

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, optimization and process investigation of gasifiers have been carried out. The main aim of this study is to develop a comprehensive process model for biomass gasification in a fluidized bed gasifier using the ASPEN PLUS simulator. A disadvantage in using ASPEN PLUS is not having of a library model to simulate fluidized bed unit process. However, it is feasible for users to input their own models, using FORTRAN codes nested within the ASPEN PLUS input file, to simulate operation of a fluidized bed. The products of homogeneous reactions are defined by Gibbs equilibrium and reaction rate kinetics are used to determine the products of char gasification. The intention of this study to evaluate 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.

I - INTRODUCTION

1.1 World Energy Outlook

Regarding world energy sources consumption and future predictions, several scenarios have been developed by different institutions based on different perspectives and techniques (Fischer & Schratzenholzer, 2001; Petroleum, 2011; Schiffer, 2008; Shell International Petroleum Company & Environment, 2001; Tanaka, 2010). According to the International Energy Outlook (IEO) 2010 published by the International Energy Agency (IEA), world marketed energy consumption will increase by 49% from 2007 to 2035 in the reference case. The most rapid growth in energy demand from 2007 to 2035 occurs in nations outside the Organization for Economic Cooperation and Development (non-OECD nations) and their total energy demand will increase by 84% compared with an increase of 14% in OECD countries (Tanaka, 2010).

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.

World net electricity generation by different fuel sources over the 2007-2035 projection periods is presented in Figure 1- 2. It can be seen that world net electricity generation will increase by 87% in the reference case, from 18.8 trillion kWh in 2007 to 25.0 trillion kWh in 2020 and 35.2 trillion kWh in 2035. From 2007 to 2035, world renewable energy use for electricity generation grows by an average of 3.0 % per year, and the renewable share of world electricity generation increases from 18% in 2007 to 23 % in 2035.

Furthermore, of the 4.5 trillion kWh of increased renewable electricity generation over the projection period, 2.4 trillion kWh (54 %) is attributed to hydroelectric power and 1.2 trillion kWh (26 %) to wind. Renewable sources other than hydroelectricity and wind—including solar, geothermal, biomass, waste, and tidal/wave/oceanic energy—do increase at a rapid rate over the projection period which can be clearly seen in Figure 1.3.

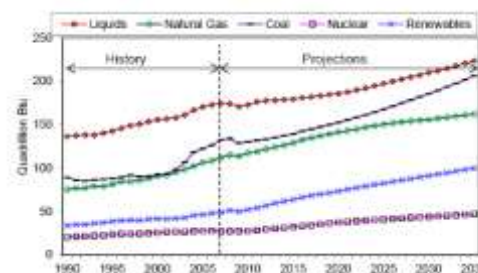


Figure 1.1 World marketed energy use from different fuel sources over 2007-2035 (Tanaka, 2010)

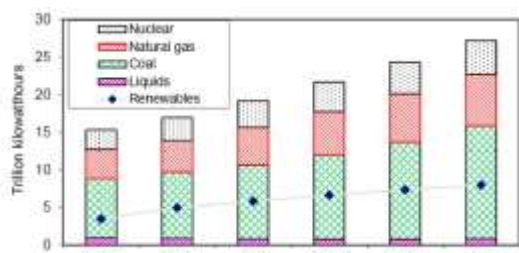


Figure 1.2 World net electricity generation by different fuel sources over 2007-2035 (Tanaka, 2010)

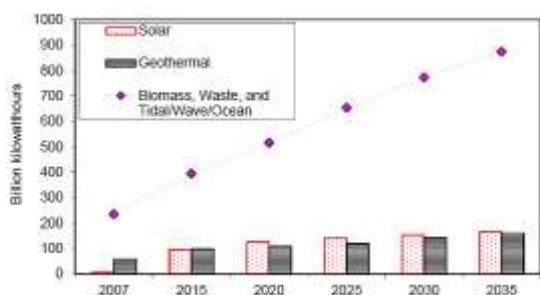


Figure 1.3 World renewable electricity generation: excluding wind and hydropower (Tanaka, 2010)

According to above mentioned 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.

Four thermochemical processes can be distinguished:

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

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 and solid) 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.

