Journal of Quality and Technology Management
Volume IX, Issue I, June 2013, Page 01 – 11

MODELING AND SIMULATION STUDIES OF HYBRID GASIFIER USING VARIOUS FEEDSTOCKS (FUELS)

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ABSTRACT

Coal gasification is one of the focus to redress the energy issue in the world. Significant efforts have been directed towards the development of coal/biomass gasifier to replace traditional combustion systems. Detailed study of the process for a large variety of feedstocks and designs is possible through modeling and simulation at manageable costs. This paper addresses the development of Steady state simulation model for gasification using Aspen Plus with a particular emphasis on the influence of process operating conditions on synthesis gas composition, high heating value and cold gas efficiency with various fuels. The Hybrid gasifier has been modeled in three stages. The simulation results are compared with the experimental results obtained through hybrid gasifier. The performance of the simulated gasifier has been compared using experimental data for Coal and Auto Shredder Waste (Used Tyres). In the simulation study, the operating parameters like Temperature, Equivalence Ratio (ER), Feed Moisture Content and Steam/Feed Injection Ratio have been varied over wide range as 400-1400°C, 0.1-0.9, 5-40%, and 0.05-0.4 respectively to investigate their effect on syngas composition, High Heating Value (HHV) and Cold Gas Efficiency (CGE). It was observed that Auto Shredder Waste has maximum value of CGE (34%) at an ER of 0.28. Coal shows highest value of CGE 55% at an ER of 0.31. Among all feed stocks considered coal shows best gasification characteristics regarding Cold Gas Efficiency. Temperature increases the production of CO and H_2*. Increasing ER decreases the production of CO and* H_2 *which decreases the CGE. Feed moisture content is an important parameter affecting the heating value of the gas. Steam injection favors hydrogen production. The study has been instrumental to identify the preferred operating parameters of gasifier under consideration.*

Keywords: *Coal gasification, simulation, feedstock variations, Gasifier operating parameters.*

1) INTRODUCTION

Coal gasification is one of the focus to redress the energy issue in the world as well as emerged as a promising technology to protect the environment due to reduce emissions as compared to the other methods available to produce energy from coal and biomass. It has low footprint relative to combustion or incineration but high energy recovery as compared to combustion and incineration. In recent years, public concern about climate change has grown significantly. Emissions of greenhouse gases such as carbon dioxide, methane and nitrous oxide from industrial activities have long been known to be major contributors to global warming. This trend has led to significant interest in the increased use of energy technologies with inherently low-carbon footprints (e.g., renewable energy sources such as wind, solar or biomass) as well as in retrofitting of existing ones (e.g., via carbon capture and storage) to reduce greenhouse gas emissions (Wendy et al., 2010). The waste tyres in the world are estimated to be $5*10^6$ tonnes per year (Holikova et al., 2005). The chemical composition of tyres is varied but typically it has 50% rubber, 25% fillers, 10% steel, 1% sulphur, 1% zinc oxide, processing oil, plasticizers and vulcanization accelerators (Seidelt et al., 2005). Pyrolysis of used tyres has been investigated by many researchers [Roy et al., 1999, Rodriguez et al., 2001, and Ucar et al. 2005) and considered as a viable route to produce energy from used tyres. Gasification of tyre waste has also been investigated (Shahid et al., 2011). Significant efforts have been directed towards the development of coal/waste material such as used tyres or biomass gasifier to replace traditional combustion systems (Doherty et al., 2009). Detailed study of the process for a large variety of feedstocks and designs is possible through modeling and simulation at manageable costs (Malgar et al., 2007).

This paper addresses the development of Steady state simulation model for gasification using Aspen Plus with a particular emphasis on the influence of process operating conditions on synthesis gas composition, high heating value and cold gas efficiency with various fuels. In this work we have investigated the experimental setup for the gasification of coal and tyres waste in a Cross draft gasifier. The simulation results have been validated with the experimental data from the Cross draft gasifier.

