Emission Measurements of Various Biofuels using a Commercial Swirl-Type Air-Assist Dual Fuel Injector

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Test Program

Introduction

Overview

A joint university-industry research program

Funded by Rolls-Royce Canada, CRIAQ, NSERQ, and MITACS

Pursued at Université Laval Combustion Laboratory

"Characterize the combustion performance"

of liquid and gaseous biofuels

on a generic combustor

Baselines & Biofuels

- standard **diesel** as a baseline
- 3 **biodiesel blends**
- standard **methane** as baseline
- 10 **syngas blends**

Fuels Characteristics

Liquid Fuels	Diesel No.2 (% vol.)			Bio-diesel (% vol.)		
Diesel (baseline)	100			0		
B20	80			20		
B50	50			50		
B100	0			100		
Gaseous Fuels	**H2/CO ratio**	**CO (% vol.)**	**H2 (% vol.)**	**CH4 (% vol.)**	**CO2 (% vol.)**	**N2 (% vol.)**
Methane (baseline)		0	0	100	0	0
B1	-	0	0	60	**40**	0
S1	0.5	**50**	25	0	25	0
S2	1	37.5	37.5	0	25	0
S3	2	25	**50**	0	25	0
S4	0.5	50	25	5	20	0
S5	1	37.5	37.5	5	20	0
S6	2	25	50	5	20	0
S14	1	42.5	42.5	0	15	0
S5M50	1	18.75	18.75	52.5	10	0
S5M25	1	28.125	28.125	28.75	15	0

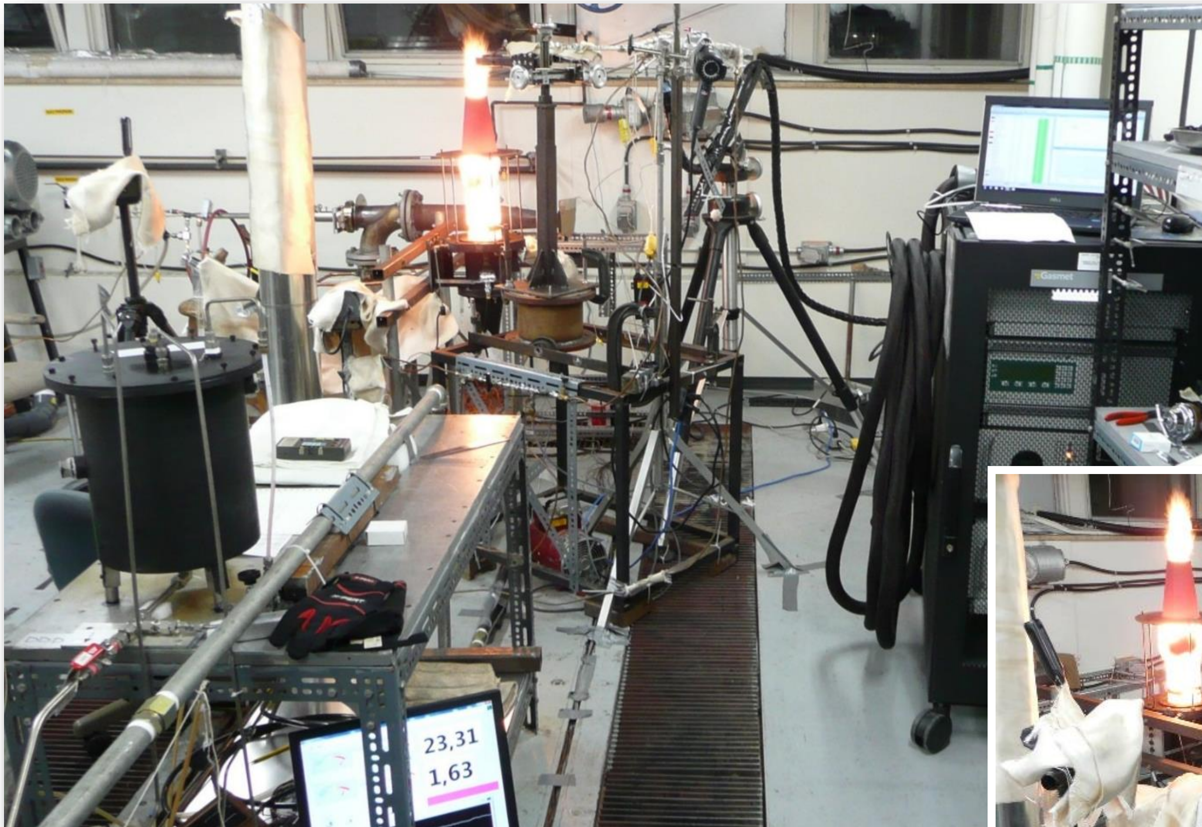
What has been measured ?

