A Review and analysis on "Simulation on Fluidised Bed Biomass Gasifier Using ASPEN Plus"

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Abstract: **The use of biomass as a resource of energy has been additional improved in recent years and special concentration has been rewarded to biomass gasification. Due to the increasing importance in biomass gasification, several models have been projected in order to explain and identify with this complex process, and the design, simulation, optimisation and process investigation of gasifiers have been carried out. The objective of this study to analyse the previous research study to develop a model of the FICFB gasifier for rice husk as a biomass feed stocks, for predicting the steady-state performance of the model, validate it against actual plant data and utilize it to examine the influence of the main operating parameters on gasifier performance**

***Keyword*: Fluidised Bed Gasification; Biomass, Simulation; Aspen Plus.**

1.1 World Energy Outlook

Over the past several decades, the world has dramatically changed, largely thanks to the contribution of fossil fuels (e.g., coal, oil and natural gas). Fossil fuels have provided us with cheap and convenient energy which we use for heating and electric power generation, and been widely used as transportation fuels and for chemical production as well. With a continuous population increase and economies expansion, global energy consumption is increasing fast, whereas cheap fossil fuels as non-renewable sources are rapidly depleting. Moreover, their massive utilization has also caused many problems such as environmental damage (e.g., ozone depletion, global warming) associated with various emissions.

Changes in the energy supply structure are required to meet the growing demand for energy. Therefore, researchers are exploring renewable energy sources to decrease our dependence on fossil fuels and increase energy security. Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, biomass and geothermal heat which are naturally replenished (Chang et.al. 2003).

The Figure 1.1 shows the world marketed energy consumption from different fuel sources over the 2007- 2035 projection periods. It can be seen that fossil fuels are going to continue sharing more than 80% of world marketed energy consumption. Among them, liquid fuels remain the world's largest source of energy due to their importance in the transportation and industrial end-use sectors, whereas their share decreases from 35% in 2007 to 30% in 2035, as the supply is projected to be driven by high and fluctuating world oil prices. Nuclear energy is predicted to grow relatively moderately. Renewables' share of world marketed energy consumption will increase from 10% in 2007 to 14 % in 2035.

Coal-fired power generation increases by an annual average of 2.3% in the reference case, making coal the second fastest-growing source for electricity generation in the projection. The outlook for coal could be altered substantially; however, by any future legislation that would reduce or limit the growth of greenhouse gas emissions. Power generation from natural gas and nuclear power—which produces relatively low levels of greenhouse gas emissions (natural gas) or none (nuclear)—will increase by 2.1 and 2.0 % per year, respectively, in the reference case.

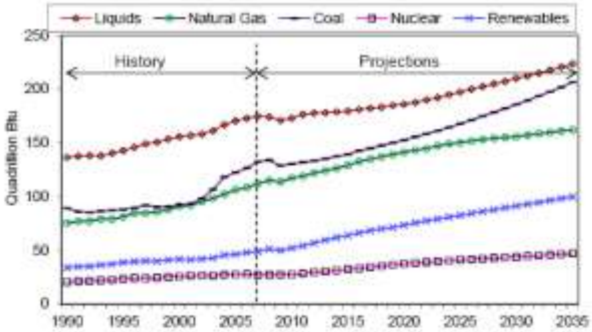


Figure 1.1 World marketed energy use from different fuel sources over 2007-2035 (Tanaka, 2010)

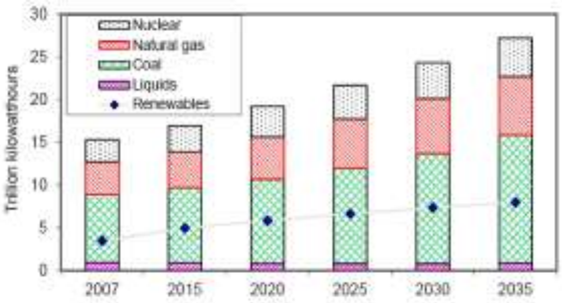


Figure 1.2 World net electricity generation by different fuel sources over 2007-2035 (Tanaka, 2010)

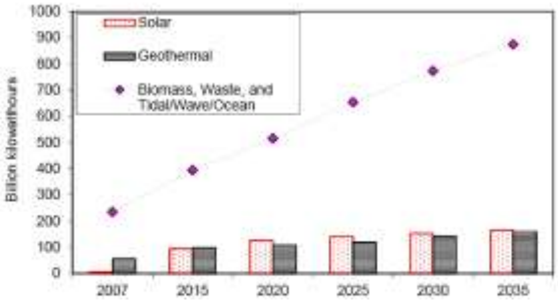


Figure 1.3 World renewable electricity generation: excluding wind and hydropower (Tanaka, 2010)

