested. Modeling will be performed to better understand the relationships between material emissivity, burner emittance, and thermal performance.

Project Implications: Improvements in radiant efficiency and selectivity, and durability of incandescent fiber materials could lead to enhancements for existing radiant burners and to new radiant burner applications. Alzeta, working with TPV Energy Systems, has demonstrated new, supported fiber burners that radiate with improved wavelength selectivity. Using equilibrium and kinetics based modelling, Alzeta has also shown that high emissivity materials may reduce the operating temperatures and prolong the life of radiant burners. Research is still needed to improve the durability of these burners and to characterize the effect of emissivity on burner performance. GRI plans to continue this research during the following year.

Project Manager: Dr. Kevin Krist
Senior Project Manager, Inorganic Chemistry
Physical Sciences Department

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONCLUDED)

LIST OF TABLES

SECTION 1
CONTRACT OBJECTIVES

Alzeta is investigating methods of modifying and enhancing the performance of radiant burners through the use of materials that exhibit spectrally selective emissivity or high broadband emissivity. More specifically this work is directed toward the study of porous surface burners, although much of what will be learned in this program should also be applicable to other types of radiant burners. The current focus of the project is an investigation of ceramic fibers which have the specific optical characteristics of interest. Fiber coatings and high emissivity additives of a non-ceramic nature will also be investigated because experience with existing commercial burners has shown that these types of additives can significantly influence burner performance.

Work to date has been directed toward the identification and testing of a number of promising ceramic fibers including rare earth oxide selective emitters and several commercially available fibers known to exhibit good high temperature stability but low emissivity. Additional materials of interest have been identified and arrangements have been made with potential suppliers of sample quantities of these materials for testing purposes. To aid in achieving our overall objective of improving radiant burner performance, we will use existing burner models to better our understanding of the relationship between material properties and the operating characteristics of radiant burners. Some consideration will also be given to understanding the aging characteristics of burners fabricated from the materials investigated during the course of this program.

More specific objectives of this project include the following:

- Demonstrate selective emitters of radiant energy that effectively incorporate previously identified rare earth oxide fibers into large and durable composite burner structures.

- Identify and demonstrate improved high temperature and high emissivity ceramic fibers or fiber coatings capable of enhancing the performance of more conventional broadband radiators.
- Investigate material degradation mechanisms affecting the performance and life of both existing and improved ceramic fiber burners by focusing on the degradation of burner emittance and spectral selectivity over time.
- Identify industrial applications for the improved burners developed under this contract, and perform a preliminary analysis of the benefits provided by both the selective emitters and the improved broadband radiators.

Progress made during the first year of this contract is briefly summarized in Section 2. Current year objectives and a work plan are presented in Section 3. The results of work completed during the second year of this contract are presented in Section 4, followed by a summary of results and conclusions in Section 5. Work planned for the third and final year of the contract is described in Section 6.

SECTION 2
SUMMARY OF PREVIOUS WORK

A summary of project status at the completion of the first year of work is presented in this section to provide a starting point for the discussion of results from the second year of work. The second year work plan and results are discussed in Sections 3 and 4. Work performed during the first year addressed two main topics. The first was the selective emitter work performed jointly by Alzeta and TPV Energy Systems, Inc. (TESI) which, in turn, was closely related to earlier GRI funded TESI work in this same area. The results of the joint Alzeta-TESI work are presented in Section 2.1. Additional work on more general high temperature and high emissivity broadband radiators was performed and, in addition, radiant burner performance modeling was conducted by Alzeta during the first year. These results are summarized in Section 2.2.

2.1 SELECTIVE EMITTER BURNER DEVELOPMENT

The primary intent of the selective emitter work performed during the first year of this contract was to combine two successful, and previously unrelated, gas combustion technologies in order to develop a new product with additional potential applications. Electric heating has been advertised as being superior to gas heating in specific heating and drying applications in part due to the ability of the electric heater to radiate energy at shorter wavelengths than competing gas heaters. At least one of the rare earth oxides investigated in this program (ytterbia) provides a means of competing with these short wavelength radiators if in fact these performance claims are justified.