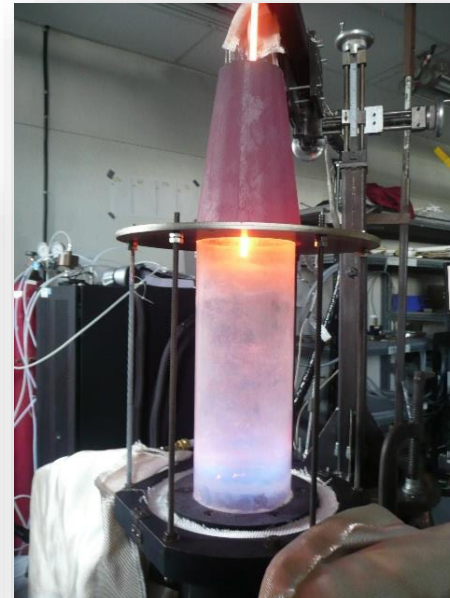
- Gaseous emissions
- Smoke (SN)
- Temperatures
- Ignition
- Flame stability
- Lean blowouts (LBO)

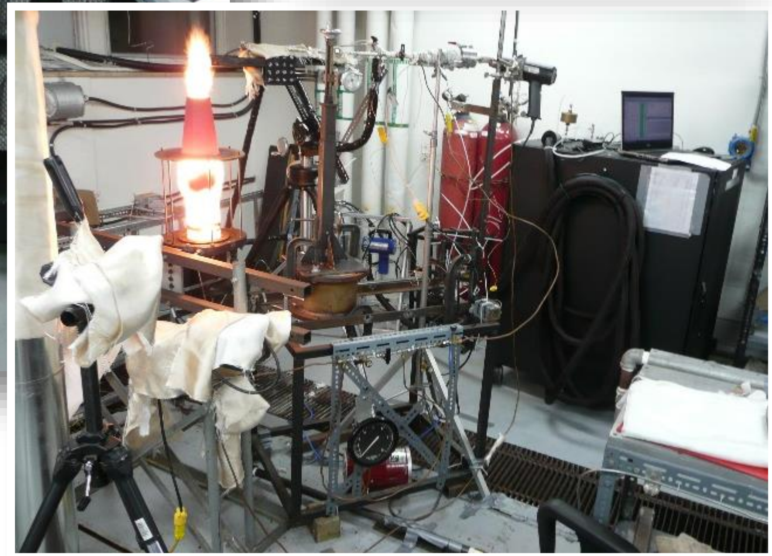
Experimental Setup

Test Rig and Instrumentation

Custom Test Rig







Instrumentation

- A **probe** connected to a **gas analyzer system** and a **smoke sampler** mounted on a 3D-axis **traverse** that allow displacement.
  - Samples of combustion products are drawn in a cross pattern at the combustor exit.
  - 5 different radial positions to get an emission profile at exit plane.
- **Burned gas temperature** was measured at the center of the exit plane
  - Wall temperatures were measured at several locations along the test rig
  - All measurements with type-K thermocouples.

Smoke & Emission Equipment

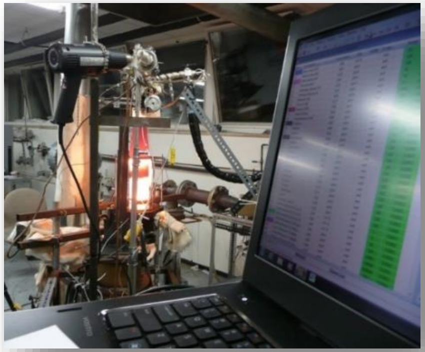
Smoke Measurement

- A designed smoke sampler.
- Smoke Number (SN) determination via SAE procedure found in ARP 1179.
- Soot samples collected by passing a predetermined volume of exhaust sample through paper filter via heated lines to prevent condensation.
- Reflectometer is used to measure reflectance of clean & stained filter to calculate smoke number (SN).

