

**INVESTIGATION ON FLASHBACK PROPENSITY OF FUEL
BLENDS: COMPOSITION EFFECT**

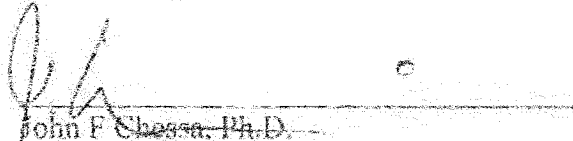
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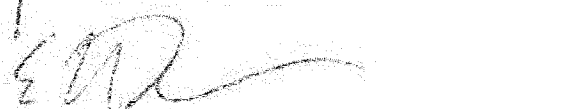
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This thesis is dedicated to those who believe in my success. Thank you Lord for blessing me with the opportunity of understanding what I did not know and to understand what I have not yet seen.

PREVIEW

**INVESTIGATION ON FLASHBACK PROPENSITY OF FUEL
BLENDS: COMPOSITION EFFECT**

by

ROGELIO FRANCO, B.S.M.E.

THESIS

Presented to the Faculty of the Graduate School of

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Abstract

An experimental investigation is presented to delineate the effects of composition and external excitation on the flashback propensity of hydrocarbon ($\text{CH}_4\text{-C}_3\text{H}_8$ and $\text{CH}_4\text{-C}_2\text{H}_6$) and hydrogen (CO-H_2 and $\text{CH}_4\text{-H}_2$) fuel blends. The flashback propensity of hydrocarbon fuel blends generally correlates with the flame velocity and stoichiometry of the fuel mixtures. The flashback propensity of hydrocarbon fuel blends is susceptible to the presence of external excitation. Flashback occurs at much leaner conditions in acoustically forced flames. The flashback characteristics of hydrogen fuel blends are generally dominated by the kinetics of the hydrogen. The effects of external excitation on the flashback propensity of CO-H_2 flames with more than 5% H_2 are not significant. For 0-700Hz forcing range the kinetic time scale of H_2 is prevalent over the external forcing time scale.

Executive Summary

There is an increasing interest in the gas turbine industry to address the issue of fuel variability and fuel flexibility. The Department of Energy's Advanced Power Systems Turbine Program has goals to develop very low emission turbine combustors which are capable of stable operation with fuel compositions ranging from natural gas to a broad range for syngas. However, for a "well-tuned," dry, low NOX, LP or LPP gas turbine designed for natural gas or No. 2 diesel fuel, any variation in the fuel properties may cause difficulties with regard to issues such as flashback, autoignition, excessive oscillations, and high emission. Flashback is a combustion condition at which the gas velocity becomes smaller than the burning velocity and the flame propagates against the gas stream into the burner tube. Flashback is a critical issue for premixed combustor designs because it not only increases emissions but also causes serious hardware damages.

Although a considerable amount of research has been done on flashback characteristics of pure fuels and their response to combustion oscillation conditions, the synergetic impacts of compositions and combustion oscillations on the flashback propensity of fuels such as natural gas and syngas are largely unknown. This research addressed fuel composition and variability issues associated with the use of syngas and alternate fuels in gas turbine combustors.

The primary objective of the proposed research was to develop fundamental understanding of the flashback propensity of syngas at different compositions. Through

experimental measurements the proposed study generated critical boundary velocity gradient (g_F) maps of different compositions of syngas with or without the presence of combustion oscillation. The influence of mixture composition and combustion oscillation (externally driven) on the flashback propensity was quantified. Of special interest of the project was to understand the effect of higher concentrations of hydrogen in syngas on flashback.

