Modelling of steam-air gasification of char in a circulating fluidised bed

Muktar Bashir[1] and Yassir Makkawi[2]

[1]European Bioenergy Research Institute (EBRI), Aston University ,UK
email:bashima1@aston.ac.uk
[2]Chemical Engineering Department, American University of Sharjah, United Arab Emirates.

Outline

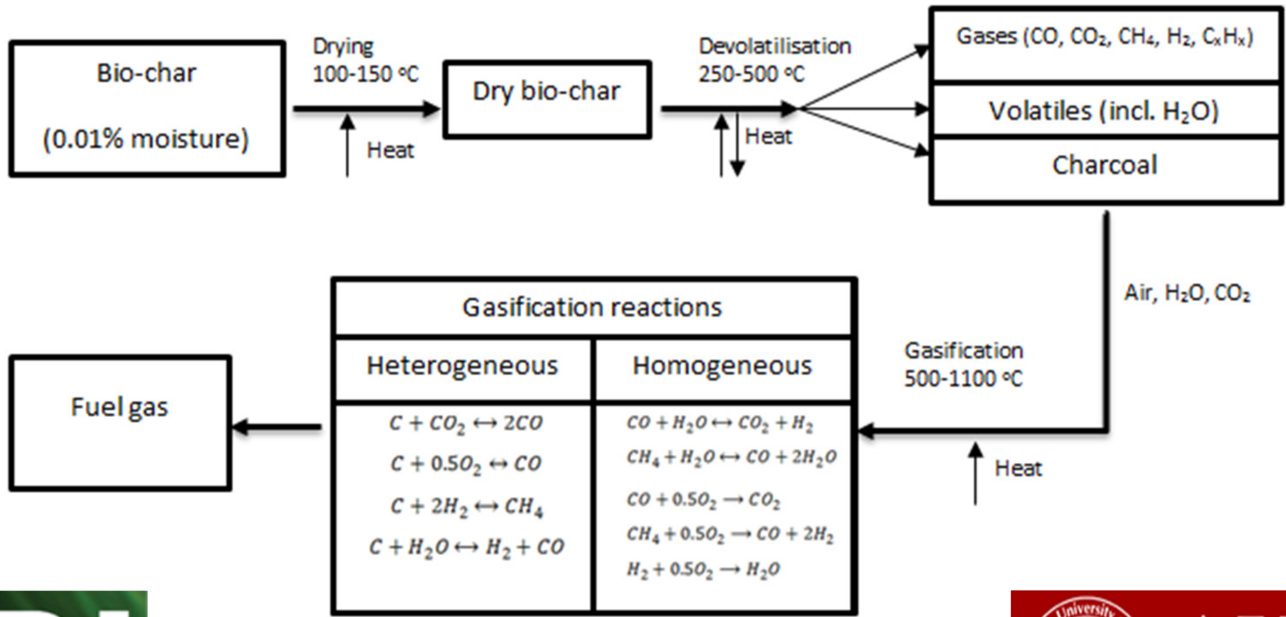
- Introduction and background
- Project objectives
- CFB Reactor
- CFD Model
- devolatilisation and gasification model
- Results and discussion
- Conclusion