Smoke & Emission Equipment

Gasmet™ CEMS – Gas Analyser

- Continuous Emission Monitoring System (CEMS)
- Fourier Transform InfraRed (FTIR) technology
- Simultaneous analysis up to 35 gaseous substances (extensible library)
- H_2O, CO_2, CO, SO_2, NO, NO_2, N_2O, HF, NH_3, O_2, O_3, many HC volatiles …
- No diatomic molecules (O_2 and noble gases)



FID – UHC Analyzer

- Flame Ionization Detector (FID)
- Total hydrocarbon analyzer
- High accuracy with Hydrocarbons

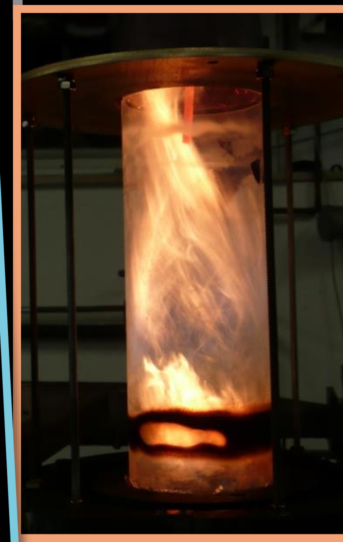
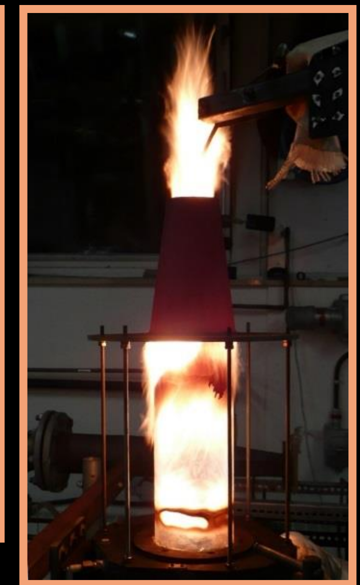
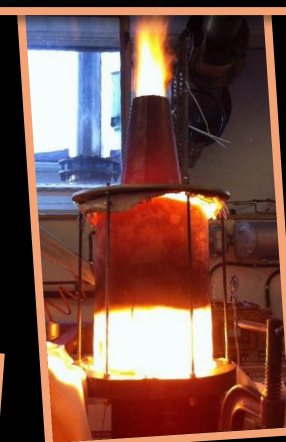
ZrO_2 – Oxygen Analyzer