The report quantified the effects of composition and external excitation on the flashback propensity of hydrocarbon (methane-propane and methane-ethane) and hydrogen (carbon monoxide-hydrogen and methane-hydrogen) fuel blends. The flashback propensity of hydrocarbon fuel blends generally correlates with the flame velocity and stoichiometry of the fuel mixtures. The flashback propensity of hydrocarbon fuel blends is susceptible to the presence of external excitation. Flashback occurs at much leaner conditions in acoustically forced flames. The flashback characteristics of hydrogen fuel blends (especially syngas: carbon monoxide-hydrogen) are generally dominated by the kinetics of the hydrogen. The effects of external excitation on the flashback propensity of carbon monoxide-hydrogen flames with more than 5% hydrogen are not significant. For low frequency (0-700Hz and an average amplitude of 95dB) externally driven forcing range the kinetic time scale of hydrogen is prevalent over the forcing time scale.

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PREVIEW

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Table of Contents

| | |
|--|------|
| Abstract | i |
| Executive Summary | ii |
| Acknowledgements | iv |
| Table of Contents | vi |
| List of Tables | viii |
| List of Figures | xi |
| Chapter 1 : Introduction | 1 |
| 1.1 Overview..... | 1 |
| 1.2 Research Objectives..... | 3 |
| 1.3 Organization of the Report..... | 3 |
| 1.4 Description of the Laboratory | 4 |
| Chapter 2 : Background and Previous Work | 6 |
| 2.1 Flashback and Critical Velocity Gradient..... | 6 |
| 2.2 Critical Velocity Gradient of Fuel Blends | 8 |
| 2.3 Laminar Flame Velocity of Fuel Blends..... | 9 |
| 2.4 Effects of Combustion Oscillation of Flashback | 11 |
| Chapter 3 : Experimental Setup | 12 |

| | |
|--|-----------|
| 3.1 Burner System..... | 13 |
| 3.2 Methodology | 18 |
| Chapter 4 : Experimental Result and Discussion | 23 |
| 4.1 Visual Observation and Qualification of the Test Apparatus | 23 |
| 4.2 Effects of Fuel Composition on the Flashback Limit | 29 |
| 4.3 Effect of Diluents on Flashback..... | 59 |
| 4.4 Effects of External Excitation of the Flashback Propensity | 75 |
| Chapter 5 : Conclusions | 82 |
| 5.1 General Remarks..... | 82 |
| 5.2 Conclusions..... | 83 |
| 5.3 Practical Implication of the Project..... | 84 |
| Bibliography | 85 |
| APPENDIX I: Experimental Hardware..... | 88 |
| Curriculum Vitae..... | 92 |

List of Tables

| | |
|--|----|
| Table 3.1: Imager specifications..... | 20 |
| Table 3.2: Electrical specifications..... | 20 |
| Table 3.3: Physical Specifications..... | 21 |
| Table 3.4: Flow meters..... | 21 |
| Table 3.5: DryCal Gas Calibrator | 21 |
| Table 3.6: DAQPad 6020E..... | 22 |
| Table 3.7: Nominal operating conditions | 22 |
| Table 4.1: Critical data of flows and velocity gradient for air methane mixture in cylindrical tubes of different diameters at room temperature..... | 25 |
| Table 4.2: Percentage of fuel in volume (%F) and velocity gradient(gf) for the 1943 natural gas composition for 10.6 mm diameter cylindrical tube..... | 28 |
| Table 4.3: Critical flows for flashback and velocity gradient of methane-ethane air gas flames in tubes of 6.0 diameter at 1) 95%CH ₄ +5%C ₂ H ₆ , 2) 85% CH ₄ +15% C ₂ H ₆ and 3) 75% CH ₄ +25% C ₂ H ₆ | 31 |
| Table 4.4: Critical flows for flashback and velocity gradient of methane-ethane air gas flames in tubes of 7.0 diameter at 1) 95%CH ₄ +5%C ₂ H ₆ , 2) 85% CH ₄ +15% C ₂ H ₆ and 3) 75% CH ₄ +25% C ₂ H ₆ | 31 |
| Table 4.5: Critical flows for flashback and velocity gradient of methane-ethane air gas flames tubes of 10.6 diameter at 1) 95%CH ₄ +5%C ₂ H ₆ , 2) 85% CH ₄ +15% C ₂ H ₆ and 3) 75% CH ₄ +25% C ₂ H ₆ | 31 |

