PERFORMANCE ANALYSIS OF CIRCULATING FLUDIZED BED BIOMASS GASIFIER: ASPEN SIMULTAION

A Project Report Submitted

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CERTIFICATE

This is to certify that the thesis entitled "**PERFORMANCE ANALYSIS OF CIRCULATING FLUDIZED BED BIOMASS GASIFIER: ASPEN SIMULTAION***"* submitted by **JASMEET SIGH BHATIA (109CH0506)** in partial fulfillment of the requirements for the award of **BACHELOR OF TECHNOLOGY** Degree in Chemical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

DATE: 10th June, 2013 **Prof. Arvind Kumar**

Supervisor

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ABSTRACT

The biomass gasification has been carried out using a fluidized bed gasifier. This work focuses on the production of syngas from biomass (wood chips). ASPEN PLUS simulator and pilot plant gasifier were used to investigate the effect of reactor temperature, equivalence ratio and steam to biomass ratio on composition of product gas. The sensitivity analysis shows that the results obtained were in good agreement with literature.

Keywords: Fluidized bed gasifier, biomass, equivalence ratio, steam to biomass ratio, ASPEN PLUS.

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CHAPTER- 1

INTRODUCTION

Biomass, fuel derived from organic matter on a renewable basis, is among the largest sources of energy in the world, third only to coal and oil [1]. Biomass adsorbs CO_2 from the atmosphere during photosynthesis, and the CO_2 is then returned to the environment after combustion. Because of this cycle, biomass is CO_2 neutral, making it an advantageous fuel source and a dominant choice for replacement of fossil fuels as the concern of global warming increases. Biomass materials known as potential sources of energy are agricultural residues such as straw, bagasse, and husk and residues from forest- related industries such as woodchips, sawdust, and bark [2, 3]. According to a recent study, oil and gas prices are set to double by 2050 [4]. Also global energy demand is set to more than double by the middle of the century, fuelled by the rapid increase in the energy demand of developing countries. Another study, World Energy Outlook [5] predicts similar trends.

Gasification is process for converting carbonaceous materials into combustible or synthetic gas [6]. It can be considered as an upgrading process taking place in a solid which is difficult to handle, stripped of some undesirable constituents and convert it into a gaseous product that can be handled with maximum convenience and minimum cost and can readily be purified to a clean fuel or feedstock for synthesis of other chemicals [7]. Gasification occurs when oxygen (O2) or air and steam or water is reacted at high temperatures with available carbon in biomass or other carbonaceous material within a gasifier. The syngas produced can be combusted in gas turbine or in an engine to generate electricity and heat or more recently syn-gas is considered a candidate fuel for fuel cell applications. Air gasification produces a poor quality gas with regard to the heating value, around 4-7 MJ m^{-3} higher heating value (HHV), while O_2 and steam blown processes result in a syn-gas with a heating value in the range of 10-18 MJ m^{-3} (HHV) [8]. However, gasification with pure O_2 is not practical for biomass gasification due to prohibitively high costs for O_2 production using current commercial technology (cryogenic air separation). This has encouraged research of novel gasification processes such as the dual indirectly heated fluidized bed [8-10].

The concept of gasification is to supply less oxidant than that would be originally required for stoichiometric combustion (complete) of a solid fuel. The resulting chemical

reactions produce a mixture of CO and H2 (syn-gas), both of which are combustible. The energy value of this gaseous fuel is typically 75% of the chemical heating value of the original solid fuel. In addition, the syn-gas temperature will be substantially higher than the original solid fuel due to the gasification process.

The process of biomass gasification can be explained by the following reactions, given in Table

I: Gasification reactions

Reaction	Reaction Number
$C + 0.5O_2 = CO$	(R1)
$C + CO_2 = 2CO$	(R2)
$C + H_2O = CO + H_2$	(R3)
$C + 2H_2 = CH_4$	(R4)
$CO + 0.5O_2 = CO_2$	(R5)
$H_2 + 0.5O_2 = H_2O$	(R6)
$CO + H_2O = CO_2 + H_2$	(R7)
$CH_4 + H_2O = CO + 3H_2$	(R8)
$H_2 + S = H_2S$	(R9)
$0.5N_2 + 1.5H_2 = NH_3$	(R10)

The complete gasification process can be divided into three separate, but linked processes; pyrolysis, gasification, and partial combustion. Partial combustion is very necessary because it supplies the heat required by the endothermic gasification reactions. Pyrolysis takes place in a temperature range of 350-800°C and results in the production of char, CO, H_2, methane (CH_4), CO_2, H_2O, tar and hydrocarbons. These products are then used in the process of gasification and combustion reactions.