- Only O_2

Lights off …

Biofuels Combustion



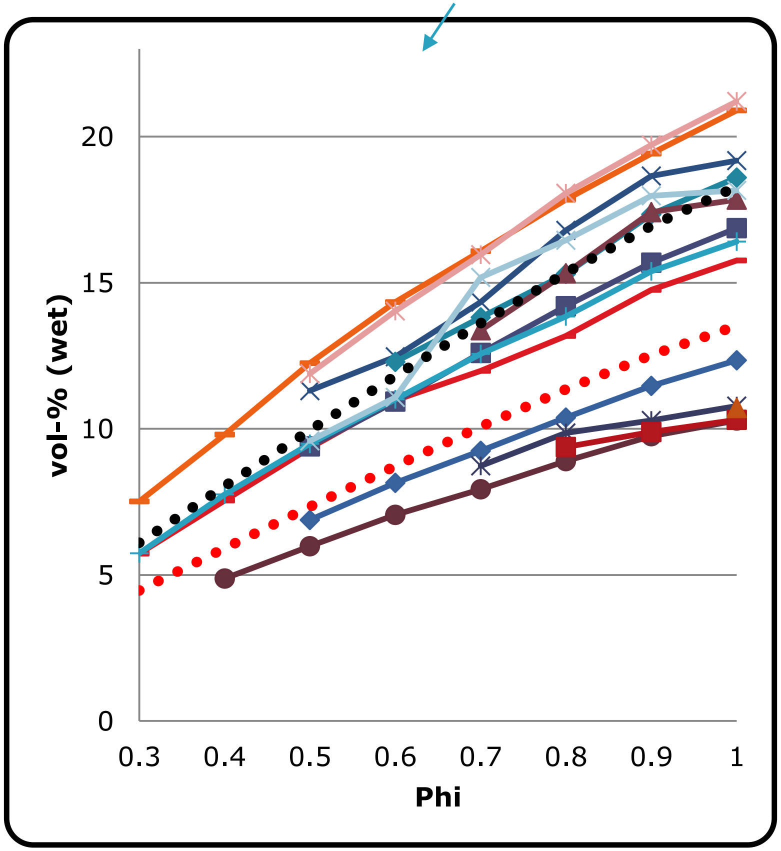





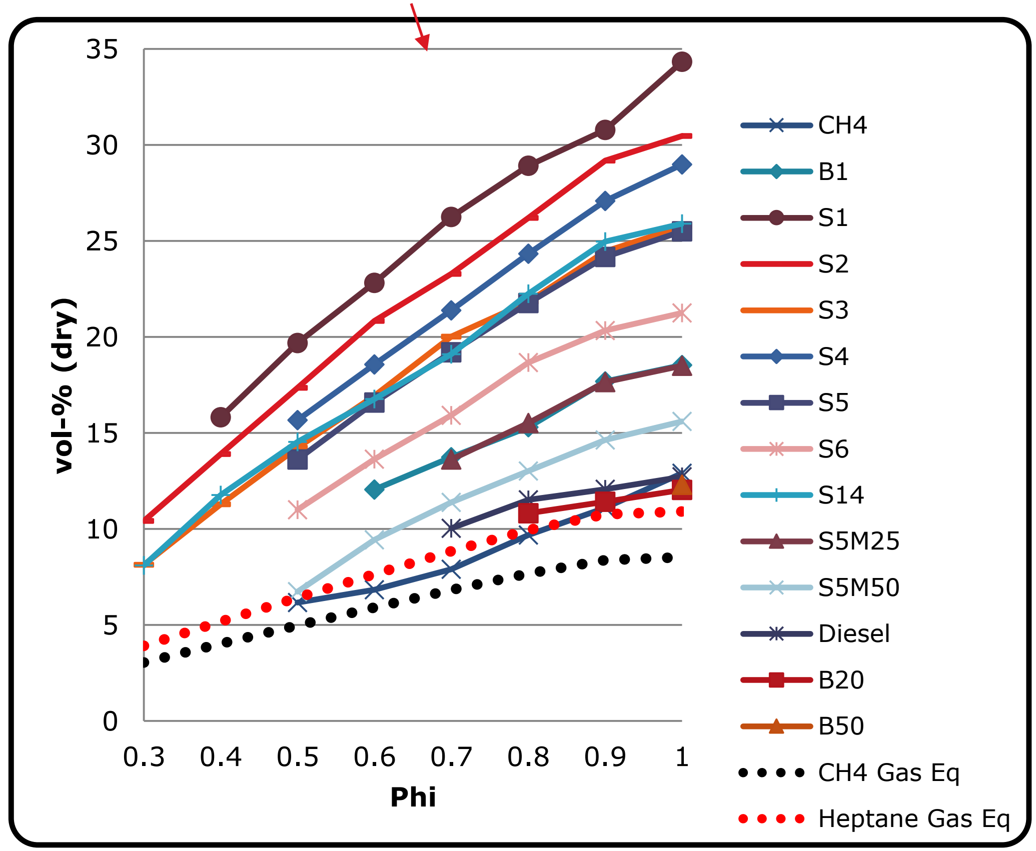



Results & Discussion

Emissions vs. Equivalent ratio

Water Vapor & Carbon Dioxide

