IOWA STATE UNIVERSITY

Center for Sustainable Environmental Technologies

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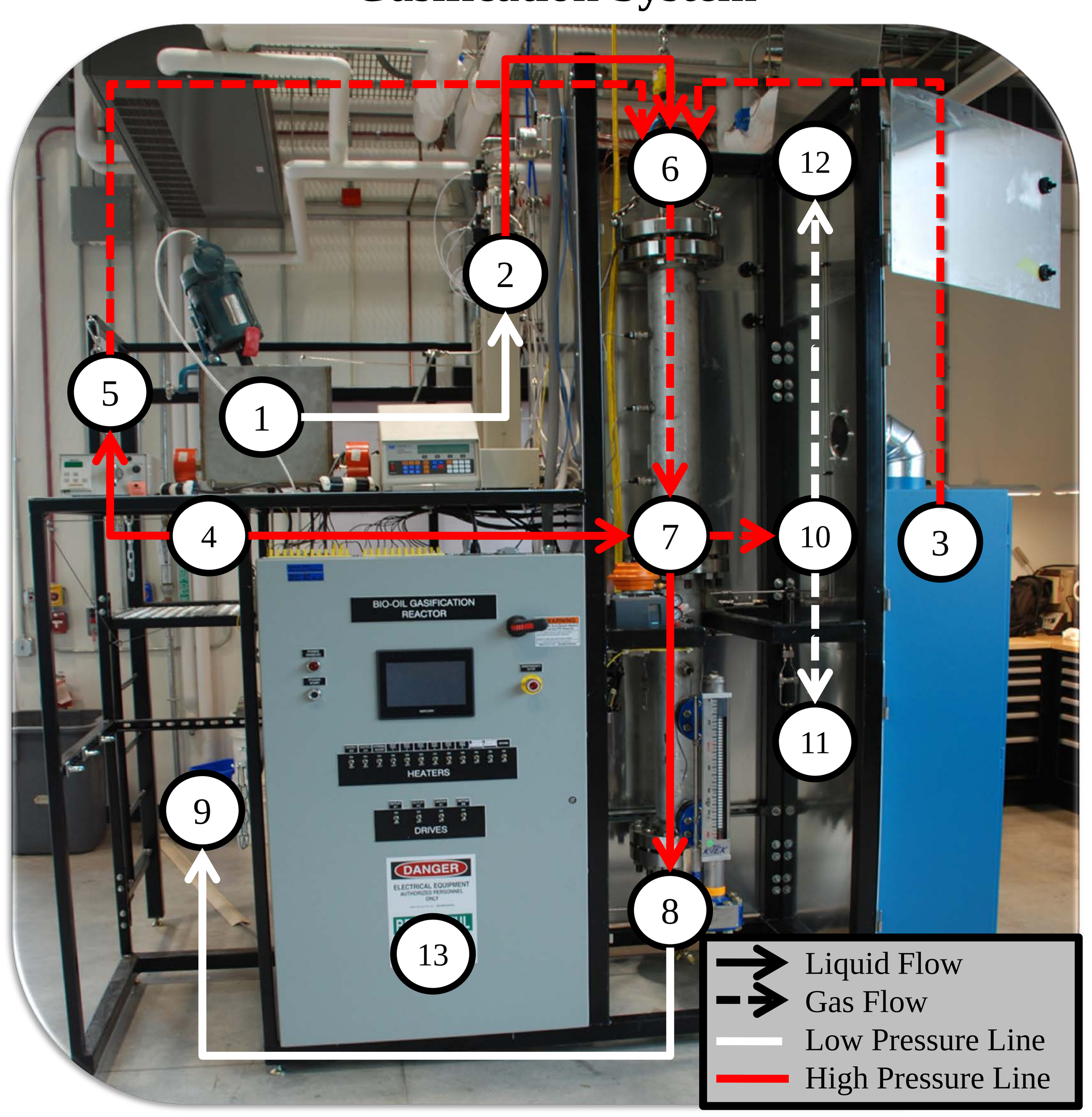
High Pressure, Oxygen Blown, Entrained Flow Gasification of Bio-oil