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Gasification

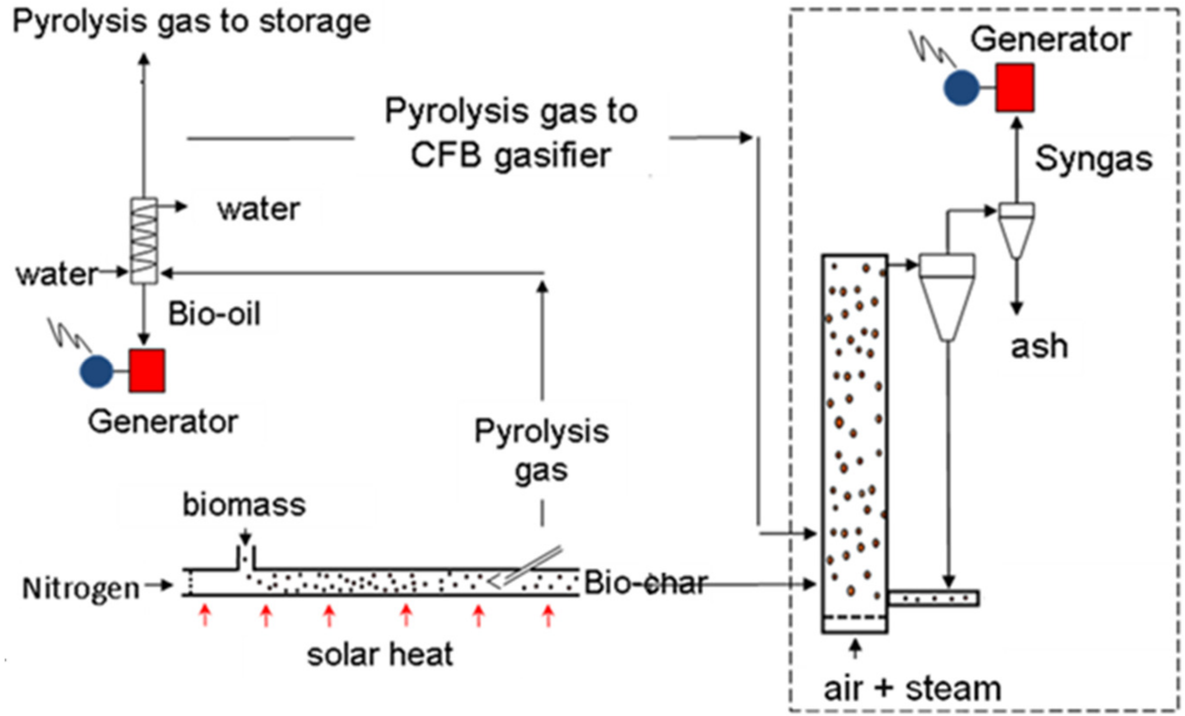
- Gasification is the thermal conversion of organic matter(biomass, char, coal etc.) through partial oxidation in normally in air, oxygen and/or steam
- The main products are mainly tar, char and non-condensable gases.
- It consist of three methods to breakdown the organic compound into these product constituents (drying, devolatilisation, and gasification reactions) .



EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Project objectives

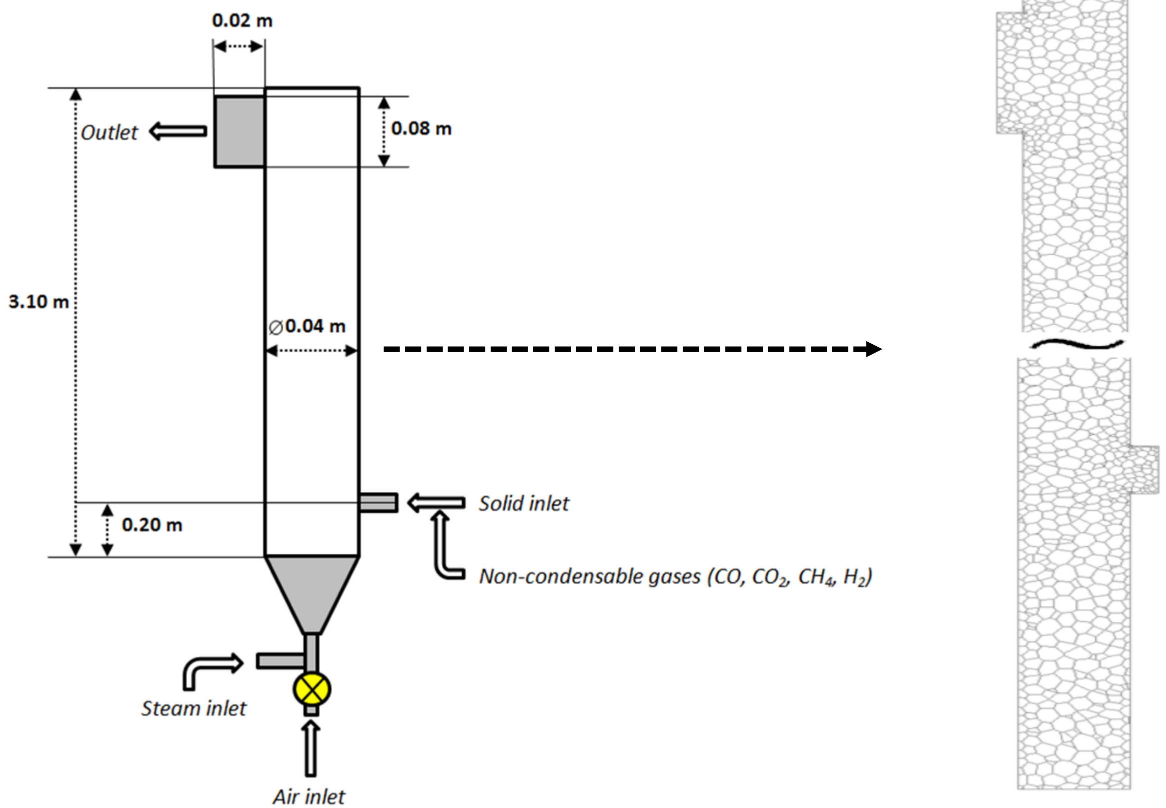


- Develop a CFD model for solar activated bio-char gasification in a circulating fluidised bed
- Predict the hydrodynamics of the process
- Implement tar catalytic cracking of bio-char in the process

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

CFB reactor



- The products were assumed to be from a solar induced pyrolysis process
- Circulating fluidised bed offers high heat and mass transfer for gasification at low temperatures

CFD model

Model

- The two fluid (Eulerian-Eulerian) model was solved using navier-stokes equations of mass, momentum, and granular temperature.
- The kinetic theory of granular flow (KTGF) was implemented to provide closure equations
- The heat transfer coefficient was calculated based on Gunn correlation in terms of Nusselts number

Boundary Conditions

- Pressure outlet is at atmospheric pressure gradient with a fully developed viscous flow (tube length >> hydraulic entry length)
- No-slip wall condition for the gas phase and shear wall condition for the solid phase
- Adiabatic temperature wall condition

devolatilisation model

- Switch grass char

Analysis	Parameters				
Proximate analysis	Moisture$(wt\%)$	Volatile$(wt\%)$	ash$(wt\%)$	Fixed carbon $(wt\%)$	HHV (MJ/Kg)
	0	62.67	5.57	31.76	19.6
Ultimate analysis	C$(wt\%)$	H$(wt\%)$	O$(wt\%)$	N$(wt\%)$	S$(wt\%)$
	51.7	5.5	37.7	0.5	4.6

- Rate of biomass devolatilisation

model	Rate Equation	A	E	T
Primary Pyrolysis	$r_{pyrolysis} = kC_{volatiles}^{0.67}$	1.032×10^8	103.7	
Thermal tar cracking	$r_{tar-cracking} = kC_{tar}$	1.55×10^5	87.6	
Tar combustion	$r_{tar-combustion} = kC_{tar}^{0.5}C_{O_2}$	$9.2 \; x \; 10^6$		9650
Catalytic Tar reforming	$r_{tar-reforming} = kC_{tar}$	1.0×10^4	61	

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Gasification model

- Heterogeneous reactions
- Homogeneous reactions

Reactions	Rate	A(1/s)	E(KJ/mol)
Boudouard Reaction	$\frac{dC_C}{} = -kC$ [illegible]	3.62×10 [illegible]	77
Carb[illegible]			
Hydr[illegible]			
Steam reaction	$\frac{dC_C}{dt} = -kC_{H_2O}$	[illegible]	[illegible]

Reactions	Rate	A(1/s)	E(KJ/mol)
Water –gas shift reaction	$\frac{dC_{CO}}{dt} = -kC_{CO}C_{H_2O} + \frac{C_{CO}C_{H_2O}}{K_pT}$	2.65×10^{-2}	66
Carbon –monoxide Oxidation	$\frac{dC_{CO}}{dt} = -kC_{CO}C_{O_2}^{0.25}C_{H_2O}^{0.5}$	8.83×10^{11}	100
Methane Oxidation	$\frac{dC_{CH_4}}{dt} = -kC_{CH_4}^{0.7}C_{O_2}^{0.8}$	1.58×10^{8}	202
Hydrogen Oxidation	$\frac{dC_{H_2}}{dt} = -kC_{CO}C_{H_2}$	3.09×10^{11}	100
Steam Reforming reaction	$\frac{dC_{CH_4}}{dt} = -kC_{CH_4}C_{H_2O}$	3.02×10^{6}	125