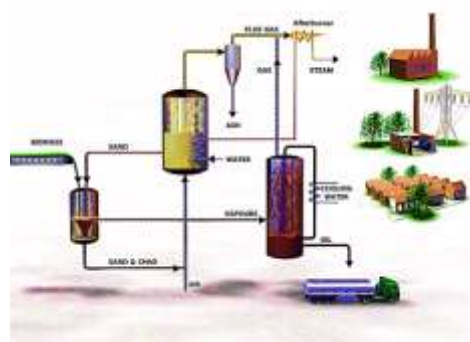


Figure 1.4 Sketch of the pyrolysis process

1.2 GASIFICATION

Char gasification is the endothermic process where the char, solid residue from a pyrolysis process, is transformed into a gaseous mixture of CO, CO₂, CH₄, H₂ and H₂O in a reducing atmosphere usually composed of CO₂ and H₂O. Being char gasification an endothermic process, some source of heat is required.

The addition of an oxidation agent is necessary for this combustion process. As already mentioned previously, the thermal degradation of biomass in the presence of an oxidation agent should rather be referred as de-volatilization and not pyrolysis.

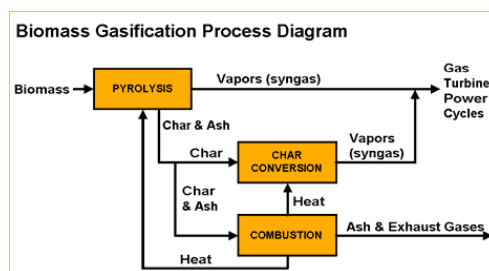


Figure 1.5 Gasification Process

It is however common to denote as “biomass gasification” the overall process where not only the char is transformed into gas but where all drying, de-volatilization, volatile matter combustion and char gasification take place.

The biomass gasification process is shown in Figure 1.5.

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 1.6 Shows the various gasification technologies.

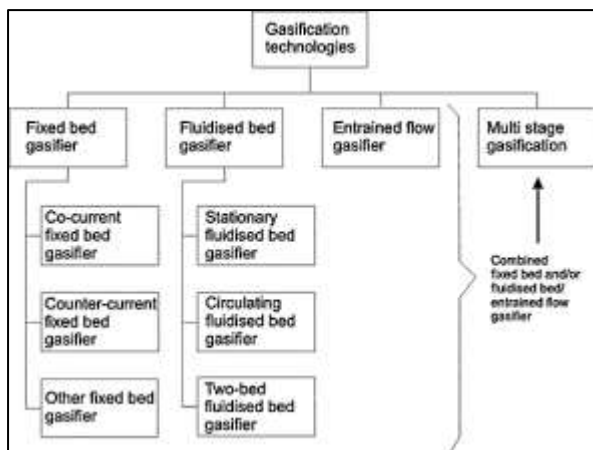


Figure 1.6 Gasification Technologies.

1.3 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 production technologies although most of the traditional processes are not sustainable. Figure 1.8 shows the process in a simplified diagram.

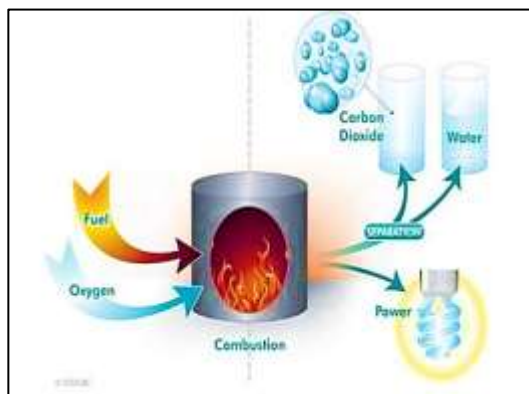


Figure 1.7 Combustion process.

1.4 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.

Table 1.1 Comparison of thermo-chemical conversion processes

Air concentra	Process	Reaction	Product/interm	Product/applications
0	Pyrolysis	Endothermic	Liquid hydrocarbon	Chemical energy
0-ER<1	Gasification	Endo-thermic	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 comparison 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.

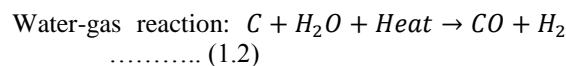
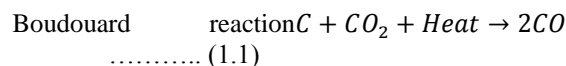
In addition, gasification allows for the utilization of fuel cells. Fuel cell applications have by definition higher electrical efficiency because the chemical energy contained in the fuel is directly transformed into electricity without the intermediate transformation into thermal energy.

