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**BASIC RESEARCH ON
RADIANT BURNERS**

FINAL REPORT
(February 1987-February 1992)

Prepared By

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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 $0.2 \text{ cal/cm}^2\text{-sec}$ (2.7 MBtu/hr-ft^2) over the following range of operating conditions: 3.6 to $10.8 \text{ cal/cm}^2\text{-sec}$ (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 $7.5 \text{ cal/cm}^2\text{-sec}$ (100 MBtu/hr-ft^2) and 105 percent theoretical air.
- The calculated gas phase contribution to total surface radiation is approximately $0.4 \text{ cal/cm}^2\text{-sec}$ (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 $3.75 \text{ cal/cm}^2\text{-sec}$ (50 MBtu/hr-ft^2) to $15 \text{ cal/cm}^2\text{-sec}$ (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/cm²-sec (50 MBtu/hr-ft²) and 7.5 cal/cm²-sec (100 MBtu/hr-ft²) 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/cm²-sec (200 MBtu/hr-ft²), 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/cm² 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/cm²-sec (50 MBtu/hr-ft²) fired duty and 115 percent theoretical air.
- A palladium catalyst loading of 0.85 mg/cm² 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.

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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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TABLE OF CONTENTS

Section		Page
1	INTRODUCTION	1-1
2	RADIANT BURNER MODEL	2-1
	2.1 Code Overview	2-1
	2.2 Modeling Methodology	2-2
	2.2.1 Flame Model	2-2
	2.2.2 Species Axial Diffusional Flux	2-4
	2.2.3 Species Production Terms	2-5
	2.2.4 Bulk Gas Volumetric Heat Loss	2-6
	2.2.5 Axial Diffusional Heat Flux	2-7
	2.2.6 Specialized Boundary Conditions	2-8
	2.3 Modeling Methodology Used in this Contract	2-11
3	RADIANT BURNER LIMITS OF OPERATION -- FLAME LIFTOFF AND FLASHBACK	3-1
	3.1 Computational Modeling of Performance Limits	3-1
	3.2 Flame Liftoff Experimental Results	3-6
	3.3 Flashback Experimental Results	3-20
4	GAS PHASE RADIATION PREDICTIONS AND MEASUREMENTS	4-1
	4.1 Gas Phase Radiation Modeling	4-1
	4.2 Gas Phase Radiation Experimental Results	4-9
5	MODELING OF NO _x FORMATION AND COMPARISONS TO EXPERIMENTAL DATA	5-1
	5.1 Qualification of Expanded Chemical Kinetics Set	5-1
	5.2 Nitrogen Oxides Emission Predictions	5-6
	5.3 Comparison to Experimental Data	5-12
6	INVESTIGATION OF RADIANT BURNER CATALYSTS	6-1
	6.1 Summary of Initial Catalytic Results	6-1
	6.2 Fabrication and Testing of Burners with UCLA Catalysts	6-4
	6.3 Alzeta Catalyst Results	6-7
7	SUMMARY OF RESULTS	7-1
8	CONCLUSIONS AND RECOMMENDATIONS	8-1
	REFERENCES	R-1
	APPENDIX A: GAS PHASE RADIATION APPROXIMATION	
	APPENDIX B: HEAT LOSS CALCULATION FROM EXPOSED METAL PLATE	
	APPENDIX C: UCLA and GALBRAITH LABORATORIES TEST REPORTS	

LIST OF FIGURES

Figure	Page
2-1 Heat and Mass Balance at Burner Surface	2-9
3-1 Radiant Flux From Burner Surface as a Function of Fired Duty and Excess Air (e.g., $7.2 \text{ cal/cm}^2\text{-sec} = 96 \text{ MBtu/hr-ft}^2$)	3-2
3-2 Radiant Burner Surface Temperature as a Function of Fired Duty and Excess Air (e.g., $7.2 \text{ cal/cm}^2\text{-sec} = 96 \text{ MBtu/hr-ft}^2$)	3-2
3-3 Radiant Efficiency of Burner as a Function of Fired Duty and Excess Air (e.g., $7.2 \text{ cal/cm}^2\text{-sec} = 96 \text{ Btu/hr-ft}^2$)	3-3
3-4 Radiant Flux as a Function of Burner Surface Emittance at Two Levels of Excess Air and Preheat (e.g., $7.2 \text{ cal/cm}^2\text{-sec}$ $= 96 \text{ MBtu/hr-ft}^2$, $1000 \text{ K} = 1340^\circ\text{R}$)	3-5
3-5 Burner Surface Temperature as a Function of Burner Surface Emittance at Two Levels of Excess Air and Preheat (e.g., $7.2 \text{ cal/cm}^2\text{-sec} = 96 \text{ MBtu/hr-ft}^2$, $1000 \text{ K} = 1340^\circ\text{R}$)	3-5
3-6 Three Types of Porous Surface Radiant Burners Tested	3-7
3-7 Radiant Burner Test Facility Schematic	3-9
3-8 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results at $3.6 \text{ cal/cm}^2\text{-sec}$ (48 MBtu/hr-ft^2) Fired Duty	3-12
3-9 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-12
3-10 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results at $10.8 \text{ cal/cm}^2\text{-sec}$ (144 MBtu/hr-ft^2) Fired Duty	3-13
3-11 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-13
3-12 Comparison of Predicted Burner Surface Temperature with Ceramic Fiber Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-14