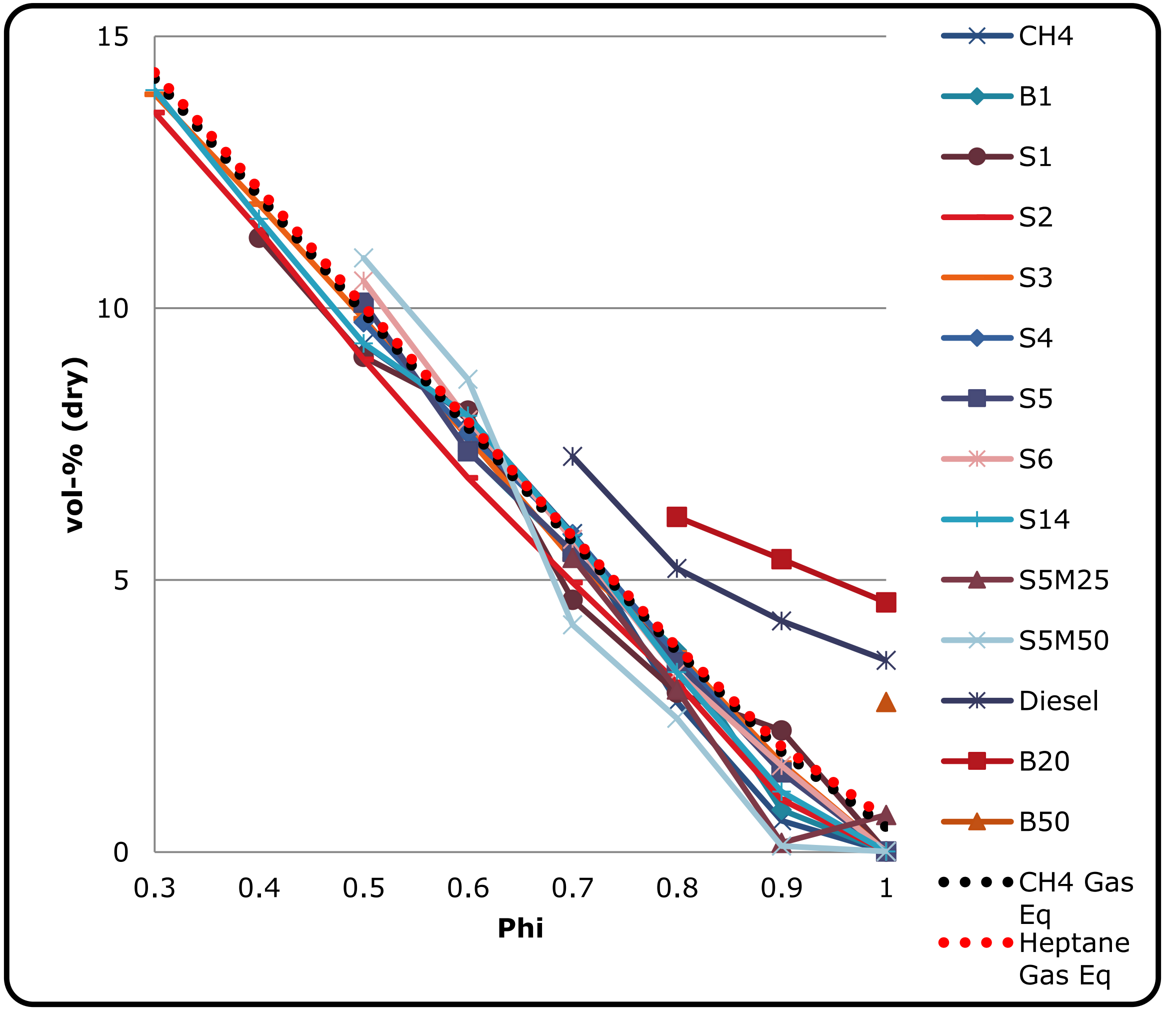




- Concentrations increase with equivalent ratio.
- Good agreement with theoretical trends.
- H_2 & CH_4-composed fuels generate greater amount of water vapor.

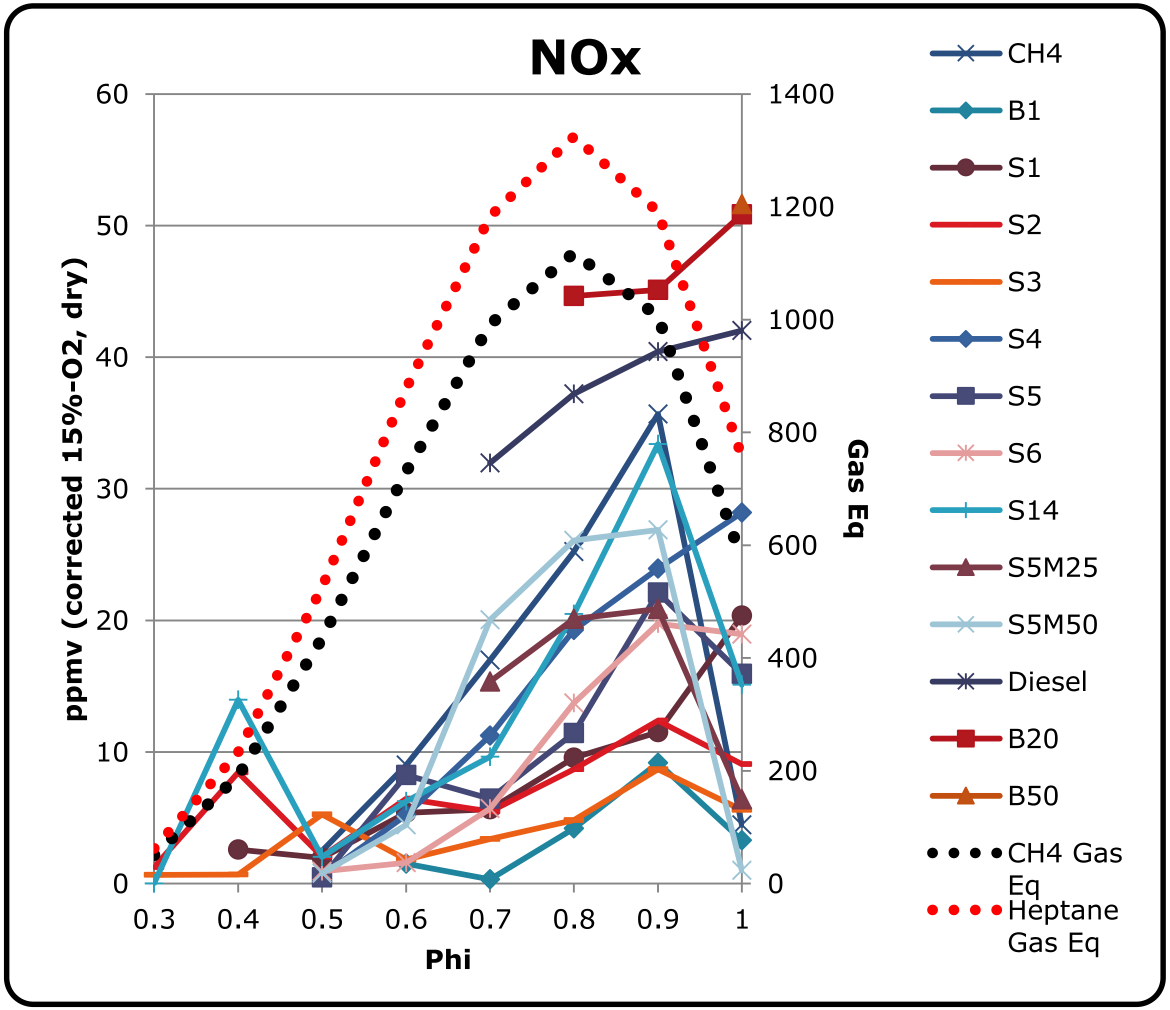
Oxygen O2 (Zr-O_2)