European Bioenergy Research Institute

American University of Sharjah

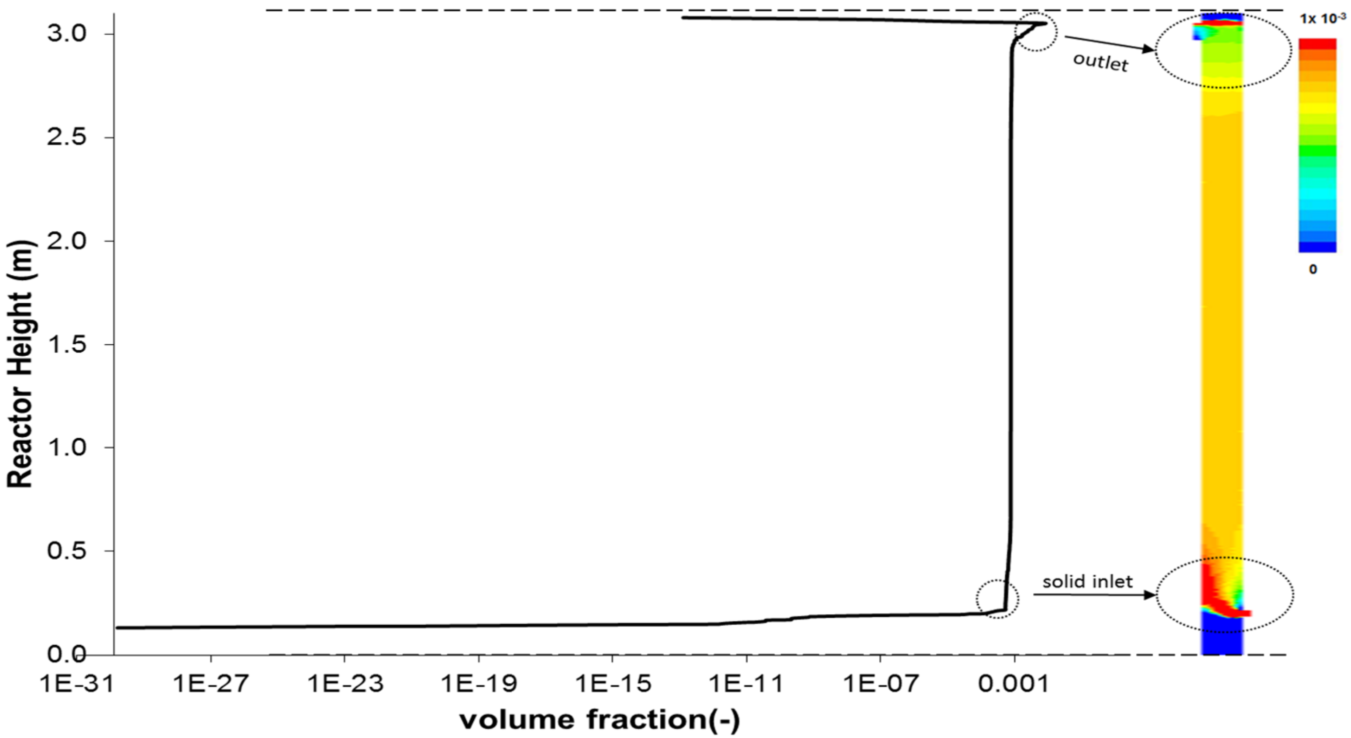
Operating conditions

Parameters	Value	Parameters	Value
Pressure outlet [atm]	1	char inlet temperature [K]	773
Biomass flow rate [g/s]	2	Gas inlet temperature [K]	300
Pyrolysis gas flow rate [g/s]	0.0003	Particle-Particle restitution	0.9
char size [μm]	250	Particle-wall restitution	0.8
Air flow rate [g/s]	1	Specularity coefficient	0.5