In addition, other rare earth oxides are also known to exibit spectral selectivity at various wavelengths in the visible and near infrared portion of the electromagnetic spectrum. It may be possible to tailor the spectral exitance from radiant burners incorporating these rare earth oxides to match the needs of particular processes. As an example, in a heating or drying application the spectral exitance from the burner would be matched to the primary absorption bands of the process to facilitate more efficient heating or drying.

Alzeta has developed and currently markets large scale porous surface radiant burners fabricated from ceramic fibers, while, as described above, TESI has previously demonstrated the use of rare earth oxides as selective emitters of high frequency thermal radiation in gas fired applications. Both companies have benefitted from the support of Gas Research Institute during the conduct of this work. It is anticipated that a combination of the selective emitters demonstrated by TESI with the large and more durable ceramic fiber burners manufactured by Alzeta could lead to new and innovative products to serve the needs of natural gas users.

During the first year of this contract, several burners were fabricated by Alzeta from ytterbia (Yb_2O_3) fibers supplied by TESI. In mantle form, the ytterbia fibers were demonstrated by TESI to be highly selective with an emissions peak at 980 nm (Reference 1). Burners fabricated by Alzeta were dual layer burners with a standard Pyrocore under layer and a ytterbia fiber outer layer. Results in terms of optical performance were very promising, as the Alzeta burner was highly selective and exhibited the same spectral peak at 980 nm that is produced by ytterbia fibers in mantle form. There was little evidence of significant off band radiation being emitted by the Pyrocore underlayer as indicated in the spectral measurement presented as Figure 1. Peak TPV radiative efficiency (defined as power radiated over the spectral region 350 nm to 1100 nm referenced to HHV of fuel) was 2.6 percent while operating on methane and 3.1 percent while operating with propane as fuel at a surface firing rate of 32 W/cm^2 and no combustion air preheat.

All selective emitter work done during the first year utilized ytterbia fibers, as opposed to other rare earth oxides known to radiate selectively, and this focus should continue at least through the current year of research. The reasons for this are as follows. First, the ytterbia fibers of required quality were readily available from TESI and additional sources of fibers have been difficult to locate. Secondly, results demonstrated using ytterbia fibers should be applicable to other rare earths emitting at other wavelengths as the fabrication process should not change (provided fibers of acceptable purity and durability can be fabricated). And lastly, an identified application exists for the ytterbia fiber burner,

