INVESTIGATION ON FLASHBACK PROPENSITY OF FUEL BLENDS: COMPOSITION EFFECT

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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.

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by

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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 (CH_4-C_3H_8 and CH_4-C_2H_6) and hydrogen (CO-H_2 and CH_4-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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Chapter 1: Introduction

1.1 Overview

Designers of Gas Turbine Combustors of advanced power systems have goals to achieve very low plant emissions (NOx 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