Optically Accessible, Entrained-Flow, Steam Gasifier

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Acknowledgements

Air Force Office of Scientific Research (AFOSR) Grant Number FA9550-08-1-0456 with Dr. Julian Tishkoff serving as the program manager. Dr. Lucht, Dr. Naik, Dr. Anderson, Dr. Nugent, Scott Meyer, Robert McGuire, Ron McGuire, Hao Wu, Yahui Wang, and Zexi Xu for scientific inputs and valuable help.

Outline

- Background and motivation
- Overview of the experimental configuration
- High-pressure dry feeding of fine particles
- Laser diagnostics for entrained flow gasification
- Summary

Background and motivation

Major scientific challenges

1. Gasification of *coal* can result in significant CO_2 emissions
   - Particularly true for coal-to-liquid (CTL) processes
2. *Biomass* gasification may be carbon neutral but requires further study to address pretreatment, handling, reactor configuration, etc.
3. Detailed experimental data are needed to verify/improve modeling efforts
   - Particularly true for the entrained flow configuration

Proposed solutions

1. Potential to add excess H_2 to the CTL process (Agrawal *et al*. 2007, 2009)

Consider water-gas shift reaction:

$$H_2 + CO_2 \Leftrightarrow CO + H_2O$$

- Excess H_2 → reduced CO_2 emissions
- Increased H_2/CO ratio → enhanced liquid fuel production

Experimental data with excess H_2 needed to quantify challenges and benefits

Proposed solutions

2. Small-scale entrained-flow experiments can be used to quantify biomass gasification kinetics

- Entrained-flow configuration is industrially relevant but is challenging to simulate in a laboratory
- High-pressure makes dry feeding of small particles particularly challenging

New experimental facilities needed for fundamental investigations of the entrained-flow configuration

Proposed solutions

3. Tunable-diode laser-spectroscopy (TDLAS) to probe the harsh environment

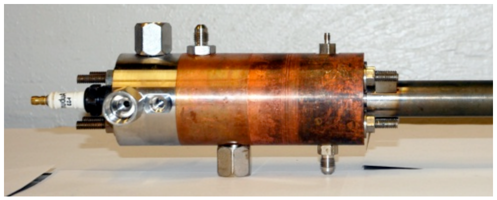
Consider the Beer-Lambert law: $I(\nu)/I_0(\nu) = e^{-\alpha_\nu L}$

- Measure $I(\nu)$, $I_0(\nu)$, and L
- Absorption theory and databases → path-average temperature and species concentration

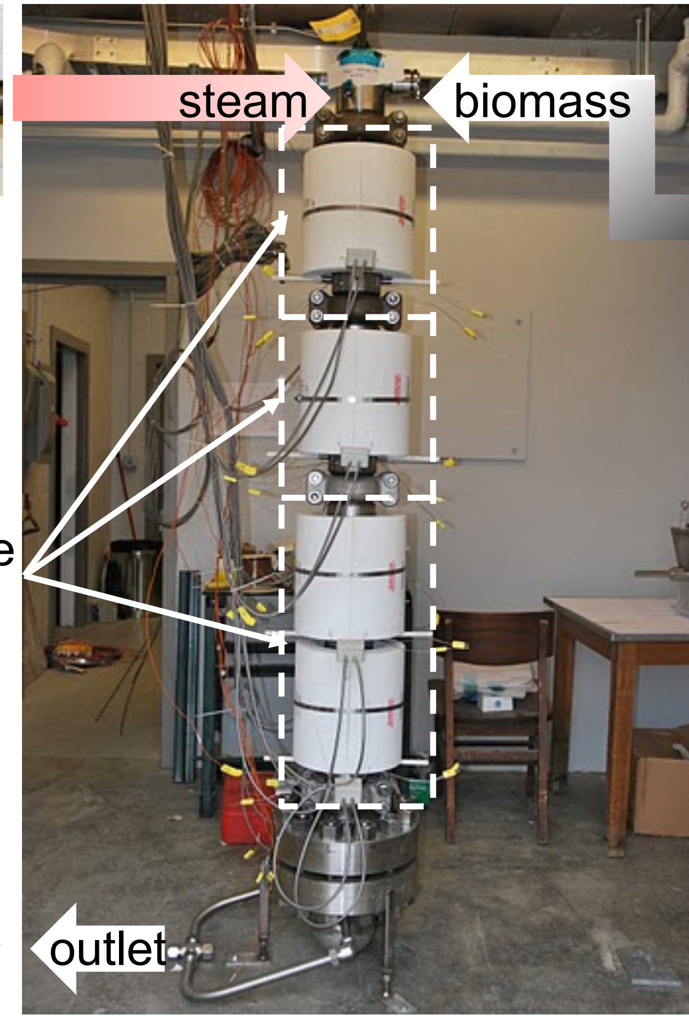
Sensors must be developed to address the particular challenges in gasifiers

