SIMULATION OF AIR-STEAM GASIFICATION OF RICE HUSK USING ASPEN PLUS

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Abstract—A thermodynamic equilibrium model for air-steam gasification of rice husk is developed using Aspen Plus (Advanced System for Process Engineering Plus) process simulator.

The model is based on Gibbs free energy minimisation and tar formation is incorporated using FORTRAN subroutine.

The prediction accuracy of the developed model is determined by comparing the model predicted syngas composition with experimental results and found to be in fair agreement. Effect of key operating parameters on syngas composition, gas yield and first law efficiency is analysed using the developed model .For an equivalence ratio of 0.25, steam to biomass ratio of 1 and temperature of 1000 K, hydrogen mole fraction, first law efficiency and heating value of syngas are found to be 23.78 %, 76.14 % and 5.038 MJ/Nm^3, respectively.

Index Terms—Gasification, equilibrium model, Aspen Plus, syngas.

I. INTRODUCTION

Biomass is one among the most promising renewable energy resources and its utilisation through gasification is in line with the requirements of sustainable development. Biomass gasification is a complex process consisting of different steps, namely drying, pyrolysis, combustion and gasification of pyrolysis products.

Mathematical models have been used extensively to investigate biomass gasification due to high costs and difficulties associated with experimentation.

Among the methods available for modelling gasification, thermodynamic equilibrium model (TEM) is one of the simpler approaches and can be used as a preliminary tool to analyse the effect of feedstock and process parameters on gasification process. Thermodynamic equilibrium modelling can be achieved through two approaches namely, stoichiometric and non-stoichiometric [1]. Non-stoichiometric equilibrium modelling is useful when temperature and pressure are known and reaction stoichiometry is unknown. However non-stoichiometric equilibrium modelling employing Gibbs free energy minimisation is relatively complex. Aspen Plus process simulator [2] provides an easier alternative for simulating non-stoichiometric models.

The Aspen Plus process simulator has been used extensively to simulate several complex processes such as coal conversion and petroleum refining using well written flexible Fortran subroutines [3]. Doherty *et al*. [4] simulated a circulating fluidised bed gasifier using Aspen Plus and studied the effect of preheating of air on gasifier performance and composition of syngas. Air gasification of olive kernel in a pilot scale bubbling fluidised bed gasifier was simulated by Michailos and Zabaniotou [5] in Aspen Plus by using a combination of two approaches-Gibbs free energy minimisation and reaction kinetics. Mathieu and Dubuisson [6] simulated wood gasification and concluded that air preheating has no significant impact on efficiency beyond a certain critical air temperature. Mansaray *et al.* [7] developed two models to simulate the performance of a dual-distributor-type fluidised bed gasifier where the first model used an overall equilibrium approach, and the hydrodynamic complexities of the reactor were incorporated in the second one. Nikoo*et al.* [8] modelled the reactions taking place in the bed and freeboard of a fluidised bed reactor separately by adopting governing hydrodynamic equations for a bubbling bed and kinetic expressions for the char combustion. Gasification of wood in a downdraft gasifier was simulated by Paviet*et al.* [9] to predict the composition of flaming pyrolysis gas and producer gas. Kumar *et al*. [10] simulated corn stover and distiller grains gasification using Aspen Plus and predicted the flow rate and composition of product gas.

The present work deals with the simulation of air-steam gasification of rice husk in a fluidised bed gasifier using Aspen Plus software, based on Gibbs free energy minimisation.

II. MODELLING APPROACH

A. *Assumptions*

The following assumptions are made for developing the model:

(i) Gasifier is a steady state system with uniform temperature and pressure throughout.

(ii) The residence time of the gases in the gasifier is high enough to establish thermodynamic and chemical equilibria.

(iii) All the gases behave ideally.

(iv) Gases except H_2, CO, CO_2, CH_4, and N_2 are considered as dilute.

(v) N_2 is inert in the entire process.

(vi) Biomass is made up of Carbon, Hydrogen and Oxygen.

(vii) Steam is supplied under superheated condition of 1 bar and 300 ^{o}C.

(viii) All elements in biomass except Sulphur take part in the chemical reactions.

(ix) Tar is modelled as benzene.

B. *Aspen Plus Model*

The different stages considered in Aspen Plus simulation are decomposition of the feed, gasification reactions and gas solid separation.

The Aspen Plus yield reactor (RYield) is normally used when reaction stoichiometry is unknown but yield distribution is known. Biomass is given as an input material stream to the RYield reactor which decomposes it into components including Hydrogen, Oxygen, Sulphur, Nitrogen and ash based on the ultimate analysis.

The Gibbs reactor (RGibbs) is used when reaction stoichiometry is unknown, but the reactor temperature and pressure are known. It can model single phase chemical equilibrium or simultaneous phase and chemical equilibria. The components of biomass are fed into the RGibbs along with the gasifying agents, air and steam. The Gibbs reactor predicts the constituents of syngas through Gibbs free energy minimisation.