LIST OF FIGURES (CONTINUED)

Figure		Page
3-13	Comparison of Predicted Radiant Flux with Metal Fiber Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-15
3-14	Comparison of Predicted Burner Surface Temperature with Metal Fiber Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-15
3-15	Comparison of Predicted Radiant Flux with Ceramic Foam Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-16
3-16	Comparison of Predicted Burner Surface Temperature with Ceramic Foam Burner Experimental Results at $7.2 \text{ cal/cm}^2\text{-sec}$ (96 MBtu/hr-ft^2) Fired Duty	3-16
3-17	Spectral Emittance Data From Ceramic Fiber Burner at $9.5 \text{ cal/cm}^2\text{-sec}$ (127 MBtu/hr-ft^2) Fired Duty (Reference 11)	3-18
3-18	Spectral Emittance Data From Metal Fiber Burner at $9.5 \text{ cal/cm}^2\text{-sec}$ (127 MBtu/hr-ft^2) Fired Duty (Reference 11)	3-18
3-19	Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results at $3.24 \text{ cal/cm}^2\text{-sec}$ (43 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-22
3-20	Comparison of Predicted Burner Surface Temperature with Ceramic Fiber Burner Experimental Results at $3.24 \text{ cal/cm}^2\text{-sec}$ (43 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-22
3-21	Comparison of Predicted Radiant Flux with Metal Fiber Burner Experimental Results at $3.02 \text{ cal/cm}^2\text{-sec}$ (40 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-23
3-22	Comparison of Predicted Burner Surface Temperature with Metal Fiber Burner Experimental Results at $3.02 \text{ cal/cm}^2\text{-sec}$ (40 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-23
3-23	Comparison of Predicted Radiant Flux with Ceramic Foam Burner Experimental Results at $2.79 \text{ cal/cm}^2\text{-sec}$ (37 MBtu/hr-ft^2) Fired Duty with Combustion Air Preheat	3-24

LIST OF FIGURES (CONTINUED)

Figure	Page
3-24 Comparison of Predicted Burner Surface Temperature with Ceramic Foam Burner Experimental Results at 2.79 cal/cm ² -sec (37 MBtu/hr-ft ²) Fired Duty with Combustion Air Preheat	3-24
3-25 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results for Burner with No Emissivity Agent at 3.77 cal/cm ² -sec (50 MBtu/hr-ft ²)	3-26
3-26 Comparison of Predicted Burner Surface Temperature with Ceramic Fiber Burner Experimental Results for Burner with No Emissivity Agent at 3.77 cal/cm ² -sec (50 MBtu/hr-ft ²)	3-26
3-27 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results for Burner with No Emissivity Agent at 3.02 cal/cm ² -sec (40 MBtu/hr-ft ²)	3-27
3-28 Comparison of Predicted Burner Surface Temperature with Ceramic Fiber Burner Experimental Results for Burner with No Emissivity Agent at 3.02 cal/cm ² -sec (40 MBtu/hr-ft ²)	3-27
3-29 Comparison of Predicted Radiant Flux with Ceramic Fiber Burner Experimental Results with Oxygen Enriched Combustion Air	3-29
3-30 Comparison of Predicted Burner Surface Temperature with Ceramic Fiber Burner Experimental Results with Oxygen Enriched Combustion Air	3-29
3-31 Comparison of Predicted Radiant Flux with Metal Fiber Burner Experimental Results with Oxygen Enriched Combustion Air	3-31
3-32 Comparison of Predicted Burner Surface Temperature with Metal Fiber Burner Experimental Results with Oxygen Enriched Combustion Air	3-31
3-33 Comparison of Predicted Radiant Flux with Ceramic Foam Burner Experimental Results with Oxygen Enriched Combustion Air	3-33
3-34 Comparison of Predicted Burner Surface Temperature with Ceramic Foam Burner Experimental Results with Oxygen Enriched Combustion Air	3-33
4-1 Components of Radiant Flux from Burner as a Function of Theoretical Air at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²) Fired Duty	4-6

LIST OF FIGURES (CONTINUED)

