Energy from Biofuels: Steam-Air Gasification of Biomass

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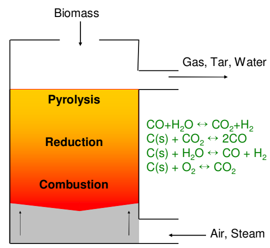
Introduction

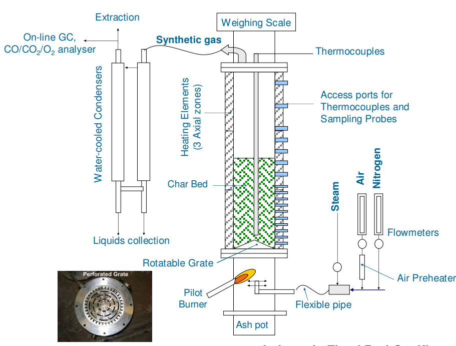
- **Biomass is an important source of renewable energy for securing a sustainable and diverse energy supply and for tackling climate change.**
- **Gasification**
  - Conversion of biomass into H_2 and CO rich gases for feedstock or energy production.
  - The end-use of the product gas and economic factor govern the selection of a particular gasification process.
  - The counter-current gasification used in this work has been traditionally ruled out in gas turbine application due to the high level of contaminants.
- **Research Objectives:**
  - Investigate the influence of operating parameters such as temperature, gasifying agents and equivalence ratio on the formation of producer gas and higher hydrocarbon.
  - Application of mathematical models to the gasification process for comprehensive understanding of the controlling mechanism.

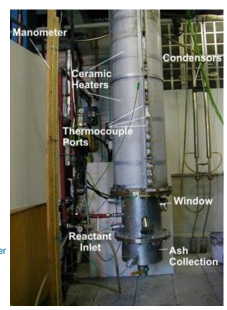


Counter-current gasifier

Experimental Methods

- **Fixed Bed Gasifier**
  - Batch type counter-current reactor (1.5m in height and 0.2m in diameter)
  - Electrically heated and maintained at temperature ≈750°C.
  - Perforated and rotatable grate allows ash removal during operation.
  - Measurement: weight, temperature, gases (CO, CO_2, O_2, H_2, CH_4, C_3H_8, NH_3, H_2S etc.)
  - This reactor will be part of a novel gasifier to produce tar-free gases from biomass





Lab-scale Fixed Bed Gasifier

- **Fuel Preparation**
  - Commercial lump-wood charcoal (particle size: ~3-4cm)
  - Charcoal is preheated in the reactor to a temperature over 700ºC before gasification tests.

Samples		Before Preheating	After Preheating
Proximate analysis (%wt)	Moisture	2.59	0.86
	Volatile matter	20.45	3.86
	Fixed carbon	74.15	3.47
	Ash	2.81	91.81
Ultimate analysis (%wt)	C	75.32	90.66
	H	3.39	0.71
	O (by difference)	15.89	4.30
Gross Calorific Value (MJ/kg)		15.89	30.32

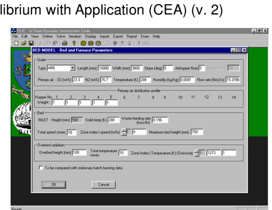
Fuel analysis for charcoal

Charcoal samples

- **Test Conditions**
  - The test runs are named according to the flow rate of each reactant supplied. For example, the 'A90-S30' run refers to the gasification using 90l/min (220kg/m²hr) of air and with steam making up 30%wt of the total input reactant.
  - The effect of air flow rate was investigated for air flow rates ranging from 90l/min (220kg/m²hr) to 120l/min (294kg/m²hr).

Chemical Equilibrium and Comprehensive Modelling

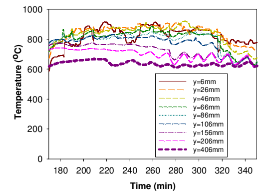
- **Chemical Equilibrium Modelling**
  - investigates the theoretical limits of gasification based on the chemical equilibrium of gasification reactions (minimisation of Gibbs free energy).
  - Using NASA Glenn's computer programme, Chemical Equilibrium with Application (CEA) (v. 2)
- **Comprehensive Mathematical Modelling by FLIC**
  - Unsteady 1D modelling of a two phase reacting bed
  - includes reactions, heat and mass transfer for the gas and solid (fuel) phases.
  - Reaction kinetics given by Hobbs et al [1] for char/CO2, char/H2O, char/H2 and char/O2.
  - Kinetics for water gas-shift reaction based on values given by Biba et al [2].