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.

As previously referred, biomass gasification can be considered as a three-step process: de-volatilization -producing volatile matter and char, secondary reactions of the volatile matter and char gasification.

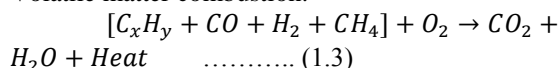
The main chemical reactions involved in char gasification are:



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:

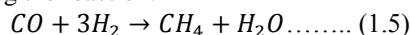
Volatile matter combustion:



Char combustion

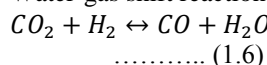


Usually there is some methane formed as well, following the reaction:

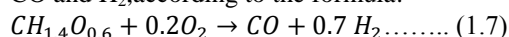


Although the reaction is slow unless a catalyst is present, it is quite exothermic and can provide heat to the system (Reed and Das, 1988). Methane formation is quite low in biomass gasification, unless the pressure is high. Finally, the interaction of the gaseous species formed during pyrolysis and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

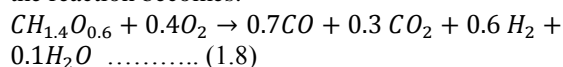
Water-gas shift reaction:



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:



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



1.6 The Aim of the Research Work

The objective of this study is 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.

II-LITERATURE REVIEW

2.1 Literature Based on Dual Fluidized Bed

Some previous research based on DFB are as follows:

- “Attempts on cardoon gasification in two different circulating fluidized beds” Chr. Christodoulou, Chr. Tsekos, G.Tsalidis, M. Fantini, K.D. Panopoulos, W.de Jong, E. Kakaras, Case Studies in 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 bio-fuel 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.

- “Comparison of the performance behavior of silica sand and olivine in a dual fluidised bed reactor system for steam gasification of biomass at pilot plant scale” Stefan Koppatz, Christoph Pfeifer, Hermann Hofbauer, Chemical Engineering Journal Volume 175, 15 November 2011, Pages 468–483

The behavior of olivine compared to silica sand as bed material was investigated in a dual fluidised bed reactor system (DFB) for steam gasification of biomass. This study presents fundamental experimental data on the impact of olivine on the product gas and distribution of condensable hydrocarbons (tars) effected by the catalytic properties of olivine.

The results obtained with olivine are compared to silica sand, which is taken as a reference as it is considered to be inert. The experimental device is a pilot plant of 100 kW fuel input and the design is comparable to large scale applications. Pressure and temperature profiles of the reactor system are presented to illustrate the system performance.

Doherty et al. (Doherty et al., 2009) studied the effect of air preheating in a biomass CFB gasifier using Aspen Plus based on the restricted thermodynamic equilibrium method. van der Meijden et al. (van der Meijden et al., 2010) used Aspen Plus as a modeling 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 modeling of the gasification of biomass and waste in a staged FB gasifier using Aspen Plus. 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 thermo-chemical stage is modeled using kinetics data obtained in dedicated tests in a laboratory-scale FB reactor or taken from the literature.

III - SIMULATION MODEL DEVELOPMENT

3.1 Process Model Simulator

In recent times, numerous processes modeling software set have become obtainable to progress computational model of gasification process and to achieve simulation and validation lessons. Usually,

investigators and authorities use Aspen Plus, Computational Fluid Dynamics (CFD, composed of GAMBIT and FLUENT), Chem CAD and MatLab software sets to advance and enhance their gasification models.

The simulations of the biomass gasification procedure were based on the mass-energy balance and chemical equilibrium for the complete progression. Aspen Plus is stranded on “blocks” linked to unit progressions in addition to chemical reactors, through which most industrial operations can be simulated. It includes numerous databases comprising physical, chemical and thermodynamic data for a extensive diversity of chemical compounds, in addition to a collection of thermodynamic models compulsory for the precise simulation of any assumed chemical system [12].