Experimental configuration

Entrained-flow steam gasifier

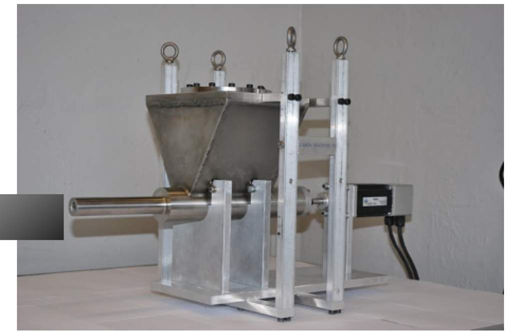


(1) H_2-O_2 steam generator

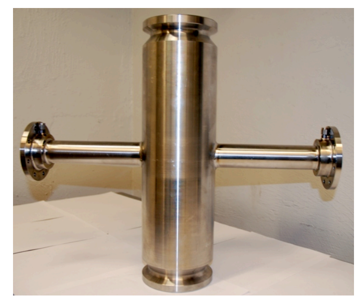


(3) Interchangeable heated spools

(5) Product gas collection



(2) High pressure coal/ biomass feeder



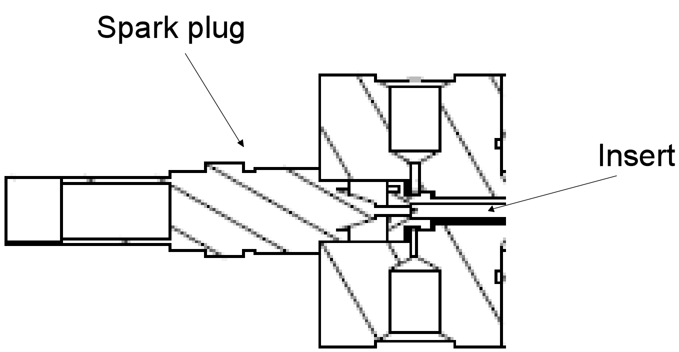
(4) Optically accessible spool-piece

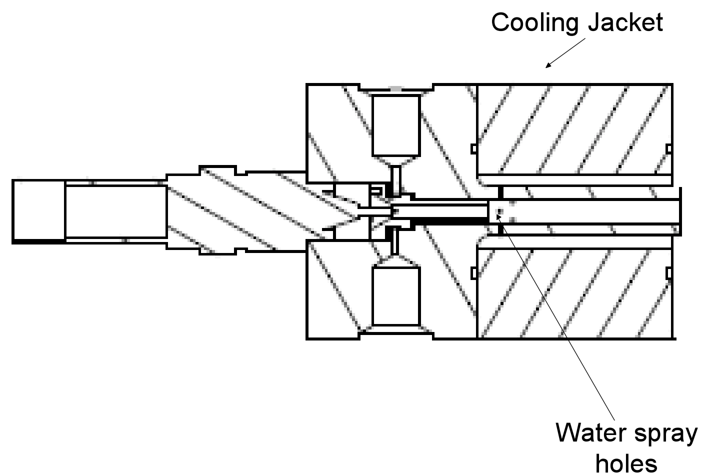
H_2-O_2 steam generator

- Design concept from rocket combustor torch igniters

Successful experiments performed exceeding one hour test durations

H_2-O_2 steam generator

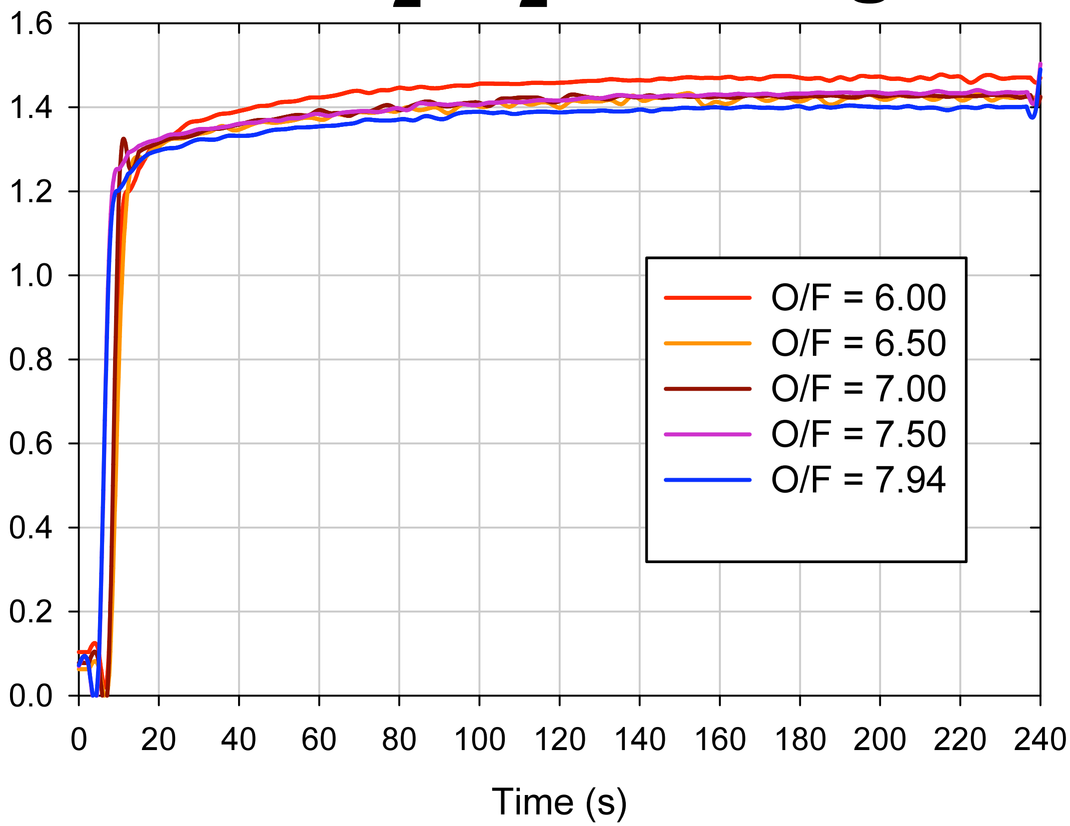


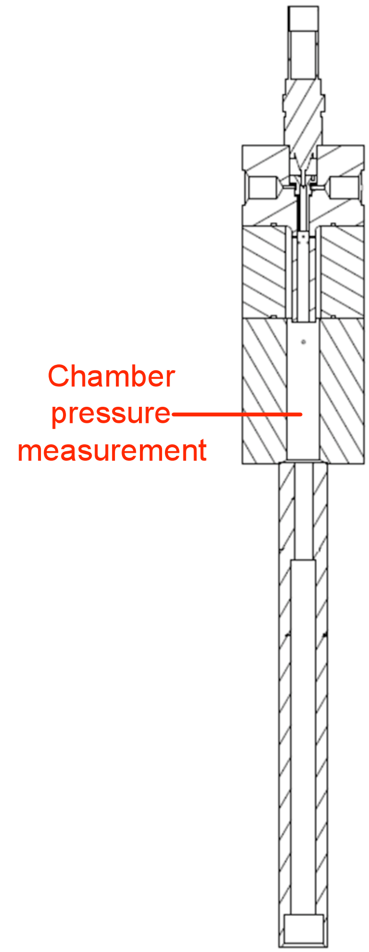


- Fuel-lean pilot flame inside the insert
- Additional H_2 flow surrounds the insert and mixes with the pilot flame at the exit
- Mass flow rates measured by sonic venturies

- Water injected downstream of the insert
- Water mass flow rate measured with a cavitating venturi

