Model based Operational Study of Downdraft Biomass Gasifier

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INTRODUCTION

The demand of energy, electricity and fuel, has been consistently increasing world over and more so in emerging countries like China, India, Brazil, etc. Major source of energy has been fossil fuel even today and will remain in future. However, recently concerns against use of fossil fuels are increasing due to reasons like fast-depletion of fossil-fuel resources, its adverse environmental effectscausing global warming, etc. Hence, globally researchers have been exploring alternate, sustainable, renewable energy sources like solar, wind, mini-hydro, biomass, tidal etc. Amongst these, biomass is of our interest due to its specific advantage, i.e. better source-side (biomass-feed side) control allowing flexing of the source-side energy, which is not possible for other popular renewableenergy sources e.g. solar, wind.

Biomass can be converted into energy via multiple routes (i) direct combustion of biomass as a fuel; (ii) converting biomass into more convenient form of gaseous or liquid-fuel (called bio-fuels) for use in furnace, boiler or in engines to generate thermal, mechanical or electrical energy. The processes to convert different types of biomass into bio-fuels are biomass-gasification, pyrolysis-oil conversion, digestion, fermentation etc. Amongst these, biomass gasification is a promising processing-route due to its feasibility to use wide-range of biomass as compared to other routes like digestion or fermentation. The biomass materials that can be generally used in gasification include forest or cultivated-wood; residuals from agriculture, agro-processing and wood-processing industry; for example, dry-wood, wood-chips or dust, rice-husks, coconut shells/husks, cotton-cobs, cashew-nut shells, groundnuts shells, etc.

Different gasification technologies available to convert biomass into bio-fuel are fixed-bed (updraft or down draft), fluidized bed, multi-stage etc. Although significant work is done to design and develop these technologies, and they are near-matured and also available commercially; still there is a need of further efforts to make them more reliable, robust, and commercially more viable. The research efforts in last 2 decades are mainly focussed on the development of various gasifier technologies, modeling, simulation and experimental study covering gasification of different biomass. There is a lack of research efforts towards systematic operational and control study of the biomass gasifier with integrated systems. Here, our initial work towards operational study based on modeling & simulation is presented.

BIOMASS GASIFICATION

Biomass gasification means incomplete combustion (or pyrolysis) of biomass resulting in production of combustible gases consisting of fuel-components Carbon monoxide (CO), Hydrogen (H_2), and traces of Methane (CH_4). Additionally, it also has significant amount of Nitrogen (N_2) and Carbon Dioxide (CO_2). This mixture is called producer gas (PG). PG can be used as a fuel to partially or fully substitute the popular fossil-fuelslike furnace oil in furnace, diesel/petrol in compression or spark ignition internal combustion engines; or PG as a raw-material for economical production of new alternate fuels like methanol or ethanol.

MATHEMATICAL MODELING AND SIMULATION

Modeling and simulation of biomass gasifier system is important to investigate its operational behaviour, modify system designs, and investigate-develop suitable operational controls. This paper involves the steady-state modeling of an Open Top Downdraft Gasifier. The steady-state model assumes that all the thermo-chemical reactions are in thermodynamic equilibrium. Therefore, an element/component-wise material balance [1][2] is used to model the gasification process and estimate PG composition and its calorific value (CV).The steady-state modelling problem is converted into a mathematical problem of numerically solving a system of below 3 nonlinear equations:

$$x_1^2K_1 = 1 - x_2 - x_3\,(1);\quad -x_1 + 3x_2 + 4x_3 = 2m + 1.94\,(2);\quad x_1x_3 = K_2x_2\,[-x_1 + 2x_2 + 2x_3 + w - 1.28](3)$$

where K_1,K_2 are equilibrium constants, 'm'and 'w' respectively are the amount of oxygen and water-moles per biomass-mole, 'x_i's are the mole-fractions of H2, CO, CO2, CH4, N2 in PG.

RESULTS DISCUSSION

We developed simulation program for this equilibrium model in matlab-simulink platform to study effects of various operational parameters like biomass-moisture, gasifier air-to-fuel ratio etc. on the gas-composition and PG CV. Some simulation results are presented here. Fig 1(a)-(b) show change in PG composition with increase in the biomass-moisture for Wood and Groundnut-shell as a biomass, respectively. Fig.1(c) shows reduction in CV with increase in biomass-moisture and higher CV PG from ground-nut shell than wood. These simulation results are in agreement with those published in literature [1][2] and with the experimental data published in [3].

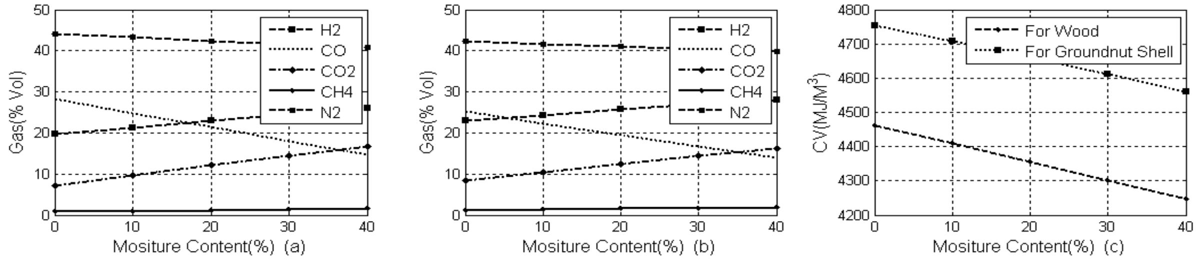

Fig.1. (a), (b) PG (Producer Gas) composition and (c) PG Calorific-Value versus biomass-moisture

CONCLUSION

The operational modelling and simulation of a downdraft biomass gasifier is performed using equilibrium or steady state model, and simulation results are given to show variation in the producer gas composition and CV with increase in biomass-moisture for wood and groundnut-shell as feed-stock. These results provide sufficient motivation to extend our work by performing experimental validationsusing suitable lab-scale/pilot gasifier to validate-tune our model-simulators using different biomass,and then carry out detailed operational study to provide necessary guidance regarding gasifier operating conditions and biomass quality.

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