According to abovementioned projected data in the IEO 2010, it is obvious that no combination of alternative technologies can completely replace the current usage of fossil fuels and the highest increase in world-wide energy consumption is predicted to be from all three fossil fuels. However, in order to mitigate global warming, it is inevitable to reduce the quantity of fossil fuels consumed as much as possible and increase the global production from alternative renewable energy sources as well. As it is well-known, most common renewable energy resources include wind, solar, hydropower, geothermal and biomass.

1.2 Thermo-chemical Conversion Processes

In order to benefit from the chemical energy contained in biomass, this energy has to be transformed into more convenient energy forms like heat or electricity. Some processes involve an intermediate transformation from the solid fuel into another energy carrier (gas or liquid fuel).

As referred by Grønli (1996), there are, in principle, three types of conversion processes:

- Biochemical -via microbiological action
- Thermo-chemical -via heat treatment
- Physical/chemical processing

Four thermo-chemical processes can be distinguished:

a. Pyrolysis
b. Gasification
c. Combustion
d. Liquefaction

Some of them are endothermic and others exothermic and often they take place simultaneously inside the same reactor. Figure 1.4 presents the thermo-chemical conversion process and the paths for energy utilization.

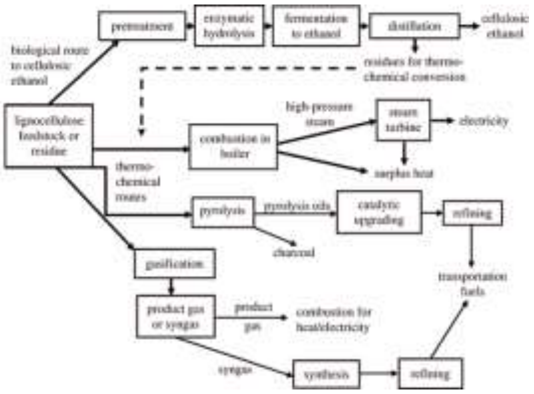


Figure 1.4 Thermo-chemical conversion processes and energy utilization. (Grønli, 1996)

The products from any thermo-chemical process are:

- a solid residue, called char
- a gas product
- a tarry liquid of complex composition, known as “tar”, often present in vapour phase at process temperature

As commented by Hallgren (1996), the characteristics of the products (gas, liquids andsolid) depend on a broad range of factors such as the chemical and physical characteristics of the feedstock, the heating rate, the initial and final process temperature, pressure and type of reactor.

1.2.1 Pyrolysis or De-volatilization

Pyrolysis is the thermal degradation of biomass in the absence of an oxidizing agent at200-500 °C. The term de-volatilization is also used as equivalent to pyrolysis but it is usually understood that de-volatilization implies the presence of an oxidizing agent. Nevertheless, the surrounding atmosphere is of little importance to the thermal degradation of the solid fuel although it might affect the subsequent reactions of the volatile matter released.

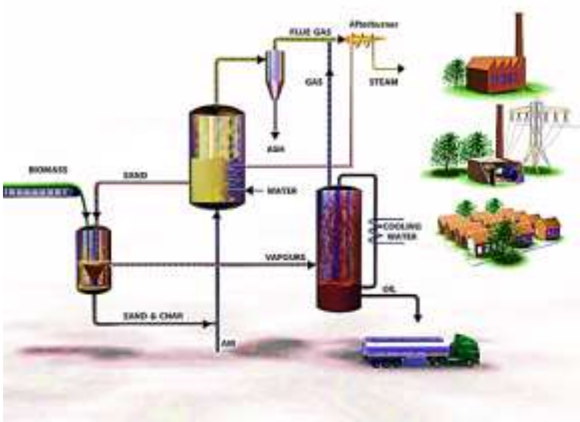


Figure 1.5 Sketch of the pyrolysis process

1.2.2 GASIFICATION

Char gasification is the endothermic process where the char, solid residue from a pyrolysis process, is transformed into a gaseous mixture of CO, CO_2, CH_4, H_2 and H_2O in a reducing atmosphere usually composed of CO_2 and H_2O.Being char gasification an endothermic process, some source of heat is required. The common heat source is the combustion of the volatile matter released during pyrolysis. The addition of an oxidation agent is necessary for this combustion process. Figure1.6 shows schematically the char gasification process.