2) EXPERIMENTAL SETUP

The gasification behavior of coal and used tyres is studied at "Cross draft" pilot plants which were designed, developed and fabricated locally. The system's key components include: a 10 kg/h novel gasifier, a two in one cyclone/scrubber followed by spark free fan assembly followed by gas engine and power generator set. Other assembly comprise of: A feed hopper, Ash removal cone, water recirculation loop, various valves and monitoring gear.

This process is unique in converting biomass into synthesis gas. The exclusive design of the gasifier offers uniform airflow through the fuel bed when fuel is allowed to flow under gravity without any constriction. Hybrid gasification design has accommodated all the features required for a perfect gasification unit to treat difficult residues with variable ash and composition. This makes it suitable for a wide variety of feed stocks.

The gasification process can be divided into three main zones (see Fig. 1)

i) Fuel feeding zone – Top one third
ii) Fuel gasification zone – Middle one third
iii) Ash discharge zone – Bottom one third

Feed is loaded in the gasifier from the top feeding hopper – situated in zone 1 through a manually operated slide valve. Blower is started and air supply controlled by a regulator valve provided at the inlet of the blower. Water flow rate to the gas scrubber is set at the desired level.

The fuel is ignited through an ignition port provided on the side of the gasifier using a Bunsen burner situated in zone 2. Initially zone 2 is filled with a small amount of charcoal to start the process. Synthesis gas generated in the gasifier is drawn through wet scrubber. Inside the scrubber, gas comes into contact with water, which gives quenching effect and also removes tar and particulates trapped in the gas. Fresh water is supplied to the scrubber and after cleaning the gas drains to re-circulation tank. After leaving the scrubber, gas is passed through an orifice plate where its flow rate is measured using a water manometer. The gas then passes through the three-way regulator valve (used to control the gas flow depending upon the fuel characteristics) to a flare where it is combusted. Once the steady state condition is achieved part of the gas is diverted to gas engine for power generation. In zone 3 the gasifier is filled with sand which is then removed slowly to help flow of ash under the gravity force. The picture plate of gasifier is shown in Fig 1 and the ultimate and proximate analysis of the feedstock used is given in Table 1.

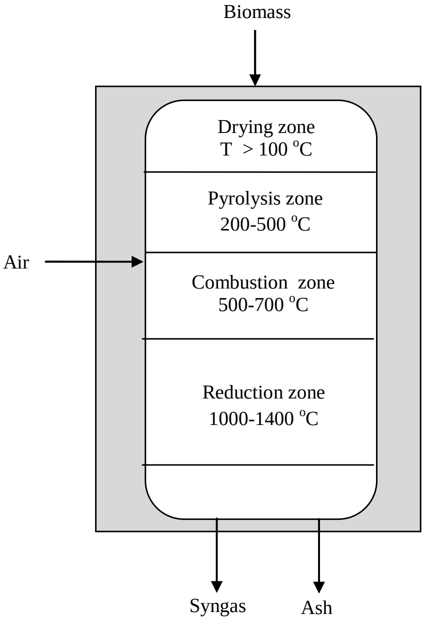

Figure 1: Cross Draft Gasifier Picture Plate and Schematic diagram of gasification Zones

Table 1: Characteristics of Feedstock

Ultimate and Proximate analysis of feed stocks		
	Coal	**Used Tyres**
Proximate analysis (%)		
FC	45.03	36.2
VM	44.168	51.29
MC	7.4	1.2
ASH	10.799	11.31
Ultimate analysis (%)		
ASH	10.799	11.31
C	75.107	67.86
H	5.6197	10.22
O	3.925	5.37
N	2.944	4.27
Cl	0	0.97

S	1.6053	0

3) MODEL DEVELOPMENT AND VALIDATION

Gasification process has been simulated by many researchers (Giltrap et al., 2003, Emun et al., 2010, Bapat, et al., 1997, and Mehrdokht, et al., 2008). These models provide good representation of the actual process and help in optimizing the process by estimating the effect of various parameters on the gasification characteristics. The simulation model developed in this study is a steady-state kinetic free model which calculates the syngas composition by using Gibbs free energy minimization approach. Three Aspen Plus reactor models along with external FORTRAN subroutines simulate the gasification process. The model has been validated by the experimental data obtained from the crossdraft gasifier. The model is in good agreement with the experimental results. The description of the simulation model has been adequately detailed in previous research articles of the same author (Ramzan et al., 2011).

