High-Pressure Turbulent Flame Speeds and Chemical Kinetics of Syngas Blends With and Without Impurities

Eric L. Petersen
Department of Mechanical Engineering
Texas A&M University

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Project Overview

Project Began in October, 2013

Project Highlights:


2. DOE NETL Award DE-FE0011778

3. Budget: $498,382 DOE + $124,595 Cost Share

4. Principal Investigator: Dr. Eric L. Petersen
This Project Addresses Several Problems for HHC Fuels

1. Improve **NOx kinetics** for High-Hydrogen Fuels at Engine Conditions

2. Effect of **Contaminant Species** on Ignition and Flame Speeds

3. Impact of **Diluents** on Ignition Kinetics and Flame Speeds

4. Data on **Turbulent Flame Speeds** at Engine Pressures
Project Overview

There are Five Main Work Tasks for the Project

Work Tasks:

**Task 1** – Project Management and Program Planning

**Task 2** – Turbulent Flame Speed Measurements at Atmospheric Pressure

**Task 3** – Experiments and Kinetics of Syngas Blends with Impurities

**Task 4** – Design and Construction of a High-Pressure Turbulent Flame Speed Facility

**Task 5** – High-Pressure Turbulent Flame Speed Measurements
Journal Publications


Conference Publications

7 Conference Papers to Date
Task 4 – Design and Construction of a Turbulent Flame Speed Facility
Borghi Diagram shows Current and Desired Regions for Turbulent Flame Speeds

Task 4 – New Facility

Borghi Diagram shows Current and Desired Regions for Turbulent Flame Speeds

Gas Turbine Conditions and Proposed Hi-P Rig Domain

Hi-P (S_L ↓; δ_L ↑)

Current Rig Domain

Laminar Flames

Methane
Hydrogen
Syngas (50:50 H₂:CO)
Task 2 – Turbulent Speeds

Recent Data Cover a Wide Range of Flamelet Regions

- CH$_4$
- Syngas
- 50-50 CH$_4$-H$_2$
- H$_2$

- Distributed Reactions
- Thin Reaction Zone
- Corrugated Flamelet
- Corrugated Flamelet
- Laminar Flame
- Wrinkled Flamelet

Graph showing the relationship between turbulent speeds and flames, with markers for different gas compositions and flamelet regions.
New Facility Designed and Built at TAMU

1. Detailed Design and Structural Analysis

2. Fabrication of Vessel Components

3. Installation of Vessel

4. Characterization of Flow Conditions
Motivation
What can we learn from other designs?

• Rich variety of approaches in design of vessel and fans.
• Marked difference in effectiveness in turbulence.
• Newer bombs do not necessarily perform better.
Motivation

Can we replicate the success of The University of Leeds?

How to get the most intense turbulence with the lowest fan speed?
Objectives

• Complement previous PIV description of the flow field with LDV.

• Try a different impeller geometry.

• Extract guidelines for a new design.
Background
The facility

- Originally a laminar flame bomb
- Aluminum construction
- Ø 305 mm
- L 356 mm

(De Vries 2009)

“Alpha” impeller

Ø 76mm
L 38mm
Pitch 20°
Background

PIV measurements

- Fan speed: $8,300 \pm 100$ rpm
- Location: central plane
- FOV: $36 \times 26$ mm

Model scale 1:1

(Ravi, Petersen et al. 2013)
Background

PIV Results

Instantaneous velocity field $\tilde{u}$

Highlights

- Nearly HIT flow field
- Vortex pattern
- $L_T$ 54 mm
- $\tau_\varepsilon$ 55 ms
- $U_x$ 0.03  $u_{x,rms}$ 1.48 m/s
- $U_y$ -0.01  $u_{y,rms}$ 1.49 m/s

\[
\tilde{u}(t, \mathbf{x}) = U(\mathbf{x}) + u(t, \mathbf{x})
\]

\[
U(\mathbf{x}) = \frac{1}{\tau} \int_0^\tau \tilde{u}(t, \mathbf{x}) \, dt
\]

(Ravi, Petersen et al. 2013)
Experimental setup

2D solid state laser LDV system (TSI)

- 60 X 60 X 60 mm test region
- Grid size 10 mm
Experimental setup

Alternative impeller

Impeller “Beta”

