Biomass gasification: Improving yield and quality of producer gas

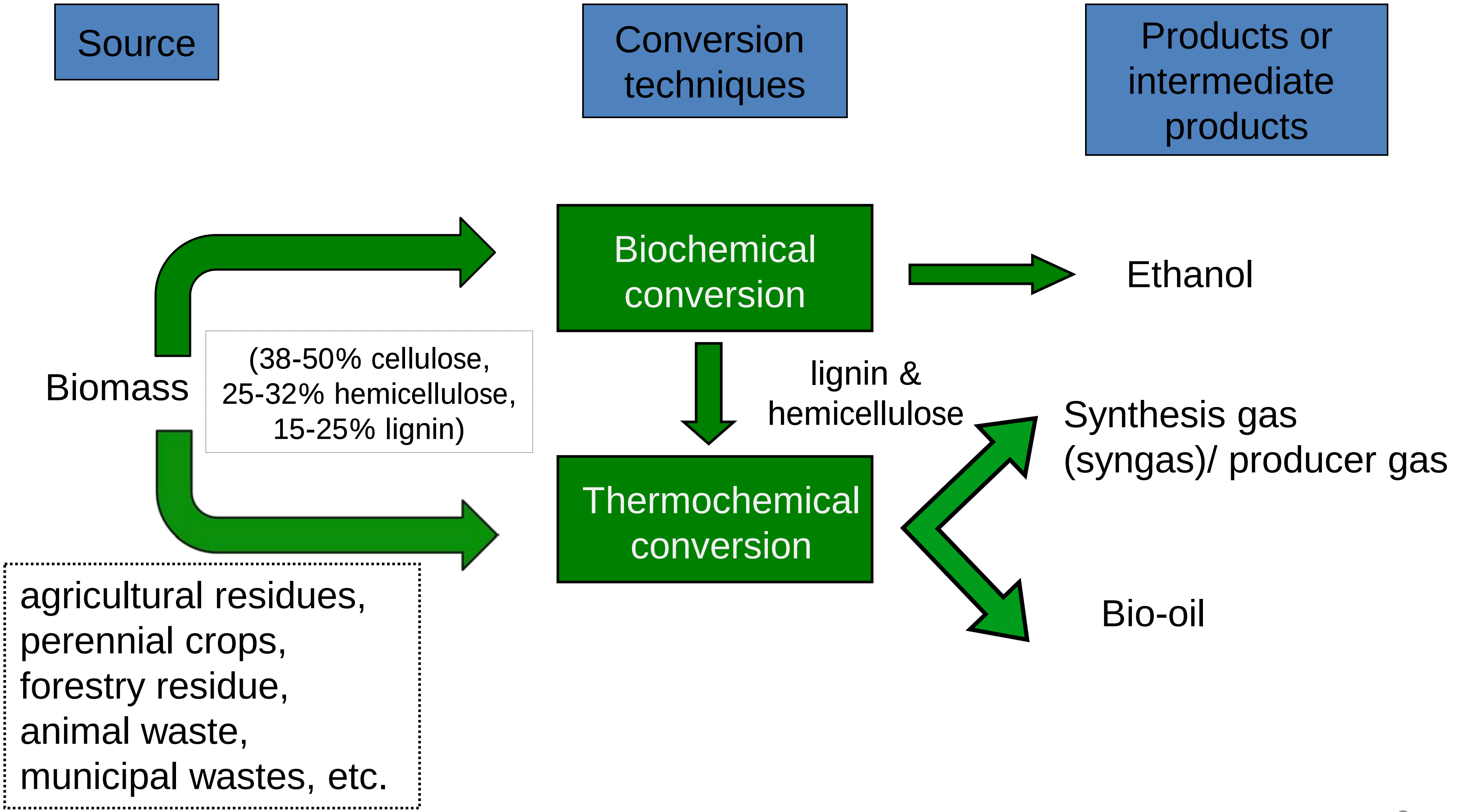
Ajay Kumar
Assistant Professor

Biosystems and Agricultural Engineering Department
Biobased Products and Energy Center (BioPEC)

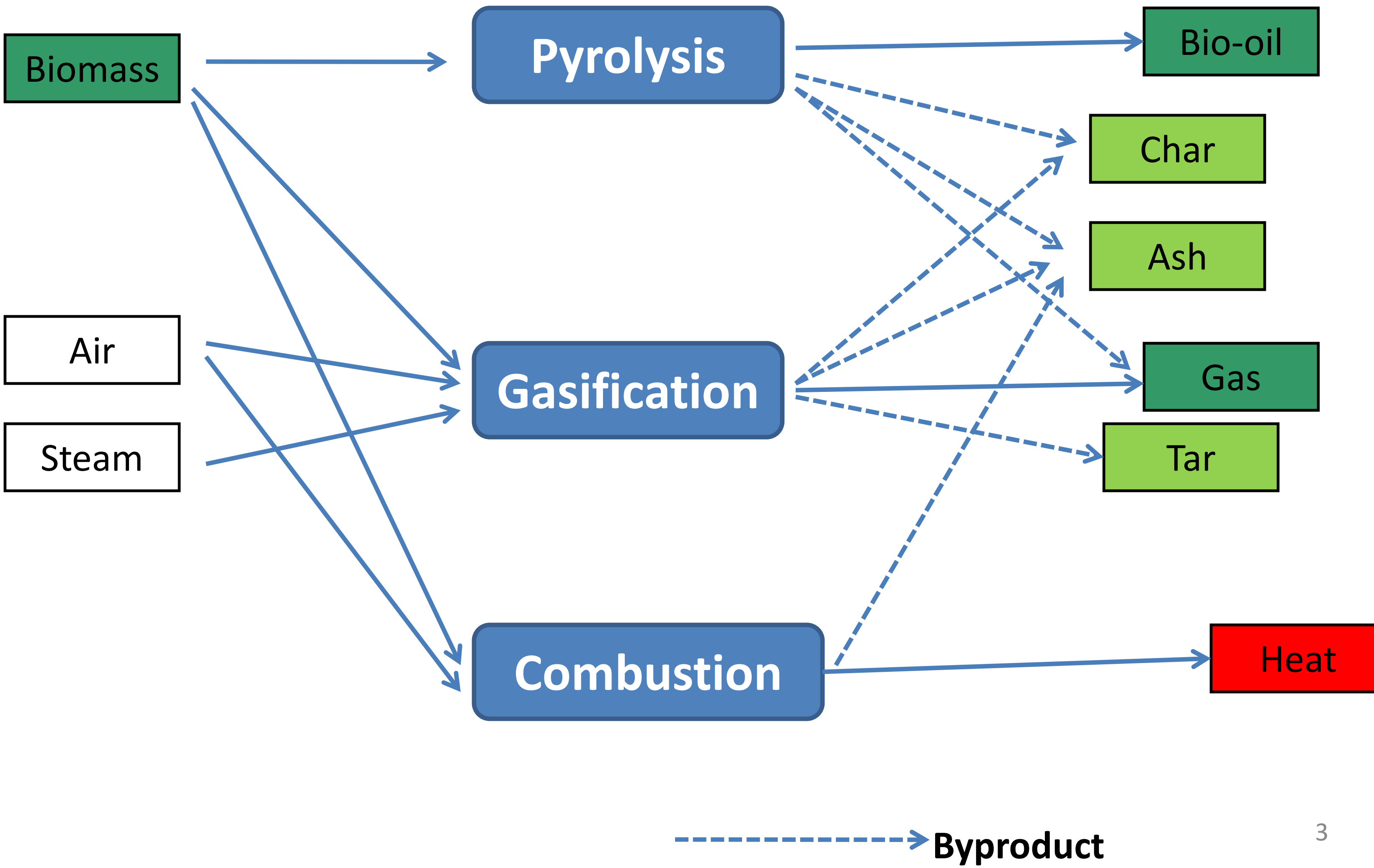
Oklahoma State University

Sep 15, 2010

Energy conversion pathways



Thermochemical Conversions



Gasification process

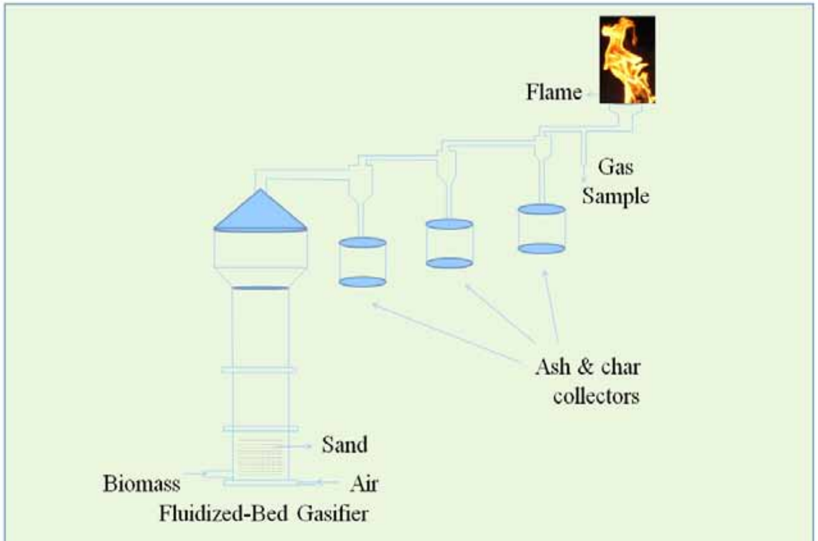
Sorghum

Switchgrass

Biomass

Air

Steam



Schematic of fluidized-bed gasification

Gas

Tar

Char

Ash

- Required: high temperature & oxidizing agent
- biomass + air + H_2O ➡ C (char)+ CH_4+ CO + H_2 + + CO_2 + N_2 + H_2O (unreacted steam) + ash + tar

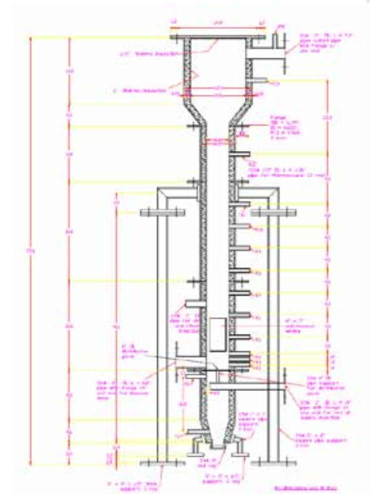
Gasification process - factors

Gasification

Heating,

Chemical reactions,

catalysis



Biomass properties

- Particle size
- Bulk density
- Proximate analysis
- Elemental analysis
- Energy content
- Cellulose, hemicelluloses & Lignin contents

Operating conditions

- Biomass flow rate
- Temperature profile
- Flow rates of oxidizing agents (equivalence ratio (ER), steam to biomass ratio, (SBR))
- Amount and type of catalyst

Product properties

- Syngas composition
- Syngas energy
- Carbon conversion efficiency
- Energy conversion efficiency
- Overall energy efficiency
- Amount of tar
- Amount of char

Gasification: technical challenges

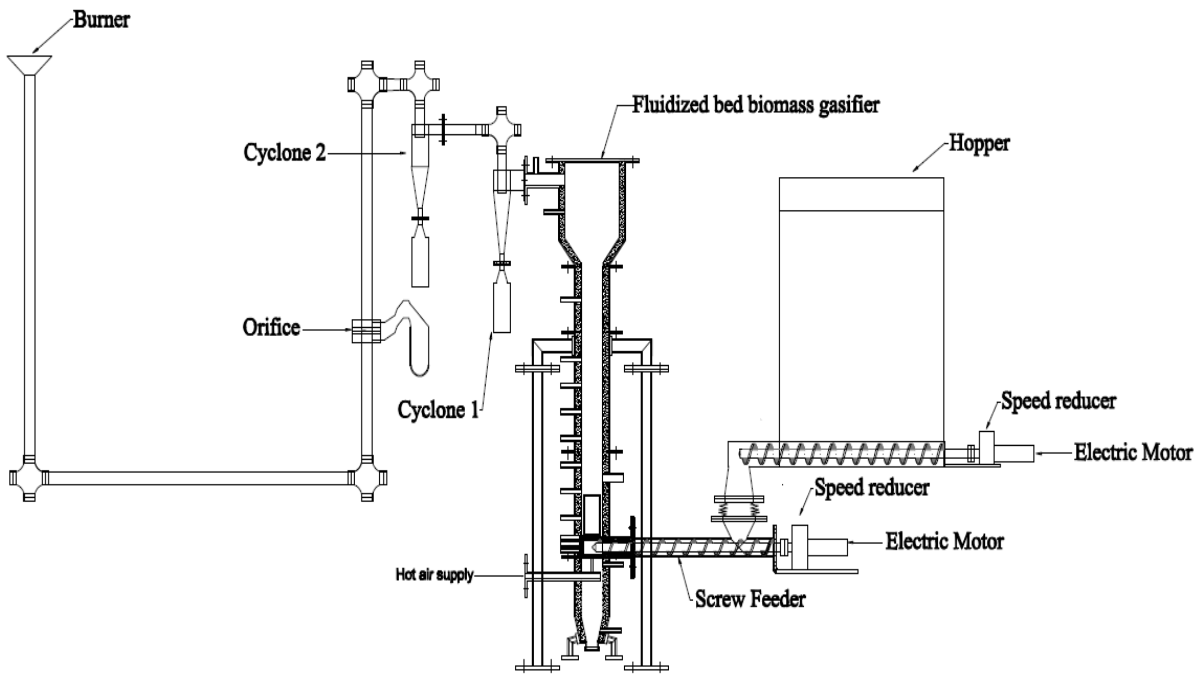
- Experimental challenge
  - Understand and predict the effects of gasification conditions and biomass properties on yield and composition of product
  - Reduce amounts of tar and impurities in the producer gas
    - Optimize gasification operating conditions & gasifier design
    - Improve cold gas cleaning technique
    - Improve hot gas cleaning technique
  - Increase percentage compositions of CO and H_2
  - Increase net energy efficiency
  - Obtain data for developing gasification reaction kinetics for a wide variety of feedstock

- Computational challenge
  - Develop gasification reaction kinetics
  - Incorporate reaction kinetics into gasification model to reliably predict gas yield and composition

Ongoing projects

1. Design, development and performance evaluation of lab-scale fluidized-bed gasifier (FBG)
2. Evaluate effectiveness of commercial reforming catalysts to crack tar
3. Investigate gasification reaction kinetics using TG-FTIR
4. Gasification of a wide variety of biomass in a downdraft gasifier

1. Design, development and performance evaluation of lab-scale fluidized-bed gasifier (FBG)



•**Biomass feedrate : 3-6 kg/h**

Objectives

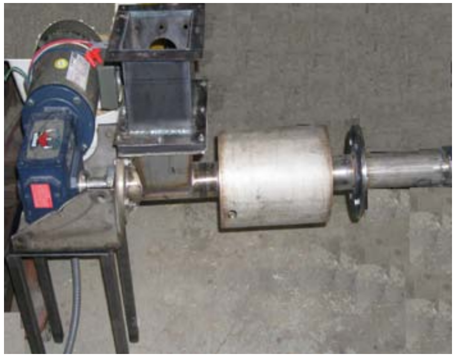
- Design a new lab-scale FBG with instruments to control and monitor process conditions
- Evaluate performance of the gasifier
- Improve the system components so that it can run continuously for longer duration