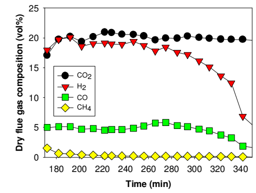
FLIC developed by SUWIC

Experimental Results

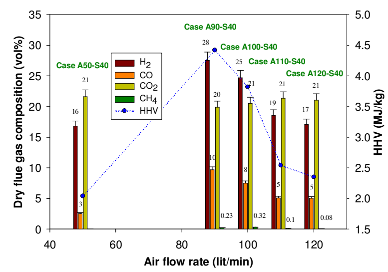
- **Bed Height Matters! Bed temperature and syngas evolution decreases at bed height <106mm.**
- **Low over-bed temperature affects the flue gas composition.**
- **Mass conversion rate ≈27kg/m²hr for Case A100-S40 (air flow rate of 100l/min (245kg/m²hr) and 40wt% steam)**



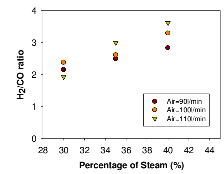
Temperature history at several locations along the gasifier (Case A100-S40).



Dry flue gas composition (Case A100-S40).



Dry syngas composition and HHV for cases with 40%wt steam at various air flow rates.



H_2/CO ratio in syngas.

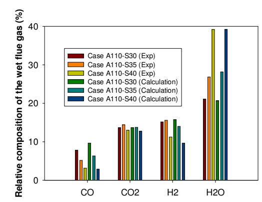
- The ratio of H_2/CO could be manipulated by adjusting the flow rate of the reactants.

Case	H_2 from char (kg/m²hr)	Syngas from char (kg/m²hr)	H_2 production ratio (%)	Syngas production ratio (%)
A50-S40	1.81	5.70	10.83	34
A90-S40	7.39	44.37	14.56	87.5
A100-S40	7.00	37.43	13.90	74.3
A110-S40	4.52	22.03	10.90	54
A120-S40	4.42	22.44	10.30	52

Conversion ratios of char to hydrogen gases.

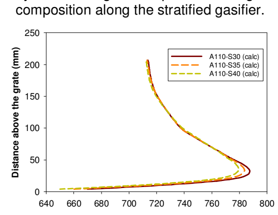
Modelling Results

- **Chemical Equilibrium Modelling**
  - Provides an insight into the chemical equilibrium based on the carbon conversion rate of the gasification experiments.
  - An increase of steam input causes a drop in CO and H_2 and a step up in H_2O concentration for cases carried out under an air flow rate of 110l/min (270kg/m²hr).

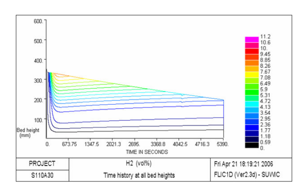


Chemical Equilibrium Modelling: gas composition (air: 110l/min, steam: 30%, 35% or 40%)

- **FLIC Modelling**
  - Calculation gave a close representation of the dynamic change in temperature and gas composition along the stratified gasifier.



FLIC: Calculated bed temperature along the bed height (air: 110l/min, steam: 30%, 35% or 40%).



FLIC: Calculated dry hydrogen composition in the bed vs. reaction time.

Conclusions

- **The production of producer gas was influenced by the air to steam ratio and total feed flow rate. By entering more air in the oxidation zone, the production of H_2 and CO decreased as combustion occurred in the reactor bed.**
- **Addition of steam increases the production of H_2 at the expense of a lower bed temperature and slower char conversion rate.**
- **Hydrogen yield obtained was about 10-14kg of hydrogen from 100kg of char.**
- **Concentration of methane was negligible and no higher hydrocarbons was detected.**

References

[1] Hobbs, M. L., Predrag, T., Smoot, D. L., Modelling Fixed-Bed Coal Gasifier, AIChE Journal, 38(5): p. 681-703. 1992.

[2] Biba, V. M., Jiri, K., Erhard, M. J., Mathematical Model for the Gasification of Coal under Pressure. Industrial & Engineering Chemistry Process Design and Development, 17(1): p. 92-98. 1978.

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EPSRC Engineering and Physical Sciences Research Council

More Information on SUWIC can be found at our websites: http://www.suwic.group.shef.ac.uk/

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