The objective of this study is to develop an ASPEN simulation model of a CFB biomass gasifier that can accurately predict its performance under various operating conditions. Aim is to study the effect of different operating parameters (temperature, equivalence ratio and air preheating) on gasification. The model is based on Gibbs free energy minimization. The approach assumes that limited number of chemical reactions (R1 to R10), which are mentioned in the Table 1, are required with respect to predict syn-gas composition, gas heating value and process efficiency.

CHAPTER- 2

LITERATURE REVIEW

2.1 BIOMASS

Biomass is biological material from living, or recently living organisms, most often referring to plants or plant-derived materials. In modern times, the term can be referred to in two meanings. In the first sense, biomass is plant matter used either to generate electricity (via steam turbines or gasifiers), or to produce heat (via direct combustion). Wood remains the largest biomass energy source today; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants, including miscanthus, switch grass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo,[3] and a variety of tree species, ranging from eucalyptus to oil palm (palm oil). As a renewable energy source, biomass can either be used directly, or indirectly—once or converted into another type of energy product such as biofuel. In the present study, the experimental results provided by Li et al. [14] on various types of sawdust species are used.

2.2 Biomass Gasification

Biomass gasification is a process that converts biomass in to a combustible mixture (mainly CO, H_2, CO_2 and CH_4).This is achieved by reacting the biomass at high temperatures, without combustion, with a controlled amount of oxygen, air and/or steam. The resulting gas mixture is called *syngas* (from *synthesis gas* or *synthetic gas*) or *producer gas* and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass. The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells. Gasification can also begin with material which would otherwise have been disposed of such as biodegradable waste.

2.3 Gasification Process: Types of Gasifiers

2.3.1. Fixed Bed Gasifiers

Fixed bed gasifiers are subdivided into updraft and downdraft gasifiers. Both require fuel particles of small size (1-3 cm) to ensure an unblocked passage of gas through the bed. So the preferred biomass form is pellets or briquettes [16].

2.3.2. Fluidized Bed Gasifiers

Two types of fluidized bed reactors are used: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB).

Advantages of Fluidized bed gasifier:

1. Fluidized bed gasifiers do not encounter scaling-up problems.
2. Particle size of feedstock is not strict.
3. Improved mass and heat transfer.
4. Reduced char formation.

The fluidized bed temperature must be kept below the ash melting point of the biomass, since a sticky ash might glue together with bed particles causing agglomeration and breakdown of fluidization. Hence, these are better suited for materials having high ash melting point e.g. woody bio-material (above 1000°C) [16].

2.3.3. Entrained Flow Gasifiers

Entrained flow gasifiers convert the mixture of biomass and oxygen into a turbulent dust flame at high temperatures (significantly above 1200°C, even 2000°C) for a very short period of and at high pressure (about 50 bars). In order to achieve high conversion of the feedstock pulverized solid (particle size below 1 mm) or liquid (e.g. pyrolysis oil) feedstock is used [16].

2.4 PREVIOUS WORKS

Nikoo M. B. and Nader M. [11] developed a process model is for biomass gasification in an atmospheric fluidized bed gasifier using the ASPEN PLUS simulator. The model addresses both hydrodynamic parameters and reaction kinetic modeling. Using pine sawdust as raw material they investigated that temperature increases the production of hydrogen. Equivalence ratio is directly proportional to carbon dioxide production and carbon conversion efficiency. With increase in steam to biomass ratio hydrogen and carbon monoxide production increases and carbon dioxide and carbon conversion efficiency decreases.