Gasifier components

<u>Factor considered while designing</u>

- Biomass feed rate
- Physical characteristics of biomass
- Test duration
- Equivalence ratio
- Superficial velocity

Biomass hopper



Screw feeder

Gasifier

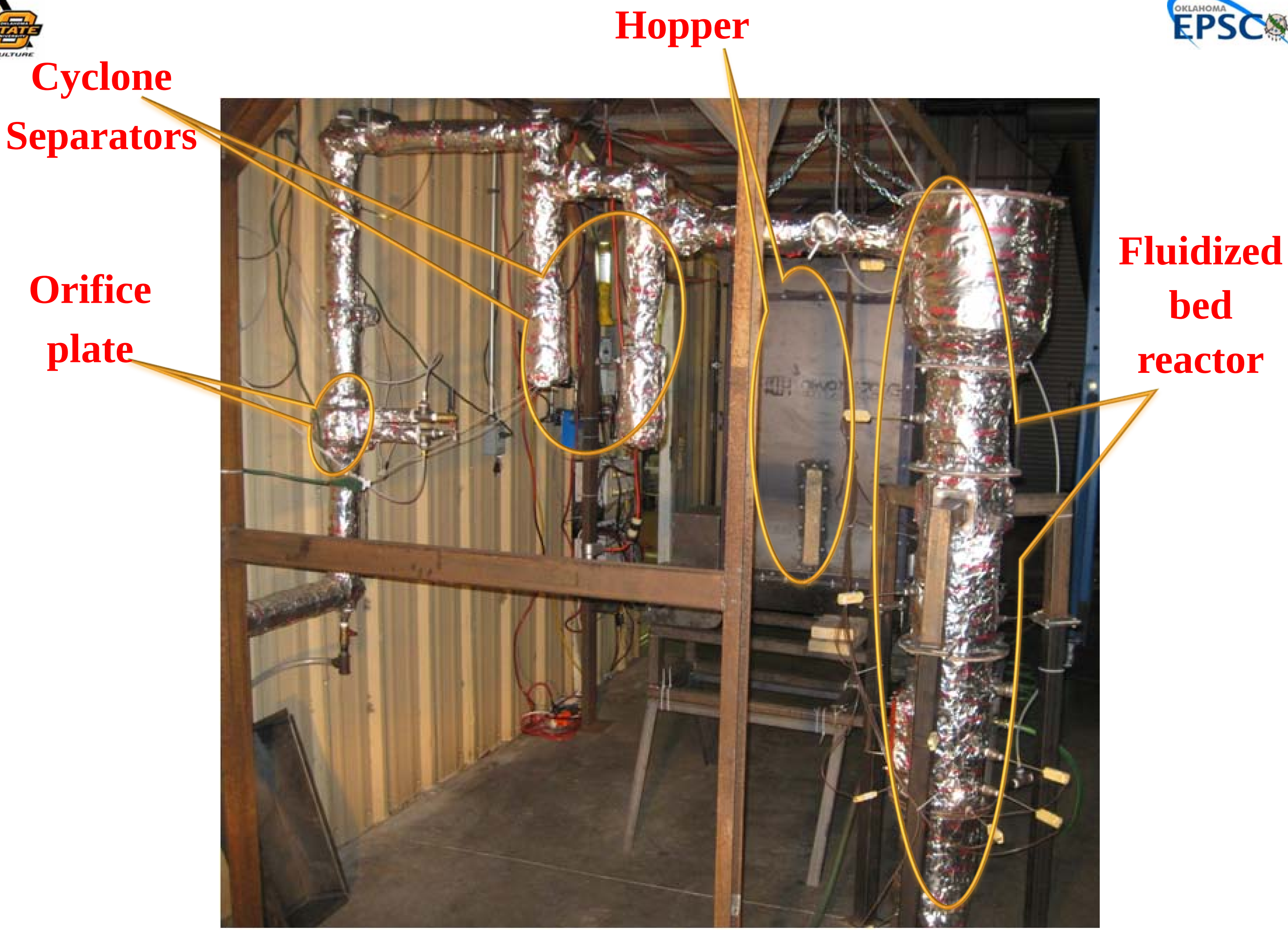
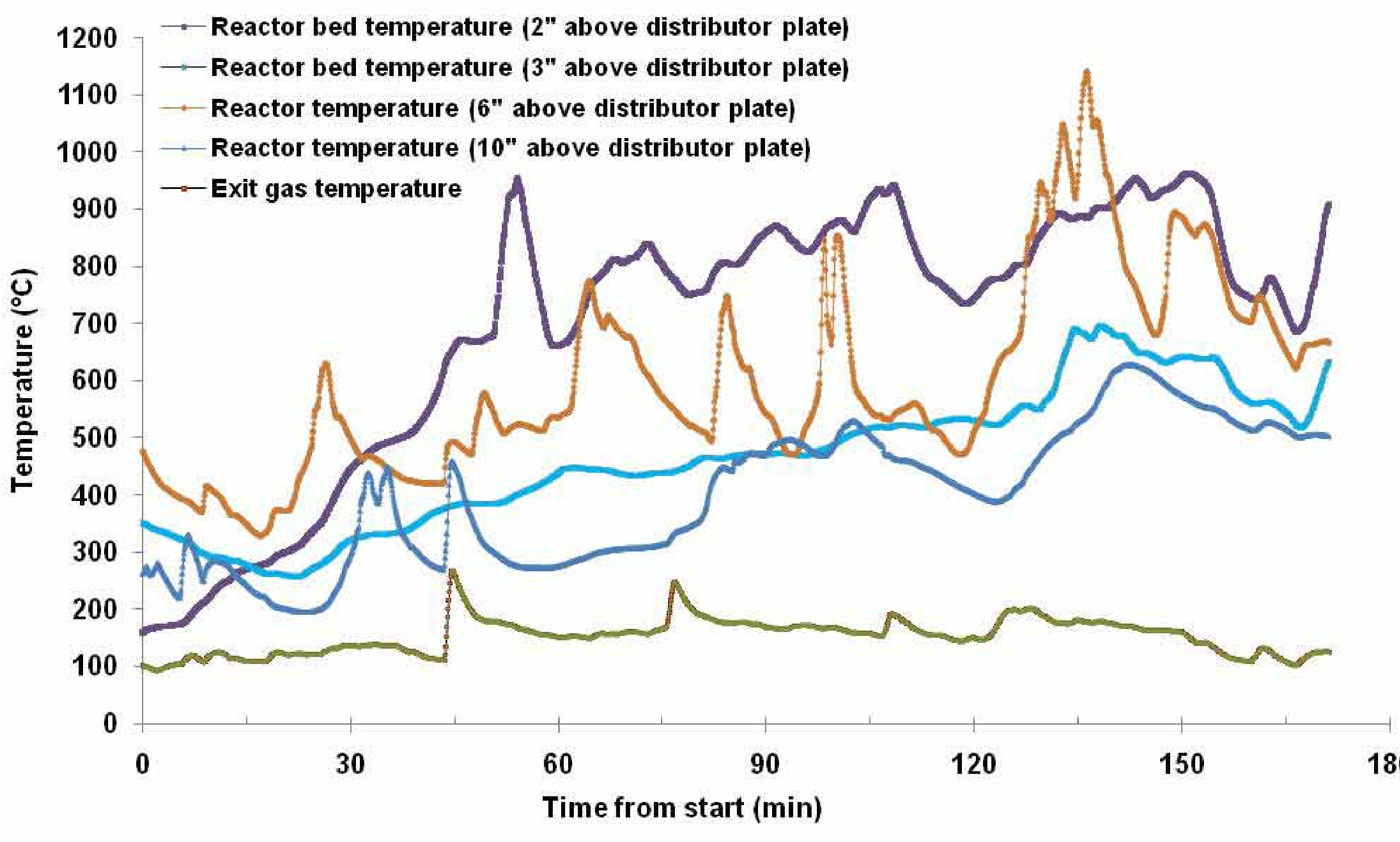
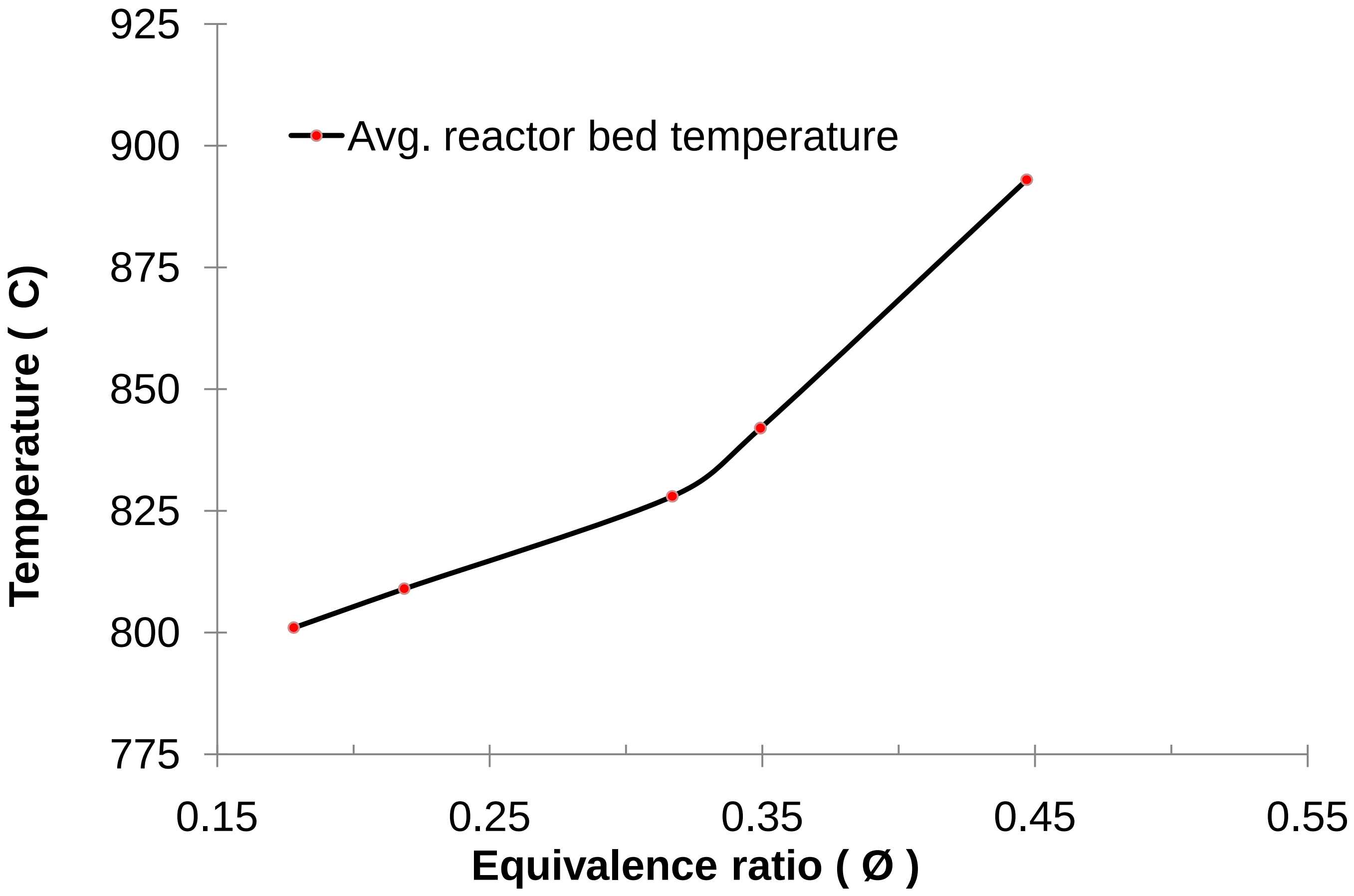