In this study, the advanced Aspen Plus model for a fixed bed gasifier includes the subsequent consecutive steps:

1. Stream class description;
2. Property method assortment;
3. System constituent description (from databank) and classifying conventional and non-conventional modules;
4. Defining the development flow sheet
5. Stipulating feed streams
6. Stipulating unit operation blocks

3.2 Assumptions

The following assumptions were considered in this study:

1. Steady state, kinetic free and isothermal model;
2. Chemical reactions take place at an equilibrium state in the gasifier, and there is nopressure loss;
3. All gases are ideal gases, including H₂, CO, CO₂, steam (H₂O), N₂ and CH₄;
4. Char is 100% carbon (C); all fuel bound N₂ is converted to NH₃
5. Tars are supposed as non- equilibrium yields to decrease the hydrodynamic difficulty
6. Zero-dimensional; operation at atmospheric pressure (~1 bar)
7. All fuel bound sulphur (S) is converted to H₂S [2, 3, 20]; all fuel bound chlorine (Cl₂) is converted to HCl [20];
8. Heat loss from the gasifier is neglected

3.3 Model Description

The Aspen Plus flow sheet of the FICFB gasifier is depicted in Fig. 3.1. The model is based on the following main assumptions as given above. A heat stream is used to simulate the heat transferred by the circulation of bed material between the gasifier CZ and GZ

The Peng-Robinson equation of state with Boston-Mathias modifications was nominated as the

property method used for the model. The Peng-Robinson equation is widely used in industry (Sadus, 1994). The advantages of these equation is that it is easy to use and that they often accurately represent the relation between temperature, pressure, and phase compositions in binary and multi component systems.

$$p = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)+b(V-b)} \dots\dots\dots (3.1)$$

Peng and Robinson defined a (T) as

$$a(T) = 0.45724 \frac{R^2 T_c^2}{P_c} \left\{ 1 + k \left[1 - \left(\frac{T}{T_c} \right)^{0.5} \right] \right\}^2 \dots\dots\dots (3.2)$$

Where k = 0.37464 + 1.5422ω - 0.26922ω²
 (3.3)

$$b = 0.077880 \frac{RT_c}{P_c} \dots\dots\dots (3.4)$$

The ultimate and proximate analysis for Rice husk are given in Table 3.1

Table 3.1 Fuel proximate, ultimate and heating value analyses for Rice Husk

Proximate analysis (wt%, dry basis)	
Moisture	13.2
Volatiles	55.07
Fixed carbon	24.46
Ash	15.28
Ultimate analysis (wt%, dry basis)	
C	42.59
H	5.4
N	1.18
S	0.45
O	31.3
Cl	0.39
Ash	17.7

The proximate and ultimate analysis which is considered for the study is given in table 3.1.

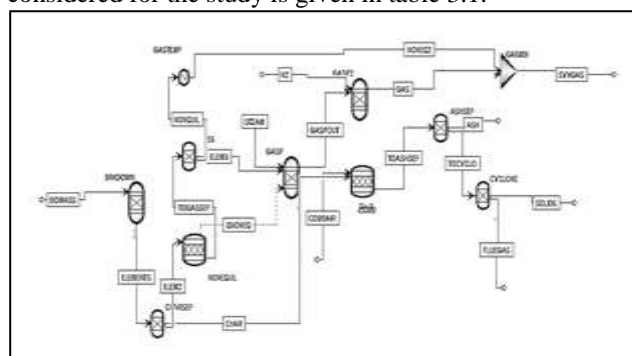
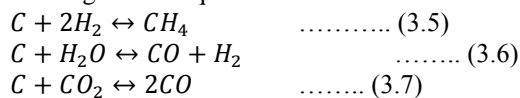


Figure 3.1 Aspen Plus model

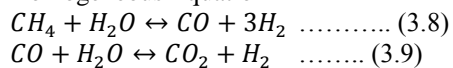
The biomass lower heating value (LHV) was also specified with the HCOALGEN and DCOALIGT property models chosen to estimate the biomass enthalpy of formation, specific heat capacity and density based on the ultimate and proximate analyses.

At normal conditions combustion takes place. The material is directed to the RS toic reactor where 100% of the fuel bound N₂, S and Cl₂ are converted to NH₃, H₂S and HCl correspondingly through Eq. (3.10)-(3.12). The NH₃, H₂S and HCl are detached from the key fuel stream using the separator.