Project Overview:

Gasification at pressure has advantages for downstream power production and fuel synthesis. However, conveying solid biomass into a pressurized reaction vessel adds expense and reduces system reliability. We are investigating conversion of biomass into bio-oil in an atmospheric pressure pyrolyzer followed by injection of the bio-oil into a pressurized gasifier, which overcomes some of the problems of directly gasifying raw biomass. The bio-oil also has reduced sulfur, nitrogen, and ash content, which reduces subsequent cleaning of the syngas product.

Gasification System



1) Bio-oil Mixing
2) Duel Syringe Pumps
3) Oxygen Supply
4) De-ionized water supply
5) Steam Generator
6) Gasifier
7) Water Quench
8) Liquid Throttling Valve
9) Water Drain
10) Gas Throttling Valve
11) Micro GC
12) Flare/Vent
13) Watlow Control Panel

Operational Goals:

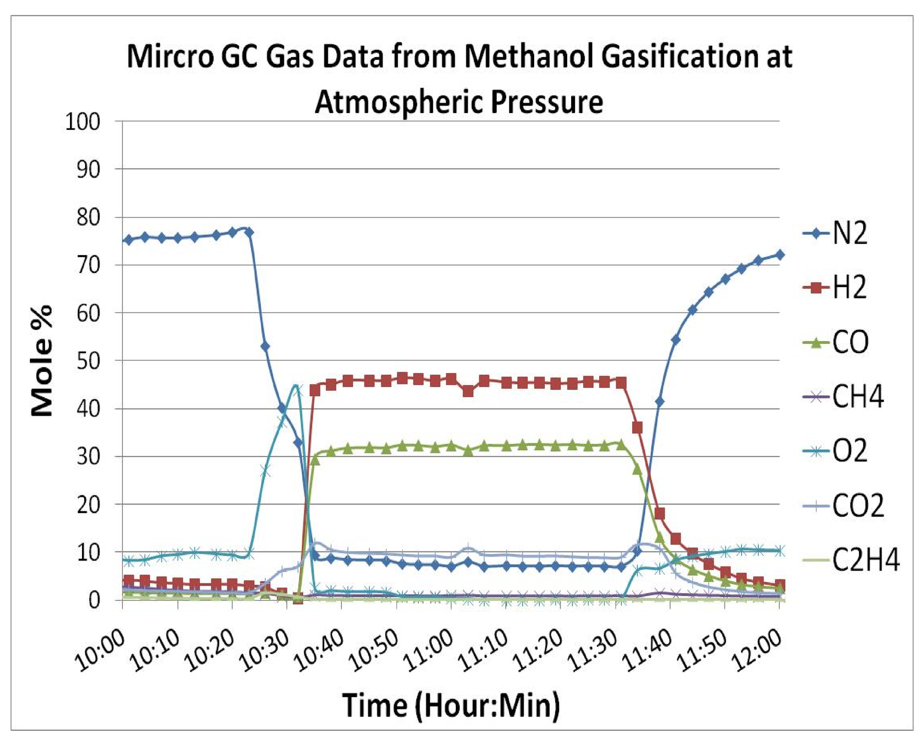
The goal of this research is to compare syngas from conventional biomass gasification with syngas from bio-oil gasification. The bio-oil gasifier is designed to operate at pressures approaching 50 atmospheres and heater temperatures up to 1000°C as well as with the ability to inject compressed air, pure oxygen or any mixture of the two. The combination of these parameters along with internal heating capability, give the reactor immense flexibility in operation, including a wide range of equivalence ratios and high-pressure/low temperature gasification reactions needed to understand the fundamentals of pressure effects on syngas production.