Fig. Fluidized bed gasifier set up

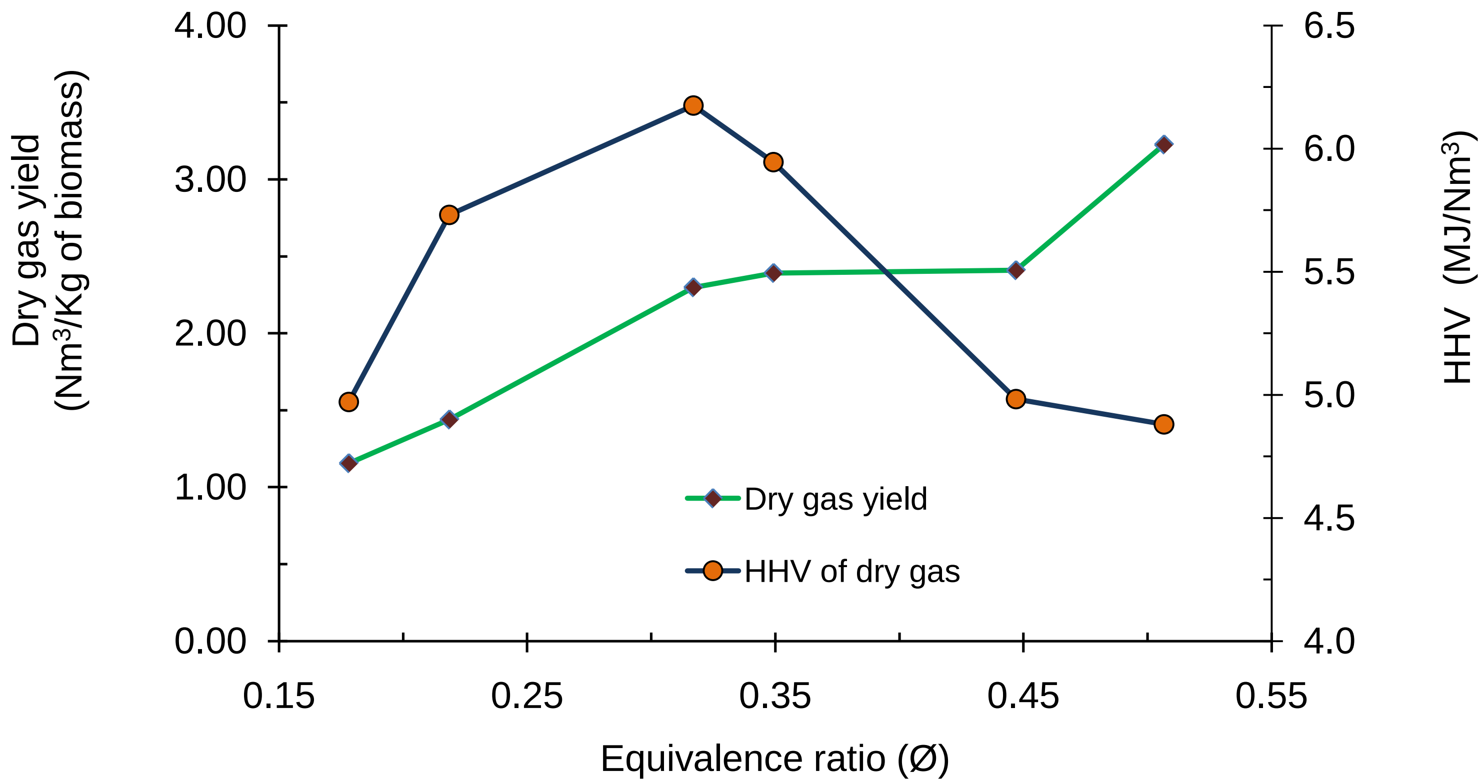
Gasifier temperature profile with time



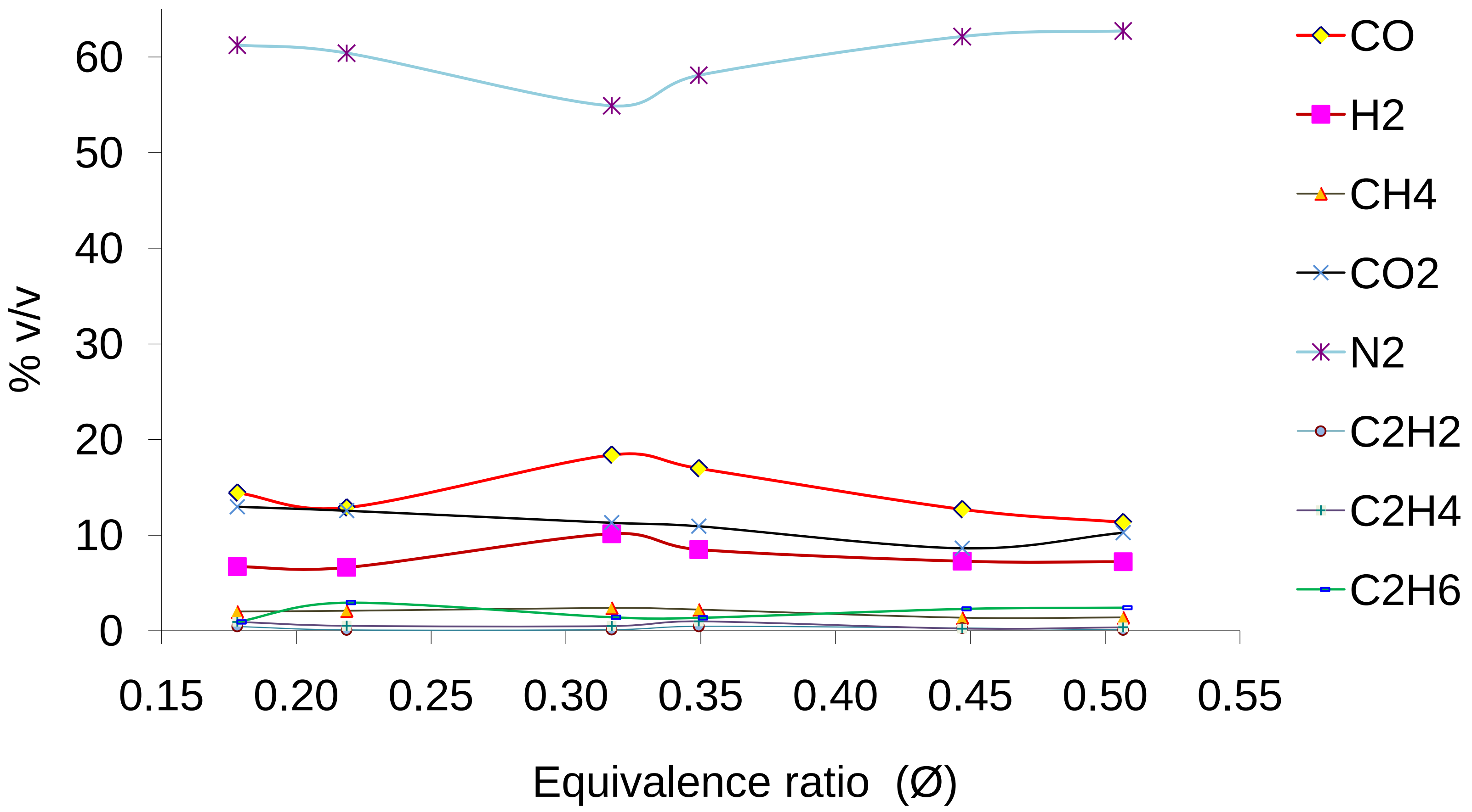
Effect of equivalence ratio (ER) on gasifier temperature



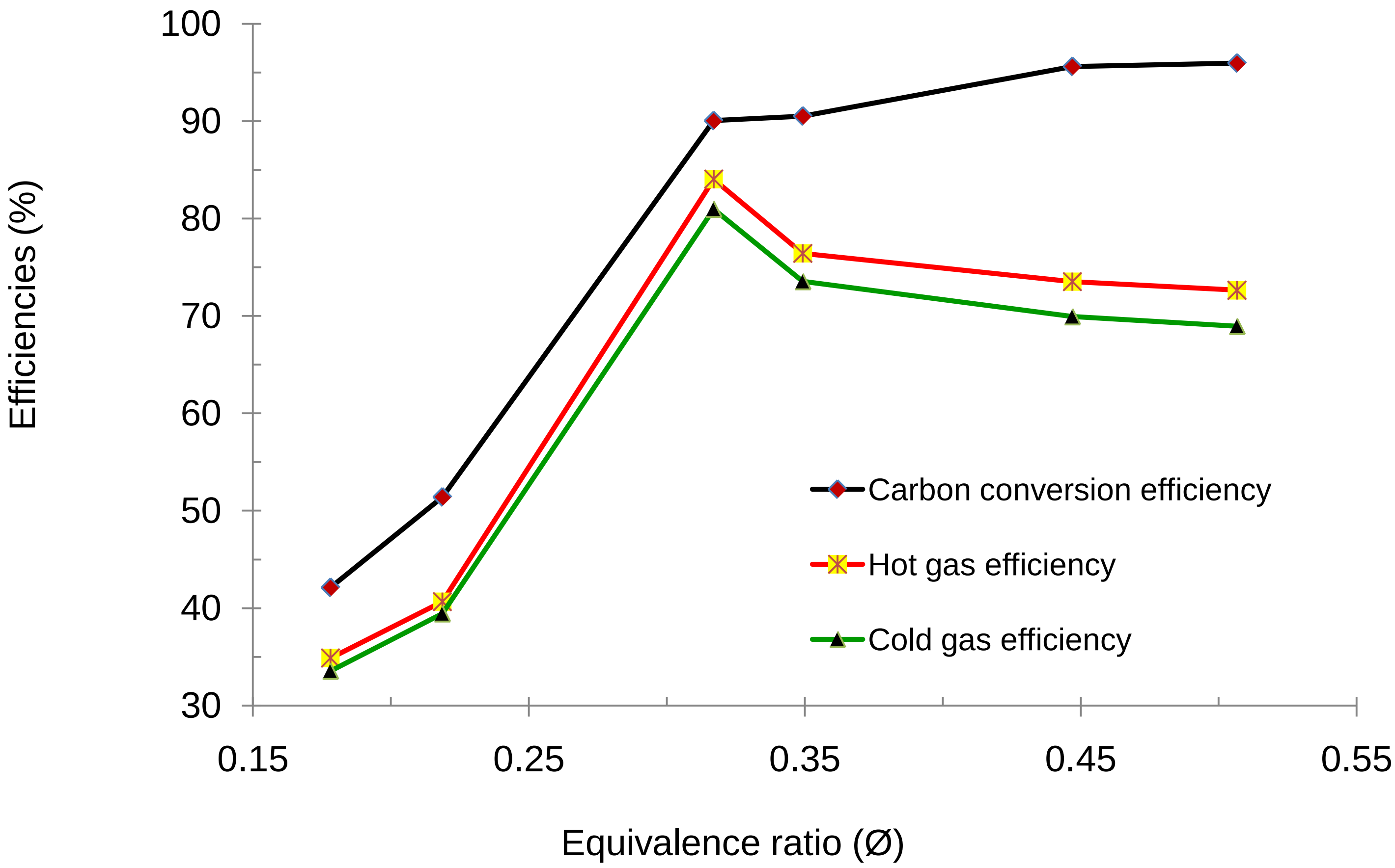
Effect of ER on yield and higher heating value (HHV) of producer gas



Effect of ER on producer gas composition



Effect of ER on gasifier efficiencies



Conclusions:

- A lab-scale fluidized bed gasifier was designed and developed.
- The gasifier performance was evaluated for switchgrass as a feedstock by varying equivalence ratio (Ø) from 0.18 to 0.51
  - At equivalence ratio of 0.32,
    - ✓ The highest gas heating value was 6.17 MJ/Nm^3 (db) ,
    - ✓ The maximum cold gas efficiency was 80% and
    - ✓ The maximum hot gas efficiency was 84%.
  - The maximum carbon conversion efficiency of 95.95% was observed at Ø value of 0.51.

Near pilot-scale FBG

•Fluidized-bed Gasifier (FBG)

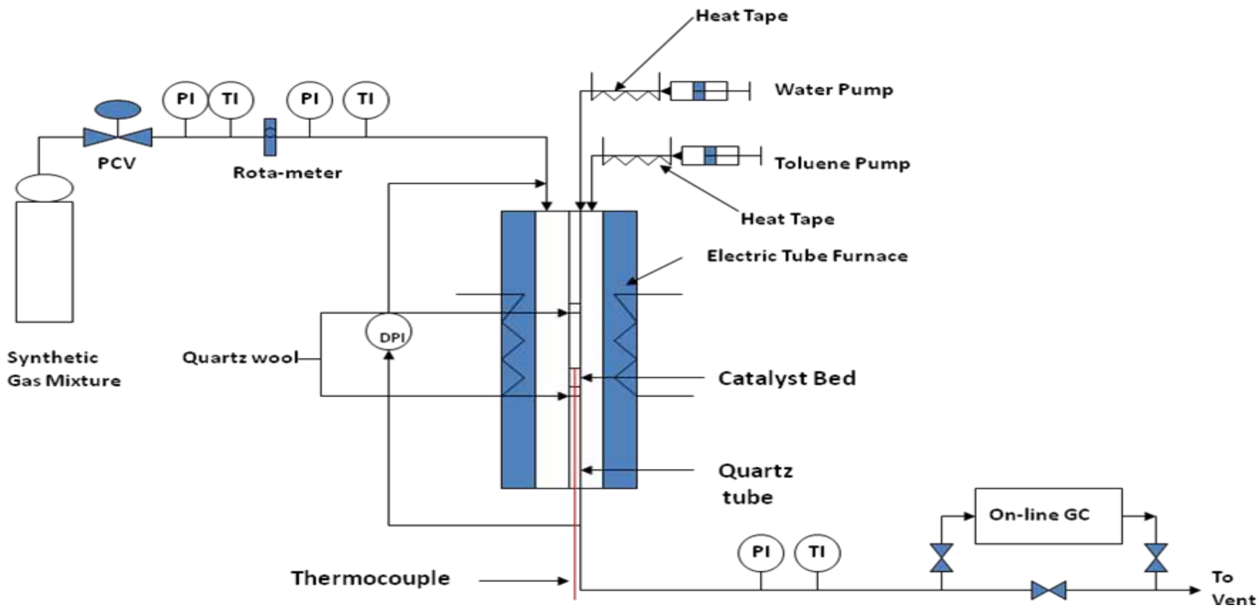
•Gas scrubbing system

•Biomass feedrate: 15-30 kg/h

2. Evaluate effectiveness of commercial reforming catalysts to crack tar

- Two stage evaluation
  - 1st stage: Test catalysts using toluene as a model tar
  - 2nd Stage: Test catalysts using real producer gas with tar

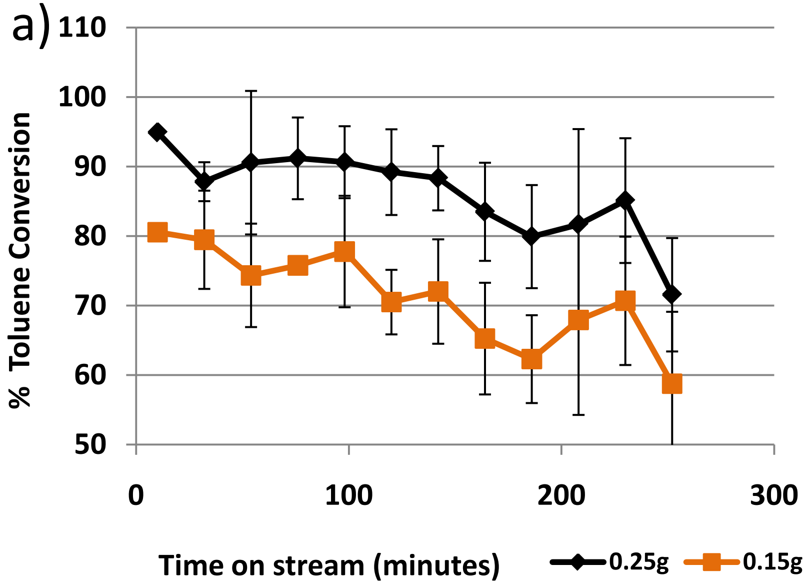
1st Stage: Evaluation of catalysts to crack toluene as a model tar

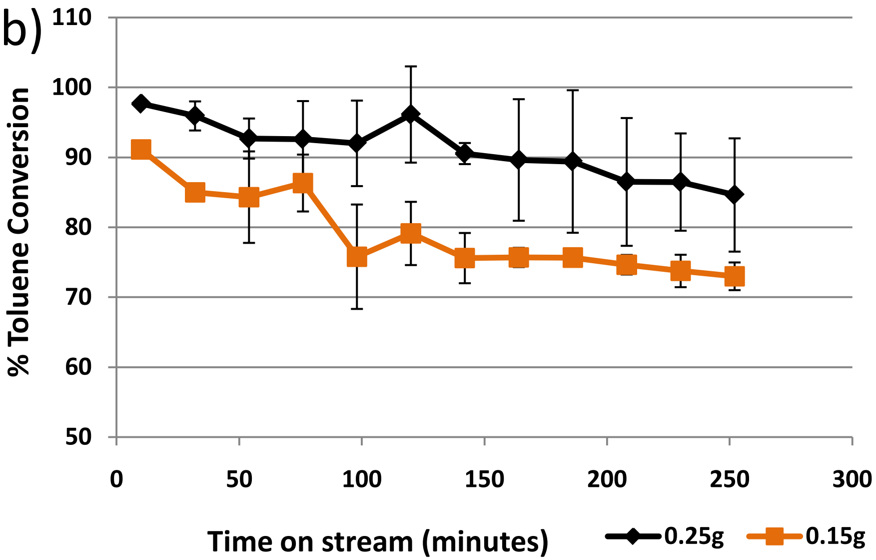


Objectives

- Evaluate selected commercially available catalysts (Cerium-Zirconium-Platinum, Hifuel R110 and Reformax 250) for their effectiveness in cracking toluene as a model tar
- Study effects of reaction conditions such as temperature, catalyst particle size, and steam to carbon ratio on tar degradation

Effect of space time (catalyst weight)

a)


b)


