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BASIC RESEARCH ON RADIANT BURNERS

FINAL REPORT
(February 1987-February 1992)

Prepared By

Robert M. Kendall, Susan T. DesJardin, and John D. Sullivan

Alzeta Corporation
2343 Calle del Mundo
Santa Clara, CA 95054

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Title:	Basic Research on Radiant Burners
Contractor:	Alzeta Corporation
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Objective:	To examine computationally and experimentally the parameters affecting flame attachment, flashback, radiant energy output, NO_x emissions, and surface catalysis of porous surface radiant burners.
Technical Perspective:	Porous surface radiant burners offer many advantages over conventional flame burners, including more uniform heat transfer, lower peak gas temperatures, and as a result of these lower gas phase temperatures, lower NO_x emissions. Radiant burner operation is limited to conditions where the flame is attached to the surface and the burner does not flashback. Under these conditions, the burner surface acts as a flameholder to stabilize the combustion of premixed fuel and air near its surface and the surface emits primarily infrared energy. Flame liftoff, when the flame stands off the surface and the burner is no longer radiant, occurs when operating a radiant burner at fuel/air mixture velocities that are too high to allow sufficient transfer of energy from the flame back to the burner surface. Flashback of a radiant burner occurs when the gas phase combustion reactions move upstream, eventually combusting at the inner burner surface. Burner stability limits, gas phase radiation, and NO_x emissions from radiant burners were studied during the conduct of this contract. Noble metal catalysts were shown experimentally to further improve the performance of porous surface radiant burners by increasing radiant flux from the burner surface and reducing NO_x emissions.
Results:	Results from this contract are grouped into the following areas of research:

- Limits of stable operation from flashback through flame liftoff,
- The effect of gas phase radiation on burner performance,
- NO_x emissions from radiant burners, and
- The effect of combustion catalysts on burner performance.

Results are presented below by research area.

Limits of Stable Operation

- The PROF flame code was modified to model radiant burner performance and was shown to accurately model different types of radiant burners including ceramic fiber, metal fiber, and ceramic foam burners. Tests were performed at conditions ranging from burner flashback to flame liftoff and results were compared to the model.

- Comparisons of predicted and measured radiant output were shown to agree to within approximately 0.2 cal/cm^2-sec (2.7 MBtu/hr-ft^2) over the following range of operating conditions: 3.6 to 10.8 cal/cm^2-sec (48 to 144 MBtu/hr-ft^2) fired duty at theoretical air levels of 105 to 170 percent.

- The model can be used to estimate flame liftoff conditions where radiant output from the burner surface drops to zero.

Gas Phase Radiation

- Modeling of gas phase radiation was performed to augment the surface radiation modeling done in earlier years using the PROF computer code.

- Gas phase radiation absorbed or reflected by the hot burner surface is significant, and increases surface radiation by 25 percent at nominal operating conditions of 7.5 cal/cm^2-sec (100 MBtu/hr-ft^2) and 105 percent theoretical air.

- The calculated gas phase contribution to total surface radiation is approximately 0.4 cal/cm^2-sec (5.3 MBtu/hr-ft^2) at the nominal condition and remains fairly constant over a range of theoretical air levels of 105 percent to 175 percent.

NO_x Emissions

- NO_x modeling was performed on ceramic and metal fiber porous surface burners using a subset of the Miller and Bowman (Reference 8) kinetics set. Modeling and tests were performed at firing rates of 3.75 cal/cm^2-sec (50 MBtu/hr-ft^2)to 15 cal/cm^2-sec (200 MBtu/hr-ft^2) and theoretical air levels of 105 to 150 percent.

- Contributions to total NO_x by the prompt and thermal NO_x mechanisms were investigated over the range of burner surface emittances of 0.1 to 0.9 and the range of firing rates described above, where emittance is defined as the ratio of radiant exitance from a body at a given temperature to that of a black body at the equivalent temperature. Contributions to total NO_x by the different mechanisms are strongly influenced by both emittance and firing rate.

- Experimentally measured NO_x values were lower than predicted values by 2 to 4 ppm at firing rates of 3.75 cal/cm^2-sec (50 MBtu/hr-ft^2) and 7.5 cal/cm^2-sec (100 MBtu/hr-ft^2) over a range of theoretical air levels of 105 to 150 percent. At higher firing rates, NO_x is under predicted, and the difference between measured and calculated NO_x increases with firing rate. At a firing rate of 15 cal/cm^2-sec (200 MBtu/hr-ft^2), NO_x is under predicted by 29 ppm.

Noble Metal Catalysts

- Platinum applied to a Pyrocore ceramic fiber burner in the form of hexachloroplatinic acid results in a significant increase in radiant output and significant decrease in the emissions of NO_x and CO.