EBRI European Bioenergy Research Institute

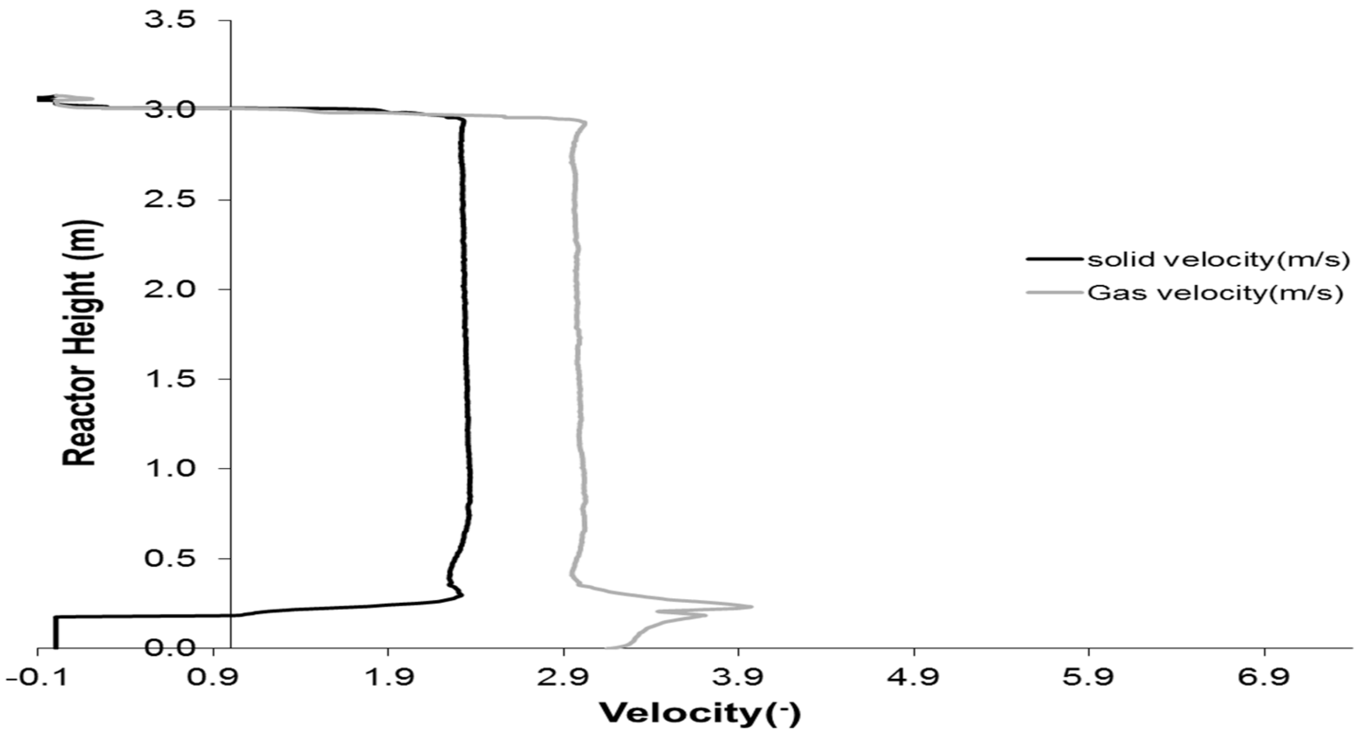
AUS American University of Sharjah

Concentration profiles



- Initial inlet turbulence showing the sweeping effect of the gas
- High concentration of solids at the wall