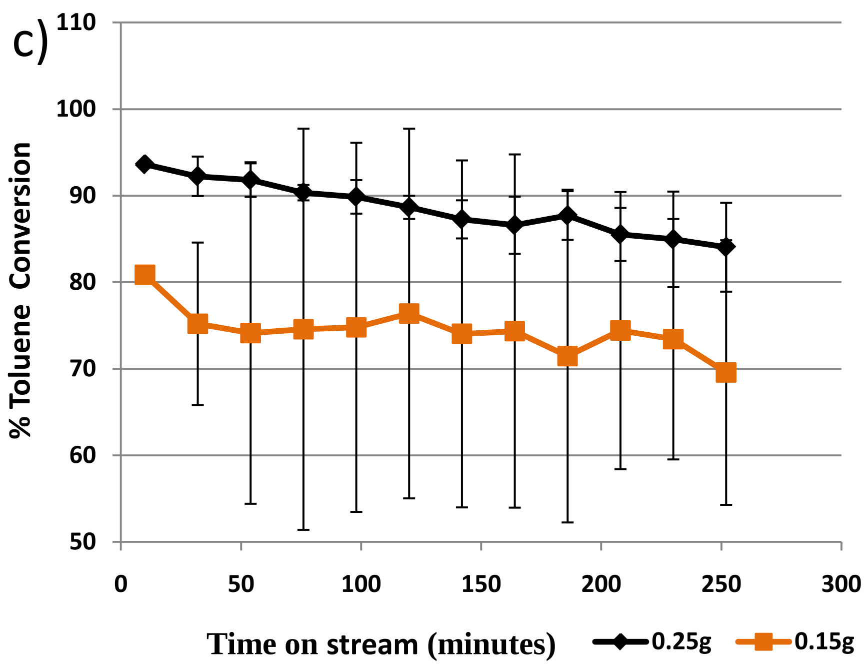
c)


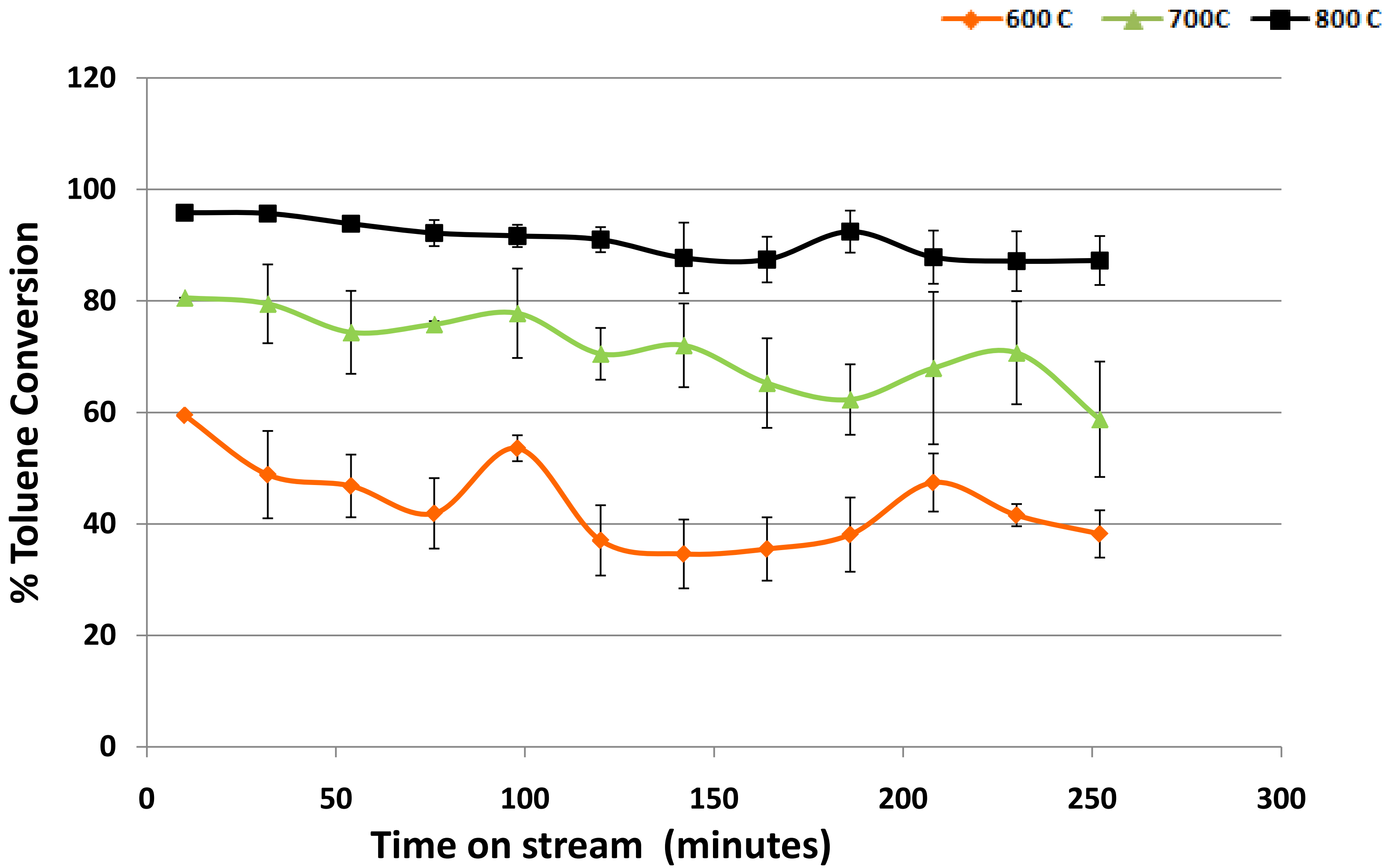
Figure Captions :

a) Cerium Zirconium Platinum catalyst powder.

b) Hifuel R110 catalyst powder.

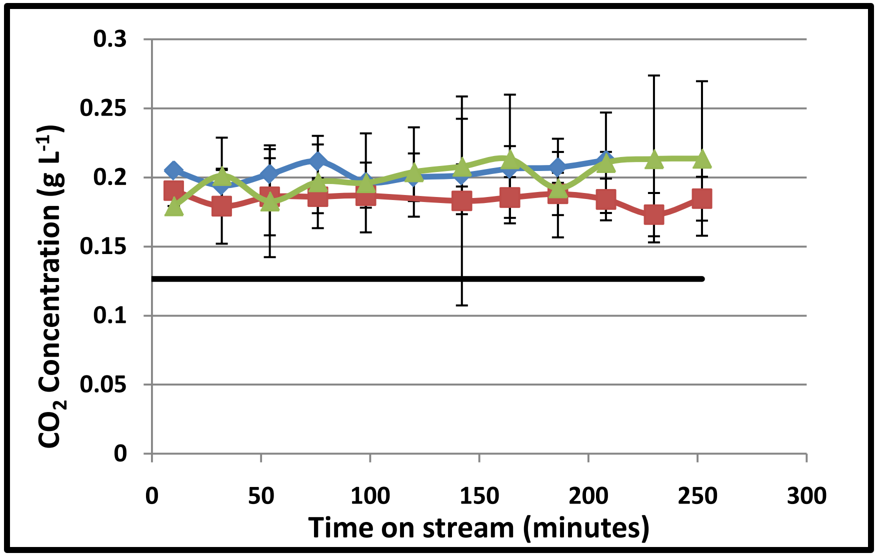
c) Reformax 250 catalyst powder.

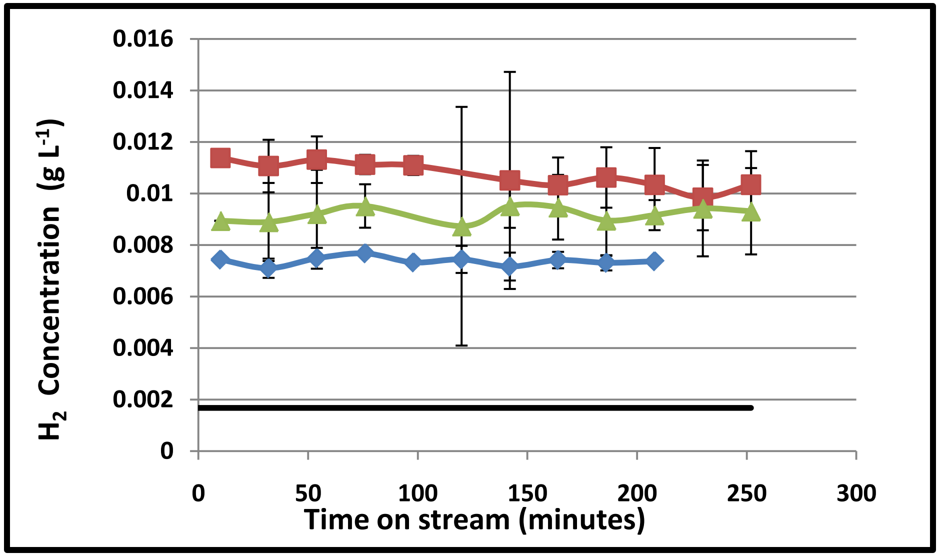
Effect of temperature on Cerium-Zirconium-Platinum catalyst

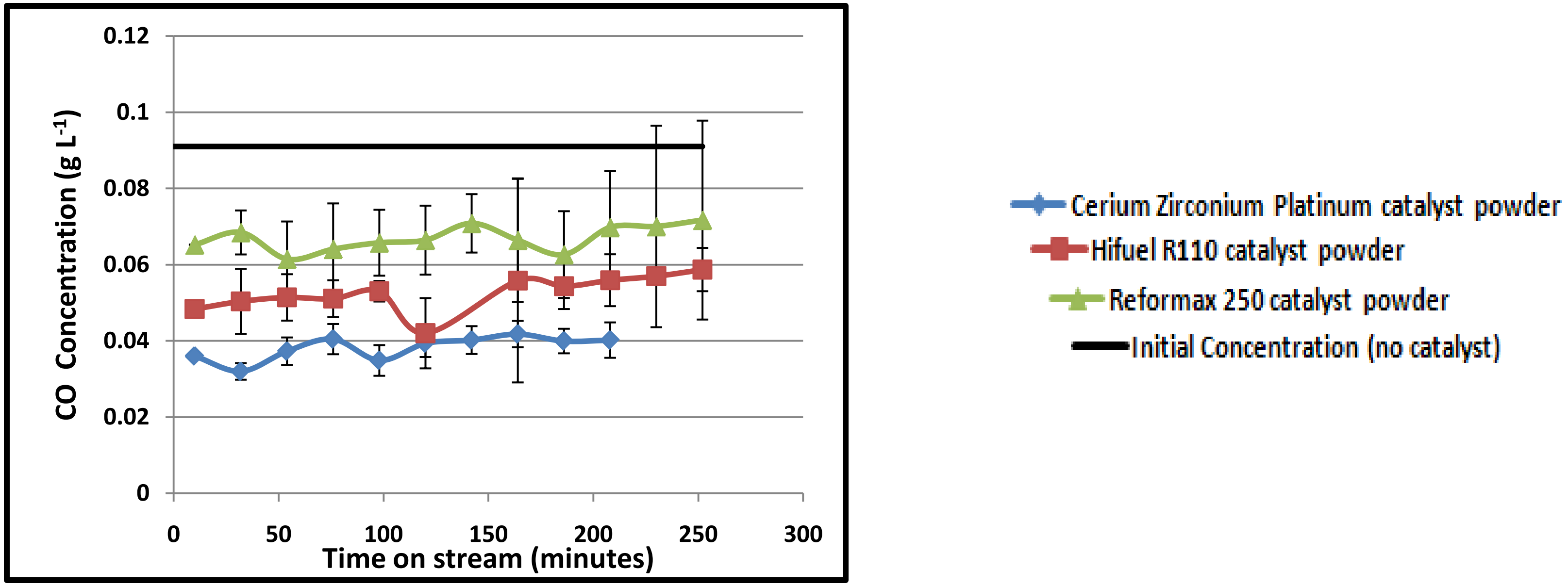


Weight of catalyst tested-0.15g, Steam to Carbon ratio-2.

Other Gas Compositions

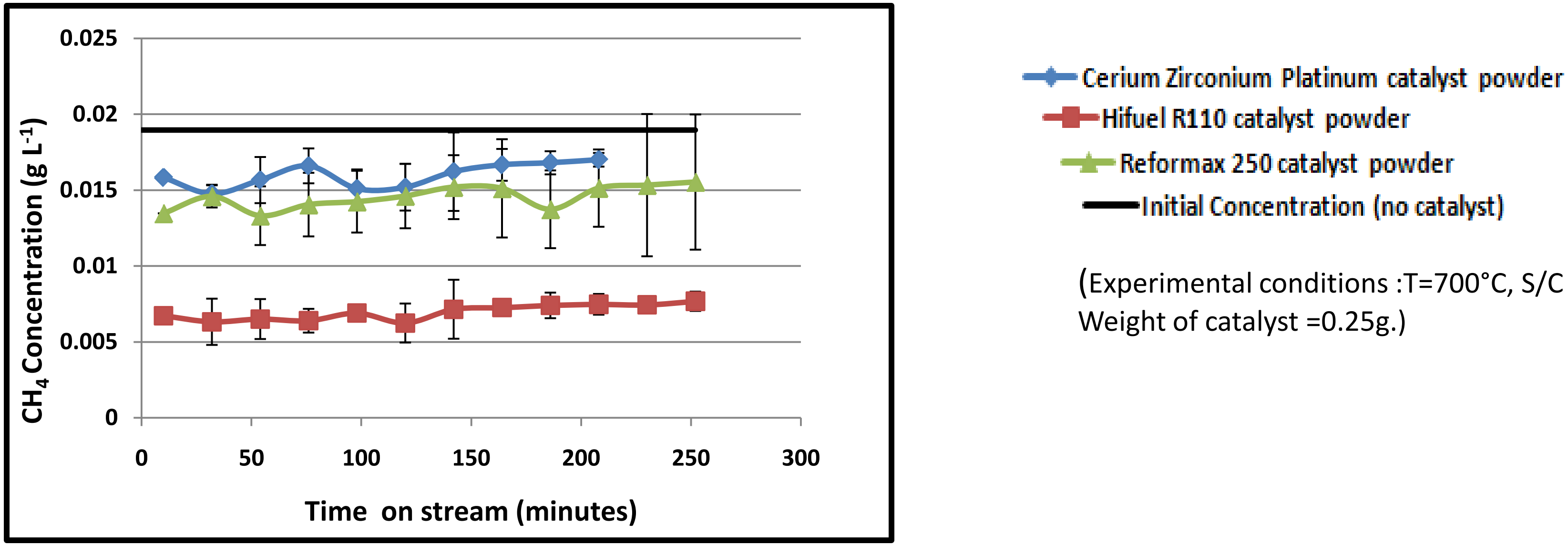






(Experimental conditions :T=700°C, S/C ratio=2, weight of catalyst =0.25g.)

Other Gas Compositions (Contd.)



(Experimental conditions :T=700°C, S/C ratio=2, Weight of catalyst =0.25g.)