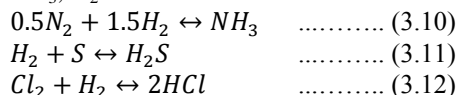
Heterogeneous Equation



Homogeneous Equation



NH₃, H₂S and HCl formation reactions



The core fuel is fed to the gasifier using an R Gibbs reactor called ‘GASIF’. The further feed stream is the steam essential to gasify the biomass and fluidised the bed. The steam temperature is measured as 550 °C.

In the block ‘GASIF’ the gasification reactions Eq. (3.5)-(3.9) were quantified with zero temperature methodology for each reaction (i.e. the chemical equilibrium constant for all reaction is considered at the reactor temperature; thus the block outputs the equilibrium gas arrangement).

3.4 Model Validation

The developed simulation model has been validated using experimental data for Performance Characteristics of an 8MW (th) Combined Heat and Power Plant Based on Dual Fluidized Bed Steam Gasification of Solid Biomass. The model inputs are presented in Table 3.1. These model inputs will be referred to as the base case values for the remainder of this chapter.

IV - RESULTS & ANALYSIS

By the validated model, the effect of various parameters like air-fuel ratio and gasification temperature on gasification performance was studied for rice husk.

4.1 Effect of Air-Fuel Ratio

The air-fuel ratio can be defined as the ratio of the quantity of air compulsory for a unit quantity of fuel to complete combustion.

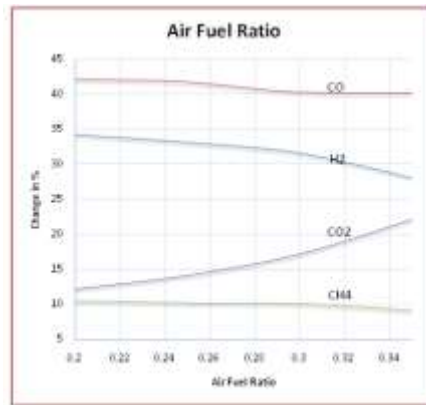


Figure 4.2 Effect of Air fuel ratio

Air fuel ratio or Equivalence ratio is a significant constraint in fluidization bed gasifier process. To study the effect of Air Fuel ratio on syngas configuration a constant 0.5 steam to biomass ratio is assumed with a constant bed temperature at 700°C. The air fuel ratio in the range of 0.20 to 0.35 is varied. With the increment of air fuel ratio the complete combustion of biomass takes place and more carbon monoxide released and this leads to reduction in concentration of carbon monoxide.

Methane concentration is nearly constant over this range of air fuel ratio. Due to whole combustion of biomass the speed of water gas shift reaction is fall and therefore the concentration of hydrogen is decline with increase the air fuel ratio.

4.2 Effect of Gasifier Temperature

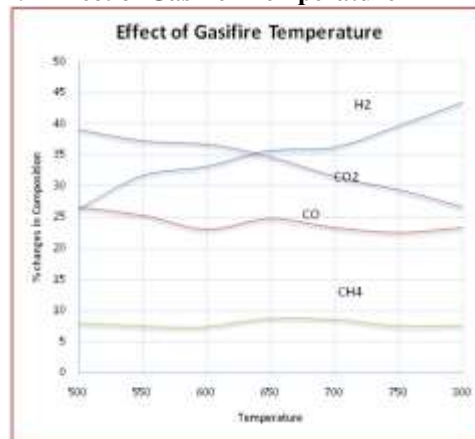


Figure 4.2 Effect of Gasifier Temperature

The effect of gasifier temperature T gon syngas composition is shown in Fig. 4.2. All gas constituents are plotted on a volume % dry basis. The gas constituents H₂S, NH₃ and HCl are not there due to their very low content. Tg is varied from 500-800 °C and it is shown in figure that Gasifier temperature has a very strong effect on syngas configuration. Fluidised bed biomass gasifier should operate below 900 °C because at the

above temperature the ash melting does occurs, which would result in agglomeration and de-fluidization. The percentage of hydrogen increases about 17% percentage points in between the temperature 500 to 800 °C. On the other hand CO₂ decrease about 13 % point; while CH₄ and CO shows a little changes.

4.3 Effect of Steam to Biomass Ratio on Syngas

Steam to biomass ratio show a main role in fluidised bed gasification of biomass. The effect of steam to biomass ratio on product gas composition was calculated over the series of 0.5 to 1.25 at 800°C constant temperature with air fuel ratio 0.5.