| | |
|--|----|
| Table 4.6: Critical flows for flashback and velocity gradient of methane-propane air gas flames in tubes of 6.0 diameter at 1) 95%CH ₄ +5%C ₃ H ₈ , 2) 85% CH ₄ +15% C ₃ H ₈ and 3) 75% CH ₄ +25% C ₃ H ₈ | 39 |
| Table 4.7: Critical flows for flashback and velocity gradient of methane-propane air gas flames in tubes of 7.0 diameter at 1) 95%CH ₄ +5%C ₃ H ₈ , 2) 85% CH ₄ +15% C ₃ H ₈ and 3) 75% CH ₄ +25% C ₃ H ₈ | 39 |
| Table 4.8: Critical flows for flashback and velocity gradient of methane-propane air gas flames in tubes of 10.6 diameter at 1) 95%CH ₄ +5%C ₃ H ₈ , 2) 85% CH ₄ +15% C ₃ H ₈ and 3) 75% CH ₄ +25% C ₃ H ₈ | 40 |
| Table 4.9: Critical flows for flashback and velocity gradient of methane-hydrogen air gas flames in tubes of 6.0 diameter at 1) 95%CH ₄ +5%H ₂ , 2) 85% CH ₄ +15% H ₂ and 3) 75% CH ₄ + 25% H ₂ | 45 |
| Table 4.10: Critical flows for flashback and velocity gradient of methane-hydrogen air gas flames in tubes of 7.0 diameter at 1) 95%CH ₄ +5%H ₂ , 2) 85% CH ₄ +15% H ₂ and 3) 75% CH ₄ +25% H ₂ | 45 |
| Table 4.11: Critical flows for flashback and velocity gradient of methane-hydrogen air gas flames in tubes of 10.6 diameter at 1) 95%CH ₄ +5%H ₂ , 2) 85% CH ₄ +15% H ₂ and 3) 75% CH ₄ +25% H ₂ | 46 |
| Table 4.12: Critical flows for flashback and velocity gradient of carbon monoxide-hydrogen air gas flames in tubes of 6.0 diameter at 1) 95%CO+5%H ₂ , 2) 85% CO+15% H ₂ and 3) 75% CO+25% H ₂ | 52 |
| Table 4.13: Critical flows for flashback and velocity gradient of carbon monoxide-hydrogen air gas flames in tubes of 7.0 diameter at 1) 95%CO+5%H ₂ , 2) 85% CO+15% H ₂ and 3) 75% CO+25% H ₂ | 52 |

Table 4.14: Critical flows for flashback and velocity gradient of carbon monoxide-hydrogen air gas flames in cylindrical tubes of 10.6 diameter at 1) 95%CO+5%H₂, and 2) 85%CO+15%H₂ and 3) 75% CO+25% H₂ 53

Table 4.15: Critical flows for flashback and velocity gradient of methane-hydrogen air gas flames in cylindrical tubes of 7.0 diameter at 1) 95%CH₄+5%N₂, 2) 85% CH₄+15% N₂ and 3) 75% CH₄+25% N₂ 59

Table 4.16: Critical flows for flashback and velocity gradient of methane-hydrogen air gas flames in cylindrical tubes of 10.6 diameter at 1) 95%CH₄+5%N₂, 2) 85% CH₄+15% N₂ and 3) 75% CH₄+25% N₂ 60

Table 4.17: Critical flows for flashback and velocity gradient of methane-propane-nitrogen air gas flames in cylindrical tubes of 7.0 diameter at 1) 80%CH₄+10%C₂H₈+10%N₂, 2) 70%CH₄+15%C₃H₈+15%N₂, and 3) 60%CH₄+20% C₃H₈+20%N₂ 65

Table 4.18: Critical flows for flashback and velocity gradient of methane-propane-nitrogen air gas flames in cylindrical tubes of 10.6 diameter at 1) 80%CH₄+10%C₂H₈+10%N₂, 2) 70%CH₄+15%C₃H₈+15%N₂, and 3) 60%CH₄+20% C₃H₈+20%N₂ 65