Conclusions from Bench Scale System

- **Cerium Zirconium Platinum , Hifuel R110 and Reformax 250- successfully reduced amount of toluene**
- **Higher catalyst weight (Space time)- Higher toluene conversion**.
- **Higher catalyst bed temperature - Higher the conversion .**
- **Gas Compositions:**

  For all three catalysts increase in H_2, CO_2, and decrease in CO and CH_4 concentration.
- **Overall reaction:**

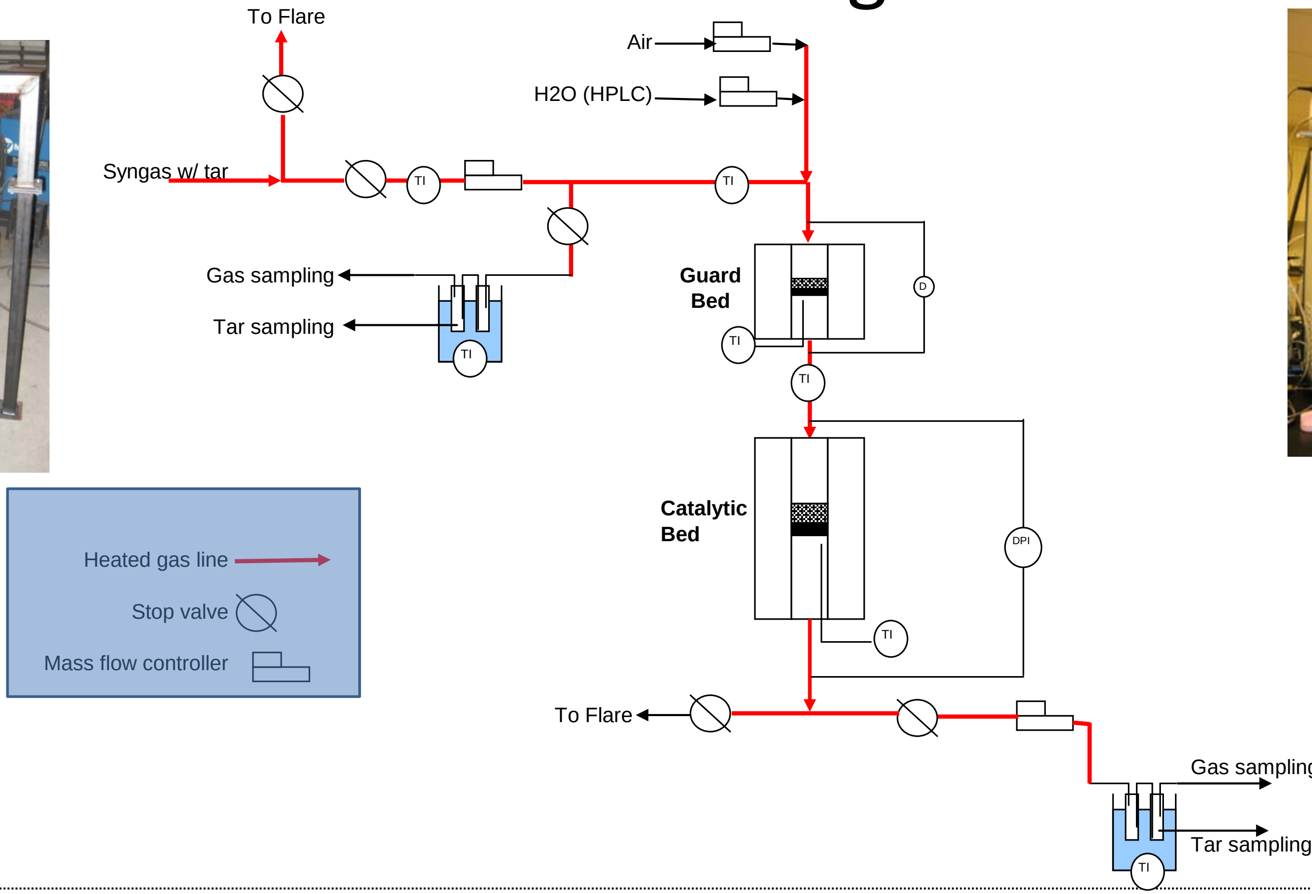
$$C_7H_8+H_20+H_2+CO_2+CO+CH_4+N_2= \downarrow C_7H_8+\downarrow H_20+\uparrow H_2+\uparrow CO_2+\downarrow CO+\downarrow CH_4+N_2+\uparrow C2\text{-}C6\ HC$$

- **Catalyst Deactivation**

  Cerium Zirconium Platinum > Hifuel R110 > Reformax 250. Powder > Pellets.

  For Cerium Zirconium Platinum catalyst - 600 > 800°C.

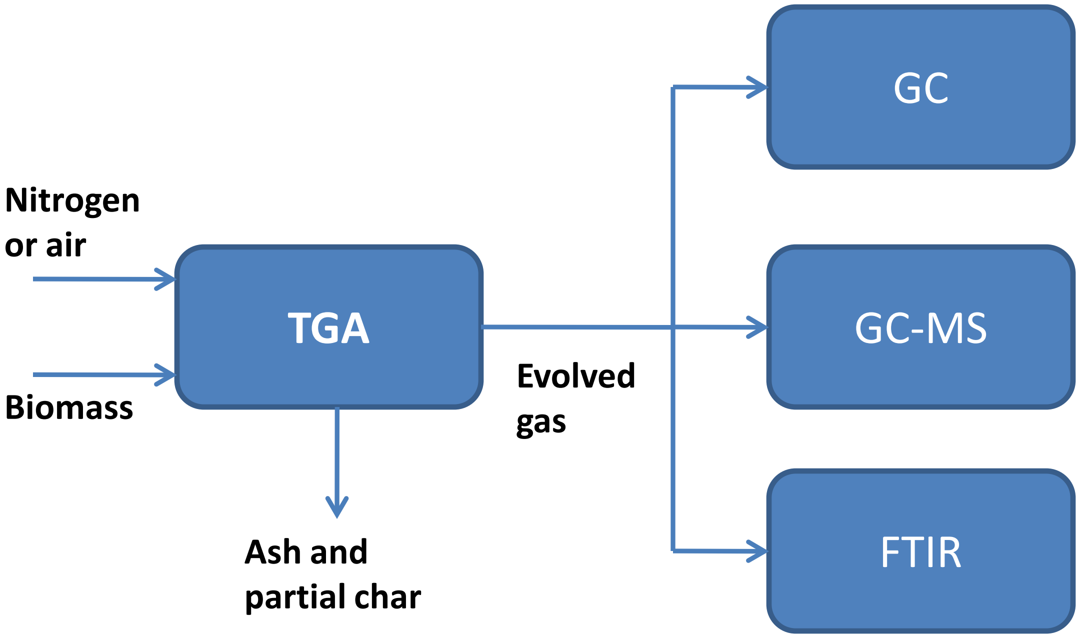
2nd Stage: New catalytic reactor for hot gas cleaning

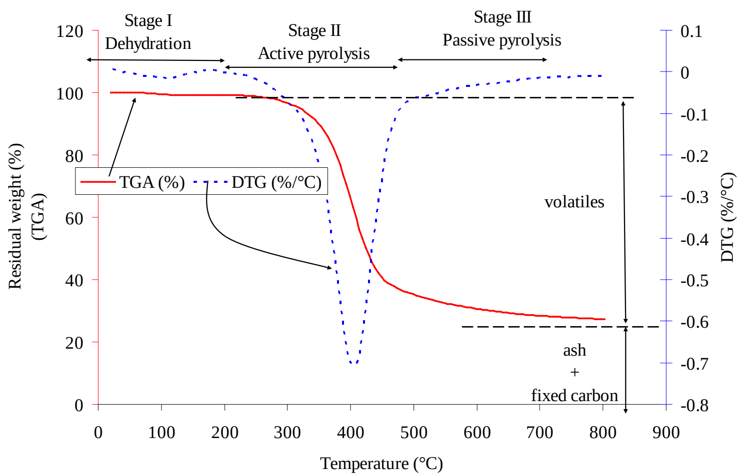


Objectives

- **Design a catalytic reactor to evaluate catalysts in cracking real tar**
- **Study effects of operating condition of catalytic cracker (air and steam flowrate, temperature, residence time) and various steam reforming catalysts on tar level and gas composition**

3. Investigate gasification reaction kinetics using TG-FTIR



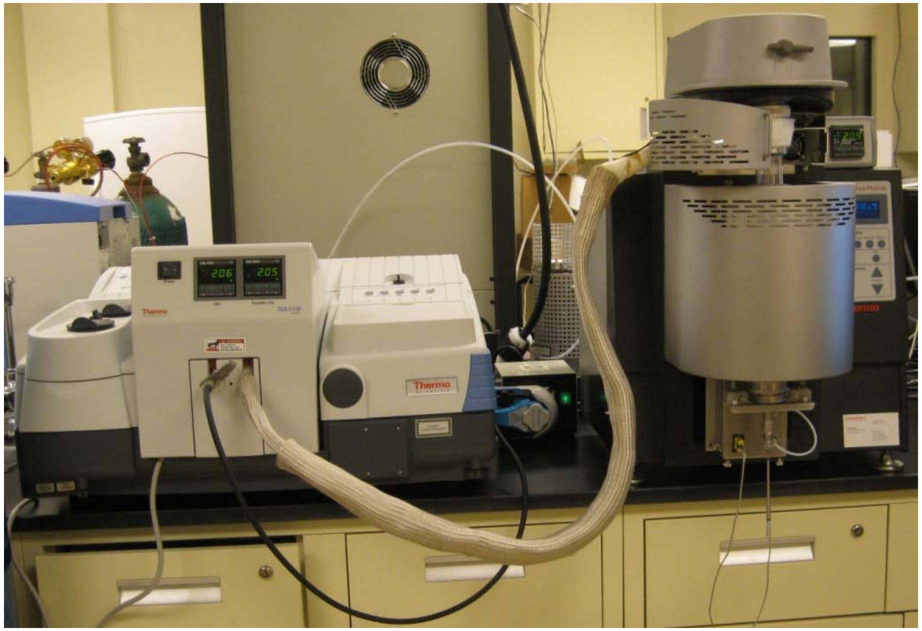


Kumar et al., 2008. Biomass and Bioenergy.

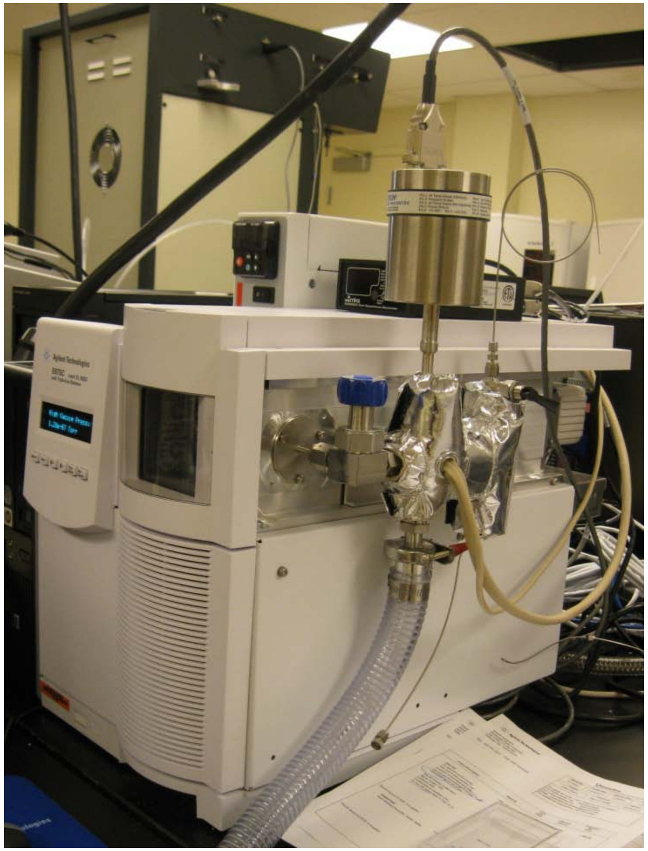
Objectives

- **Investigate the effects of oxidizing atmosphere, temperature and heating rate on rate of weight loss, gas and tar composition**
- **Derive volatization kinetics of various feedstocks**
- **Incorporate the kinetic parameter into gasification model to predict producer gas yield and composition**

Equipment

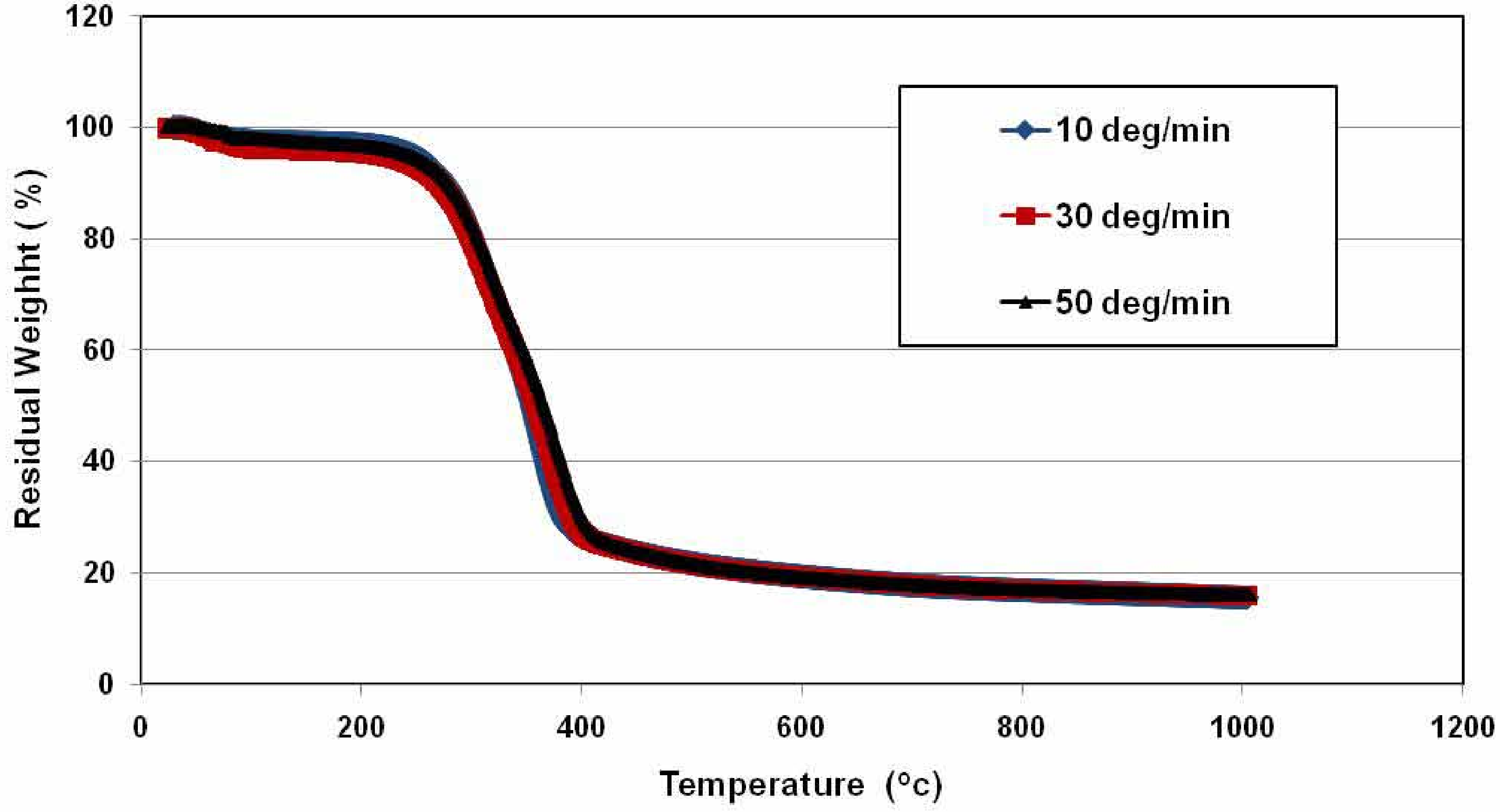


Coupled TGA-FTIR set-up
•Studying reaction kinetics of gasification
•Identifying compounds at various reaction conditions