Li et al. [12] presented the results from biomass gasification tests in a pilot-scale (6.5-m tall × 0.1-m diameter) air-blown circulating fluidized bed gasifier, and compares them with model predictions. The operating temperature was maintained in the range 700–850◦C, while the sawdust feed rate varied from 16 to 45 kg/h. Temperature, air ratio, suspension density, fly ash re-injection and steam injection were found to influence the composition and heating value of the product gas. An experimental study was completed on a circulating fluidized bed gasifier to examine the effects of operating parameters on the gas composition, gasification efficiency and tar yield. The modeling work started with a non-stoichiometric equilibrium model based on free energy minimization to predict gasifier performance under ideal equilibrium conditions. The present study not only gives experimental evidence that real gasifier deviate from chemical equilibrium in a number of ways, but also provides a phenomenological approach to correct the model by introducing an elemental availability function which corrects for non-equilibrium of certain components

Franco et al. [13] studied the effect of temperature and steam to biomass (pinuspinaster, Eucalyptus globules and holm-oak) ratio on gasification using atmospheric fluidized bed. It was found that with increase in temperature, concentration of hydrogen increases and the concentration of carbon monoxide and methane decreases. Carbon dioxide concentration remains almost constant over the temperature range. Optimum steam to biomass ratio was found to be 0.6-0.7 w/w.

Doherty et al. [14] developed a computer simulation model of a circulating fluidized bed biomass gasifier was developed using ASPEN Plus. The model was calibrated against experimental data. The restricted equilibrium method was used. In addition the results obtained from the sensitivity analyses are in good agreement with published work. They investigated the effects of varying ER, temperature, level of air preheating, biomass moisture and steam injection on product gas composition, gas heating value, and CGE. It was found out that the syn-gas heating value decreases with increasing ER. Further, without air preheating, the CGE reaches a maximum value of 66.1% at an ER of 0.34. Air preheating increases the production of combustible gases, H2 and CO, which increases the product gas heating value and the gasifier CGE.

Legros et al. [15] developed a model for the combustion of coal in a circulating fluidized bed using the ASPEN PLUS simulator. The resulting model was used to predict the performance of the CANMET CFBC pilot plant in terms of combustion efficiency, emission levels of CO, SO_2 and NO,, and 0_2 and CO concentration profiles. The predictions of CO and NO, were achieved using two and one fitting parameters, respectively. The agreement between the model prediction and experimental data is satisfactory but more experimental data are still required to confirm the proposed CFBC model in order to make it more comprehensive and reliable. The model can now be used to represent a CFBC unit in various process simulation flow sheets plants such as power generation plants.

CHAPTER -3

METHODOLOGY

3.1 GASIFIER SELECTION

Atmospheric CFB was selected for the current study because of its near commercial status. This technology is proven for biomass gasification, has potential for scale-up (low MW to over 100 MW) and high fuel flexibility. The Värnamo biomass integrated gasification combined cycle (BIGCC) demonstration plant, which operated in Sweden from 1996 to 2000, used pressurized CFB gasification technology. Fig. 1 shows a schematic of a typical CFB gasifier.