Velocity Profiles

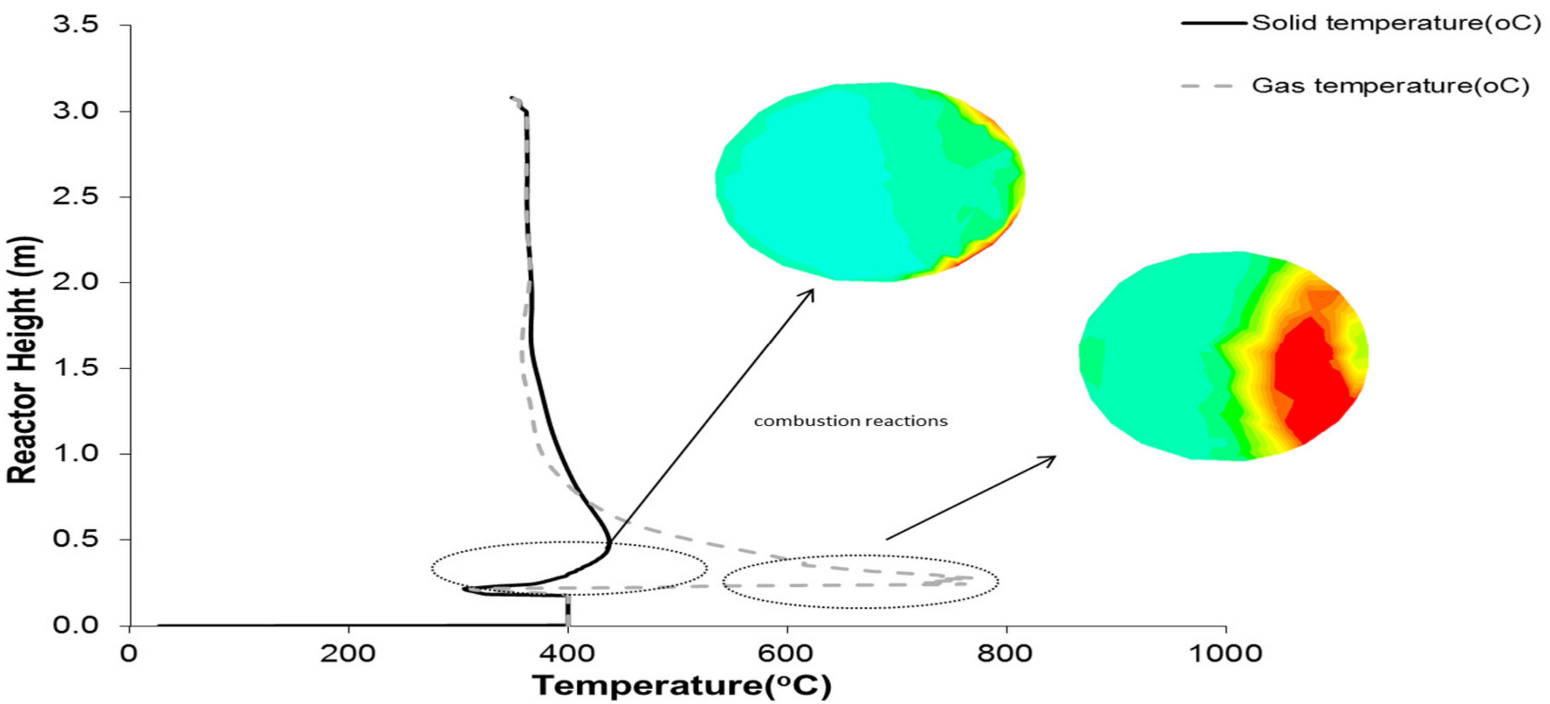


- Uniform flow of char particles observed along the reactor, except towards the exit section
- Highest char velocity is near the core region except at the outlet section due to the effect of cone solid-gas separator

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Temperature distribution

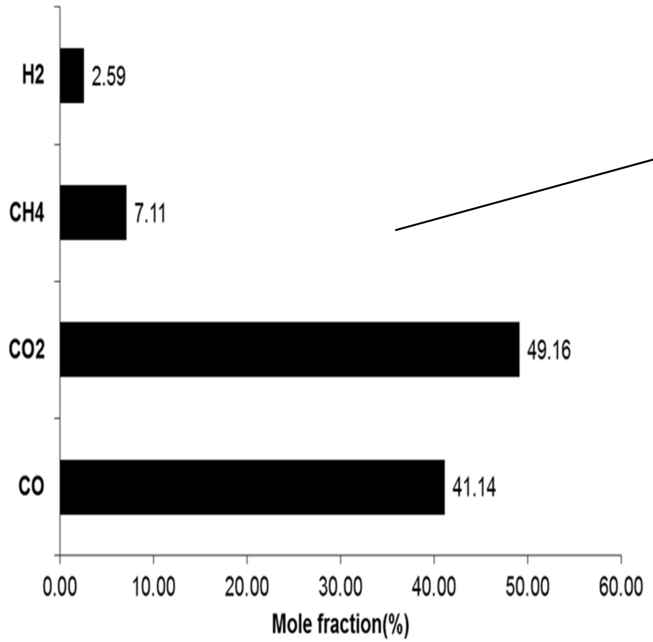


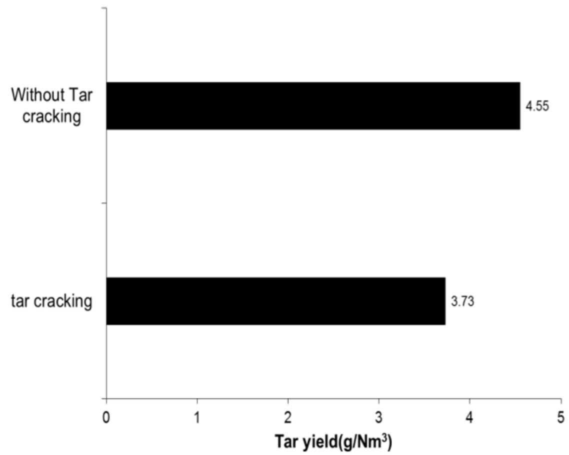
- Uniform temperature distribution
- Sort entrance length of ~ 1 m