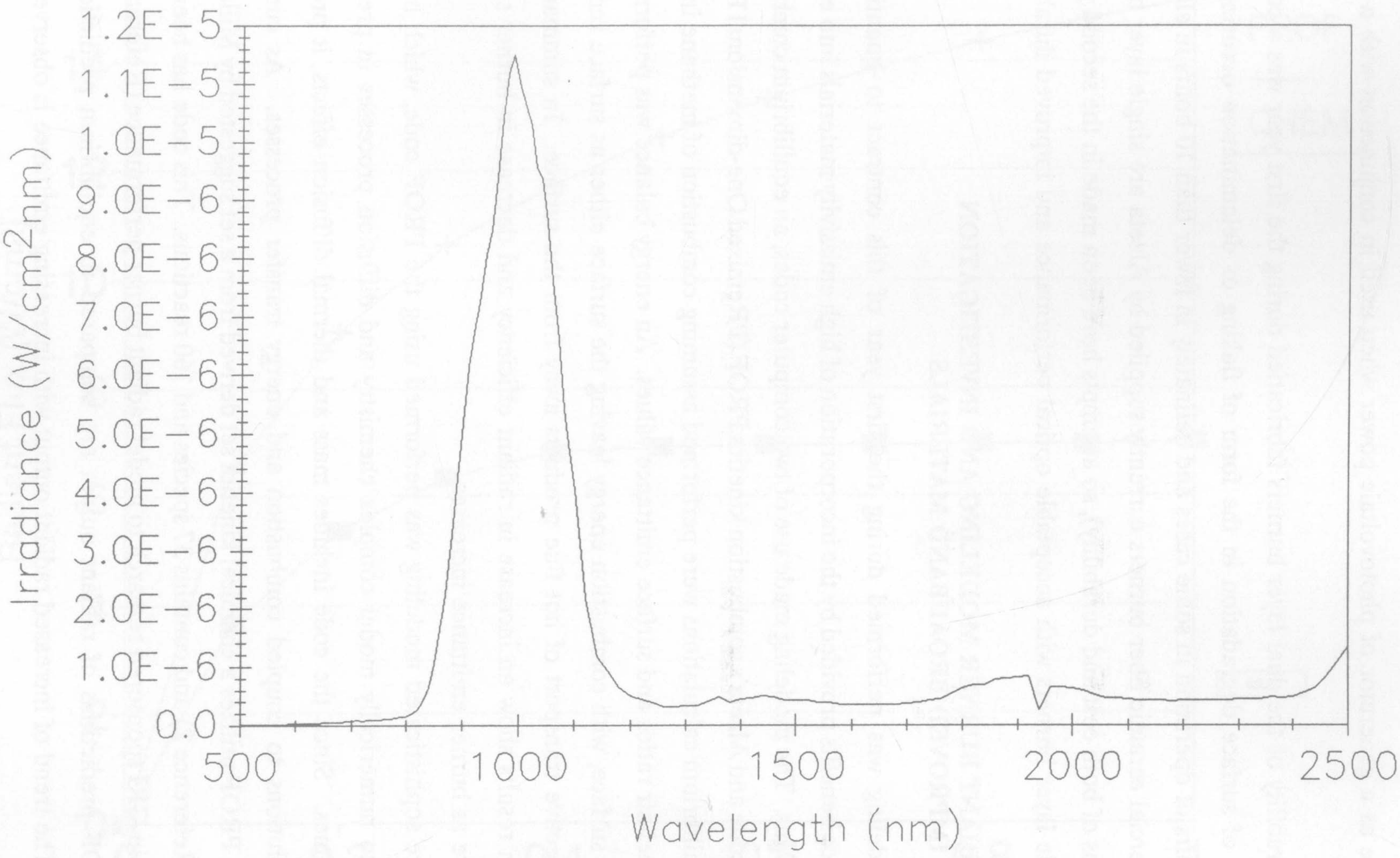

Figure 1. Spectral Irradiance Measured at a Distance of 84 cm. from a 3 1/2 inch Diameter Alzeta Ytterbia Fiber Burner Fired on Methane/Air at a Port Loading of 32.2 Watts/cm^2 (102 MBtu/hr-ft^2), Based on HHV of Fuel

namely use as a generator of photovoltaic power when used in conjunction with a silicon cell.

Durability of the dual layer burners fabricatied during the first year was a concern, with signs of surface degradation in the form of flaking or delamination occuring after several hours of operation in some cases and definately in fewer than 10 hours in all cases. All commercial ceramic fiber burners currently supplied by Alzeta are single layer burners (for reasons of both cost and durability), so attempts have been made in the second year to make single layer burners with acceptable optical performance and improved durability.

2.2 RADIANT BURNER MODELING AND INVESTIGATION OF IMPROVED BROADBAND MATERIALS

Modeling was performed during the first year of this contract to quantify the performance benefits provided by the incorporation of high emissivity materials into existing burner designs. The modeling made use of two computer codes, an equilibrium combustion chemistry code and Alzeta's combustion kinetics PROF (PRemixed One-dimensional Flame) Code. Equilibrium calculations were performed assuming combustion of methane in air at different fuel-air ratios and surface emittance values. An energy balance was performed at the burner surface, with combustion energy leaving the surface either as surface radiation or by convective transport of hot flue products away from the surface. In summary, the equilibrium results show an increase in radiant efficiency and decrease in burner surface temperature as burner emittance increases.

More sophisticated modeling was performed using the PROF code, which has the capability to numerically model complex chemistry and diffusion processes in premixed laminar flames. Since the code includes mass and thermal diffusion effects, it provides realistic solutions to coupled combustion and energy transfer processes. As currently configured, PROF utilizes a chemical kinetics set derived from a set suggested by Miller and Bowman (Reference 2) and contains 37 species and 160 reactions. This code has been used extensively in GRI sponsored research to model radiant burner performance (Reference 3).

PROF predictions of radiant output are compared to equilibrium predictions in Figure 2. The trend of increased radiant output with increasing emittance is observed for