- Concentration decrease to 0% with equivalent ratio reaching stoichiometric φ.
- Gaseous fuels follow closely theoretical trends.
- Liquids fuels give slightly higher concentrations
  - Suggest local excess air
  - O_2 calculated, not measured
  - Carbon/O_2 balance → add uncertainty



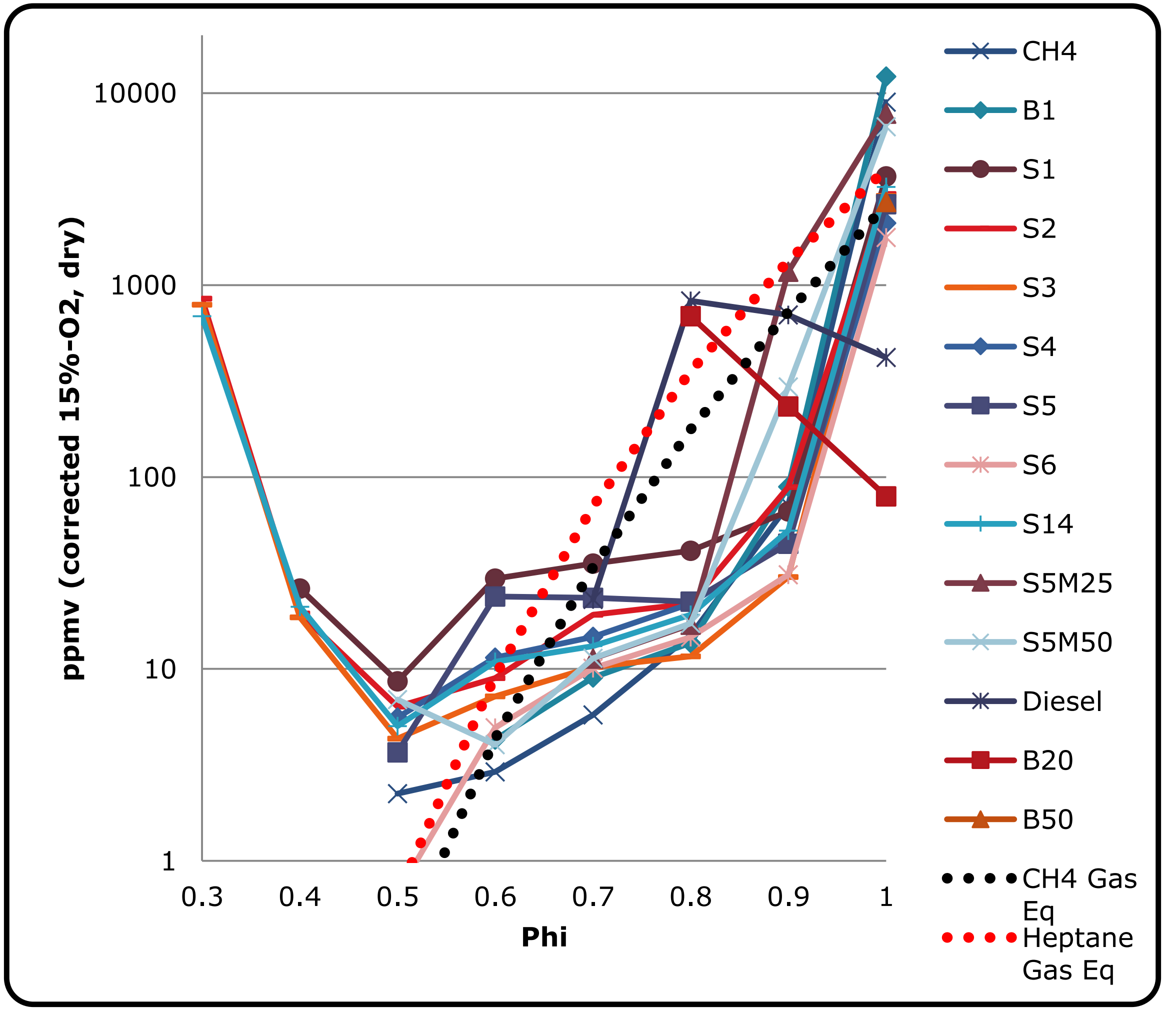
Nitrogen Oxides (NO_x)