Table 4.19: Critical flows for flashback and velocity gradient of carbon monoxide-hydrogen-nitrogen air gas flames in tubes of 7.0 diameter at 1) 80%CO+10%H₂+10%N₂ 2) 70%CO+15%H₂+15%N₂ and 3) 60%CO+20%H₂+20%N₂..... 71

Table 4.20: Critical flows for flashback and velocity gradient of carbon monoxide-hydrogen-nitrogen air gas flames in tubes of 10.6 diameter at 1) 80%CO+10%H₂+10%N₂ 2) 70%CO+15%H₂+15%N₂ and 3) 60%CO+20%H₂+20%N₂..... 71

List of Figures

| | |
|---|----|
| Figure 3.1: Schematic of the experimental set up | 12 |
| Figure 3.2: Experimental set up | 13 |
| Figure 3.3: Drawing and assembly of the burner | 13 |
| Figure 3.4: Primary sections of the burner: (from left to right) mixing manifold, flow excitation hub, flow conditioner and burner tube assembly | 14 |
| Figure 3.5: Flow excitation sections of the burner: (from left to right) flow excitation hub, c-clamps and burner tube assembly mixing manifold | 15 |
| Figure 3.6: Glass tube adapter drawing manufactured part and mounted over the converging nozzle adapter | 15 |
| Figure 3.7: SS-4P4T4 plug valves for shutoff and SS-SS4VH metering valves for precise control | 16 |
| Figure 3.8: SS-4TF-40 Micron Strainer | 16 |
| Figure 3.9: Omega 1800 FMA Mass Flow Meter | 17 |
| Figure 3.10: DryCal Flow Meter Calibrator | 17 |
| Figure 3.11: PHOTRON FASTCAM super 10 K series | 17 |
| Figure 3.12: Speaker and a copper membrane | 18 |
| Figure 4.1: Flame undergoing through the process of flashback | 24 |
| Figure 4.2: Flashback limit of 6.0, 7.0 and 10.6 mm diameter glass tube at different air methane mixtures..... | 26 |

| | |
|---|----|
| Figure 4.3: Critical velocity gradient boundary for flashback of pure methane air flames in cylindrical tubes | 26 |
| Figure 4.4: Critical flashback limit(left) and Critical velocity gradients at boundary of 1943 natural gas-air flames in cylindrical tubes of different diameters acquired by Lewis and von Elbe | 27 |
| Figure 4.5: Comparison between present data and Lewis data for critical flows for critical flashback limit of 1943 natural gas-air flames in 10.6mm diameter tube | 28 |
| Figure 4.6: Comparison between present investigation and Lewis of data for critical velocity gradients of 1943 natural gas-air flames of 10.6mm diameter tubes | 29 |
| Figure 4.7: Flame profile comparison between Lewis and present work | 29 |
| Figure 4.8: Critical flows for flashback of methane-ethane air flames of 6.0 mm diameter tube | 32 |
| Figure 4.9: Critical flows for flashback of methane-ethane air flames of 7.0 mm diameter tube | 33 |
| Figure 4.10: Critical flows for flashback of methane-ethane air flames of 10.6 mm diameter tube | 33 |
| Figure 4.11: Critical velocity gradients at boundary of gas stream for flashback of 75% CH ₄ +25%C ₂ H ₆ gas composition in tubes of different diameters | 35 |
| Figure 4.12: Critical velocity gradients at boundary of gas stream for flashback of 85% CH ₄ +15%C ₂ H ₆ gas composition in tubes of different diameters | 35 |
| Figure 4.13: Critical velocity gradients at boundary of gas stream for flashback of 95% CH ₄ +5%C ₂ H ₆ gas composition in tubes of different diameters | 36 |
| Figure 4.14: Highest velocity gradients in cylindrical tubes at different fuel ethane concentration of different diameters | 36 |