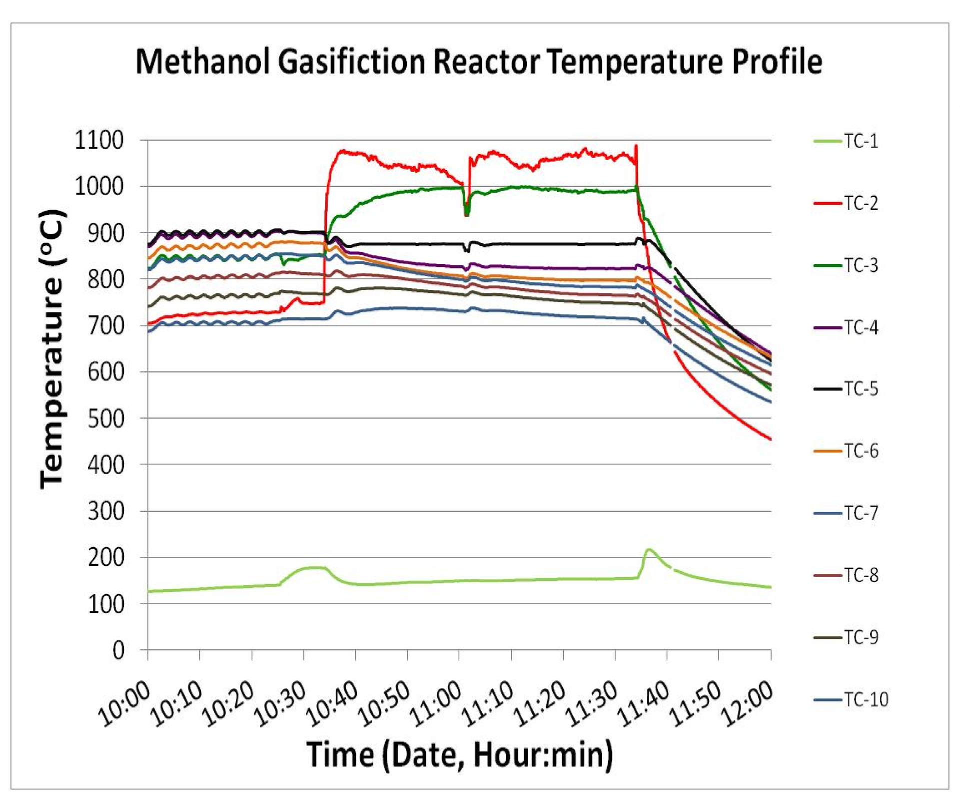
Reactor Design:

The gasification vessel incorporates a novel design to allow near adiabatic gasification at small scale. A silicon carbide tube is wrapped with a high temperature cable heater, which provides reliable heat for start up. The heater and silicon carbide are wrapped with high density insulation to protect the pressure vessel from the extreme gasification conditions. This heated section is contained within a pressure vessel. This section is followed by a quench vessel to reduce gas temperature before the pressure is let down. The Watlow controllers inside the control panel provide continuous monitoring of multiple sensors and functional components required to operate the reactor

Operational Verification with Model Fuel:

Experiments were preformed using methanol as a control fuel for the liquids gasifier to prove reliability and consistency of the equipment and micro gas-chromatograph (Micro GC) for analyzing the produced syngas. All systems were operational and high quality results for methanol gasification were recorded as shown below.



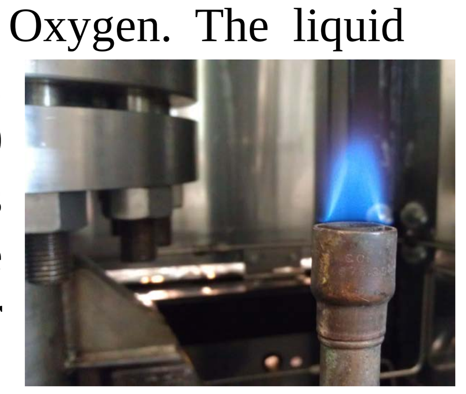


Temperature Fluctuations:

A sharp temperature gradient is observed along the axis of the gasification vessel. Very high temperatures (>1000 C) are observed near the oxygen-assisted atomization nozzle (see TC 2 and 3) where locally high equivalence ratios drive combustion reactions. As the reactions consume the available oxygen, temperature drops as endothermic gasification reactions brings the syngas toward equilibrium composition.