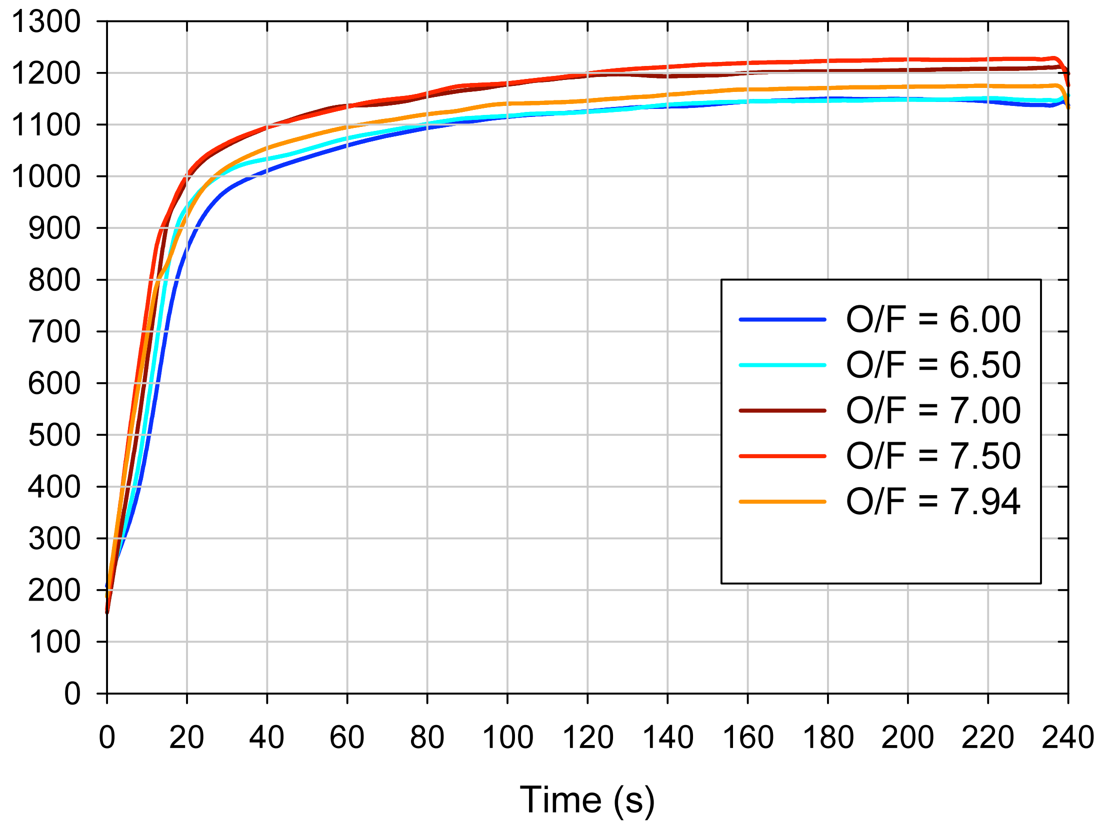
H_2-O_2 steam generator

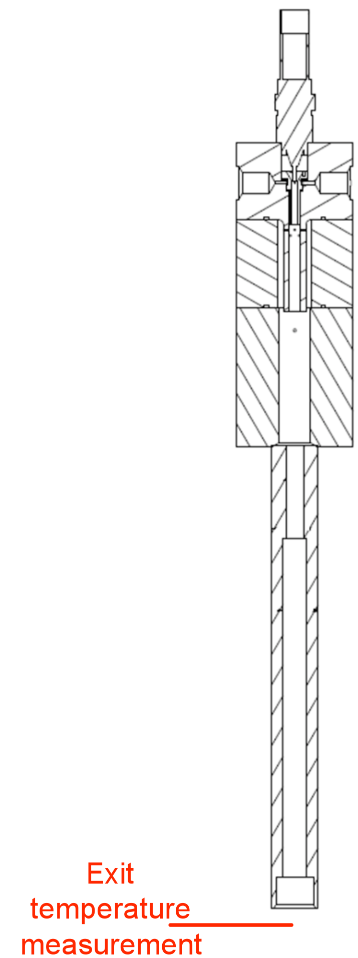




Nearly constant pressure inside the SG verifies stable operation

H_2-O_2 steam generator





Exit temperatures are likewise constant after the ~2 min startup transient

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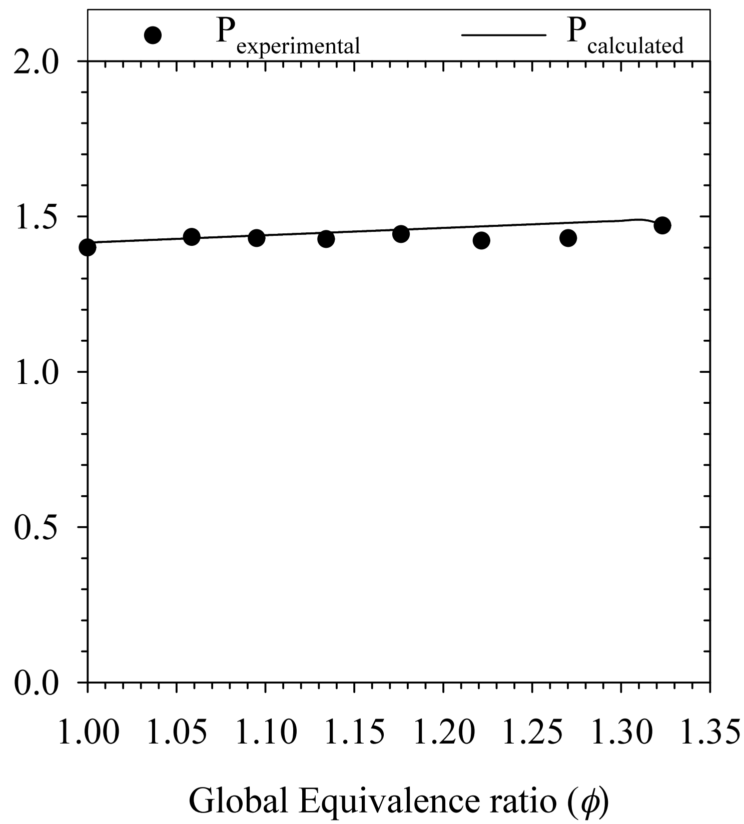
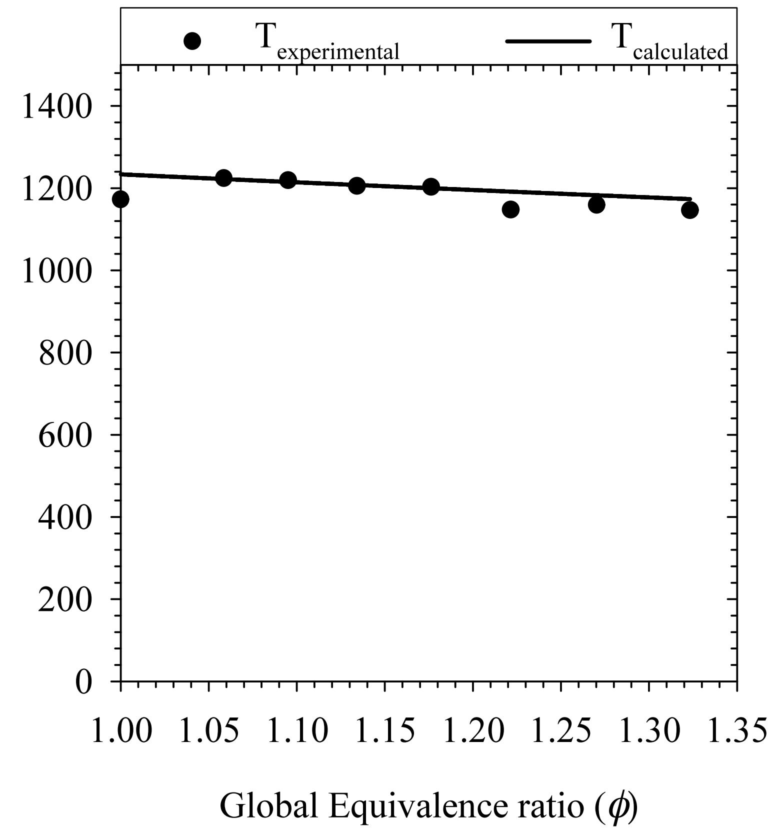
H_2-O_2 steam generator