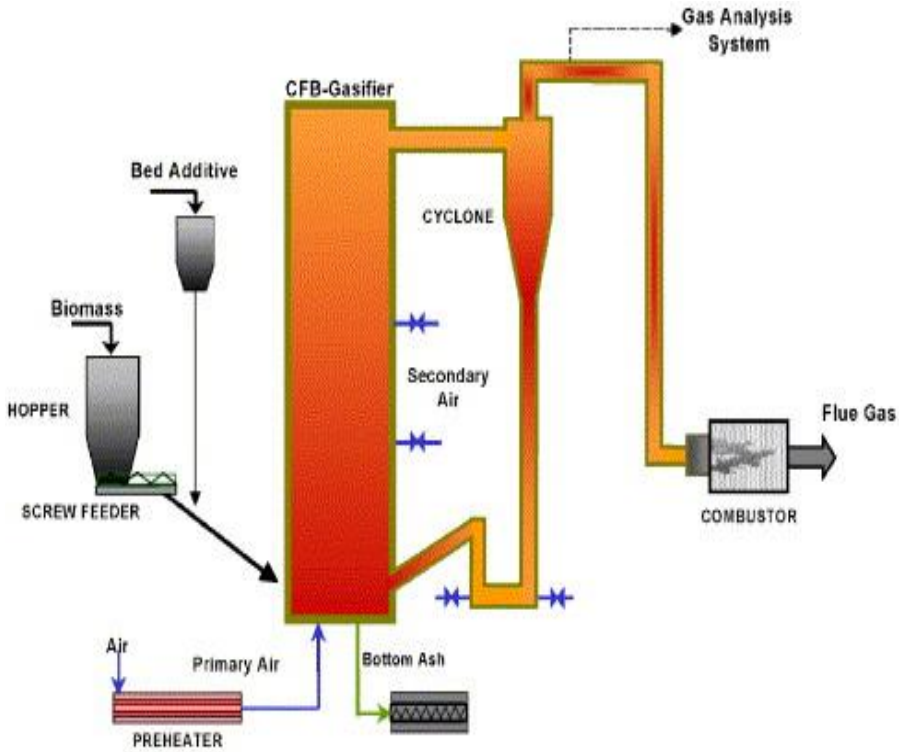

Fig. 1. Schematic diagram of a CFB biomass gasifier.

3.2 PROCESS SIMULATION SOFTWARE

ASPEN Plus was selected for modeling the gasifier. This simulation package has been used for modeling coal and biomass power generation systems in many research projects [9-15]. It is a steady state chemical process simulator, which was developed at Massachusetts Institute of Technology (MIT) for the US DOE, to evaluate synthetic fuel technologies. It uses unit operation

blocks, which are models of specific process operations (reactors, heaters, pumps etc.). The user places these blocks on a flow sheet, specifying material and energy streams. An extensive built in physical properties database is used for the simulation calculations. The program uses a sequential modular (SM) approach, i.e. solves the process scheme module by module, calculating the outlet stream properties using the inlet stream properties for each block. ASPEN Plus has the capability to incorporate FORTRAN code, written by the user, into the model. This feature is utilized for the definition of non-conventional fuels, e.g. biomass, municipal solid waste (MSW), specific coals and for ensuring the system operates within user defined limits and constraints. User models can be created in Excel or written using FORTRAN and can be fully integrated into the ASPEN Plus flow sheet.

3.3 UNCOUPLING THE GASIFICATION PROCESS

To model a CFB gasifier using ASPEN Plus, the overall process must be broken down into a number of sub-processes. Fig. 2 shows the overall gasification process broken down or uncoupled into its sub-processes.

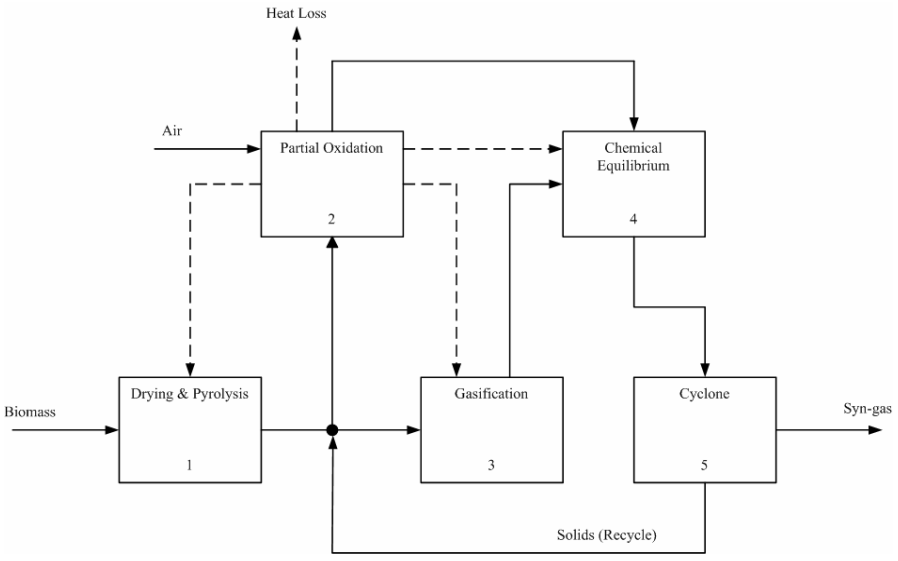

Fig. 2. Uncoupled CFB gasification process.