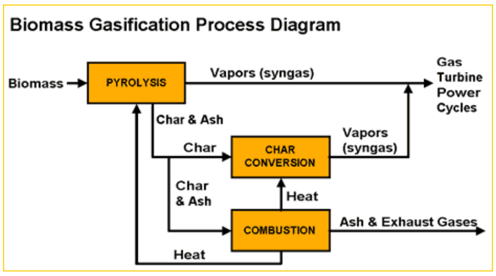


Figure 1.6 Gasification Process

Chemical synthesis generally requires the use of a medium calorific value gas (MCV)(non-nitrogen diluted) with minimum contaminants for optimal conversion to chemicals(Paisley et al., 1994).If the product gas is to be used for electricity production, the gas needs to be clean from char-particles, tar and ash before entering a gas turbine or a combustion engine. Still, the hot outlet gas from the gas turbine can be used to produce steam for a steam turbine, being the process an Integrate Gasification Combined Cycle (IGCC).

Figure 1.7 Shows the various gasification technologies.

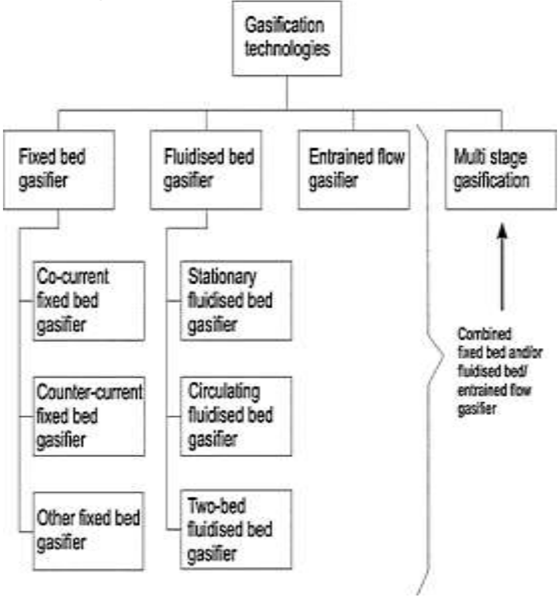


Figure 1.7 Gasification Technologies.

1.2.3 Combustion

Combustion means the complete oxidation of the biomass feedstock. The process provides very hot gases that can be used to raise steam or to provide a heat space for a Stirling engine. The combustion process of biomass is far better known than the other thermo-chemical processes and it is one of the oldest heat productions though most of the traditional processes are not sustainable. Figure 1.8 shows the process in a simplified diagram.

Figure 1.8 Combustion process.

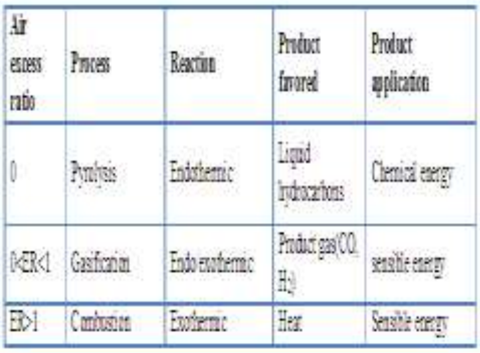
1.2.4 Liquefaction

The process takes place at low temperatures (250-350 °C) and high pressures (100-200 bar). The objective is to maximize the liquid product as well as its quality (35-40 MJ/kg) and lower the oxygen content. With less oxygen content, comments Gronli (1996), the liquid is more stable and needs less upgrading to a hydrocarbon product. High hydrogen, partial pressure and a catalyst can improve the selectivity of the process and accelerate the reaction.

1.2.5 Comparison and Interaction between the Different Conversion Processes

Pyrolysis, gasification and combustion can be distinguished by the air excess ratio. Table1.1 compares the conversion processes. Liquefaction is not considered in this comparison because the high operational pressure makes the process very different from the others. Gasification can give a higher efficiency in electricity production technology compared to combustion.