4) PARAMETRIC STUDY

The simulation model developed for gasifier has been used for parametric study of the gasification process. Two feed stocks have been used for the analysis. These are coal and used tyres. The parameters considered are gasifier temperature, Equivalence Ratio (ER), steam to feed ratio. The effect of these parameters has been investigated on syngas mole fraction, hydrogen production, and Cold Gas Efficiency (CGE) of the gasification process.

4.1) Effect of Gasifier Temperature on Syngas Composition

The gasifier temperature affects the composition of syngas. Gasification involves oxidation and reduction reactions taking place simultaneously. At very low temperature the fuel is not completely converted. When temperature increases due to combustion reactions the fuel is converted into carbon dioxide, carbon monoxide and other gases. Reduction reactions like boudouard and CO shift reaction increase the conversion of fuel into carbon monoxide and hydrogen. The effect of temperature on the syngas composition is shown in Fig. (2 a,b). The temperature has been varied from 400°C to 2000°C. At very high temperatures mole fraction of methane in syngas is very small but at low temperatures it is produced in significant amounts.

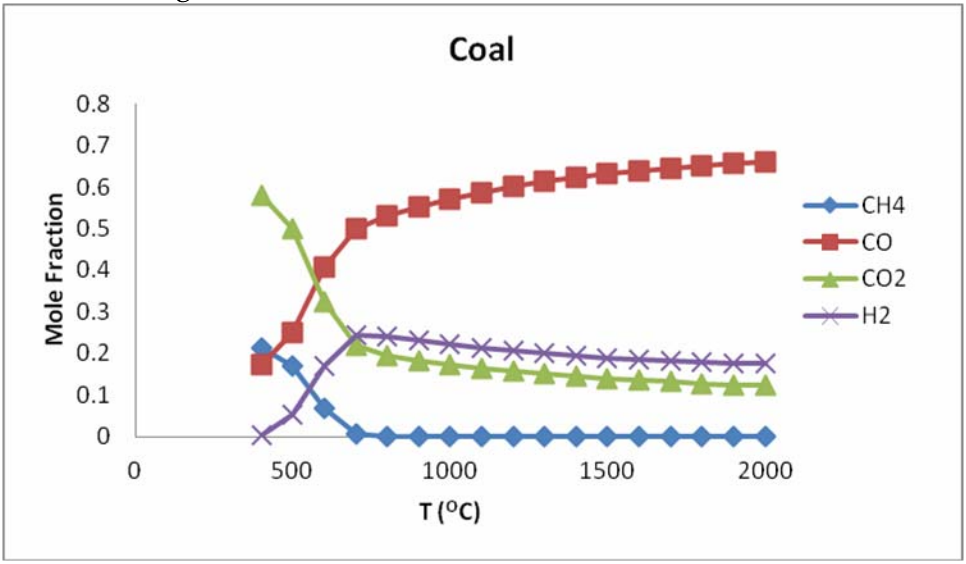

Figure 2 (a): Effect of Temperature on Synthesis Gas Composition

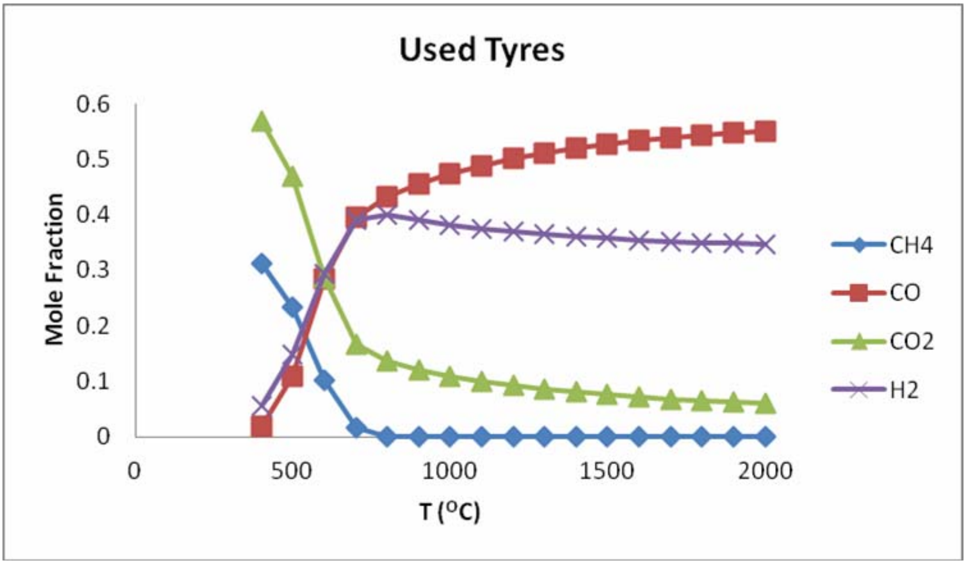

Figure 2 (b): Effect of Temperature on Synthesis Gas Composition

4.2) Effect of Equivalence Ratio (ER) on Syngas Composition

ER is the ratio of actual amount of air supplied to the gasifier and the stoichiometric amount of air required for the complete combustion of feed. It is the most important parameter which controls the composition of syngas. Fig. (3 a,b) shows the effect of ER on the syngas composition for the coal and used tyres. The ER has been varied in the range of 0.1-0.9. At very low ER the conversion of feed is not complete. At very high ER close to unity the carbon and hydrogen present in the feed are converted into carbon dioxide and water respectively and no combustible gas is produced. So practically the ER is kept around 0.25-0.35 for the syngas to contain significant amount of combustible gases.

