A Review Paper on Study of Bubbling Fluidized Bed Gasifier

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Abstract

Fluidized bed gasifiers have been adopted for gasification of solid fuels like coal and biomass along with other gasification technologies like moving bed and entrained flow gasifiers. Fluidized bed gasifiers offers better mixing, uniform temperature and have ability to handle low quality fuels. Such units are industrially proven for combustion of solid fuels. Bubbling fluidized beds are commonly used for small to medium scale capacities. Gasification being order of magnitude slower than combustion process, handling it in fluidized bed gasifier pose many challenges as it may lead to loss of efficiency, unburnt carbon and so on. Hence study of fluidized bed gasifier is important from aspects like gas-solid hydrodynamics, reaction kinetics and inter-phase mass transfer that control the overall performance of the gasifier unit. In this paper, the objective of the study is to develop method for predicting the performance of the bubbling fluidized bed gasifier. This will critically evaluate the various correlations/methods available in literature which enables the research/ process designer to predict the performance of bubbling fluidized bed gasifier.

Keywords: Bubbling fluidized bed, Entrained Flow, Gasification, Hydrodynamics, Kinetics, Mass transfer

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I. INTRODUCTION

The gasification is the process in which conversion of carbonaceous fuels like coals, pet coke, biomass, MSW (Municipal solid waste) etc. in to a synthesis gas (syngas/producer gas) that contains CO, H_2 and CH_4 as major components and also contains CO_2, H_2O, NH_3 etc. This is achieved by reacting the material at high temperatures (>700 °C), with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel. And this resulting gas from gasification process is used to generate the power or replacement of Furnace oil or to generate chemicals. There are several gasifiers are used for this gasification process including Fixed bed gasifier, Fluidized bed gasifier and Entrained flow gasifier. The fluidized bed gasifier consists of two different methods which are bubbling fluidized bed gasifier and circulating fluidized bed gasifier. Among these gasifiers, the bubbling fluidized bed gasifier is very effective and economical to use at smaller to medium scale capacity. So this study includes the evaluation of performance of bubbling fluidized bed gasifier. Bubbling fluidized bed gasifier, will be simulated using equilibrium approach based on minimization of Gibbs free energy. The other aspects like hydrodynamic and reaction kinetics will be also studied in this. The hydrodynamic study contains minimum fluidization velocity (Umf); superficial to minimum fluidization velocity ratio, bubble size formed at the distributor and bed level and such information will be sought from various correlations available in literature. Mass and heat balance will be performed using steady state solvers like Aspen plus. Model predictions will compared with the experimental data from the literature or plant data.

A. Problem Statement

Study of bubbling fluidized bed gasifier and develops a method for predicting a performance of bubbling fluidized bed gasifier and also compares the results with the correlations or data available in literature.

B. Objective

- Develop method (based on the pseudo-equilibrium approach) for performance evaluation of the bubbling fluidized bed gasifier.
- Study of gas-solid hydrodynamics in bubbling fluidized bed regime,
- Study of gasification and oxidation reaction kinetics
- Study of heat and mass transfer in fluidized beds.

II. LITERATURE REVIEW

[1]Biomass gasification with air in an atmospheric bubbling fluidized bed was studied by Narvaez et al., 1996. It includes effect of variables such as equivalence ratio, temperature of gasifier bed and its freeboard, H/C ratio, use of secondary air in to the freeboard and addition of calcined dolomite mixed the biomass used as the feedstock on the quality of produced raw gas. Using tar and gas sampling and analysis, the gas composition and the tar content in the gas are determined and the variation with the

