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Biomass Gasification: Study of effect of Biomass properties and Operating parameters

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Abstract- Biomass gasification is a thermal conversion process which converts solid biomass into syngas which is can be used for various applications including power generation. India vast amount of the agri-waste residue is generated in agriculture field which can be used for power generation using gasification technology. In this study, thermodynamic equilibrium model for biomass gasification is developed to calculate the syngas composition and gas calorific value. Model is solved using 'Fsolve' function in MATLAB. Four biomasses wheat straw, paddy straw, rice straw and rice husk from Punjab state in India are studied. Gross calorific value of four biomasses at 1073K and oxygen/biomass=0.45 is in the range 24.0-26.6 kcal/mol. For steam/biomass=0.6 and 1073 K temperature, GCV of four biomasses is in the range 23.7-25.9 kcal/mol.

Index Terms- Wheat straw, Paddy straw, Rice straw, Rice husk, Gasification.

1. INTRODUCTION

The overall energy demand of world is increasing at faster rate than the increase in population [1]. Fossil energy resources that can be exploited economically are believed to be finite. Biomass is of major interest as a renewable energy source in the context of both climate change mitigation and energy security [2]. According to a recent study, oil and gas prices are set to double by 2050 [2]. There are many areas in India which don't have any access of electricity. As in India most of the people has agriculture as their occupation, the agri-waste residue can be used as the major source for power generation using gasification technology.

2. LITERATURE REVIEW

2.1. Biomass available in India

The bio-power potential in India is 16881 MW. The total energy potential using biomass and waste in India is give in Table 1. India produces 98 million tonnes of paddy with roughly 130 million tonnes of straw. Of this, about half is used as animal fodder. The rest is mostly burned in the fields, though a small amount is also consumed by brick kilns and paper and packaging industry. Gasification has higher efficiency compared to other processes such as direct combustion, pyrolysis and liquefaction [4].

The northern states in India like Punjab and Haryana are rich due to multi cropping practices. The main biomass is wheat and rice straw. Some amount of cotton stalks is also available in the western part of Punjab [1]. Last year Punjab Biomass Power Ltd (PBPL) generated 12 MW and helped farmer to reduce pollution with generation of electricity using biomass [6]. Gasification would be the one of the option for utilization of this vast amount of biomass in India.

2.2 Various gasification technologies

The major gasifiers types are downdraft, updraft, bubbling fluidized (BF) and circulating fluidized bed (CFB). Suitability of gasifier type for biomass is studied. Fluidized bed is better option for biomass gasification because: Fluidized bed gasifier shows potential in high capacity biomass gasification applications due to uniform temperature and clean gas, it is compact because of high heat exchange and high reaction rate due to intensive mixing in the bed and it tolerates many types of feedstock and have ability to deal with fluffy and fine grained materials with high ash contents and low bulk density [3]

2.3 Modelling approaches for gasification

The thermodynamic equilibrium, quasi equilibrium, kinetic and CFD model had been used for the study of biomass gasification [7,8]. Thermodynamic equilibrium modeling approach is widely used to evaluate the performance of gasification system in terms product gas composition and efficiency [8]. A kinetic model can predict the profiles of gas composition and temperature inside the gasifier. Kinetic model takes into consideration both the kinetics of gasification reactions inside the gasifier and the hydrodynamics of the gasifier reactor. CFD models are used to predict distribution of temperature, concentration, and other parameters within the reactor. CFD models are based on solutions of a set of simultaneous equations for conservation of mass, momentum, energy, and species over a discrete region of the gasifier [5].

3. MODEL DEVELOPMENT FOR BIOMASS GASIFICATION

The global reaction of biomass gasification can be written as,

$$CH_xO_y + p(O_2 + 3.76)N_2 + mH_2O \rightarrow x_1H_2 + x_2CO + x_3CO_2 + x_4H_2O + x_5CH_4 + (3.76p)N_2 \quad (1)$$

By solving elemental balance equations and equilibrium constant equations, we will get composition of gas.

Solution strategy: model equations are nonlinear equations and need to be solved simultaneously. Fsolve function in MATLAB is used for solution of set of non-linear equations.

4. RESULTS AND DISCUSSIONS

Model is used to calculate gas composition and calorific value for four biomasses- wheat straw, Paddy straw, rice straw, rice husk from Punjab India. The proximate and ultimate analysis is given in Table 2. Before predictions, the results of developed model are validated with experiment for fluidized bed steam biomass gasification of rice husk at 750 °C and steam/biomass=1.7 [9].