Table 1.1 Comparison of thermo-chemical conversion processes



Air excess ratio	Process	Reaction	Product favored	Product application
0	Pyrolysis	Endothermic	Liquid hydrocarbons	Chemical energy
0<ER<1	Gasification	Endo exothermic	Product gas(CO, H_2)	sensible energy
ER>1	Combustion	Exothermic	Heat	Sensible energy

Gasification can give a higher efficiency in electricity production technology compared to combustion. Other differences concerning emissions and cleaning costs have been studied by Hashler et al. (Babu, 1995). Larson and Williams (1988) present a compare is on between several combustion and gasification processes from a power generation point of view, favorable to the gasification option. Di Blasi et al. (1999) refer that the advantages of gasification over combustion are related to the fact that gasification implies gas phase combustion while combustion is a solid-phase combustion.

1.5 Biomass Gasification

This section focuses on the chemical and thermal processes occurring during biomass gasification. Other aspects like the influence of oxidizing agent, type of reactor and gas quality are also mentioned. Regarding gas quality, tar formation and destruction is of great importance and has therefore been commented with more detail.

Biomass gasification has attracted considerable interest worldwide probably due to the high overall system flexibility and efficiency it offers with respect to biomass combustion and pyrolysis (Ruoppolo et al., 2010). Gasification converts biomass to a combustible product gas or syngas at a typical temperature range of 800 to 1000 °C by using various gasifying agents such as air, O_2, steam, CO_2 or their mixtures. The main chemical reactions involved in char gasification are:

Boudouard reaction

$$\mathrm{C + CO_2 + Heat \rightarrow 2CO} \quad \text{……….. (1.1)}$$

Water-gas reaction:

$$\mathrm{C + H_2O + Heat \rightarrow CO + H_2} \quad \text{……….. (1.2)}$$

These reactions are endothermic and very slow at temperatures below 800 °C.

The heat required by the char gasification reactions is provided by the following exothermic reactions:

Volatile matter combustion:

$$\mathrm{[C_xH_y + CO + H_2 + CH_4] + O_2 \rightarrow CO_2 + H_2O + Heat} \quad \text{……….. (1.3)}$$

Char combustion

$$\mathrm{C + O_2 \rightarrow CO_2 + Heat} \quad \text{……….. (1.4)}$$

Usually there is some methane formed as well, following the reaction:

$$\mathrm{CO + 3H_2 \rightarrow CH_4 + H_2O} \quad \text{……….. (1.5)}$$

Although the reaction is slow unless a catalyst is present, it is quite exothermic and can provide heat to the system (Reed and Das, 1988). Methane formation is quite low in biomass gasification, unless the pressure is high. Finally, the interaction of the gaseous species formed during pyrolysis and gasification is governed by the following reaction:

Water-gas shift reaction:

$$\mathrm{CO_2 + H_2 \leftrightarrow CO + H_2O} \quad \text{……….. (1.6)}$$

Alternatively, biomass gasification could be expressed as a single reaction, as suggested by Reed and Das (1988). Ideally, biomass, expressed as $CH_{1.4}O_{0.6}$, will react with the minimum amount of oxygen required in order to obtain a mixture of CO and H_2, according to the formula:

$$\mathrm{CH_{1.4}O_{0.6} + 0.2O_2 \rightarrow CO + 0.7\,H_2} \quad \text{……….. (1.7)}$$

But, in practice, some extra oxygen is needed and the reaction becomes:

$$\mathrm{CH_{1.4}O_{0.6} + 0.4O_2 \rightarrow 0.7CO + 0.3\,CO_2 + 0.6\,H_2 + 0.1H_2O} \quad \text{……….. (1.8)}$$

1.6 Types of Reactor

1.6.1 Fixed-Bed Gasifier

These reactors are rather easy to construct and operate and are widely available, especially in developing countries. They are suitable for small scale applications but have in general limited scale-up properties. The size of fixed bed gasifier is in most cases below 1 MW. The reason for its limited size is that a high temperature zone is required to reduce the tar content of the product gas; as the gasifier diameter increases, it is more difficult to create such a high temperature zone.

To sum up, the fixed bed gasifier are simple and most suitable for small-scale with capacities of less than a 100 kWth up to a few MWth heat, and power applications combined with the gas cleaning and cooling system normally consisting of filtration through cyclones, wet scrubbers and dry filters (Demirbas, 2002).