operation parameter is given. This shows the best values of operational variables for better result. [2]Gil et al., 1991 studied the biomass gasification in the atmospheric and bubbling fluidized bed which includes the effect of the type of gasifying agent on the product distribution and gas quality. Here gasifying agent taken in to account are air, pure steam, and steam-O_2 mixture. This is helpful for the choice of better gasification agent. [3]Steam gasification of coal at low-medium temperature with simultaneously CO_2 capture in a bubbling fluidized bed at atmospheric pressure was studied by Corella et al.,2008 in which they have stated that CO_2 reacts with CaO which produces $CaCO_3$. This is the way of reducing CO_2 in the producer gas composition and increasing the H_2 concentration. So this research will be taken in to consideration for the designing of bubbling fluidized bed gasifier. [4]The concept of net flow from the emulsion phase to bubble phase in the conservation equation was studied by Yan et al.,1998 in developing the performance evaluation of bubbling fluidized bed coal gasifier incorporating the two phase theory for an isothermal model. This net flow concept significantly changes the fluidization conditions in the bed and thus alters the reaction rates and heat and mass transfer properties. Simulation without net flow deviates from the experimental results. [5]Hamel et al., 2001 has been developed a mathematical model for simulation of gasification processes of solid fuels. The model has been used to simulate four bubbling fluidized bed gasifiers of different scales from atmospheric laboratory scale up to pressurised commercial scale, processing blown air, peat and sawdust. A wide range of operation modes is tested using air, air/steam or O_2/steam (ER= 0.23-0.44), processing brown coal, peat and sawdust, operating with or without recirculation of fines, operating with or without secondary gasification supply at pressure up to 2.5 MPa. Simulation result of the present model agree sufficiently well with the experimental data represented by overall carbon conversion, freeboard temperature and the concentrations of individual gas species. [6]Air blown gasification of woody biomass was investigated in a pilot scale bubbling fluidized bed gasifier by Kim et al., 2013. Air was used as the gasifying agent as well as fluidizing gas. In order to control the composition of the product gas, the amount of feedstock and gasifying agent being fed in to the gasifier were varied and temperature in the gasifier and the syngas composition were monitored. It was shown that the distribution of the reaction zones in the gasifier could be controlled by the air injection rate and the composition of the syngas by the equivalence ratio of the reactants. [7]Perez et al., 2014 studied that the fluid bed gasification of the sugarcane bagasse is a promising option for the large scale production of fuel gas in order to increase the energetic efficiency of the sugar industry. A fluid dynamic assessment of the use of sugarcane bagasse as feedstock for a bubbling fluidized bed gasifier was performed. It was determined the required range of sugarcane bagasse particle sizes to permit the use this biomass as a feedstock in a bubbling fluidized bed gasifier. A range of particle sized between 0.8 and 1.21 mm was suggested.[8]A comprehensive mathematical model for biomass gasification in a bubbling fluidized bed reactor has been developed by Kaushal et al., 2010. The model is based on global reaction kinetics, mass and energy balances and is capable of predicting temperature, solid hold ups and gas concentration along the reactors major axis. The overall model has sub-models to deal with biomass pyrolysis, gasification, bed hydrodynamics, material classification and property calculation. Results show that during devolatilization step, gases release and mixing are sensitive and critical parameters. They have a strong influence on the overall performance of a gasifier.

III. MODEL FORMULATION

A. *General Assumptions*

1) The system is in steady state and
2) The hydrodynamic behaviour of the fluidized bed will be estimated based on correlations
3) The fluidization state in the bed is maintained in the bubbling mode.
4) The bubble size in the bed is variable with respect to the bed height.

B. *Conservation Equations*

Generalized Overall mass balance equation:
Accumulation of mass = mass in- Mass out

$$\frac{dM}{dt} = M_{in} - M_{out} \qquad (1)$$

$$\frac{d}{dt}\rho V = \rho_{in}F_{in} - \rho_{out}F_{out} \qquad (2)$$

1) *Component Balance:*

Accumulation of species ‘k’ = mass flow of species ‘k’ in- mass flow of species ‘k’ out + source term for species ‘k’ +/- species consumed or generated

$$V\frac{dC_{kout}}{dt} = F_1 C_{kin} - F_{out}C_{kout} + r_k V \pm Q_k \qquad (3)$$

2) *Energy Balance:*

Accumulation of Enthalpy = Enthalpy in- Enthalpy out – heat transferred + heat generated due to reaction

$$\frac{d}{dt}V\rho C_p T = F_{in}\rho_{in}C_{pin}T_{in} - F_{out}\rho_{out}C_{pout}T_{out} + Q \qquad (4)$$

C. *Bed Hydrodynamics*

The bubble size is one of the most critical parameters in modelling a fluidised bed. It affects bubble rise velocity, fractions of the bubble and emulsion phases, solids mixing, and interface mass transfer between the phases. Numerous experiments and analyses aiming at determining the bubble size in the fluidised bed have been carried out. Results have shown that bubbles form as soon as the gas velocity exceeds the minimum fluidisation velocity. Bubble coalescence and net flow lead to increasing bubble size with an increase in bed height.