The Gibbs reactor is followed by a separation column to separate gases and solids.

All the components are integrated to model the gasification process and the process flow sheet is shown in Fig. 1.

Rice husk, the feed stock used is defined as a nonconventional solid and is specified by its proximate and ultimate analyses. The stream class used for modelling is MCINCPSD as it includes the substreams mixed, conventional solids and nonconventional solids. All the gases are taken as mixed substreams, char as conventional solid substream, biomass and ash as nonconventional solid substreams.

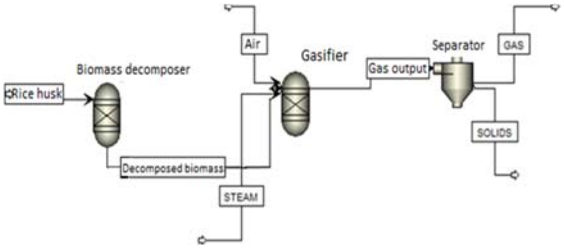

Fig. 1 Process Flowsheet

C. *Model Validation*

The accuracy of the model is checked by comparing the gas composition predicted by the model with the experimental results of Campoy *et al.* [11]. The comparison is shown in Fig. 2.

D. *Model Application*

The developed model is used to analyse the effect of temperature, steam to biomass ratio (SBR) and equivalence ratio (ER) on syngas composition, gas yield and first law efficiency. Lower heating value of the dry product gas is estimated from the gas composition and is expressed in volume basis as [12],

$$\mathrm{LHV} = 10.79\,\mathrm{Y}_{\mathrm{H}_2} + 12.26\mathrm{Y}_{\mathrm{CO}} + 35.81\mathrm{Y}_{\mathrm{CH}_4} \quad (1)$$

The flow rate of dry synthesis gas was calculated using the relation [12],

$$V_{dg} = \frac{V_m \times (m_{N_a} + m_{N_b})}{Y_N \dot{M}_N} \quad (2)$$

Gasification efficiency of the process is given by,

$$\eta_{\mathrm{gas}} = \frac{\text{Energy content in the product gas}}{\text{Energy content in biomass} + \text{Energy content in steam}} \quad (3)$$

Table. 1 Proximate and ultimate analyses of rice husk [13]

Proximate analysis (wt. %)		Ultimate analysis (wt. %)	
Moisture	12	C	34.35
Volatile Matter	58	H	5.22
Ash	18	O	57.66
Fixed Carbon	12	N	2.43
		S	0.31

III. RESULTS AND DISCUSSION

A. *Effect of ER, SBR and Temperature on gas composition*

The effects of equivalence ratio, steam to biomass ratio and temperature on product gas composition are shown in the Figs. 3-5. It is seen that the volume fraction of carbon dioxide increases while that of all other gaseous species decreases with increase in ER. The shifting of the process towards combustion with increase in air flow rate is the reason for this. Similar variations were reported by Puig-Arnavat *et al.* [14] and Rupesh *et al.* [15].

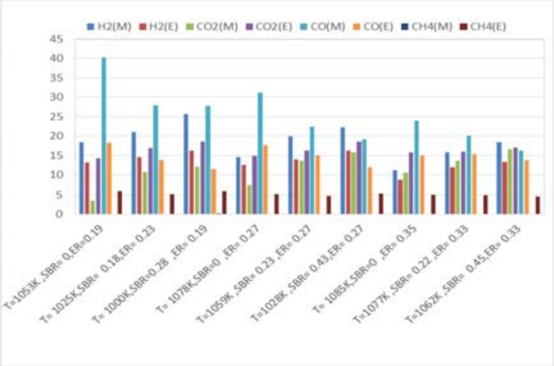

Fig. 2 Comparison between experimental and model results. E: Experimental result; M: model results.

Fig. 4 depicts the variation in product gas composition with steam to biomass ratio. The hydrogen concentration increases with SBR but the rate of increase declines gradually.