- A platinum loading of approximately 1.5 mg/cm^2 causes an initial increase in radiant performance of 23 percent over the baseline value, and a reduction in NO_x emissions of 50 percent at 3.75 cal/cm^2-sec (50 MBtu/hr-ft^2) fired duty and 115 percent theoretical air.

- A palladium catalyst loading of 0.85 mg/cm^2 increased radiant output by 34 percent and reduced NO_x by 33 percent at equivalent operating conditions.

Technical Approach: Flame attachment, flashback, radiant energy output, and NO_x emissions were addressed separately in consecutive studies. Each year, computational work was performed to integrate burner surface effects into a one-dimensional pre-mixed flame chemistry model. Experimental work was performed to determine the validity and limitations of the computational results. During the fourth year, noble metal catalysts were applied to the surface of laboratory-scale burners to increase radiant flux from the burner surface and to reduce NO_x emissions. Performance improvements were measured and compared to baseline radiant burner performance values.

Project Implications:	Natural gas fired radiant burners can have more uniform heat transfer and lower NO_x emissions than conventional flame burners. NO_x is lower primarily because the peak gas temperature is lowered by surface radiation. Alzeta's work addressed flame liftoff, flame flashback, radiant output, and NO_x emissions, and their model development to describe porous surface radiant burners is important to the transfer of basic research to applied R&D. Alzeta's work on catalyzed burners shows that catalysts can significantly improve performance and reduce emissions from radiant burners. The catalyst durability must still be improved to be suitable for use in commercial products. Catalyst durability is an important research issue that GRI will continue to address. As these modeling and experimental results are translated into design guidelines, more controllable natural gas fired radiant burners with better performance and lower emissions will be possible.
	GRI Project Manager Thomas R. Roose, Ph.D. Assistant Director Physical Sciences Department

SECTION 1
INTRODUCTION

The objective of this contract was to develop and test the accuracy of a computer model used to predict the operating characteristics of natural gas fired porous surface radiant burners. Performance parameters studied during this contract include radiant flux from the burner surface, burner surface temperature, NO_x emissions, and flame attachment and flashback stability limits. Each year, computational work was performed to predict radiant burner performance. Concurrently, experimental work was performed to compare to these computational results. Validation of the code against experimental data allows the code to be used as a design tool in the further development of radiant burner combustion systems. Thermal performance, limits of stable operation, and NO_x emissions have been correlated to experimental data in this report.

Porous surface radiant burners offer many advantages over conventional flame burners, including more uniform heat transfer, lower peak gas temperatures, and as a result of these lower gas phase temperatures, lower NO_x emissions. Radiant burner operation is limited to conditions where the flame is attached to the surface and the burner does not flashback. Under these conditions, the burner surface acts as a flameholder to stabilize the combustion of premixed fuel and air near its surface and the surface emits primarily infrared energy. Flame liftoff, when the flame stands off the surface and the burner is no longer radiant, occurs when operating a radiant burner at fuel/air mixture velocities that are too high to allow sufficient transfer of energy from the flame back to the burner surface. Flashback of a radiant burner occurs when the gas phase combustion reactions move upstream, eventually combusting at the inner burner surface.

The model used in the prediction of radiant burner performance is described in Section 2. Studies of flame attachment and flashback were completed during the first two years of this study, and these results are presented in Section 3. During the third year, two tasks were undertaken. The first was to study the effect of gas phase radiation on thermal performance and the second was to model and measure NO_x emissions from radiant burners. The results of these tasks are presented in Sections 4 and 5 respectively. During the fourth and final year of the contract, an investigation of catalytic radiant burner surfaces was performed, and these results are discussed in Section 6. A summary of results for the entire four year effort is presented in Section 7, followed by conclusions and recommendations for future work in Section 8.

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7. Author(s)
Robert M. Kendall, Susan T. DesJardin, and John D. Sullivan

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Alzeta Corporation
2343 Calle Del Mundo
Santa Clara, CA 95054

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A computer model was modified and used to predict the operating characteristics of natural gas fired porous surface radiant burners. Performance parameters studied during this contract included radiant flux from the burner surface, burner surface temperature, NOx emissions, and flame attachment and flashback stability limits. Each year, computational work was performed to predict radiant burner performance. Concurrently, experimental work was performed to compare to these computational results. Validation of the code against experimental data allows the code to be used as a design tool in the further development of radiant burner combustion systems. Thermal performance, limits of stable operation, and NOx emissions have been correlated to experimental data in this report. In addition, catalytic radiant burners were fabricated and tested during the first and fourth years of the contract.

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