Correlations for axial distribution of bubble sizes:

$$D_{B0} = 0.347\left(\frac{A(u_0-u_{mf})}{n_d}\right)^{0.4} \tag{5}$$

$$D_{BM} = 0.652\left[A\left(u_0 - u_{mf}\right)\right]^{0.4} \tag{6}$$

$$d_b = D_{BM} - (D_{BM} - D_{B0})exp\left(\frac{-0.3z}{D_t}\right) \tag{7}$$

Volume fractions occupied by bubbles:

$$B = \frac{H}{H_{mf}} = 1.0 + \frac{10.978(u_0-u_{mf})^{0.738}\rho_s{}^{0.376}d_p{}^{1.006}}{u_{mf}{}^{0.937}\rho_g{}^{0.126}} \tag{8}$$

$$\varepsilon_b = 1 - \frac{1}{B} \tag{9}$$

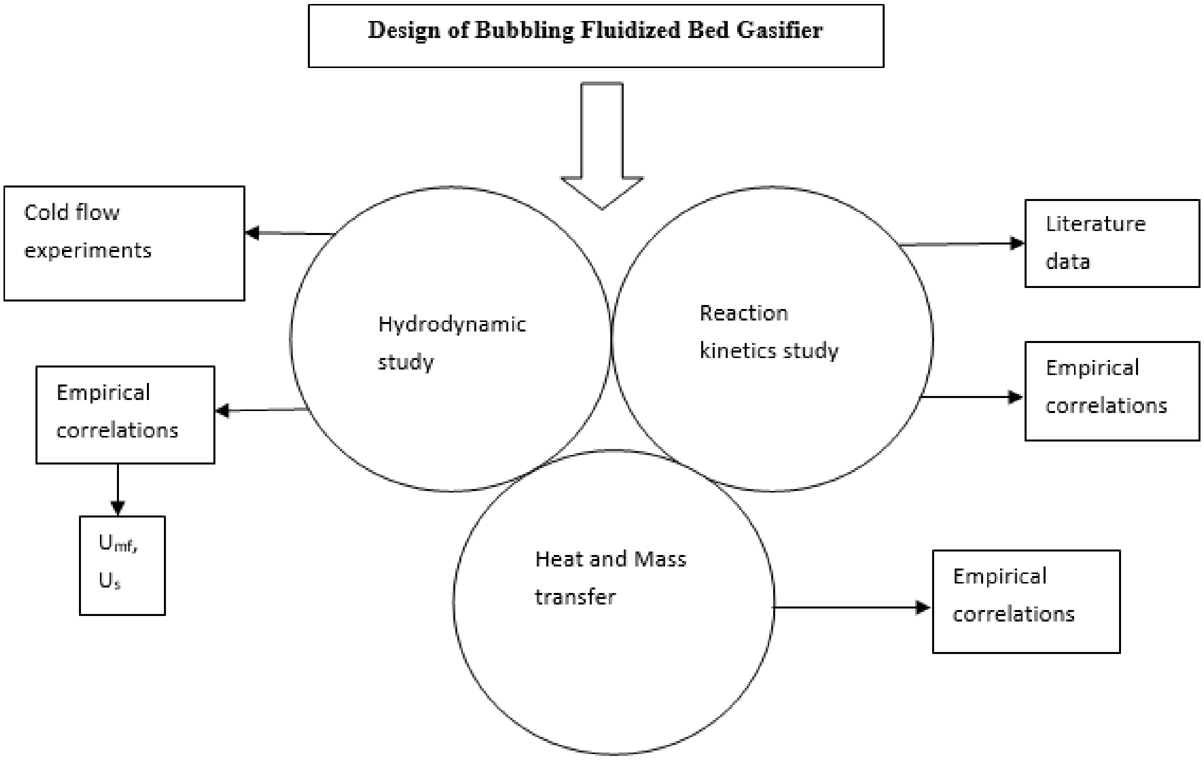
Bubble rising velocity:

$$u_b = u_0 - u_{mf} + 0.711(gd_b)^{0.5} \tag{10}$$

The bed void fraction:

$$\varepsilon_f = \varepsilon_b + (1-\varepsilon_b)\varepsilon_{mf} \tag{11}$$

IV. METHODOLOGY



A. Hydrodynamic Data

The cold flow model of bubbling fluidized bed gasifier contains fluidized bed with material like sand. Solids are in batch and air fed is in continuous mode. Air is introduced from the bottom of the fluidized bed and distributed through the bed by distributer plate in the form of bubbles. The velocity of gas in to the reactor must be sufficient to fluidize the particles within the bed and should not exceed the certain value so as to entrain them out of the bed. This velocity is called as minimum fluidization velocity. Cold flow experiments will be performed to obtain key hydrodynamic parameters and validation of the correlations available in literature. This will acts as input to the numerical model of the gasifier.