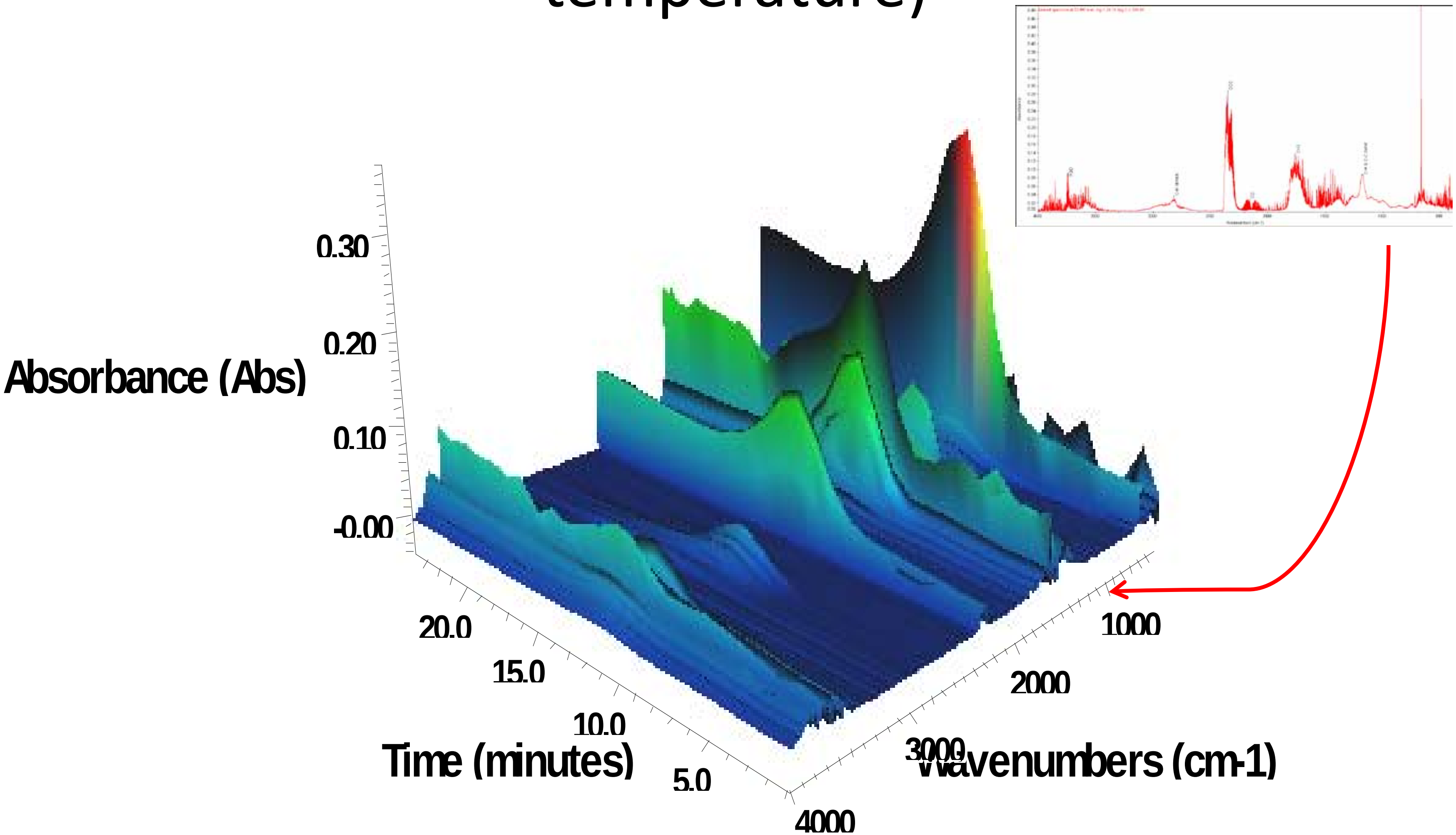


Mass Spec with precision sampling system
•Online measurement of gas composition

TGA profiles of switchgrass for different heating rates in nitrogen atmosphere



Online FTIR spectra with varying time (and temperature)



Results and discussion

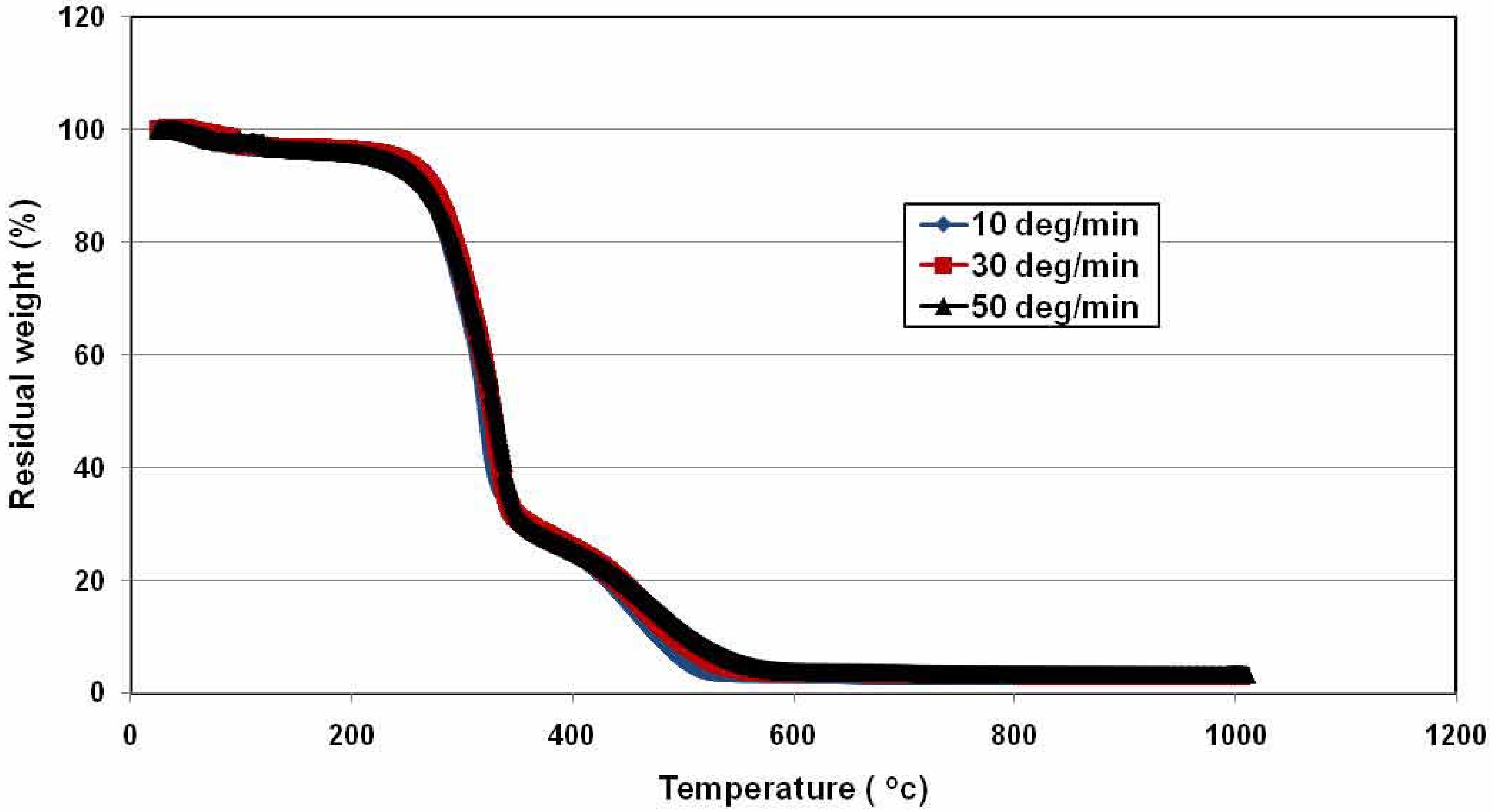


Figure. TGA profiles of switchgrass at different heating rates in air atmosphere

Results and discussion

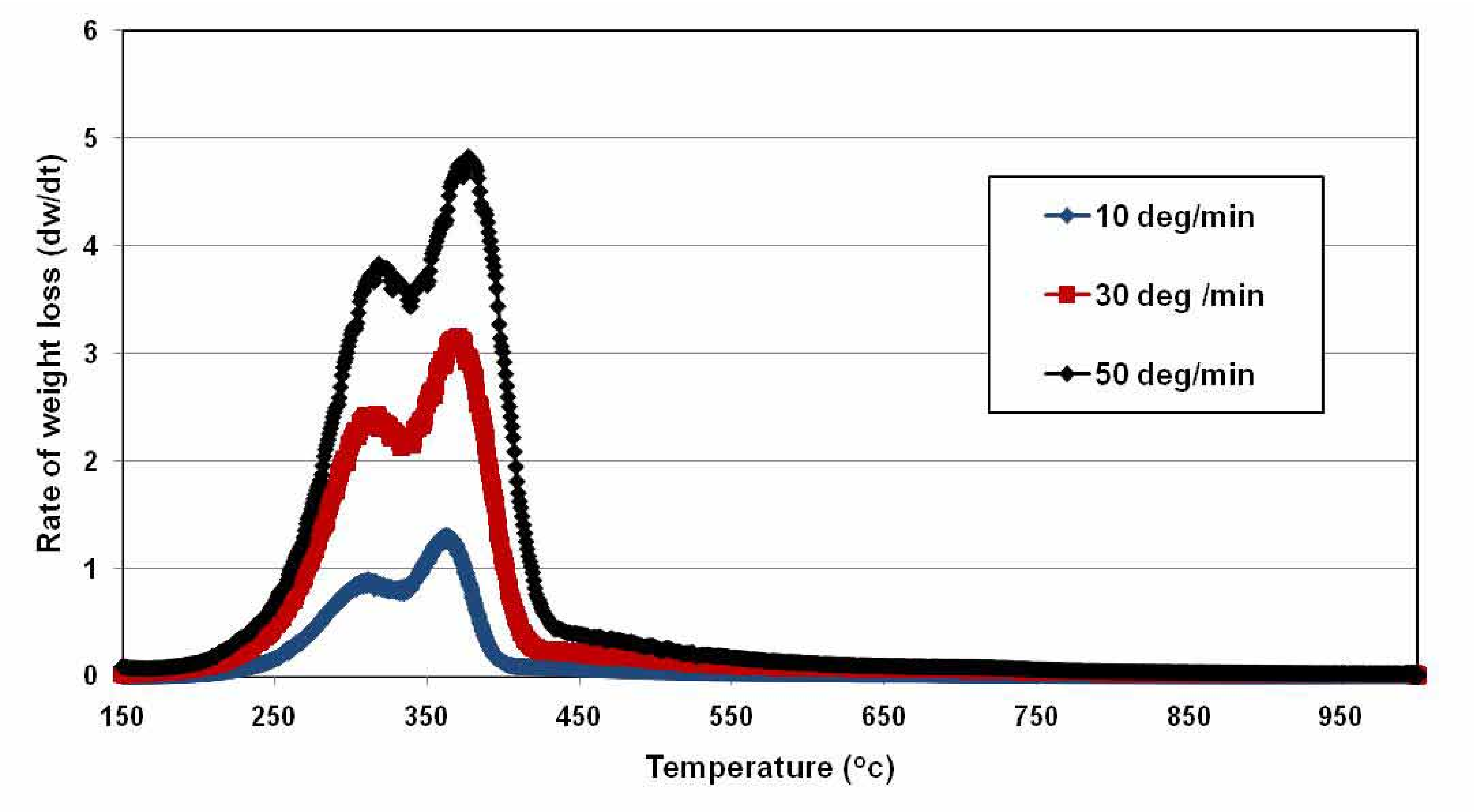


Figure. DTG profiles of switchgrass at different heating rates in nitrogen atmosphere

Results and discussion

Table 1. Kinetic parameters during second stage decomposition in air atmosphere

Heating rate (^oc/min)	Activation Energy (E) in $KJ.mol^{-1}$	Frequency factor (A)	Order of the reaction (n)	R^2
10	99.15	1.91×10^8	0.39	0.99
30	92.90	1.11×10^8	0.38	0.99
50	87.85	0.5×10^8	0.49	0.99

Table 2. Kinetic parameters during second stage decomposition in nitrogen atmosphere

Heating rate (^oc/min)	Activation energy (E)in $KJ.mol^{-1}$	Frequency factor (A)	Order of the reaction (n)	R^2
10	73.12	3.1×10^5	0.67	0.96
30	68.516	3.09×10^5	0.74	0.96
50	66.015	2.6×10^5	0.77	0.96