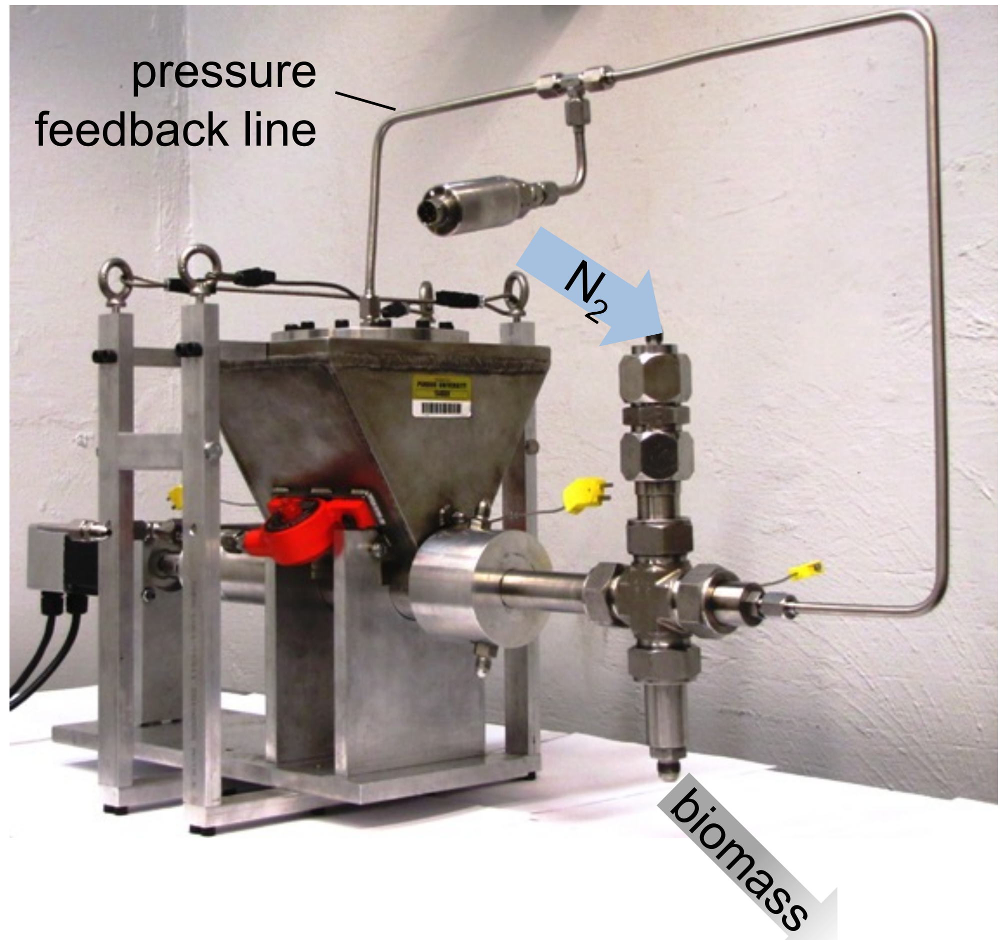




Experiments verified with first-principle calculations

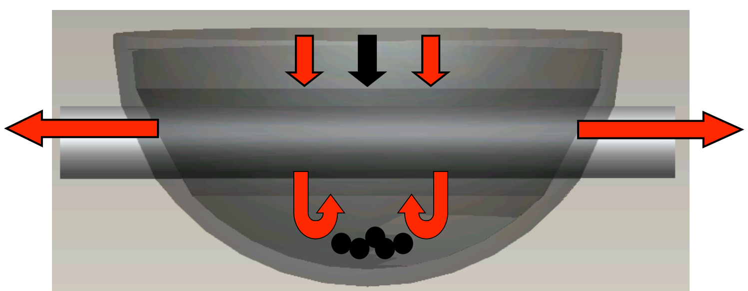
High-pressure coal/biomass feeder

- Auger style coal/ biomass feeder
- Sealed for high-pressure operation
- Feedback minimizes pressure differential across auger

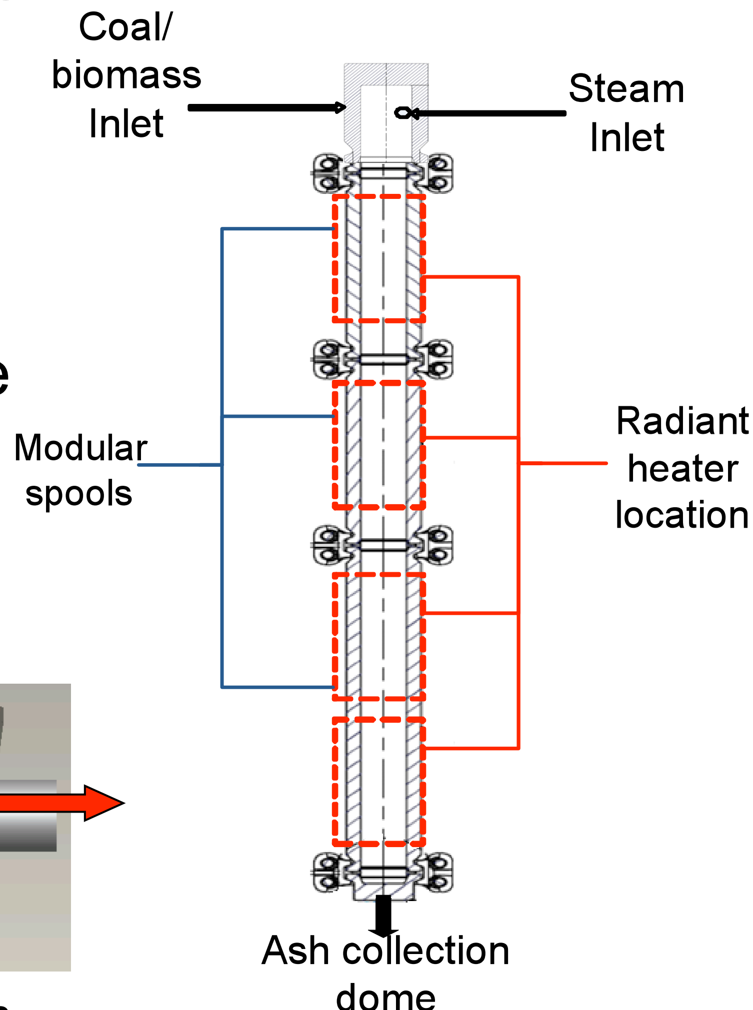


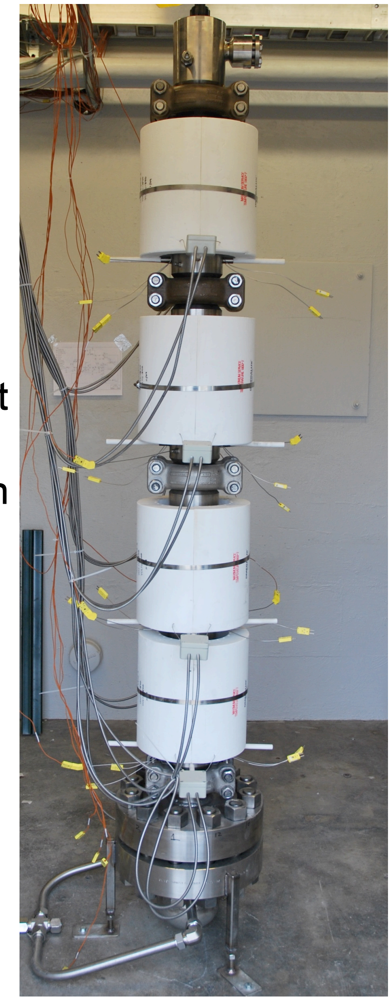
Interchangeable heated spools

- 16 kW radiant heaters
- Temperature up to 1200 K and pressure up to 10 atm
- Ash separated from effluent gas at exit