Figure		Page
4-2	Burner Surface Temperature as a Function of Theoretical Air at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²) Fired Duty	4-6
4-3	Radiant Output as a Function of Fired Duty at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	4-8
4-4	Radiant Efficiency as a Function of Fired Duty at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	4-8
4-6	Components of Radiant Flux from Burner as a Function of Combustion Air Preheat at 15.0 cal/cm ² -sec (200 MBtu/hr-ft ²) Fired Duty	4-10
4-7	Burner Surface Temperature as a Function of Combustion Air Preheat at 15.0 cal/cm ² -sec (200 MBtu/hr-ft ²) Fired Duty	4-10
4-8	Components of Radiant Flux from Burner as a Function of Gas Layer Thickness at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²) Fired Duty	4-11
4-9	Burner Surface Temperature as a Function of Gas Layer Thickness at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²) Fired Duty	4-11
4-10	Radiant Output as a Function of Fired Duty at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	4-13
4-11	Radiant Efficiency as a Function of Fired Duty at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	4-14
4-12	Radiant Output as a Function of Theoretical Air at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	4-15
4-13	Comparison of Technical University of Denmark Data to Predictions as a Function of Fired Duty at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	4-15
5-1	Comparison of Predicted Radiant Output From Ceramic and Metal Fiber Burners to Experimental Data as a Function of Fired Duty (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	5-2
5-2	Comparison of Predicted Burner Surface Temperature of Ceramic and Metal Fiber Burners to Experimental Data as a Function of Fired Duty (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	5-2

LIST OF FIGURES (CONTINUED)

Figure		Page
5-3	Comparison of Predicted Radiant Output From Ceramic and Metal Fiber Burners to Experimental Data as a Function of Theoretical Air at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	5-4
5-4	Comparison of Predicted Burner Surface Temperature of Ceramic and Metal Fiber Burners to Experimental Data as a Function of Theoretical Air at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	5-4
5-5	Comparison of Predicted Radiant Output From Ceramic and Metal Fiber Burners to Experimental Data as a Function of Combustion Air Preheat	5-5
5-6	Comparison of Predicted Burner Surface Temperature of Ceramic and Metal Fiber Burners to Experimental Data as a Function of Combustion Air Preheat	5-5
5-7	Total NO _x Production as a Function of Burner Surface Emittance and Firing Rate at 105 Percent Theoretical Air (7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	5-7
5-8	Thermal and Prompt NO _x Production as a Function of Burner Surface Emittance at 3.75 cal/cm ² -sec (50 MBtu/hr-ft ²)	5-9
5-9	Thermal and Prompt NO _x Production as a Function of Burner Surface Emittance at 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	5-9
5-10	Thermal and Prompt NO _x Production as a Function of Burner Surface Emittance at 11.25 cal/cm ² -sec (150 MBtu/hr-ft ²)	5-10
5-11	Thermal and Prompt NO _x Production as a Function of Burner Surface Emittance at 15.0 cal/cm ² -sec (200 MBtu/hr-ft ²)	5-11
5-12	Radiant Efficiency as a Function of Surface Emittance and Firing Rate at 105 Percent Theoretical Air (7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	5-11
5-13	Thermal and Prompt NO _x Production as a Function of Distance From Burner Surface at a Firing Rate of 3.75 cal/cm ² -sec (50 MBtu/hr-ft ²)	5-13

LIST OF FIGURES (CONTINUED)

Figure	Page
5-14 Thermal and Prompt NO _x Production as a Function of Distance From Burner Surface at a Firing Rate of 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	5-13
5-15 Thermal and Prompt NO _x Production as a Function of Distance From Burner Surface at a Firing Rate of 11.25 cal/cm ² -sec (150 MBtu/hr-ft ²)	5-14
5-16 Thermal and Prompt NO _x Production as a Function of Distance From Burner Surface at a Firing Rate of 15.0 cal/cm ² -sec (200 MBtu/hr-ft ²)	5-14
5-17 Gas Temperature as a Function of Distance From Burner Surface for Two Firing Rates and Surface Emittances (e.g., 7.5 cal/cm ² = 100 MBtu/hr-ft ²)	5-15
5-18 Comparison of Measured and Predicted NO _x as a Function of Surface Firing Rate at 105 Percent Theoretical Air (e.g., 7.5 cal/cm ² -sec = 100 MBtu/hr-ft ²)	5-17
5-19 Comparison of Measured and Predicted NO _x as a Function of Theoretical Air at a Surface Firing Rate of 7.5 cal/cm ² -sec (100 MBtu/hr-ft ²)	5-17
6-1 Radiant Output as a Function of Excess Air at 7.2 cal/cm ² (96 MBtu/hr-ft ²) Fired Duty for Four Different Burner Formulations	6-2
6-2 Burner Surface Temperature as a Function of Excess Air at 7.2 cal/cm ² -sec (96 MBtu/hr-ft ²) Fired Duty for Four Different Burner Formulations	6-2
6-3 Comparison of Radiant Efficiency of Burners Catalyzed with UCLA Palladium Catalyst Samples Referenced to Baseline Performance at 4.8 and 7.5 cal/cm ² -sec (63.5 and 100 MBtu/hr-ft ²)	6-8
6-4 Comparison of NO _x Emissions From Burners Catalyzed with UCLA Palladium Catalyst Samples Referenced to Baseline Performance at 4.8 and 7.5 cal/cm ² -sec (63.5 and 100 MBtu/hr-ft ²)	6-8
6-5 Comparison of Radiant Efficiency of Burners Catalyzed with Hexachloroplatinic Acid Spray Referenced to Baseline Performance	6-10