| | |
|--|----|
| Figure 4.15: Critical flows for flashback of methane-propane air flames of 6.0 mm diameter tube | 40 |
| Figure 4.16: Critical flows for flashback of methane-propane air flames of 7.0 mm diameter tube | 41 |
| Figure 4.17: Critical flows for flashback of methane-propane air flames of 10.6 mm diameter | 41 |
| Figure 4.18: Critical velocity gradients at boundary of gas stream for flashback of 75% $\text{CH}_4 + 25\% \text{C}_3\text{H}_8$ gas composition in tubes of different diameters | 42 |
| Figure 4.19: Critical velocity gradients at boundary of gas stream for flashback of 85% $\text{CH}_4 + 15\% \text{C}_3\text{H}_8$ gas composition in tubes of different diameters | 42 |
| Figure 4.20: Critical velocity gradients at boundary of gas stream for flashback of 95% $\text{CH}_4 + 5\% \text{C}_3\text{H}_8$ gas composition in tubes of different diameters | 43 |
| Figure 4.22: Critical flows for flashback of methane-hydrogen air flames of 6.0 mm diameter tube | 46 |
| Figure 4.23: Critical flows for flashback of methane-hydrogen air flames of 7.0 mm diameter tube | 47 |
| Figure 4.24: Critical flows for flashback of methane-hydrogen air flames of 10.6 mm diameter tube | 47 |
| Figure 4.25: Critical velocity gradients at boundary of gas stream for flashback of 75% $\text{CH}_4 + 25\% \text{H}_2$ gas composition in tubes of different diameters | 49 |
| Figure 4.26: Critical velocity gradients at boundary of gas stream for flashback of 85% $\text{CH}_4 + 15\% \text{H}_2$ gas composition in tubes of different diameters | 49 |

| | |
|---|----|
| Figure 4.27: Critical velocity gradients at boundary of gas stream for flashback of 95% CH ₄ +5% H ₂ gas composition in tubes of different diameters..... | 50 |
| Figure 4.28: Highest velocity gradients in cylindrical tubes at different fuel hydrogen concentration of different diameters..... | 50 |
| Figure 4.29: Critical flows for flashback of carbon monoxide-hydrogen air flames of 6.0 mm diameter tube | 54 |
| Figure 4.30: Critical flows for flashback of carbon monoxide-hydrogen air flames of 7.0 mm diameter tube | 54 |
| Figure 4.31: Critical flows for flashback of carbon monoxide-hydrogen air flames of 10.6 mm diameter..... | 55 |
| Figure 4.32: Critical velocity gradients at boundary of gas stream for flashback of 75% CO+25% H ₂ gas composition in tubes of different diameters..... | 57 |
| Figure 4.33: Critical velocity gradients at boundary of gas stream for flashback of 85% CO+15% H ₂ gas composition in tubes of different diameters..... | 57 |
| Figure 4.34: Critical velocity gradients at boundary of gas stream for flashback of 95% CO+5% H ₂ gas composition in tubes of different diameters..... | 58 |
| Figure 4.35: Highest velocity gradients in cylindrical tubes at different fuel hydrogen concentration of different diameters..... | 58 |
| Figure 4.36: Critical flows for flashback of methane-nitrogen air flames of 7.0 mm diameter tube | 60 |
| Figure 4.38: Critical velocity gradients at boundary of gas stream for flashback of 75% CH ₄ +25% N ₂ gas composition in tubes of different diameters..... | 62 |