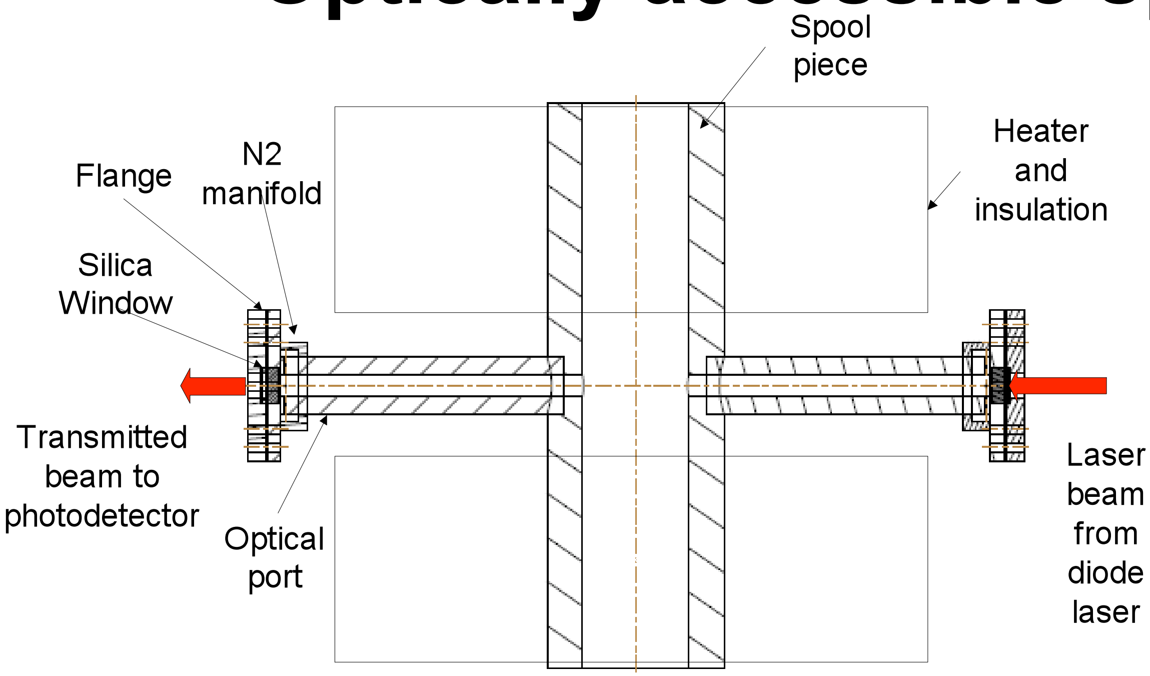


Ash collection system

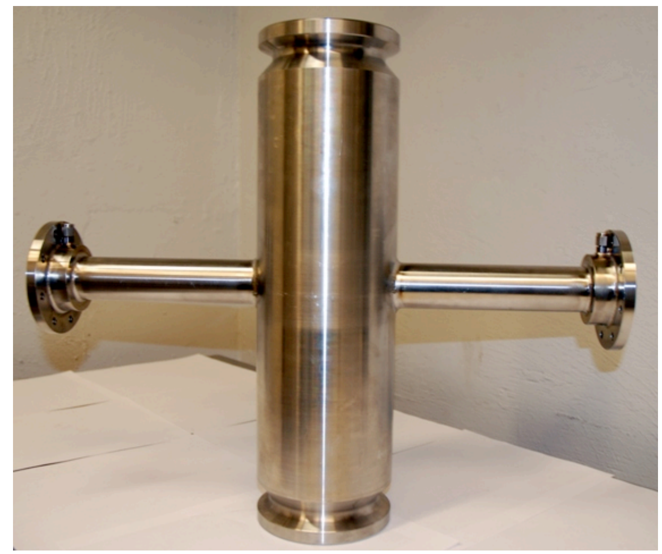




Optically accessible spool-piece



Schematic for the laser absorption arrangement



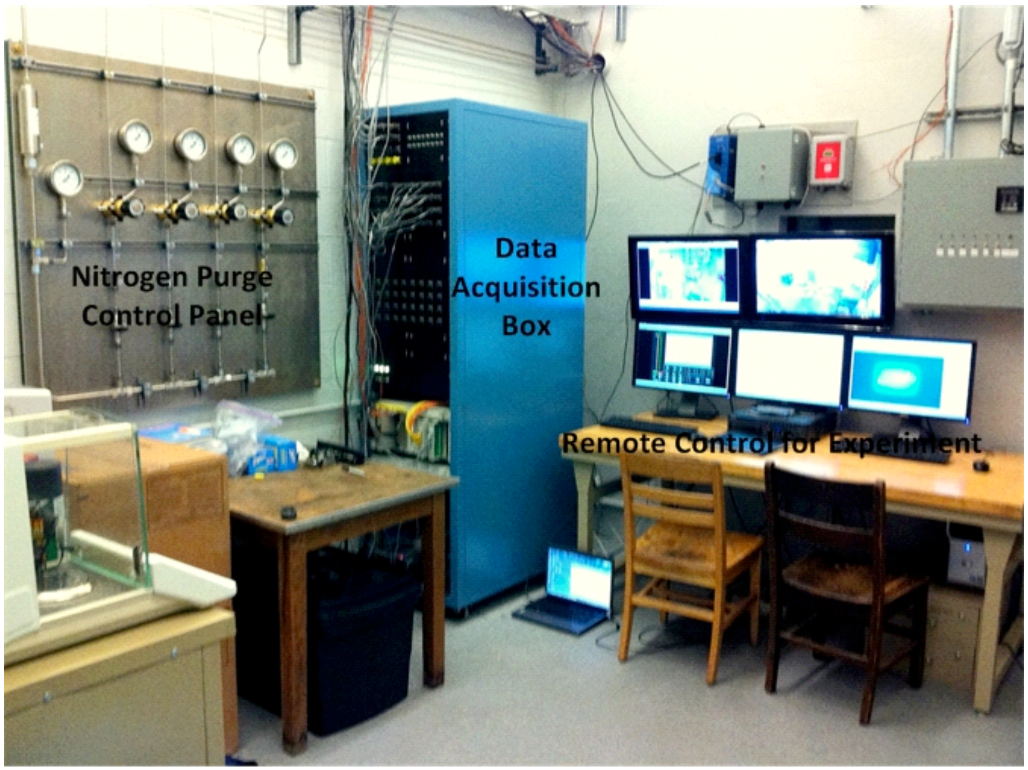
Photograph of the spool piece with optical access

- Fused silica windows
- Nitrogen purge for cleansing of windows

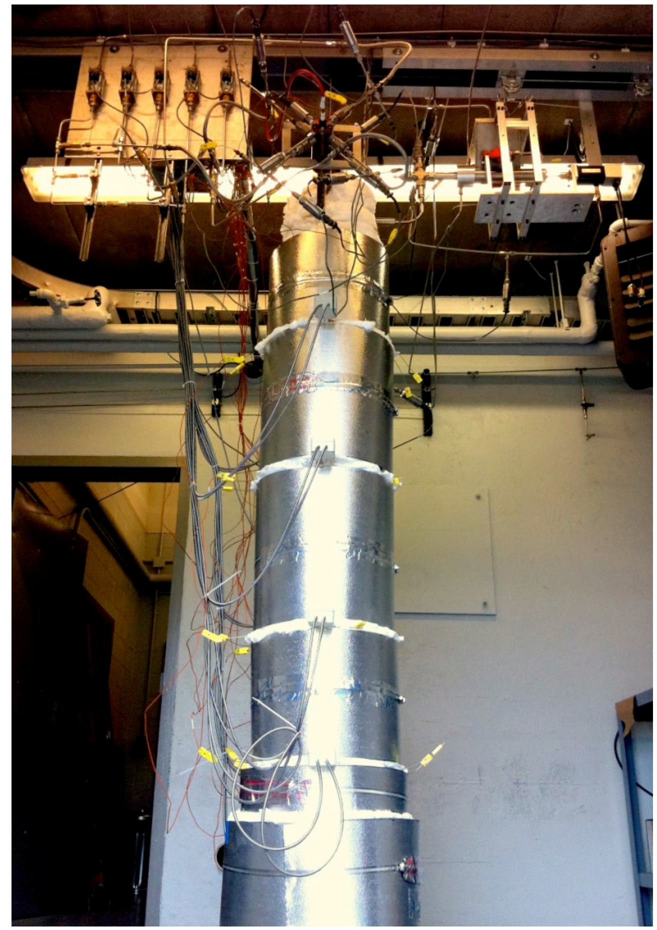
Product gas collection

- Effluent gases cooled to room temperature and collected in sampling cylinders
- Following the experiment, gases are analyzed with gas chromatography and an FTIR based multi-gas analyzer
- Species detected include: CO_2, CO, CH_4, NO, NH_3, C_2H_6, C_2H_4, O_2, C_2H_2, H_2O, SO_2, NO_2, C_3H_6, C_3H_8, and H_2