The drying and pyrolysis zone simulates the first stage of gasification and produces char, H_2, CO, CH_4, CO_2, H_2O, other hydrocarbons, and tars. These products are then either burnt or gasified. The partial oxidation zone simulates the burning of char as well as some H_2 and CO,

which generates the heat required for all the sub-processes. This heat is represented by broken lines in Fig. 2. A percentage of the heat generated is lost from the system and products other than heat from this zone include CO, CO_2, and H_2O. The third zone, the gasification zone, simulates the gasification reactions, reactions such as the Boudouard, the water-gas and the methanation. The products of both the partial oxidation and the gasification zone are fed into an additional zone. This zone sets the final syn-gas composition, which is composed mainly of H_2, CO, CO2 and some CH_4. In this zone the chemical equilibrium of the gasification reactions is restricted in order to give a realistic syn-gas composition. The final zone, box 5, represents the CFB cyclone separator, which separates out and recycles the solids entrained in the gas.

3.4 ASPEN Plus Flowsheet

Fig. 3 displays the CFB biomass gasifier ASPEN Plus flowsheet. Table 1 presents a brief description of the unit operation blocks shown in Fig. 3. It gives the ASPEN Plus name, that is the name given to each unit operation block by the software developers, the block ID, which is the name given to each block by the user and a short description.