The equation used for calculation of minimum fluidized bed is

$$U_{mf} = \{(d_p{}^2.(\rho_p-\rho_f).g)/(150.\mu_f)\}*\{(\mathcal{E}_{mf}{}^3.\varphi^2)/(1-\mathcal{E}_{mf})\} \tag{12}$$

The equation used for calculation of superficial velocity is

$$U_s = [\{(1.25-1).U_{mf}{}^{0.937}.\rho_f{}^{0.126}\}/\{10.978.\rho_p{}^{0.376}.d_p{}^{1.006}\}]^{1.355} + U_{mf} \tag{13}$$

The equation for calculation of terminal velocity is

$$U_t = [\{4.(\rho_p-\rho_f).g.d_p\}/(3.C_D.\rho_f)]^{0.5} \qquad (14)$$

Where d_p is diameter of particle, ρ_p & ρ_f are the densities of the particle and flowing fluid, ε_{mf} is a minimum porosity, φ is the sphericity, μ_f is the viscosity of the fluid and C_D is the drag coefficient.

B. *Kinetic Study*

The study of reaction kinetics will be taken by using the following reaction:

1) $C + O_2 \rightarrow CO_2$ (-393.5 KJ/mol)
2) $C + 0.5O_2 \rightarrow CO$ (-110.5 KJ/mol)
3) $C + CO_2 \rightarrow 2CO$ (+171 KJ/mol)
4) $C + H_2O \rightarrow CO + H_2$ (+118.9 KJ/mol) Solid Fuel
5) $C + 2H_2 \rightarrow CH_4$ (-74.9 KJ/mol)
6) $H_2 + 0.5O_2 \rightarrow H_2O$ (-242 KJ/mol)
7) $CO + H_2O \rightarrow CO_2 + H_2$ (-41.09 KJ/mol)
8) $CH_4 + H_2O \rightarrow CO + 3H_2$ (+206 KJ/mol)

The kinetic parameters and rate equations forms for all above reactions will be obtained from literature.
The correlations used for this study is as follows

$$K = K_0 * e^{(E/RT)} \qquad (15)$$

This is known as Arrhenius law.

Where K is the rate constant, K_0 is the pre-exponential factor, E is the activation energy in J/mol, R is gas constant and T is the absolute temperature in K.

And the rate equation is

$$-r_A = K.C_A^n.C_B^m \qquad (16)$$

Where $(-r_A)$ is rate of reaction, C_A & C_B are the concentrations of reactants A & B resp., n & m are the orders of the reaction with respect to A & B resp.

C. *Heat and Mass Transfer*

Heat and mass transfer between bubbles and the solid (emulsion phase) is quite important. The information's and correlations available for this will be supplemented from literature.

The correlation for heat transfer coefficient is as follows:

$$Nup = 2 + 0.6.Rep^{0.5}.Pr^{0.33} \qquad (17)$$

Where Nup = Particle Nusselt no. = $h_{gp}d_p$ / Kg,
h_{gp} is a heat transfer coefficient,
Rep = particle Reynolds no. = $(U-Up)d_p\rho_g / \mu$
The correlation for mass transfer coefficient is as follows:

$$Sh = 2.0 + 0.6.Re^{1/2}.Sc^{1/3} \qquad (18)$$

Where Sh = KL/D = Sherwood no.,
K = mass transfer coefficient.

V. CONCLUSION

1) The proposed combined transport and kinetic model is successfully validated with the experimental data reported in the literature.
2) The model predicted composition of producer gas matches very well with the experimental data.
3) The molar fractions of CO and CH_4 increase and that of water vapour decreases with time in the pyrolysis zone of the gasifier due to a subsequent increase in the temperature of pyrolysis zone.
4) The molar fraction of water vapour in the gaseous phase is the highest in the pyrolysis zone and decreases as it travels through the oxidation and reduction zone of the gasifier.
5) The molar fractions of CO and CH_4 in the gaseous phase increase in the pyrolysis zone as gas travels through it. However, the molar fractions of CO, H_2 and CH_4 decreases in the oxidation zone due to high temperature oxidation and hence the molar fraction of CO_2 increases.

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