System control/safety



Control room

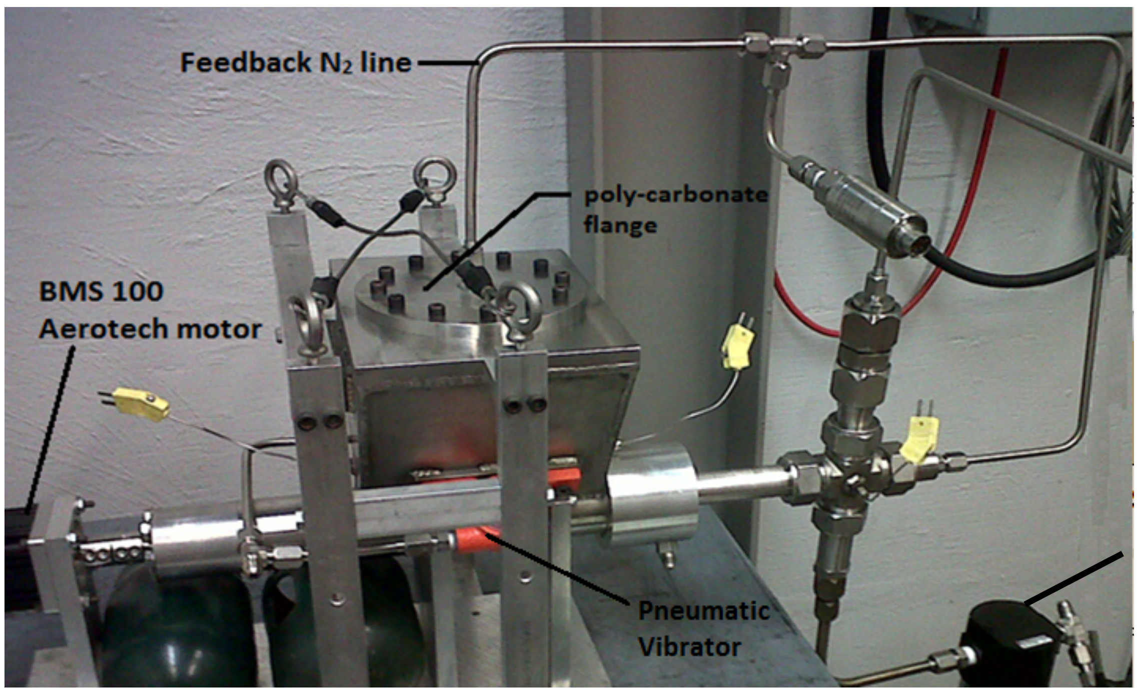


Gasifier in isolated test cell

Experimental results

Powder feeder calibration

- Calibration based on collection of powder in a downstream filter for a fixed period of time
- Flow issues diagnosed with a transparent flange

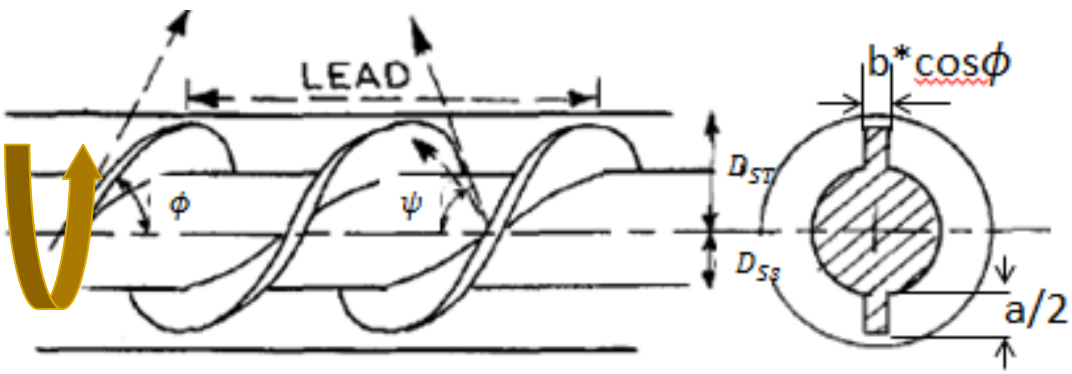


Powder feeder calibration

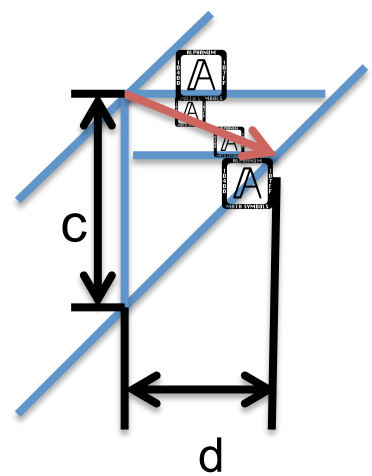
Theoretical model

Mass delivered per second
= filling ratio × bulk density ×
free cross-sectional area ×
axial distance traveled per revolution ×
revolution per second

$$\dot{m} = \kappa \delta_{sf} \times$$
$$\left[\pi\left(D_{ST}^2 - D_{SS}^2\right) - ab\right]/4 \times$$
$$\pi D_S / \left(\tan\phi + \tan\psi\right) \times$$
$$n_s$$

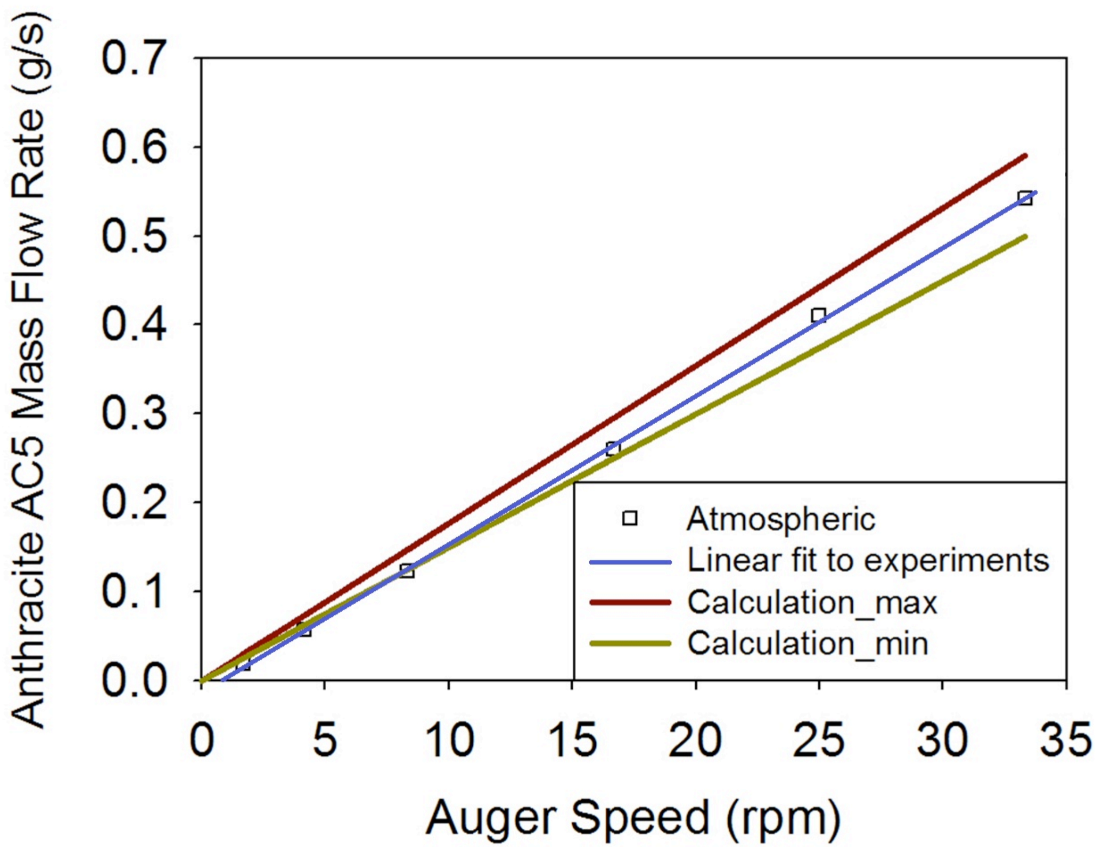


Picture modified from Metcalf (1965)