Figure 4.3 shows the variations in syngas configuration in answer to difference in STBR (mass basis). Over this STBR kind H₂ rises by 4.5 percentage points. From these results it is clear that STBR is the second most important parameter in respect of syngas composition. Greater steam to biomass ratio helps for more conversion of carbon monoxide to carbon dioxide and hydrogen over water gas shift reaction

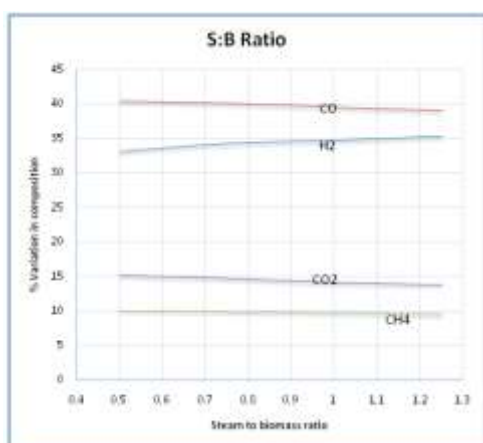


Figure 4.3 Effect of Steam to Biomass ratio

4.4 Effect of Steam Temperature on Syngas

Syngas composition continues lightly unaffected with increase in steam temperature (150-500 °C). The increases steam temperature does moderate the amount of char required in the gasifier up to about 5-10%, which has optimistic consequence on gasifier performance.

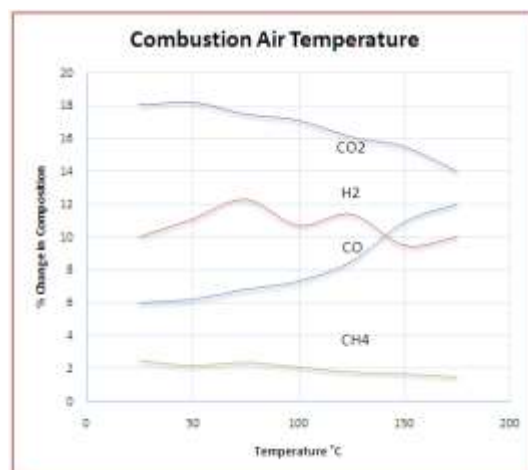
4.5 Effect of Biomass Moisture Content

Biomass moisture content (mass basis) have slight influence on syngas composition. Only H₂ content increased about 2-3% percentage over the moisture range 5-50%. The Steam to Biomass Ratio was considered a constant value 0.75 during this analysis.

4.6 Effect of Combustion Air Temperature

Preheating the combustion air from 25-175 °C causes slight changes in syngas composition. With

the increment of temperature, H₂ percentage increases about 2-3%.



The figure 4.4 show that an increase in combustion air temperature results in an increase in the proportion of hydrogen and carbon monoxide, and a decrease in the proportion of carbon dioxide and methane. This is due to the decreasing speed of the mechanizing reactions, and the higher probability of reactions of water gas.

V- CONCLUSIONS

A computer simulation model of the FICFB gasifier is established using Aspen Plus software tool. The goal of the research work, which was to develop a model of the FICFB gasifier, and utilize it to inspect the effect of the key operating parameters on gasifier performance, was attained. The following conclusions have been obtained:

- With the increment of air fuel ratio the complete combustion of biomass takes place and more carbon monoxide released and this leads to reduction in concentration of carbon monoxide.
- Gasifier temperature has a very strong effect on syngas configuration. The percentage of hydrogen increases about 17% percentage points in between the temperature 500 to 800 °C. On the other hand CO₂ decrease about 13 % point; while CH₄ and CO shows a little changes.
- STBR is the second most important parameter in respect of syngas composition. Greater steam to biomass ratio helps for more conversion of carbon monoxide to carbon dioxide and hydrogen over water gas shift reaction.
- Syngas composition continue slightly unaffected with increase in steam temperature (150-500 °C).
- Biomass moisture content (mass basis) have slight influence on syngas composition. Only H₂ content increased about 2-3% percentage over the moisture range 5-50%.
- Due to the decreasing speed of the mechanizing reactions there is Increase in

combustion air temperature results in an increase in the proportion of hydrogen and carbon monoxide, and a decrease in the proportion of carbon dioxide and methane.

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