Table 2 Biomass from Punjab used for model prediction

Biomass	Wheat straw	Paddy straw	Rice straw	Rice husk
Proximate analysis (%)				
VM	71.41	61.62	63.12	58.07
Ash	7.58	20.49	10.1	17.82
FC	16.02	14.01	18.2	16.65
M	4.99	4.3	8.58	7.5
GCV	4010	3309	3343	3582
Ultimate analysis (%)				
C	46.46	39.97	41.04	38.9
H	5.12	3.97	6.26	5.1
O	35.5	30.26	38	37.9
N	0.47	0.79	1.22	2.17
S	0.18	0.23	0.64	0.12

Effect of temperature, oxygen/biomass ratio and steam to biomass ratio on gas composition and gross calorific value (GCV) has been studied. Oxygen/biomass ratio directly gives amount of oxygen required. As air consists of nitrogen as well, syngas produced using air gasification is diluted with nitrogen. The optimum oxygen/Biomass ratio for four biomasses based on maximum GCV is estimated and tabulated Table 3. Table 4 shows the results for biomass gasification using oxygen as gasifying agent for four biomasses as Oxygen/biomass = 0.45 and T = 1073 K. Rice straw has maximum GCV among four biomass samples.

Table 3 Optimum Oxygen to biomass ratio and GCV

Biomasses	GCV (kcal/mol)	CO	CO_2	CH_4	H_2
Paddy straw	24.3738	0.2145	0.1034	0.5394	0.1417
Rice husk	24.0366	0.1852	0.1228	0.5231	0.1676
Rice straw	26.6479	0.1887	0.1074	0.5039	0.1982
Wheat straw	25.2356	0.2121	0.1003	0.5303	0.1562

at 1073 K

Biomasses	Oxygen/Biomass Ratio	GCV (kcal/mol)
Paddy straw	0.2	46.2761
Rice husk	0.45	24.03664
Rice straw	0.45	26.64799
Wheat straw	0.4	28.68094

Table 4 Gas compositions and calorific values at 1073 K and oxygen / biomass = 0.45

Effect of temperature on gross calorific value is also studied for various biomass using Oxygen / biomass = 0.45 which is shown in Figure 1. As temperature is increasing gross calorific value is also increasing. When temperature in the gasifier increases amount of tar decreases due to which composition of gases increases which results in increase of GCV.

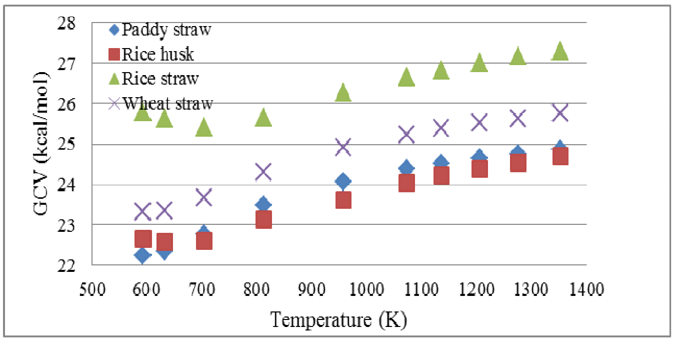

Fig. 1 Effect of temperature on gross calorific value with Oxygen / biomass = 0.45

Effect of steam/biomass ratio on gas composition and GCV of various biomasses have studied. Steam/biomass ratio varies from 0.6 to 3.75. As steam/biomass ratio increases composition of CO_2 and H_2 increases and CO and CH_4 decreases. The gas composition and GCV at 1073K and steam/biomass ratio of 0.6 for four biomasses are tabulated in Table5. Wheat straw gives maximum GCV among the four biomasses.

Table 5 Gas compositions and calorific values at 1073 K and Steam / biomass = 0.6

biomasses	GCV (kcal/mol)	CO	CO_2	CH_4	H_2
Paddy straw	65.8852	0.4160	0.0551	0.0112	0.5175
Rice husk	63.7414	0.3612	0.3612	0.0115	0.5394
Rice straw	64.7671	0.3451	0.0756	0.0128	0.5664
Wheat straw	65.9511	0.4019	0.0554	0.0117	0.5307

5. CONCLUSION

The model developed in this work predicts gas composition and calorific value based on composition of biomass and inlet condition. The choice of gasifying agent steam/ O_2 depends on application of syngas. The optimum inlet conditions are different for different biomasses. This will be useful for industry at the initial project development stage in absence of experimental or actual data.

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