Particle path traveled per revolution
d Axial distance traveled per revolution
c Circumference of the screw

Powder feeder calibration



Calculation parameters:

D_{st}=1.35 cm

D_s=1.27 cm

S_s=1.27 cm

D_{ss}=0.48 cm

b=0.25 cm

δ_{sf}=1800 kg/m^3

Assume: κ=0.8-1,

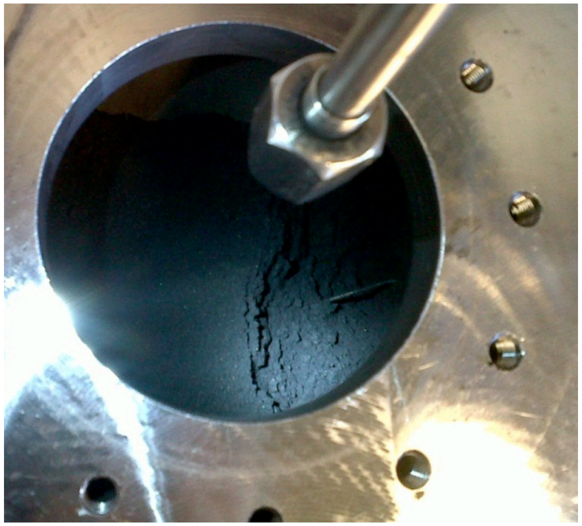
ψ=15-23°

(Sander and Schönert, 1999)

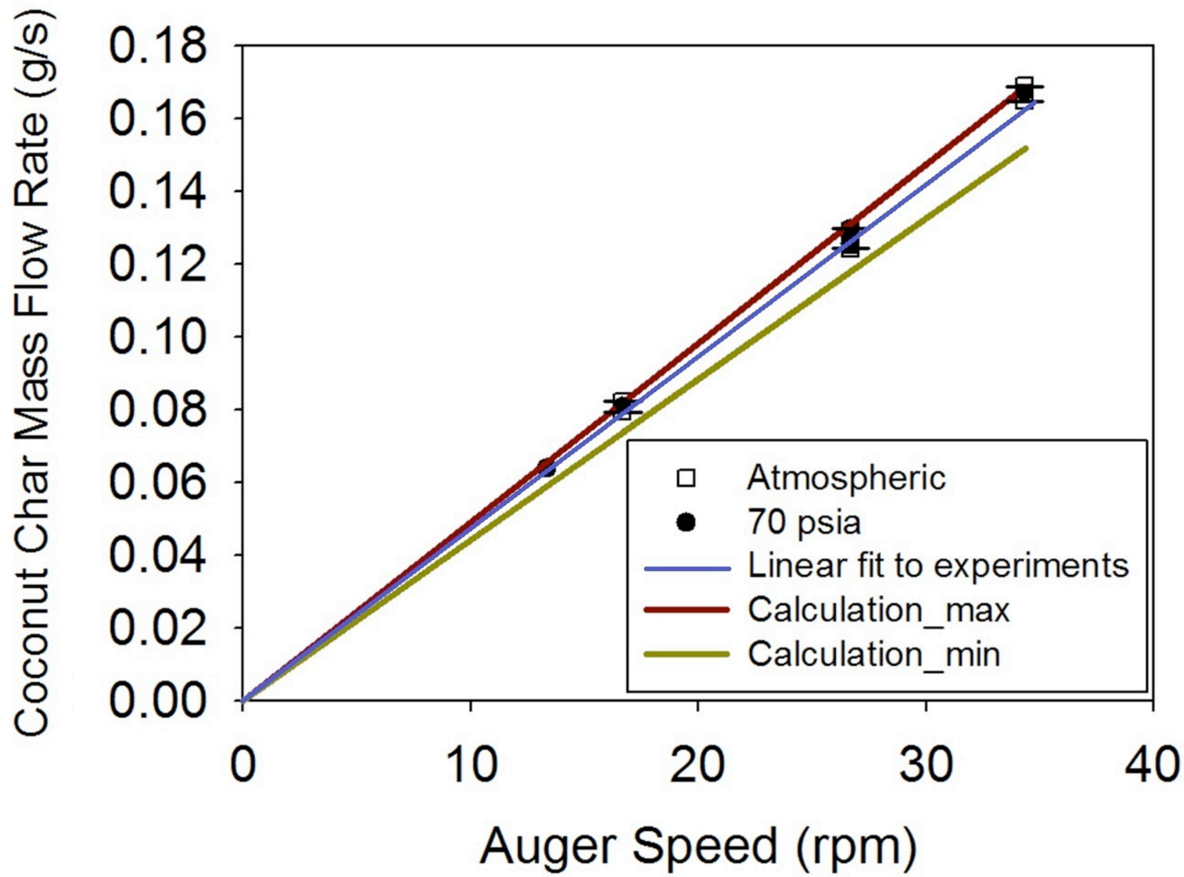
Good agreement for atmospheric pressures

Powder feeder calibration

- Initial high-pressure results showed significant inconsistencies in flow
- Diagnosed and corrected with optical access to the feed hopper



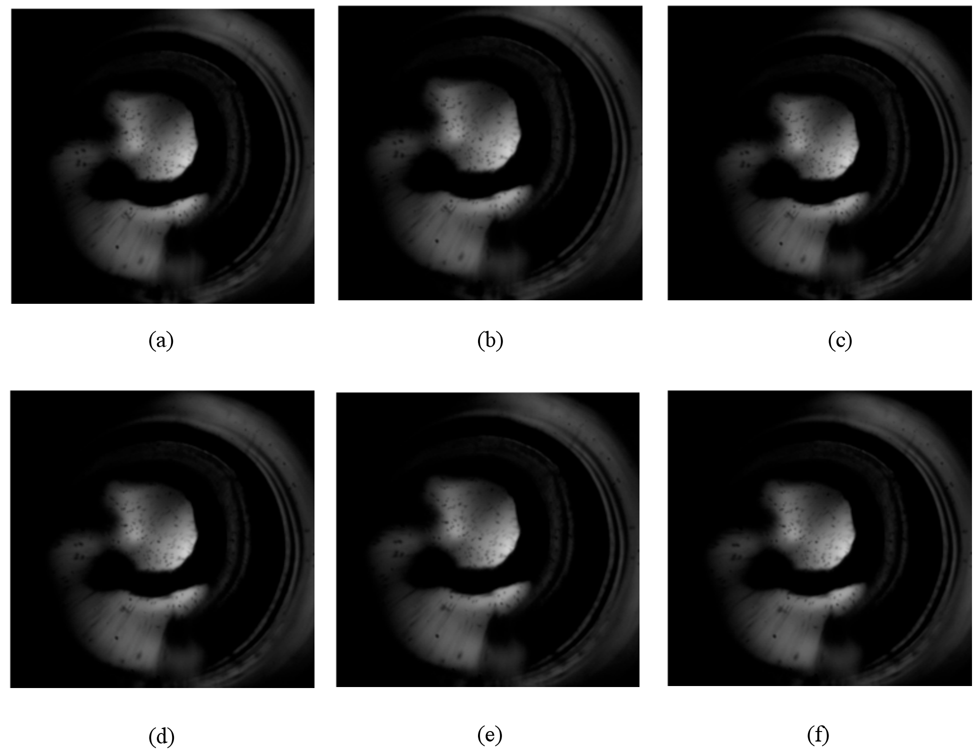
Powder feeder calibration



Finally, good agreement achieved for high-pressure

High-speed videos

- The optical spool piece allows for visualization of the entrained flow
- For clarity, 150 μm particles are shown here
- Initial gasification data is being analyzed