- Radial
- 8 blades
- Ø 102 mm
- L 38 mm
Mean velocity field at central plane

Flow pattern ratified

Alpha, PIV

Alpha, LDV
Impeller Alpha

Fairly homogenous and isotropic turbulence fluctuation

Mean velocity, $U_x$

Turbulence fluctuation, $u_x$

- $U_x = -0.07$ m/s, $u_{x,rms} = 1.60$ m/s
- $U_y = -0.21$ m/s, $u_{y,rms} = 1.63$ m/s
Impeller Beta

Higher magnitudes everywhere

Mean velocity, $U_x$  
Turbulence fluctuation, $u_x$

- $U = 1.2$  
  $u_{rms} = 6.5 \text{ m/s}$

We improved, but can we do better?
Fan-stirred bombs

Turbulence fluctuation rms, [m/s]

Fan speed [rpm]

GM / UMI 1990
Kyushu U 2006
U Leeds Cyl. 1984
U Leeds Sph. 1998
Taiwan NCU 2000
UMI 2001
TAMU 2015
U d’Orléan 2014
The role of impeller diameter

In general, larger impellers are more effective
Total fan blade area

The more, the better

Alpha

Beta

Present - alpha
UMI 2001
U d’Orléan  2014
Taiwan NCU 2000

Present - beta
GM / UMI 1990
Kyushu U 2006

U d’Orléans 2014
Task 4 – New Facility

Task 4 Design and Installation is Underway

- Survey of Existing Turbulent Flame Speed Facilities Completed

- Trade-off Study for Final Design Finished

- Critical Aspect is how to Handle or Reduce the Overpressure

- Will Have a Design that Involves a Blowout Disk and Reservoir for Overpressure

- Detail Design is Complete

- Main Fabrication is Complete
Task 4 – New Facility

New Design is Complete

- Built in forged SS
- ID 14”; height 18”
- 4 windows; Ø5” aperture
- 4 stirring fans; Ø5.75”
- Max. allowable pressure: 200 atm
Task 4 – New Facility

Breach and Diaphragm Method Selected for Venting

- Breach Ø8"

- Vented deflagration through diaphragm (top)

- Bottom breach is reconfigurable:
  - Heater
  - Injection port
  - Spark plug gland
Task 4 – New Facility

New Fan Design is Being Implemented, Based on LDV Results from Existing Rig

- Arranged in tetrahedral configuration
- Max. speed: 10,000 rpm
- 8-bladed radial impeller with 30° pitch and 1.25” axial depth.
Fabrication of Rig
Rig Installation

Facility Space Required Modification to Accommodate The New Rig
Rig Installation

Initial Assembly and Installation is Complete

Assembly rendering
Rig Installation

Front View Showing Motors and Windows

- Stirring assembly
- Main body OD 533 mm
- End cap
Rig Installation

Detail View of Motor Assembly

- DC motor
- Bellows coupling
- Bearings housing
Rig Installation

Detail View of Window and Igniter Assemblies

Window Ø127 mm
Electrode
Spark plug
Shaft bore plug
Rig Installation

View from Top of Rig

- Vent Ø203 mm
- Retaining ring
- Bottom vent
- Fan shaft
- Electrode
Conclusions

- The flow field characterization with LDV agreed with that of PIV and was extended to 3D.

- An alternative impeller design has better performance, (but there is still room for improvement).

- New apparatus has been installed, and characterization has begun.
Task 5 – High-Pressure Turbulent Flame Speed Measurements
Task 5 – High-Pressure Turbulence

High-Pressure Experiments Will be Performed for Selected Syngas Blends

- Identify Two Test Matrices (Fuel Blends) for Study
- Utilize Results from Tasks 2 and 3 for Guidance
- Perform Experiments at Elevated Pressures
- Parallel High-Pressure Laminar Tests Should also be Done
TAMU Work is a Team Effort of Several People

Dr. Olivier Mathieu

Anibal Morones

Charles Keesee

Clayton Mulvihill
Progress on the Five Main Work Tasks for the Project Was Presented

Task 1 – Project Management and Program Planning

Task 2 – Turbulent Flame Speed Measurements at Atmospheric Pressure

Task 3 – Experiments and Kinetics of Syngas Blends with Impurities

Task 4 – Design and Construction of a High-Pressure Turbulent Flame Speed Facility

Task 5 – High-Pressure Turbulent Flame Speed Measurements