| | |
|---|----|
| Figure 4.39: Critical velocity gradients at boundary of gas stream for flashback of 85% $\text{CH}_4 + 15\% \text{N}_2$ gas composition in tubes of different diameters..... | 62 |
| Figure 4.40: Critical velocity gradients at boundary of gas stream for flashback of 95% $\text{CH}_4 + 5\% \text{N}_2$ gas composition in tubes of different diameters..... | 63 |
| Figure 4.41: Highest velocity gradients in cylindrical tubes at different fuel nitrogen concentration of different diameters..... | 63 |
| Figure 4.42: Critical flows for flashback of methane-propane-nitrogen air flames of 7.0 mm diameter tube | 66 |
| Figure 4.43: Critical flows for flashback of methane-propane-nitrogen air flames of 10.6 mm diameter tube | 66 |
| Figure 4.44: Critical velocity gradients at boundary of gas stream for flashback of 60% $\text{CH}_4 + 20\% \text{C}_3\text{H}_8 + 20\% \text{N}_2$ gas composition in tubes of different diameters..... | 67 |
| Figure 4.45: Critical velocity gradients at boundary of gas stream for flashback of 70% $\text{CH}_4 + 15\% \text{C}_3\text{H}_8 + 15\% \text{N}_2$ gas composition in tubes of different diameters..... | 68 |
| Figure 4.46: Critical velocity gradients at boundary of gas stream for flashback of 60% $\text{CH}_4 + 20\% \text{C}_3\text{H}_8 + 20\% \text{N}_2$ gas composition in tubes of different diameters..... | 68 |
| Figure 4.47: Highest velocity gradients in cylindrical tubes at different fuel propane-nitrogen concentration of different diameters..... | 69 |
| Figure 4.48: Critical flows for flashback of carbon monoxide-hydrogen-nitrogen air flames of 7.0 mm diameter tube..... | 72 |
| Figure 4.49: Critical flows for flashback of carbon monoxide-hydrogen-nitrogen air flames of 10.6 mm diameter tube | 72 |

| | |
|---|----|
| Figure 4.50: Critical velocity gradients at boundary of gas stream for flashback of 60%CO+20%H ₂ +20%N ₂ gas composition in cylindrical tubes of different diameters | 73 |
| Figure 4.51: Critical velocity gradients at boundary of gas stream for flashback of 70%CO+15%H ₂ +15%N ₂ gas composition in tubes of different diameters | 74 |
| Figure 4.52: Critical velocity gradients at boundary of gas stream for flashback of 80%CO+10%H ₂ +10%N ₂ gas composition in tubes of different diameters..... | 74 |
| Figure 4.53: Highest velocity gradients in cylindrical tubes at different fuel hydrogen-nitrogen concentration of different diameters at room temperature; the gas percentages on the x axis represents the addition of H ₂ and N ₂ by equal parts | 75 |
| Figure 4.54: Comparison of critical velocity gradient for 100% CH ₄ at 300Hz, 500Hz and 700Hz in cylindrical tube of 10.6mm at room temperature. | 77 |
| Figure 4.55: Comparison of critical velocity gradient for 95% - 5% of CH ₄ – C ₃ H ₈ at 300Hz, 500Hz and 700Hz in cylindrical tube of 10.6mm at room temperature..... | 78 |
| Figure 4.56: Comparison of critical velocity gradient for 85% -15% of CH ₄ – C ₃ H ₈ at 300Hz, 500Hz and 700Hz in cylindrical tube of 10.6mm at room temperature..... | 78 |
| Figure 4.57: Comparison of critical velocity gradient for 75% - 25% of CH ₄ – C ₃ H ₈ at 300Hz, 500Hz and 700Hz in a cylindrical tube of 10.6mm at room temperature. | 79 |
| Figure 4.58: Comparison of critical velocity gradient for 100% CH ₄ at 300Hz, 500Hz and 700Hz in cylindrical tube of 7mm at room temperature. | 79 |
| Figure 4.59: Comparison of critical velocity gradient for 100% CH ₄ at 300Hz, 500Hz and 700Hz in cylindrical tube of 6mm at room temperature. | 80 |

| | |
|---|----|
| Figure 4.60: Comparison of critical velocity gradient for 95% CO-5% H ₂ at 300Hz, 500Hz and 700Hz in cylindrical tube of 6mm at room temperature | 80 |
| Figure 4.61: Comparison of critical velocity gradient for 85% CO-15% H ₂ at 300Hz, 500Hz and 700Hz in cylindrical tube of 6mm at room temperature | 81 |
| Figure 4.62: Comparison of critical velocity gradient for 75% CO-25% H ₂ at 300Hz, 500Hz and 700Hz in cylindrical tube of 6mm at room temperature | 81 |