- NO_x=**NO**+NO_2
- T>>1500ºC ➔ *Thermal NO* formed in large quantities
- NO is found to peak to close to fuel-lean side of stoichiometric φ
- NO production declines very rapidly as temperatures are reduced at low φ
- CO_2 reduces peak flame temperature
- Liquid fuels drops : potential for near-stoichiometric combustion temperature



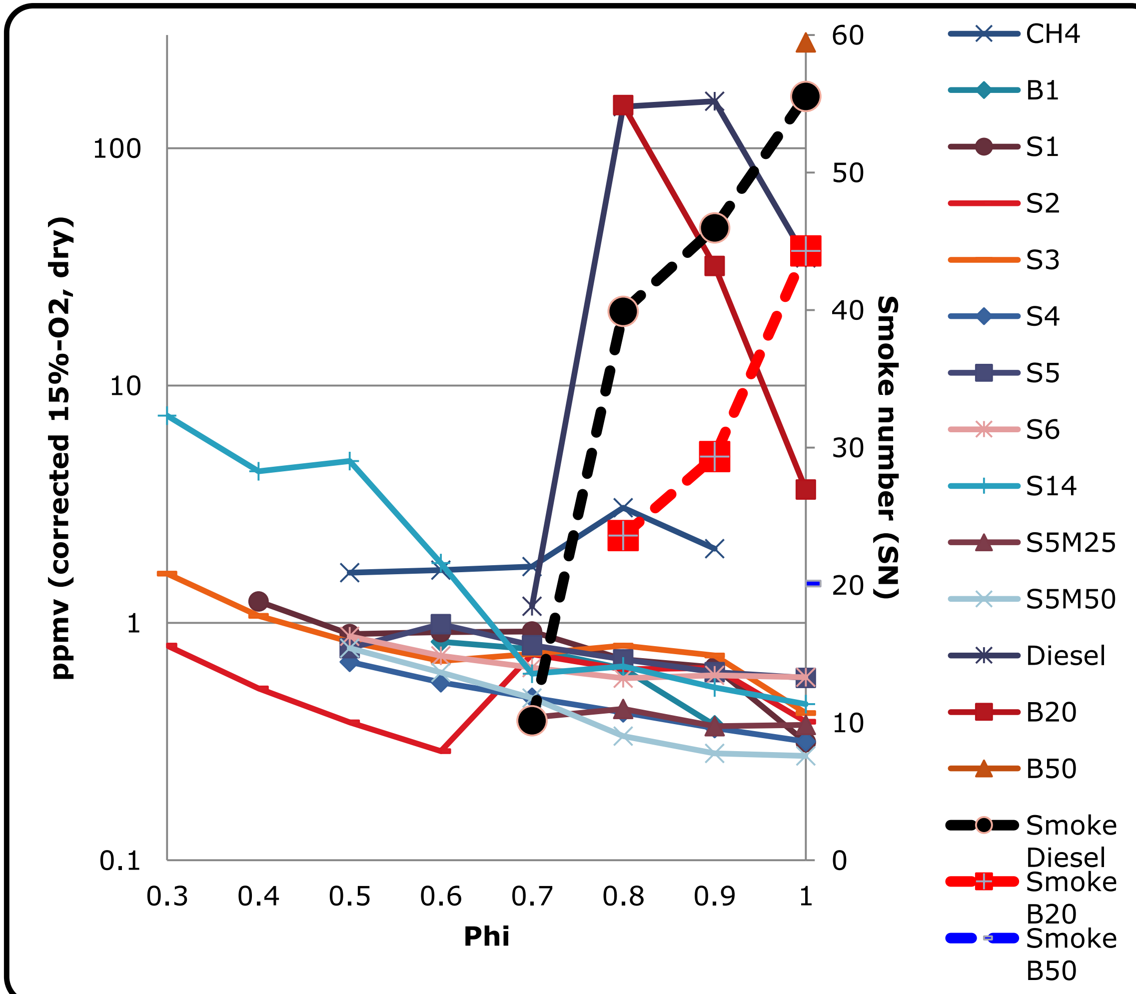
Carbon Monoxides (CO)

- CO = Inefficient mixing and/or **incomplete combustion.**
- Significant amount of CO due to dissociation of CO_2 close to stoichiometric φ.
- CO arises from incomplete combustion at low φ ➔ inadequate burning rate and/or unsufficient residence time.
- Liquid fuels emissions increase while φ increase ➔ Mean drop size affects evaporation → high volume occupied by evaporation = less available volume for chemical reaction.