Controlled, high-pressure, high-temperature entrained flow is verified

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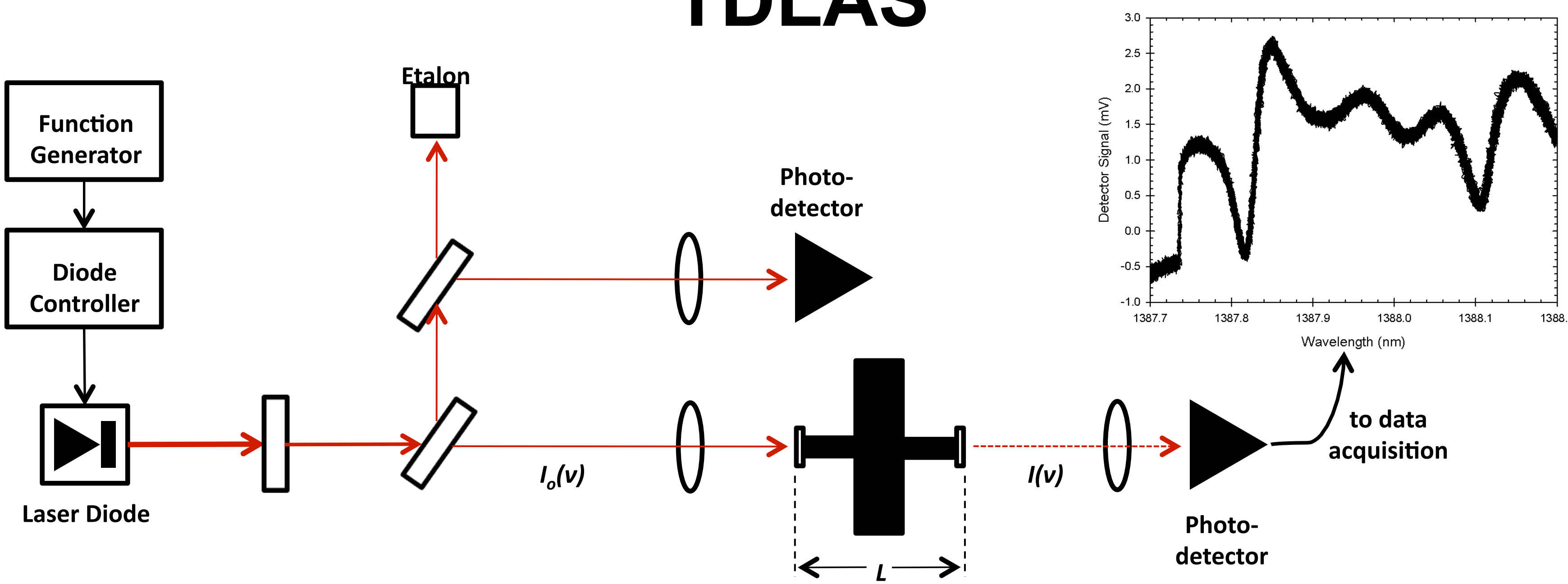
Laser diagnostics

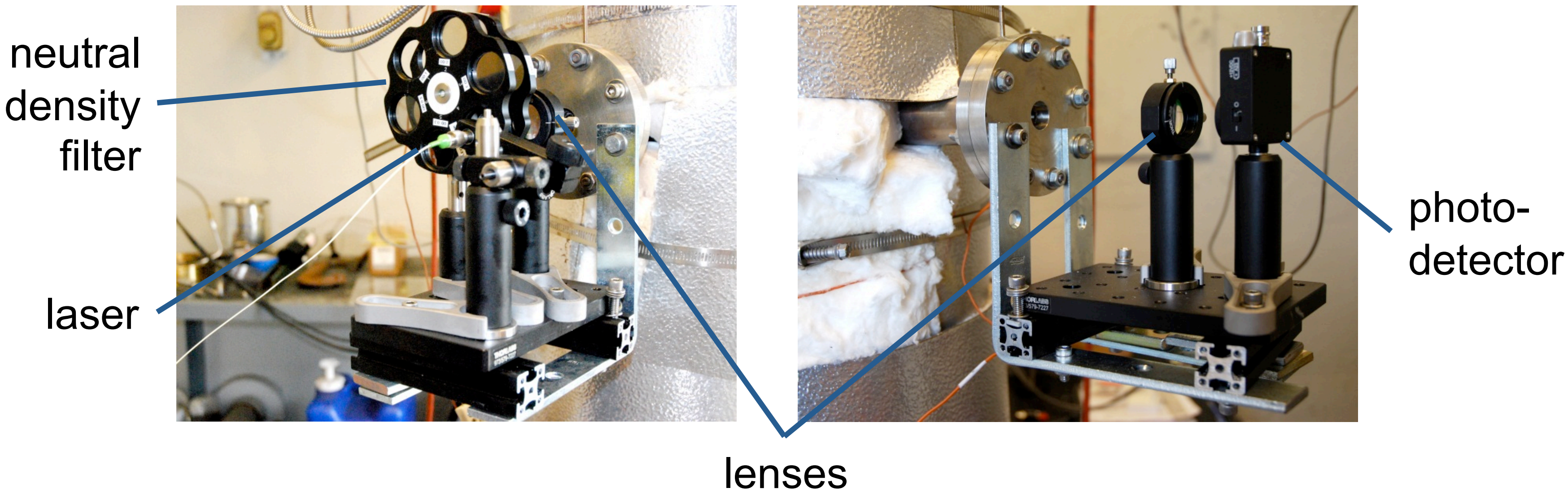
TDLAS



- Beer-Lambert: $I(\nu)/I_0(\nu) = e^{-\alpha_\nu L}$
- Emission wavelength and intensity are dependent on the diode temperature and current
- Challenges: thermal and pressure broadening, scattering

Experimental configuration

The hardware was recently installed on the gasifier



Initial results confirm operation of TDLAS in a particle-laden flow

Summary

- A unique gasifier apparatus combining multidisciplinary technologies has been developed.
- An H_2-O_2 combustor is an effective method of steam generation in the laboratory environment
- Powder feeder operation has been verified at atmospheric and elevated pressures
- Initial results confirm entrained flow
- TDLAS will quantify intermediate temperature and species

Results will be used to validate/improve models and study the effect of excess H_2 and biomass feedstock

Acknowledgements

- We thank our sponsor, Dr. Julian Tishkoff (Program Manager, AFOSR), for financial support and suggestions.
- We thank Dr. Robert Lucht and Dr. Sameer Naik for the inputs regarding the development of optical access.
- We thank Scott Meyer, Dr. William Anderson, and Dr. Nick Nugent for their scientific inputs related to the development of steam generator.
- We appreciate the help of our dedicated undergraduate researchers: Yahui Wang, Hao Wu, and Zexi Xu.
- We thank Rob and Ron McGuire, Purdue ASL machine shop, Grayloc Products, Anderson Tool and Engineering Company, Wirecut Technologies, and Asbury Carbons.

Thank you for your time

Questions?