Results and discussion

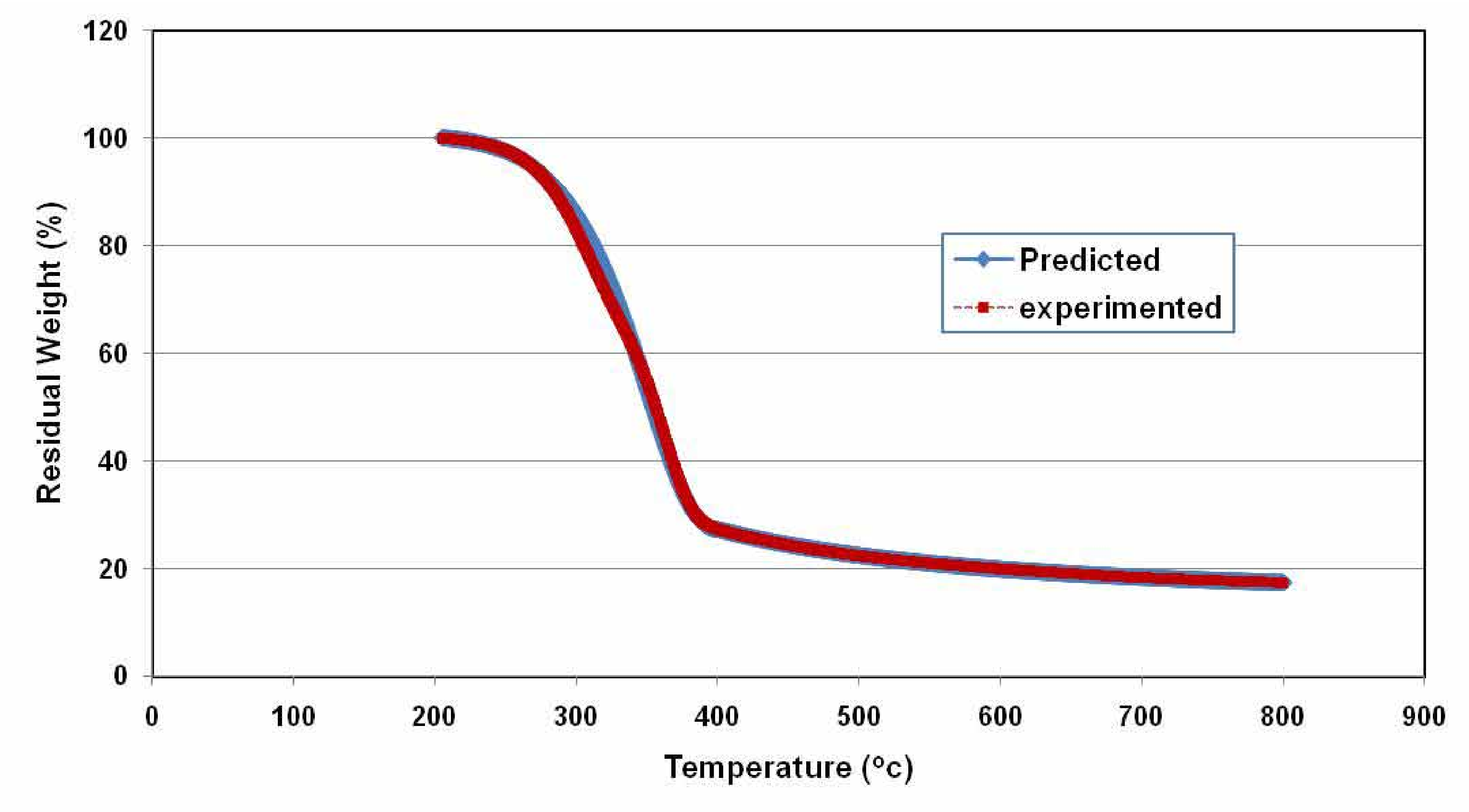
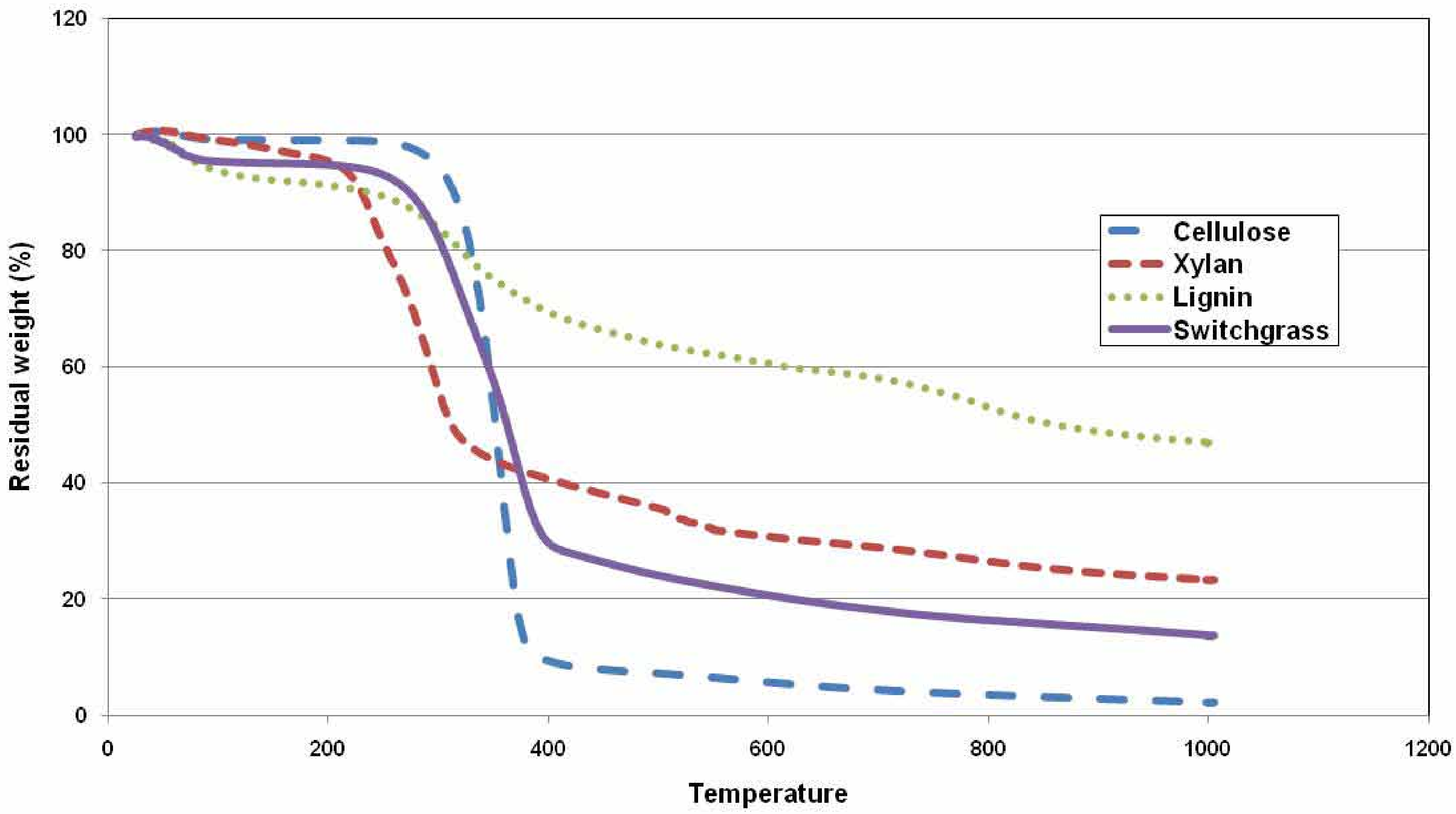
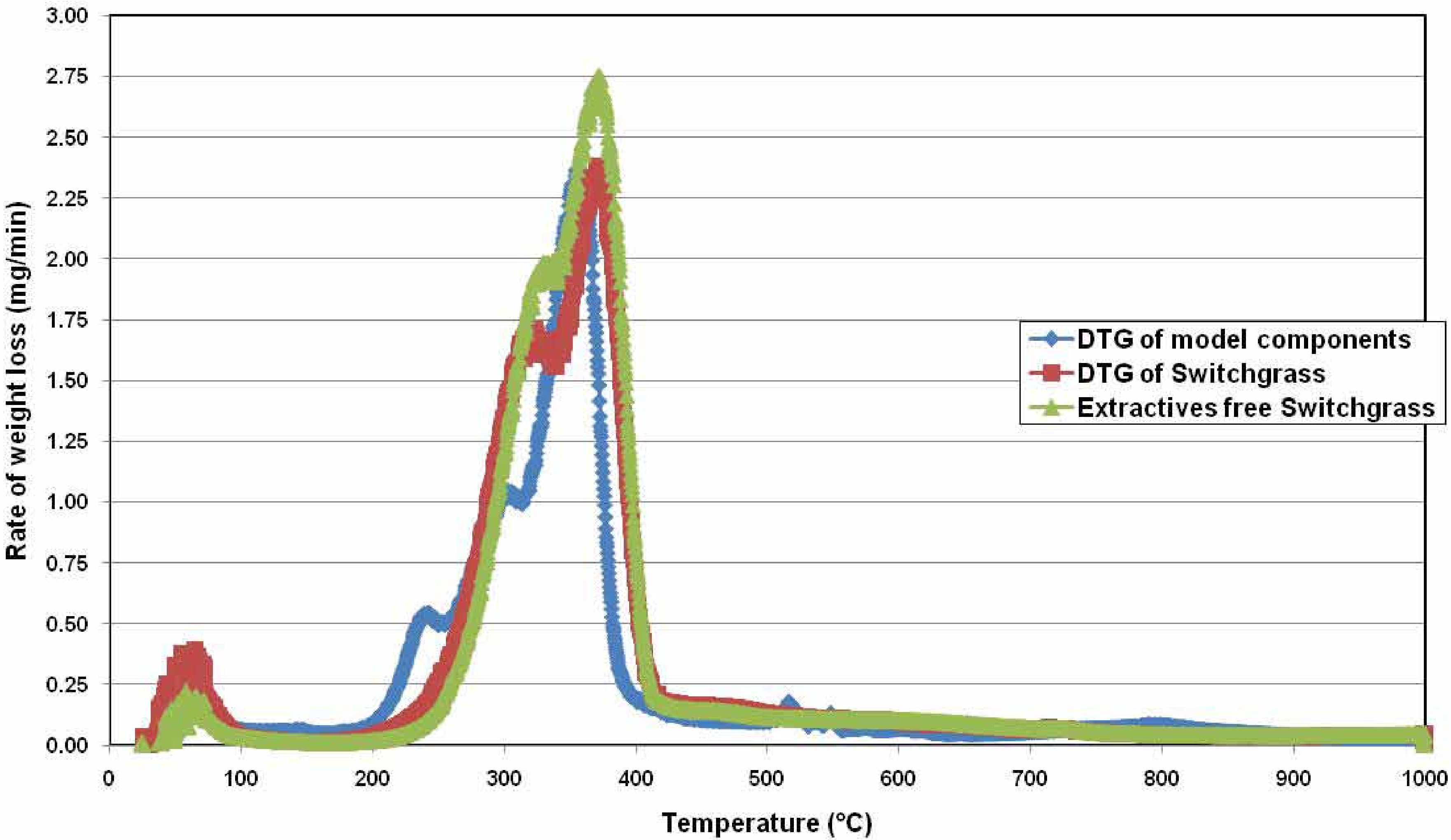


Figure. TGA plot of switchgrass pyrolysis in nitrogen atmosphere

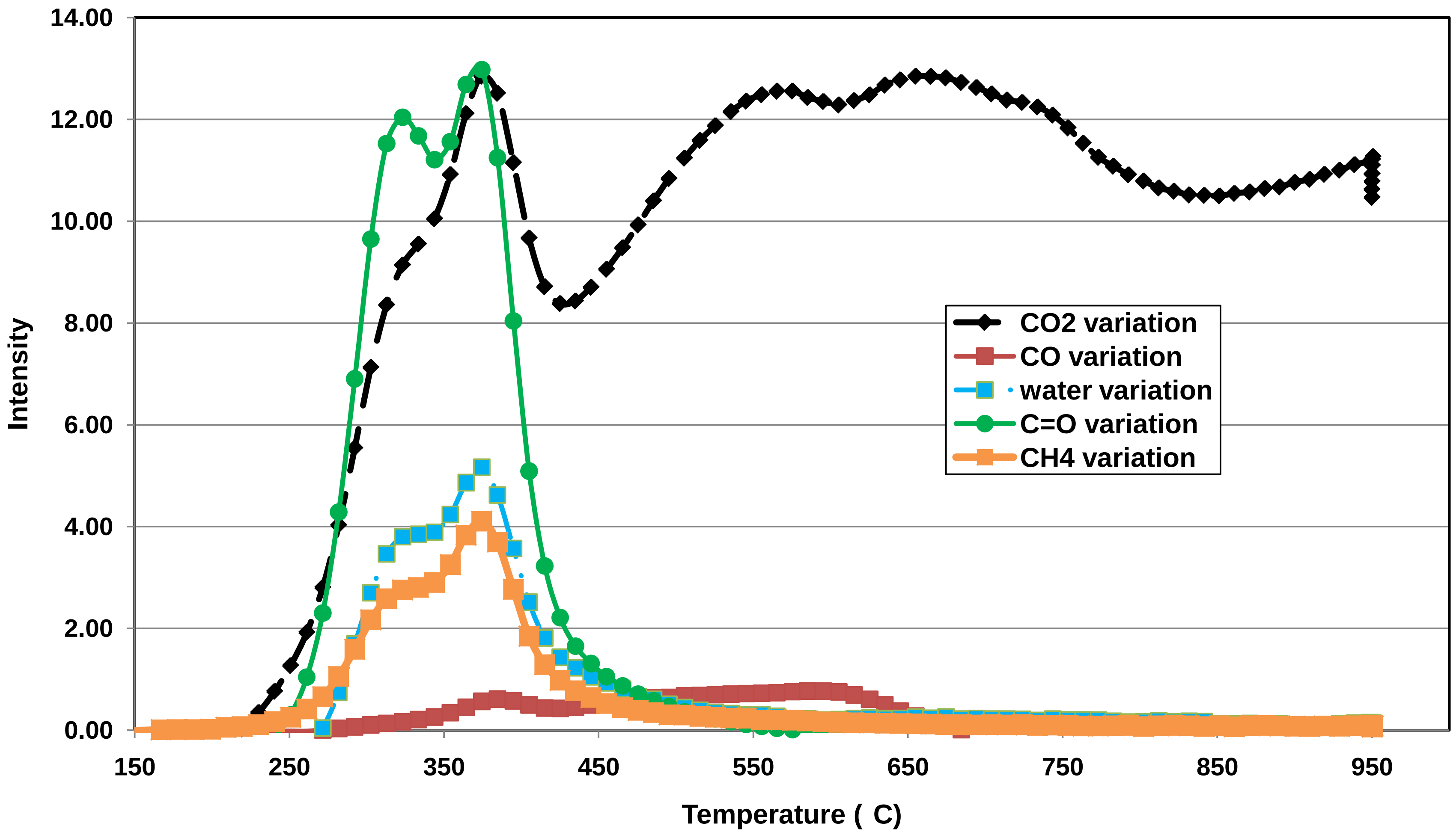
Weight loss with temperature



Rate of weight loss with temperature



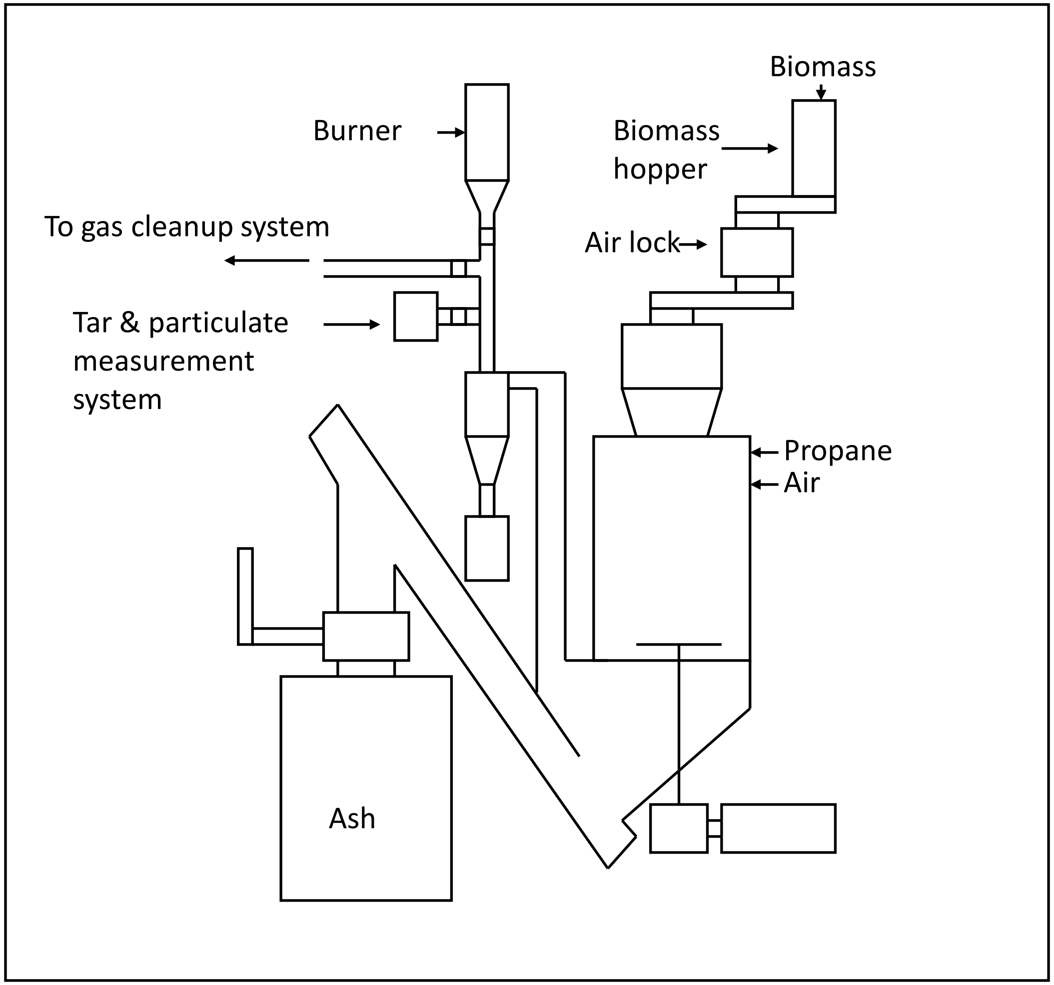
Products with increase in temperature (detected by FTIR)