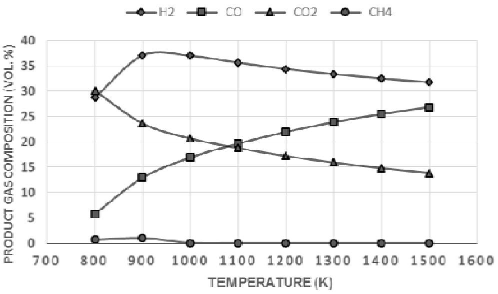

Fig. 3 Variation of syngas composition with temperature

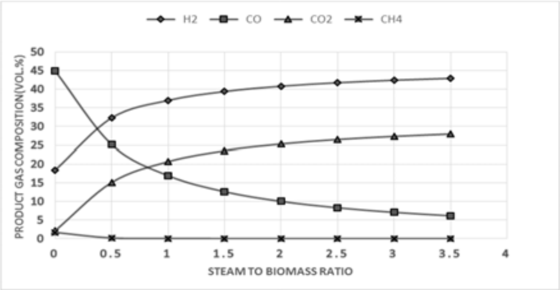

Fig. 4 Variation of syngas composition with SBR

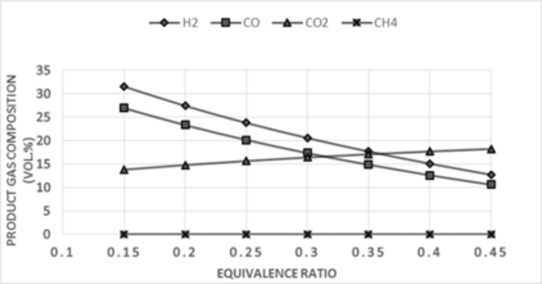

Fig. 5 Variation of product gas composition with ER

The combined effect of water gas, steam methane reforming and water gas shift reactions is responsible for this increase. It can also be noted that with steam addition the mole fraction of carbon dioxide increases while that of carbon monoxide decreases. The exothermic nature of water gas shift reaction is responsible for the rapid increase in CO_2 at lower temperatures.

It is also found that hydrogen concentration initially increases with reactor temperature up to a maximum value and then shows a gradual decrease similar to the variation reported by Lv *et al.* [16]. This is due to the exothermic nature of the water gas shift reaction.

At higher temperatures the reaction proceeds in the reverse direction as per Le-Chatelier's principle which results in a decrease in Hydrogen concentration. The endothermic char gasification reaction, water gas reaction, methane reformation and the reversal of water gas shift reaction contribute to the increase in carbon monoxide concentration with temperature. The yield of carbon dioxide and methane are found to decrease with temperature. Methane concentration decreases as the endothermic steam methane reforming proceeds in the forward direction and the exothermic methanation reaction proceeds in the reverse direction.

B. Effect of ER, SBR, and Temperature on Efficiency

The variation of efficiency with process parameters is shown in Figs. 6-8. It is observed that the efficiency initially increases as steam is supplied and then decreases with increase in steam to biomass ratio. This decrease in efficiency is due to the increased energy input in the form of steam. As the equivalence ratio increases the LHV of the product gas decreases, which again results in a decrease in efficiency. For a steam to biomass ratio of 1 and equivalence ratio 0.25 the maximum efficiency of 77.83% is achieved at 1500 K.

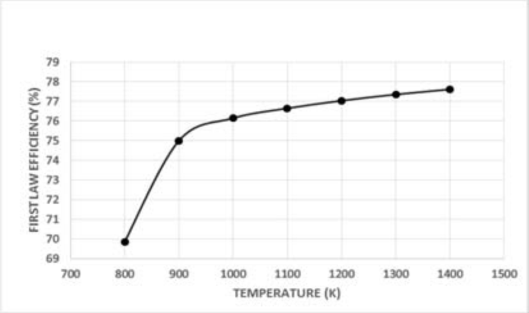

Fig. 6 Variation of first law efficiency with temperature

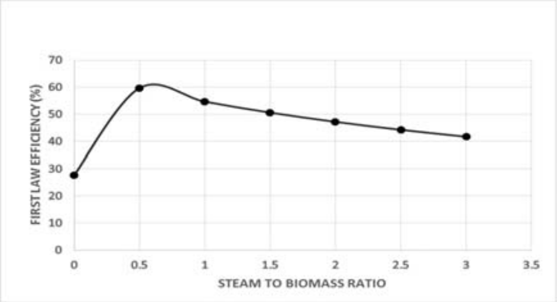

Fig. 7 Variation of first law efficiency with SBR

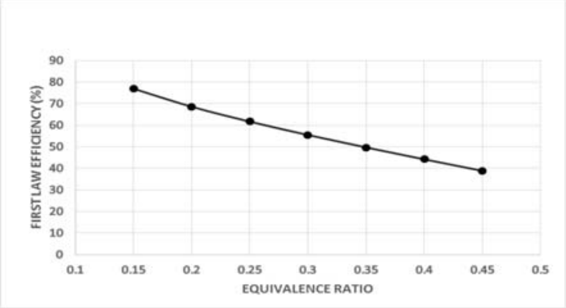

Fig. 8 Variation of first law efficiency with ER

IV. CONCLUSION

A one compartment Aspen Plus model was developed to simulate air-steam gasification of rice-husk in a fluidised bed gasifier and the effect of process parameters on gasifier yield and efficiency was investigated. For an SBR of unity and ER of 0.25, the maximum hydrogen yield was found to be 37.05 % at 1000 K. A two compartment model incorporating reaction kinetics may give better results.

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