Unburned Carbons (UHC) and Soot

- UHC = unburned fuel (drops or vapor)
- UHCs ➔ Poor atomization and/or inadequate burning rate.
- Relatively low UHC for all gaseous fuels ➔ high swirl capabilities = Good air/fuel mixing.
- Liquid Fuels limitations: droplets impingements on combustor wall interfered combustion = High soot generation !
  - Soot = Solid carbon



Conclusions and Recommendations

Experimental issues

Wobbe index

Summary and Conclusions

Characterize alternate liquid & gaseous fuels on a generic combustor

- Emissions & smoke measurement.
- Operability indicators.

Test rig not fully adequate for liquid fuel combustion

- Massive droplet impingements.
- Intermediate size quartz tube ?
- High accumulations of black soot along the quartz tube wall.

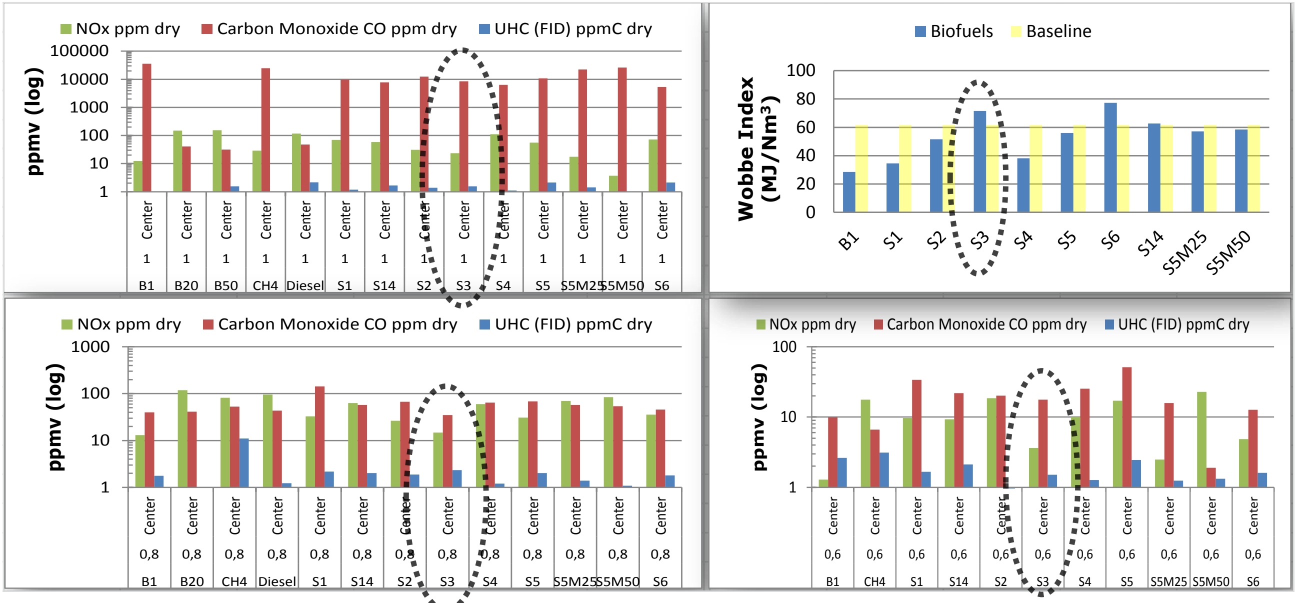
Working conditions far from real conditions in gas turbine

- Only the primary zone was simulated.
- Missing feed holes in the liner that promote mixing and prevent droplets from reaching combustor wall.

Summary and Conclusions

Gaseous fuel emissions

- Much simpler combustion process.
- Almost no soot.
- S3 and S6 seem the most promising fuel regarding:
  - Relatively low NOx, CO and UHCs emissions generated.
  - Very competitive Wobbe Index compared to baseline.



Thank you for your attention.

- Any questions ?
- Contact me at **j@agou.ca**

Back up slides

Sulfur Species (SO_2)

- Primary sulfur component in syngas is hydrogen sulfide.
- Biofuels nearly sulfur-free ➔ relatively low sulfurous emissions.
- Sulfur species are oxidized primarily to SO_2.
- Some of SO_2 undergoes further oxidation to SO_3.
- Partitionning between SO_2 and SO_3 and reduced species depends on the combustor performance and gas mixing .