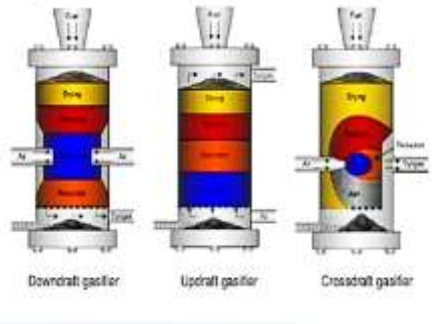


Figure 1.9 Types of Fixed bed Gasifire

1.6.2 Fluidized-Bed Gasifier

Current development activities on large scale biomass gasification have been mainly devoted to FB technologies, since FB gasifiers have better heat and mass transfer between the gas and solid phases, and can also meet the challenges of wide variations in fuel quality with a broad fuel particle-size distribution. FB gasifiers can be divided into two main types: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). A schematic of bubbling and circulating fluidized bed gasifier is presented in Figure 1- 10. The main difference between them are fluidizing velocity and gas path.

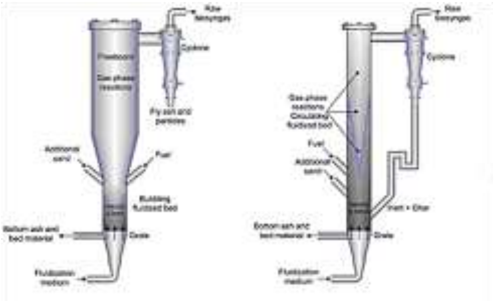


Figure 1.10 Schematic of bubbling and circulating fluidized bed gasifier

1.7 The Aim of the Research Work

The objective of this study is analysing the previous research study to develop a model of the FICFB gasifier for rice husk as a biomass feed stocks, for predicting the steady-state performance of the model, validate it against actual plant data and utilize it to examine the influence of the main operating parameters on gasifier performance.

2.1 Literature Based on Dual Fluidized Bed

Some previous research based on DFB is as follows:

- **“Dual fluidized bed design for the fast pyrolysis of biomass”** S.D. Swart, M.D. Heydenrych, A.A. Boateng
  A mechanism for the transport of solids between fluidised beds in dual fluidised bed systems for the fast pyrolysis of biomass process was selected. This mechanism makes use of an overflow standpipe to transport solids from the fluidised bed used for the combustion reactions to a second fluidised bed, which is used for the endothermic pyrolysis reactions. A screw conveyor is used to transport the solids back to the combustion fluidised bed.

  The solid transfer mechanism conformed to the requirements which were identified for the feasibility of the mechanism in the fast pyrolysis of biomass process. The proposed dual fluidised bed system is therefore a feasible system for the fast pyrolysis of biomass.
- **“Attempts on cardoon gasification in two different circulating fluidized beds”**Chr. Christodoulou, Chr.Tsekos , G.Tsalidis , M. Fantini , K.D. Panopoulos, W.deJong , E.Kakaras, Case Studiesin Thermal Engineering 4 (2014) 42–52, 2014 Published by Elsevier Ltd.
  Few tests have been carried out in order to evaluate the use of cardoon in gasification and combustion applications most of the researchers dealt with agglomeration problems. The aim of this work is to deal with the agglomeration problem and to present a solution for the utilization of this biofuel at a near industrial application scale. For this reason, two experiments were conducted, one in TU Delft and one in Centre for Research and Technology Hellas (CERTH), using fuel cardoon and 50% w/w cardoon blended with 50% w/w giant reed respectively. Both experimental campaigns were carried out in similar atmospheric circulating fluidized bed gasifiers. Apart from the feedstock, the other differences were the gasification medium and the bed material used in each trial.
- **“Synergetic Utilization of Renewable and Fossil Fuels: Dual Fluidized Bed Steam Co-gasification of Coal and Wood”**Stefan Kern, Christoph Pfeifer, Hermann Hofbauer , International Conference on Environmental Science and Development (ICESD 2012), 5-7 January 2012, Hong Kong
  Gasification of biomass and coal is an attractive technology for combined heat and power production, as well as for synthesis processes such as the production of liquid and gaseous biofuels. The all thermal steam blown gasification process yields a high calorific product gas, practically free of nitrogen. Originally designed for wood chips, the system can also handle a large number of alternative fuels.