PREVIEW

Chapter 1: Introduction

1.1 Overview

Designers of Gas Turbine Combustors of advanced power systems have goals to achieve very low plant emissions (NO_x less than 2-ppm), fuel variability, and fuel flexibility [1]. Future generation gas turbine combustors are expected to function with varying fuel compositions ranging from natural gas to synthesized gases (Syngas) without compromising their low emission characteristics [1-2]. Although older gas turbine engines employ purely non-premixed combustion systems, current designs of advanced turbine combustors use various degrees of premixing to avoid high temperature NO_x forming zones [3-4]. As a result of NO_x control from premixed combustion, a number of concerns came, especially combustor flashback. Flashback is a combustion condition at which the burning velocity exceeds the gas flow velocity and the flame propagates against the gas stream into the burner tube. Flashback is a critical issue for premixed combustor designs, because it not only increases emissions but also causes serious hardware damages. The variation in fuel properties may cause a “well-tuned,” low NO_x , LP or LPP gas turbine designed for natural gas or No. 2 diesel fuel to suffer significant operational (flashback, auto-ignition, excessive oscillations) and performance (high emissions and fuel consumptions) penalties [5].

A typical syngas contains 25% H_2 , 40% CO and 20% H_2O . Syngas produced by oxygen blown coal gasification process may contain hydrogen as high as 30% by volume. The presence of hydrogen in syngas increases the potential for flashback. Due to its high burning velocity and low lean flammability limit, hydrogen tends to shift the combustor

operating conditions towards flashback regime. Even a small amount of hydrogen in a fuel can trigger the onset of flashback by altering the chemical kinetics and thermo-physical characteristics of the reactant mixture [6-14]. The presence of hydrogen in the fuel also changes the response of the flame to the general effects of stretch and preferential diffusion. Similar effects are also observed due to the presence of C_2 and higher hydrocarbons in natural gas. Combustion instabilities may also aggravate combustor flashback conditions. Instabilities induce large oscillations of the flow-field causing the flame to move back and forth in the combustion chamber and to propagate upstream periodically during the pulsation cycle.

Although a considerable amount of research has been done on flashback characteristics of pure fuels and their response to combustion oscillation conditions [15-18], the synergetic impacts of compositions and combustion oscillations on the flashback propensity of fuels such as natural gas and syngas are largely unknown. In addition, fundamental information and data regarding the combustion characteristics of commercial and alternative fuels are essential because of the emerging need to address gas turbine combustor issues such as ultra-low emission, fuel variability and fuel flexibility. This research addressed fuel composition and variability issues associated with the use of syngas and alternate fuels in gas turbine combustors. The primary goal for this research project was to understand the synergetic effects of fuel compositions and combustion oscillations on the flashback propensity of syngas. The project used laboratory experiments to generate flashback propensity maps of syngas with different compositions. The outcomes of the project will enable design of syngas fueled gas turbine combustors with improved stability and emissions.

1.2 Research Objectives

The overall objective of this research was to understand the flashback propensity of fuel blends at different mixture composition and combustion oscillations (externally driven). This proposed study concentrated on generating critical boundary velocity gradient maps (g_F) of different compositions of syngas with the presence of combustion oscillations. Of special interest of the project was to understand the effect of higher concentrations of H_2 in syngas on flashback. The specific objectives of the project are:

1. To quantify the effects of syngas and blended fuel compositions on the flashback propensity of premixed flames.
2. To understand the synergetic effect of combustion oscillations (externally driven) and syngas compositions on the flash back propensity of premixed flames.

1.3 Organization of the Report

The approach used to fulfill the primary objective, and results obtained are discussed in five chapters. In *Chapter 1*, followed by the Introduction are the project motivation and objectives, organization of the report and a brief description of the laboratory. *Chapter 2* contains the background information and literature review which are essential to understand the objectives and outcomes of the project. The chapter explains various aspects of flashback behavior of flames. The discussions are provided in the context of fuel blends. *Chapter 3* explains the experimental setup and the methodology used in the research. It contains figures and photographs of the experimental setup and tables of specifications of the different apparatuses used. The