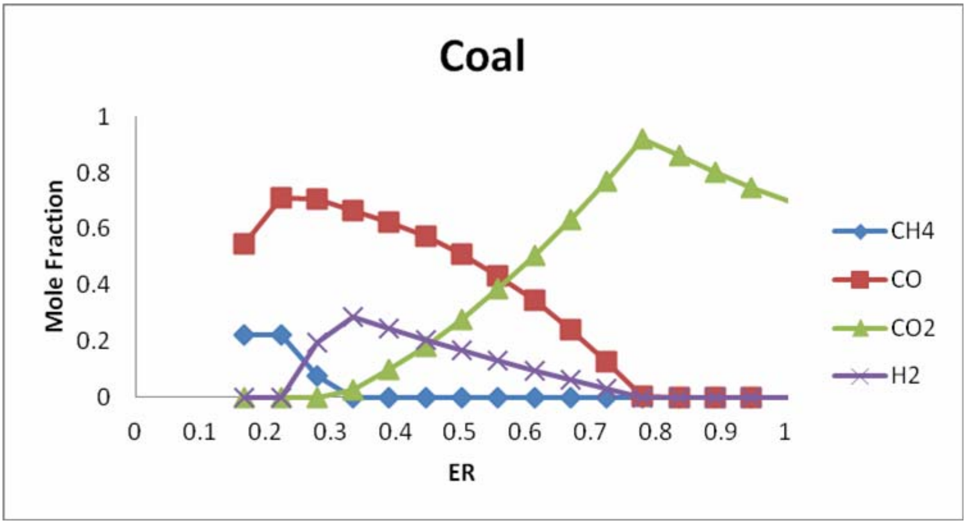

Figure 3 (a) Effect of Equivalent Ratio on Synthesis Gas Composition

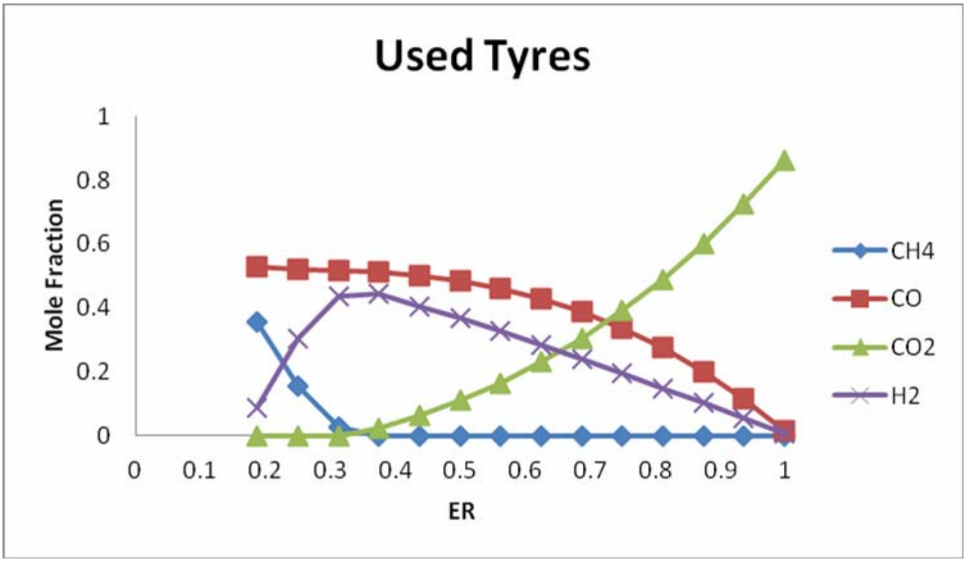

Figure 3 (b) Effect of Equivalent Ratio on Synthesis Gas Composition

4.3) Effect of Steam Injection on Syngas Composition and Hydrogen Production

The effect of steam injection on the production of carbon monoxide and hydrogen is shown in Fig. (4). The