  To demonstrate the influence on the system performance of fuels that have a different origin, wood pellets, as the designated feedstock, and hard coal as an example fossil fuel were fed into the DFB gasifier with a fuel blend ratio of 20 % coal in terms of energy. A fuel power of 78 kW and a steam to fuel ratio of 1.0 kg/kgdb were achieved. The system was operated at gasification temperatures between 830and 870°C. This paper points out the influence of the temperature on the system.
- **“Experimental investigation of the effect of physical pre-treatment on air-blown fluidized bed biomass gasification”** Benjamin Bronsona, , Peter Gogoleka, Poupak Mehranib, Fernando Pretoa, Biomass and Bio-energy, Volume 88, May 2016, Pages 77–88

  The effect of combination, drying, and densification on bubbling fluidized bed gasification was investigated by fractionating a forestry residue into a feedstock consisting of different particle sizes, moisture levels, and by densifying to pellets. The gasification performance was evaluated at nominal average bed temperatures of 725°, 800° and 875°C at a constant fluidizing velocity (0.91 m s−1) with feed input rates between 9 and 24 kg h^{-1}.

  The gas composition was observed to be influenced by both the particle size and form. Smaller particles led to a gas richer in carbon monoxide and depleted in hydrogen. The gasification of pellets led to a gas with the greatest hydrogen to carbon monoxide ratio. The smallest particles tested resulted in the worst gasification performance, as defined by cold gas efficiency, carbon conversion, and tar production. Despite differences in the gas composition among the larger particles and the pellets, similar carbon conversion and cold gas efficiency was observed.

- **"Biomass steam gasification--an extensive parametric modeling study."** Schuster G, Löffler G, Weigl K, Hofbauer H., Bioresource Technology Volume 77, Issue 1, March 2001, Pages 71–79
  A model for steam gasification of biomass was developed by applying thermodynamic equilibrium calculations. With this model, the simulation of a decentralized combined heat and power station based on a dual fluidized-bed steam gasifier was carried out. Fuel composition (ultimate analysis and moisture content) and the operating parameters, temperature and amount of gasification agent, were varied over a wide range. Their influences on amount, composition, and heating value of product gas and process efficiencies were evaluated.

  It was shown that the accuracy of an equilibrium model for the gas composition is sufficient for thermodynamic considerations. Net electric efficiency of about 20% can be expected with a rather simple process. Sensitivity analysis showed that gasification temperature and fuel oxygen content were the most significant parameters determining the chemical efficiency of the gasification.

2.2Literature Based on Modeling of (D) FB biomass gasification

Although experimental investigation towards the fluid dynamics, reaction kinetics and heat transfer during biomass gasification is essentially important, a good simulation model can provide lots of valuable information for process parameter optimization, product gas formation. Several reviews of the current knowledge on FB models have been published (Basu & Kaushal, 2009; Gómez-Barea & Leckner, 2010; Puig-Arnavat et al., 2010).

According to Gómez-Barea and Leckner (Gómez-Barea& Leckner, 2010), the existing FB models can be generally divided into three groups: Computational fluid-dynamic models (CFDM), Fluidization models (FM) and Black-box models (BBM). They reported that less CFDMs have been developed dueto the requirement details of complex gas–solid dynamics and considerable computational times for CFD computations. FM models are a compromise between BBM and CFDM. They are the most successful models applied up to date with the major fluid-dynamics effects captured by assuming multiphase pattern in the bed (e.g., two or three phase theory of fluidization) and simplified by semi empirical correlations. BBM models deal with less or no kinetics involved in the particle conversion process and two approaches have been widely used among BBM: equilibrium models (EM) or modified equilibrium models complemented by empirical correlations obtained from experiments.

An overview of the mathematical gasifier models based on kinetic models presented in the literature has been summarized by De Jong (De Jong, 2005). Here emphasis is put on the application of FM and EM models during CFB biomass gasification.

2.2.1 Kinetic models

Among currently developed FB models, in general the development of models for BFBs preceded that of CFBs. Also, the field of combustion was ahead of that of gasification and the conversion of coal proceeded biomass. Regarding the hydrodynamics of CFB modelling, a number of CFB coal combustor and gasifier models have been developed and reported in the literature, which can be classified in three broad groups of details of sophistication:

1. Group I: 1D model based on two phase bubbling bed model with a simple mass and energy balance, where gases are in plug flow and solids are well mixed. The models only predict the axial variation of solids holdup and do not consider solid flow in the annular region of the riser where temperature, gas concentration and velocity can differ from that in the core (Basu et al., 1987; Heinbockel&Fett, 1995; Smolders &Baeyens, 2001; Sotudeh-Gharebaagh et al., 1998).
2. Group II: 1.5-2D core-annulus models with broad consideration; they predict the axial and the radial variation of solids holdup (Adanez et al., 2001; Fang et al., 2001; Gungor&Eskin, 2007; Gungor&Eskin, 2008; Hua et al., 2004; Huilin et al., 2000; Kim et al., 2000; Siedlecki, 2011; Wang et al., 2003).
3. Group III: 3D models based on gas and solid phase continuity equations, energy momentum balances and the appropriate constitutive equations with detailed consideration of chemical kinetics and individual physical processes (Hartge et al., 1999; Hyppanen et al., 1991; Knoebig et al., 1999; Yunhau et al., 2006).