Bio-oil Gasification Parameters:

All runs on the high pressure reactor were performed with the heater set at 850°C and at a gasification equivalence ratio of 25% Oxygen. The liquid feedstock was injected at a rate of 10 mL/min. Compressed nitrogen gas was used as a tracer at 1.0 SLPM in order to calculate the volume of syngas produced. Syngas was sampled for gas analysis before being tested for flammability with an online burner (see photo).



Bio-oil Gasification Data and Results:

Bio-oil Gasification Micro GC Data in Mole %			
Equivalence ratio (ø) = 25%			
Heater Temperature 850°C			
	Atmospheric Pressure		
	Nozzle Config 1	Nozzle Config 2	Nozzle Config 3
H_2	23.9%	22.9%	18.6%
CO	39.6%	34.1%	41.1%
CH_4	6.1%	7.7%	7.6%
CO_2	26.9%	31.4%	28.2%
C_2H_6	0.3%	0.2%	0.4%
C_2H_4	1.7%	2.1%	2.6%

Baseline testing revealed variability in syngas composition between bio-oil gasification trials. The table demonstrates the importance of proper fuel atomization and its effect on gas composition during development of the nozzle configuration. Nozzles one and two developed agglomerates at the end of the nozzle due to poor atomization. Nozzle three mixes the oil with the oxygen before it is introduced to the high temperature environment, reducing the chance for clogging and increasing the oxygen's interaction with the bio-oil.

Nearly 12% of the dry bio-oil mass was being converted to insoluble tars indicating further optimization is needed. Bio-oil homogeneity is also expected to play an important role in both syngas composition and conversion efficiency. These tests were run with whole BTG pine bio-oil due to its relatively clean and consistent properties.

Atmospheric Bio-oil Gasification Mass Balance					
	Reactants		Products		
	Bio-oil	Oxygen	Syngas	Water	Tar
Mass (g)	22	9	22.6	3.7	3.6
% Mass	72.0%	28.0%	75.7%	12.4%	11.9%
Total Reactants Mass (g)	30.8		Recovered Mass 97%		

Hypothesis: At elevated pressures H_2 formation will decrease in favor of CH_4

Bio-oil Gasification Micro GC Data in Mole %		
ø = 25%	Heater Temperature 850°C	
	1 atm_g	6.8 atm_g
H_2	23.4%	31.3%
CO	44.6%	40.6%
CH_4	8.0%	9.2%
CO_2	21.1%	18.2%
C_2H_6	0.4%	0.2%
C_2H_4	2.0%	0.3%

Two exploratory tests were preformed at elevated pressure to check the validity of the above hypothesis. Despite the variability in syngas composition observed previously, it was observed that hydrogen production increased with pressure while no changes in CH_4 concentration were apparent as depicted in the table to the left. Further testing is needed to validate these results and further explore pressure effects. Additional tests will be conducted at pressures up to 50 bar to identify any optimum operating pressures for the production of H2 from bio-oil and the following hypothesis has been proposed:

Revised Hypothesis: H_2 conversion from bio-oil will increase with relatively low pressure increases (at least < 6.8atm_g) before favoring CH_4 production at high pressures.

Next Steps:

- Duplicate gasification runs with bio-oil under pressure
- Complete a response surface methodology study exploring reaction temperatures and pressures with respect to syngas composition

Acknowledgements: **CSET colleagues**

References:
Lin, S.-Y., Brown, R.C, Catalytic Production of Ethanol from Biomass-Derived Synthesis Gas, Overcoming Recalcitrance of Cellulosic Biomass, 2008

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