ratio has been varied from 0.1-0.4. Steam injection in the gasifier favors the production of hydrogen but it decreases the amount of carbon monoxide slightly. This effect is supported by the gasification chemistry.

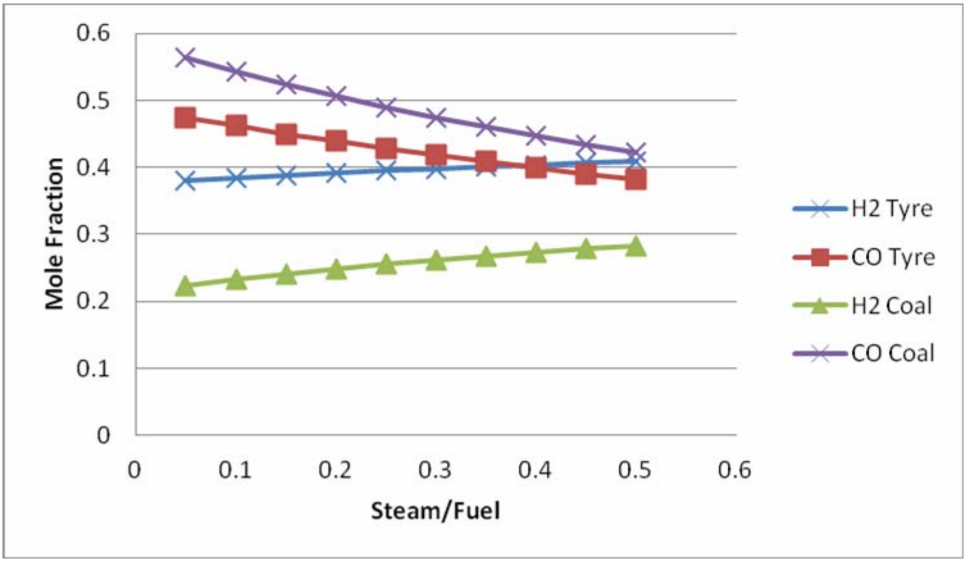

Figure 4: Effect of Steam to Fuel Ratio on Synthesis Gas Composition

4.4) Effect of Equivalence Ratio (ER) on Cold Gas Efficiency (CGE)