According to Corella et al. (Corella&Sanz, 2005), modelling studies of coal based CFB reactors offer valuable information and help to model CFB biomass gasification, but they are not adequate enough due to the difference in physic-chemical property of biomass compared to coal.

2.2.2 Fluidization models (FM)

So far, some FM models of CFB biomass gasifier are available in the literature. Kersten et al. (Kerstenet al., 2003) provided a two-dimensional model for the pilot CFB biomass gasifier at ECN validated with the results obtained from measurements with the pilot plant and the cold-flow model. Liu and Gibbs (Liu & Gibbs, 2003) developed a CFB biomass gasifier model which was mainly addressed toNH3 and HCN emissions. Corella et al. (Corella&Sanz, 2005; Sanz&Corella, 2006) presented a 1-dimensional model for an atmospheric CFB biomass gasifier under stationary state which was based on the kinetic equations for the reaction network solved together with mass and heat balances and with several hydrodynamic considerations.

Petersen and Werther (Petersen &Werther, 2005a; Petersen &Werther, 2005b) developed 1.5D and 3D models of a CFB sewage sludge gasifier which used continuous radial profiles of velocities and solids hold-up with regard to the description of fluid mechanics and also contained a complex reaction network of sewage sludge gasification. Jennen et al.(Jennen et al., 1999) developed a mathematical model of CFB wood gasifier, which consists of the description of the flow structure, the kinetics of the gasification reactions, the particle-size distributions of the solids and the energy balances.

2.2.3 Aspen Plus^{TM} models

To avoid complex process description but still incorporating chemical kinetics of relevant reactions involved in the gasification process, some models using Aspen Plus TM software, a flow sheeting software package, have been developed. For example, Mansaray et al. (Mansaray et al., 2000) simulated a dual-distributor-type FB rice husk gasifier using Aspen PlusTM. Two different types of thermodynamic models have been developed: a one-compartment model, in which the hydrodynamic complexity of the FB gasifier was neglected and an overall equilibrium approach was used; and a two compartment model, where the complex hydrodynamic conditions presented within the gasification chamber were taken into account. Mitta et al. (Mitta et al., 2006) modelled an FB tyre gasification plant using Aspen Plus^{TM}, where the gasification model was divided into three different stages: drying, de-volatilization and gasification-combustion, but an overall equilibrium approach was employed by neglecting the hydrodynamic complexity of the gasifier. Nikoo and Mahinpey (Nikoo&Mahinpey,2008) developed a model capable of predicting the steady-state performance of an atmospheric FB gasifier by considering the hydrodynamic and reaction kinetics simultaneously.

Doherty et al.(Doherty et al., 2009) studied the effect of air preheating in a biomass CFB gasifier using AspenPlus^{TM} based on the restricted thermodynamic equilibrium method. van der Meijden et al. (van derMeijden et al., 2010) used Aspen Plus^{TM} as a modelling tool to quantify the differences in overall process efficiency for producing synthetic natural gas in three different gasifiers: entrained-flow, all thermal and CFB. Recently, Nilsson et al. (Nilsson et al., 2012) performed the modelling of theg asification of biomass and waste in a staged FB gasifier using Aspen Plus^{TM}. In the model, the process includes three main stages: de-volatilization of the fuel, homogeneous reactions of volatiles, and heterogeneous reforming of gas and the generated char. And each thermochemical stage is modeled using kinetics data obtained in dedicated tests in a laboratory-scale FB reactor or taken from the literature.

Conclusion

Models of several different types have been investigated for gasification systems—kinetic, equilibrium and artificial neural networks. It also provides a constructive design aid in evaluating the possible limiting performance of a composite reacting system that is difficult or unsafe to reproduce experimentally or in commercial operation. Some researchers, trying to avoid complex processes and focusing to develop the simplest possible model that incorporates the principal gasification reactions and the gross physical description of the reactor, have developed models using the process simulator Aspen Plus

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