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Product composition



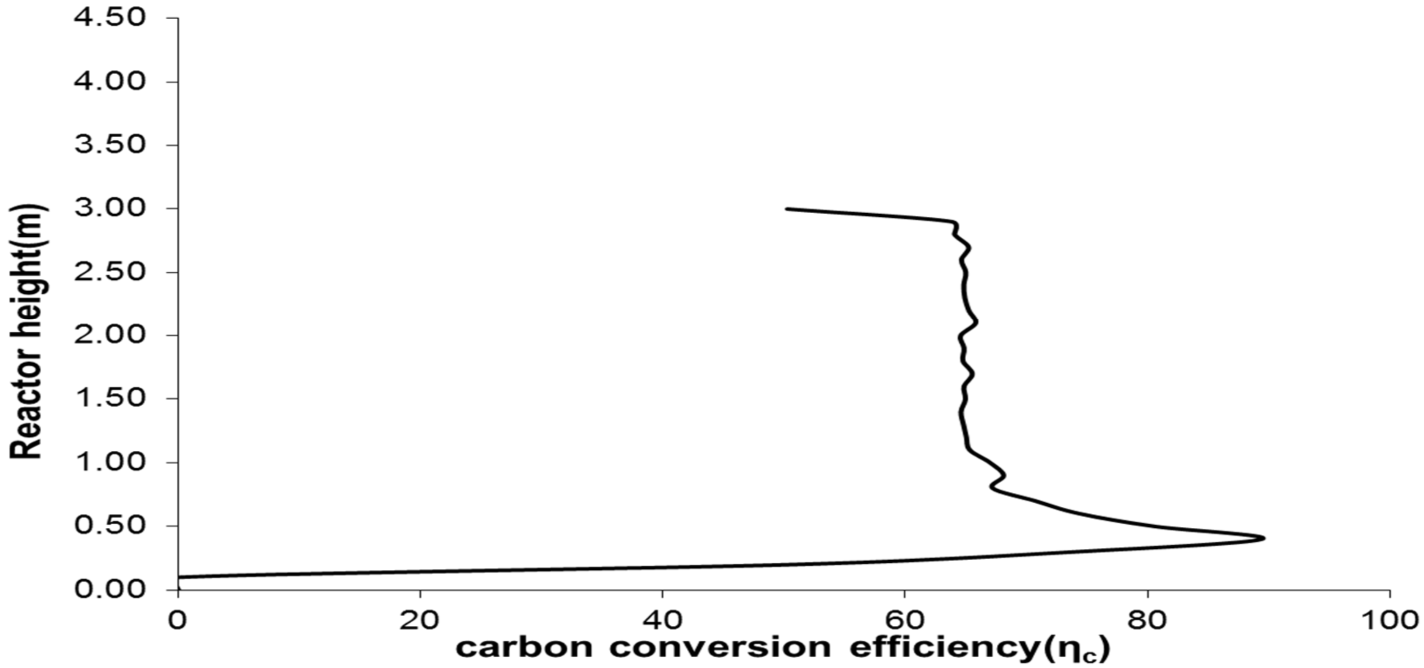


- The gas composition produced a heating value of 6.96MJ/Nm^3
- The tar content is reduced by 4%

European Bioenergy Research Institute

American University of Sharjah

Carbon conversion efficiency



- Achieved carbon conversion efficiency of 65%
- The effect is prevalent at the entrance of the bio-char into the reactor

European Bioenergy Research Institute

American University of Sharjah

Conclusion

- Switch grass char gasification has been modelled in circulating fluidised bed
- CFD analysis of the heat transfer and flow along the reactor is studied
- Effect of tar cracking was implemented to simulate a realistic process

NEXT STEP

- Solve the solid low temperature issue by using sand to improve heat and mass transfer
- Carry out parametric and sensitivity analysis of the reactor

EBRI European Bioenergy Research Institute

AUS American University of Sharjah

Thank You

EBRI
European Bioenergy Research Institute

AUS
American University of Sharjah