Cold Gas Efficiency (CGE) is the parameter which is used to estimate the conversion efficiency of the gasification process or the energy recovery from the fuel. It tells how much energy contained in the feed is available in the syngas produced. The CGE has been calculated by the following formula:

$$CGE = \frac{\dot{m}_{gas} \times HHV_{gas}}{\dot{m}_{gas} \times HHV_{fuel}}$$

The effect of ER on the CGE is shown in the Fig. (5).

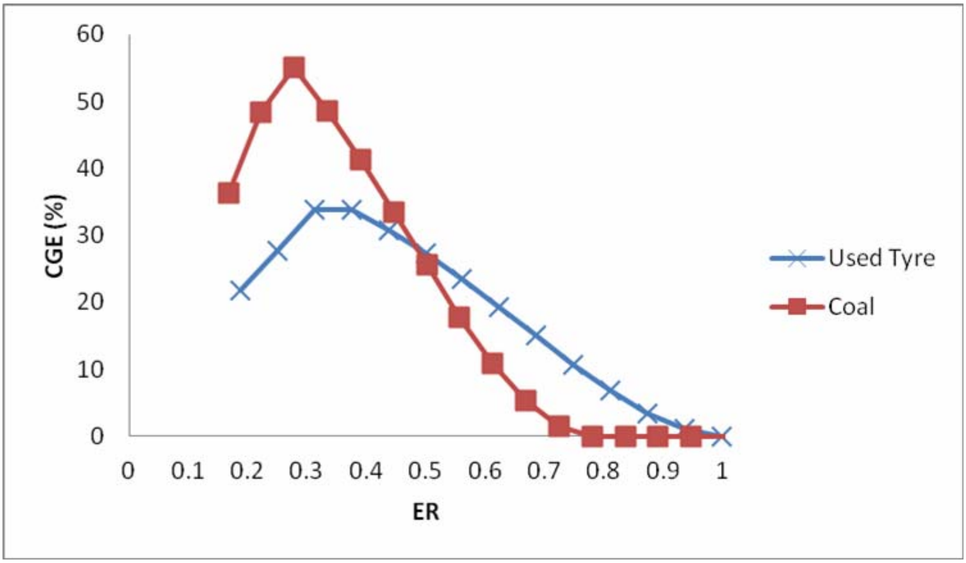

Figure 5 Effect of Equivalent Ratio on CGE (%)

Higher the CGE higher is the energy recovery from the fuel. At low ER the CGE is low. It is due to the fact that feed is not converted significantly at low ER. As the amount of air supplied to the gasifier increases the CGE increases due to the production of combustible gases in the syngas. But when the ER is further increased beyond the practical limit (around 0.25-0.35) the CGE decreases and becomes almost zero when ER approaches to unity. It is due to the fact that all the carbon and hydrogen is converted into carbon dioxide and water so no combustible gas is produced.

5) CONCLUSION

Gasification of coal and used tyres has been investigated experimentally in a downdraft gasifier. A steady-state simulation model for the process has been developed using process simulator Aspen Plus. The simulation model has been used to perform parametric analysis to investigate the parameters of the gasification process and to optimize the performance of gasification process for various feed stocks.

Coal shows highest CGE (55%) at an ER 0.28 whereas used tyres show maximum CGE (34%) at an ER of 0.31.

6) FUTURE WORK

A simulation model for the complete gasification process is being developed. This model includes gasification model along with simulation of the syngas purification section to remove the acid gases like carbon dioxide and hydrogen sulfide to increase the quality of syngas and to make it more environment friendly. Absorption of acid gases by a solvent has been used in the model for downstream gas purification section.

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