Observations

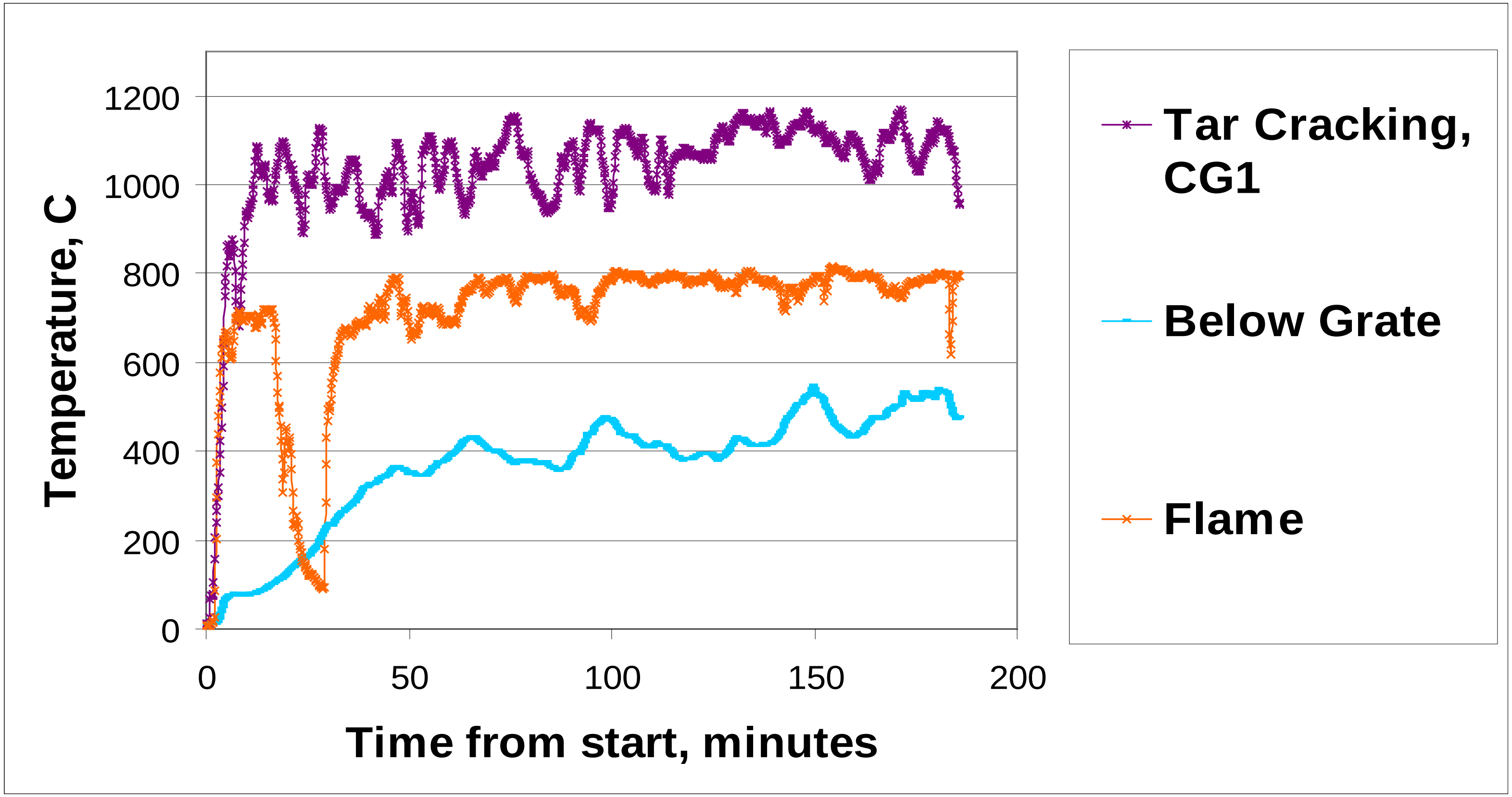
- Switchgrass decomposition takes place in three stages
- The significant weight loss was observed corresponding to hemicellulose and cellulose decompositions
- Lignin decomposes slowly over a wide range of temperature
- CO_2,CO, water, formaldehyde, methane were observed by FTIR as major products during switchgrass pyrolysis

4. Gasification of a wide variety of biomass in a downdraft gasifier



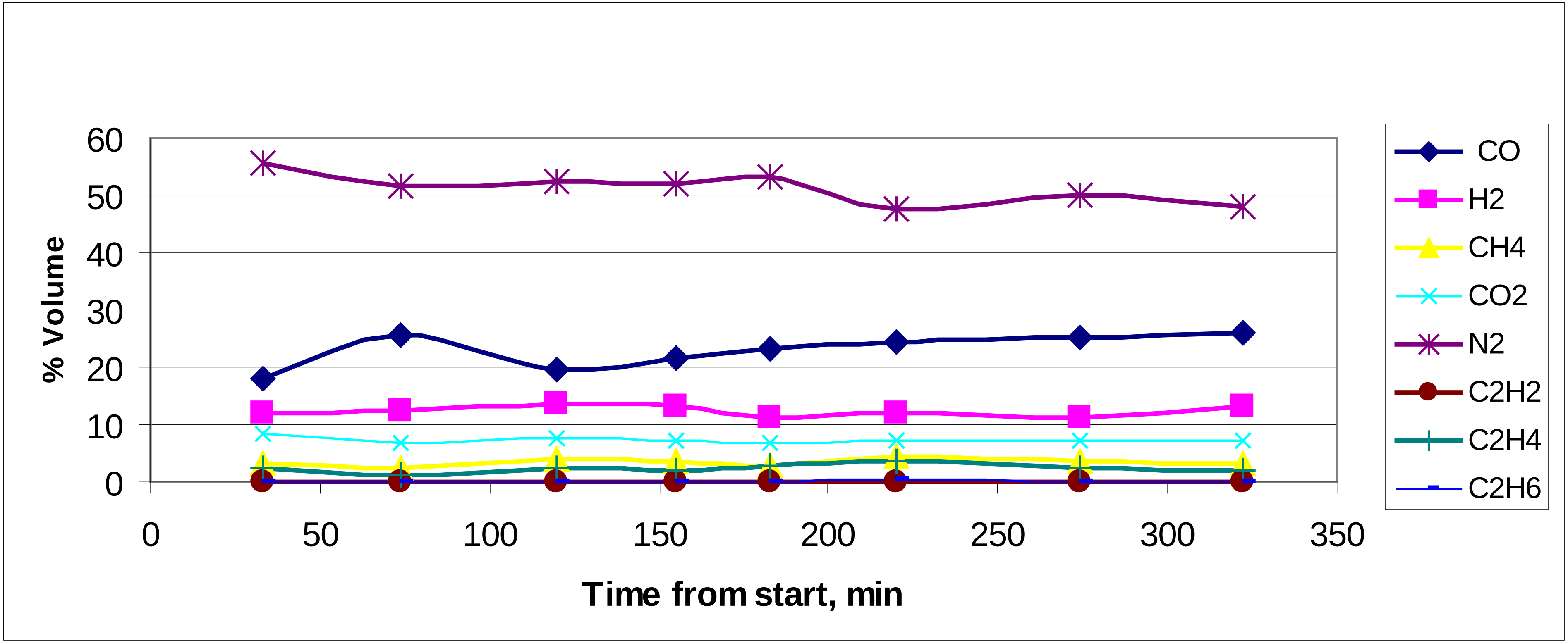
Temperature profile

for switchgrass gasification

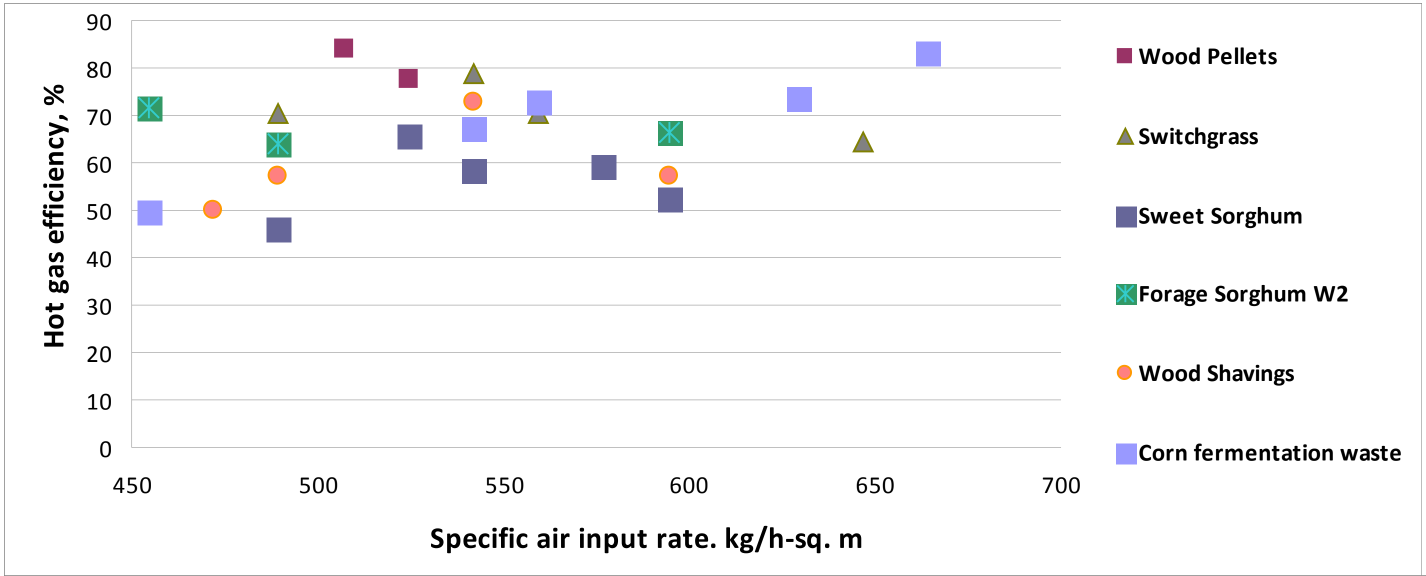


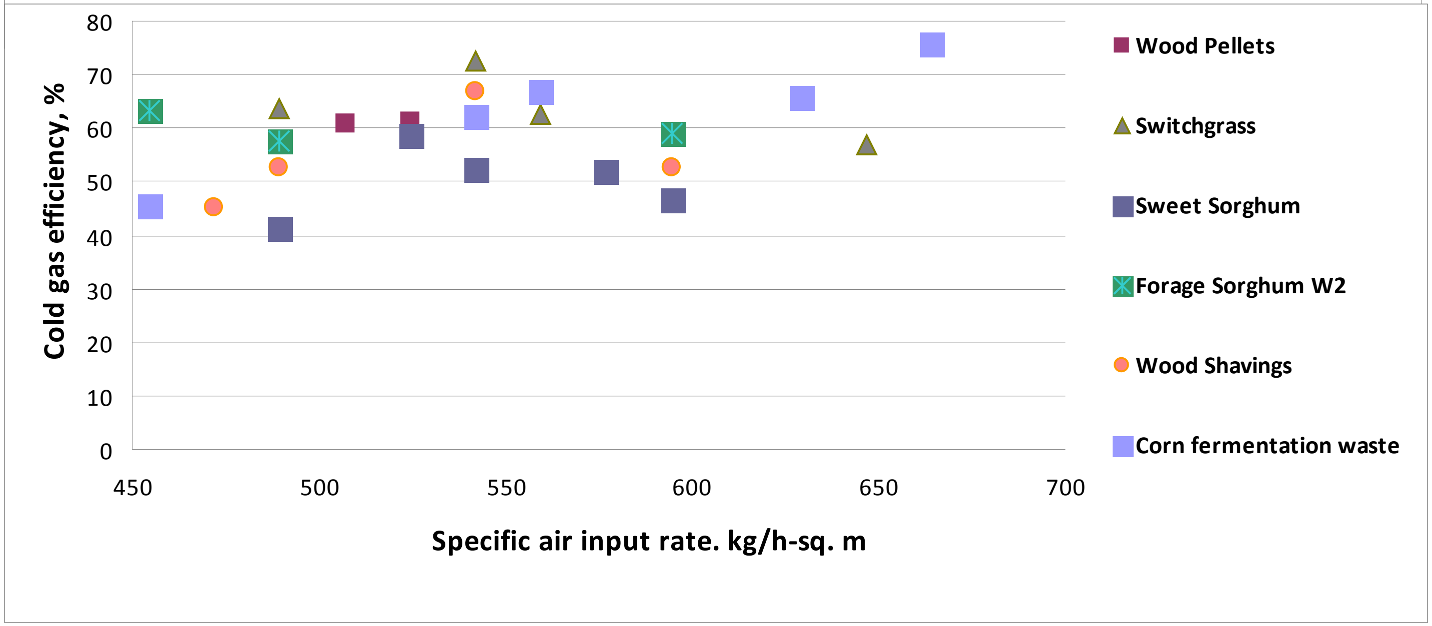
Gas composition

Switchgrass gasification



Energy efficiencies





Personnel and Financial Support

PIs:

- **Ajay Kumar**
- **Krushna Patil**
- **Danielle Bellmer**
- **Raymond Huhnke**

Graduate students/Research engineer:

  - Ashokkumar Sharma – Design and study of lab-scale FBG
  - Prakash Bhoi – Study of downdraft gasification
  - Vamsee Pasangulapati – Thermochemical characterization of biomass
  - Akshata Modinoor & Pushpak Bhandari– Design and study of a new catalytic tar cracker
  - Luz Martin & Akshata Modinoor– Characterization and evaluation of selected catalysts for tar cracking

- Financial Support provided by:
  - **Oklahoma State Regents for Higher Education**
  - **NSF OK-EPSCoR**
  - **Oklahoma Bioenergy Center**
  - **USDA Special Grant**
  - **Director of the Oklahoma Agricultural Experiment Station**

Thank you

Questions?