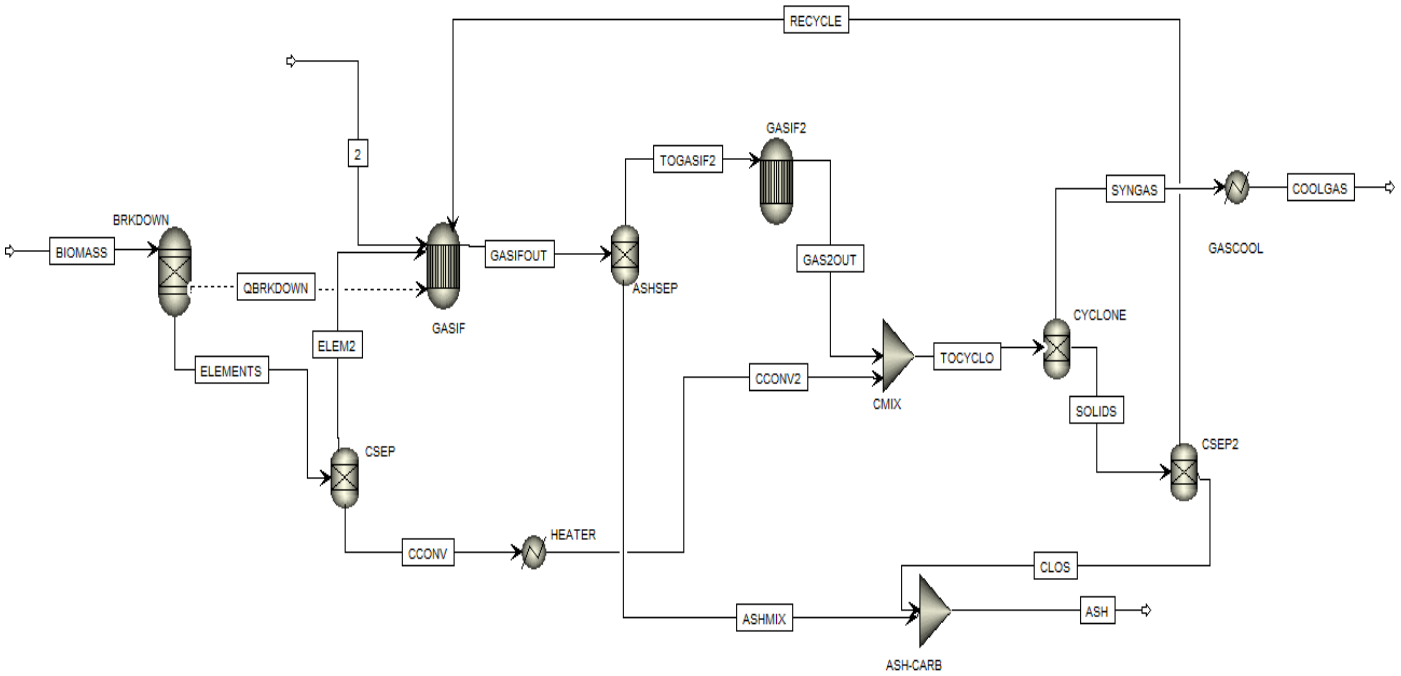

Fig. 3. ASPEN Plus flowsheet of biomass CFB gasifier.

Table 2
Description of ASPEN Plus flowsheet unit operation blocks presented in Fig. 3

ASPEN Plus name	Block ID	Description
RYIELD	BRKDOWN	Yield reactor – converts the non-conventional stream 'BIOMASS' into conventional components
SEP2	CSEP	Separator – extracts a portion of the carbon contained in the fuel so that it remains un-reacted
	ASHSEP	Separator – separates the inert ash from the gas to allow removal from the system
	CYCLONE	Separator – simulates the CFB cyclone by separating out a specified percentage of the solid carbon
	CSEP2	Separator – extracts a portion of the carbon to simulate carbon loss in the ash, with the rest recycled
RGIBBS	GASIF	Gibbs free energy reactor – simulates drying and pyrolysis, partial oxidation, and gasification
	GASIF2	Gibbs free energy reactor – restricts chemical equilibrium of the specified reactions to set the syn-gas composition
HEATER	HEATER	Heater – increases the temperature of the un-reacted carbon to the reactor temperature
	GASCOOL	Cooler – simulates syn-gas cooling to a typical gas cleanup temperature
MIXER	CMIX	Mixer – mixes the un-reacted carbon separated in block 'CSEP' with the syn-gas
	ASH-CARB	Mixer – mixes the carbon lost with the ash before leaving the system
FSPLIT	QSPLIT	Splitter – splits the heat available from syn-gas cooling in 'GASCOOL' into two heat streams with one of them representing the heat lost from the gasifier

3.5 Model Description

From Fig. 3, the stream 'BIOMASS' was specified as a non-conventional stream and the ultimate and proximate analyses were inputted. The stream thermodynamic condition and mass flow rate were also entered. The enthalpy of this stream will not equal the enthalpy of the feed stream 'BIOMASS', as the enthalpies of the individual constituents that make up a fuel do not equal the enthalpy of the fuel because chemical bonds etc. are not taken into consideration. Thus, the heat stream 'QBRKDOWN' was inserted to add back the enthalpy loss to the system.

The function of the next block is to simulate carbon conversion by separating out a specified portion of the carbon from the fuel. Reported carbon conversion for CFB gasifiers in the literature ranged from 90 to 99% [29-32]. Before this carbon can be mixed with the gas downstream it must be brought up to the gasifier temperature, which is accomplished using the block entitled 'HEATER'. The un-reacted carbon represents solids contained in the product gas that must be removed by the CFB gasifier cyclone or other solids removal steps downstream. In reality there would also be fly ash and bed material entrained in the gas but these components cannot be modeled in ASPEN Plus. Thus, in this model the solid carbon that remains in the syn-gas represents all solids. The streams 'ELEM2', '2', and 'RECYCLE' enter the block 'GASIF', where pyrolysis, partial oxidation, and gasification reactions occur. The mass flow of air entering the reactor is set using a design specification, which varies the oxidant mass flow rate so that a specific gasifier temperature is achieved.

Ash removal is simulated in the model using the unit operation block ‘ASHSEP’. The material stream ‘TOGASIF2’ is fed to the unit operation block ‘GASIF2’, which is an ‘RGIBBS’ reactor. ‘RGIBBS’ reactors allow restricted equilibrium specifications for systems that do not reach complete equilibrium. The next block mixes the un-reacted carbon that was separated upstream with the gas from ‘GASIF2’ and its product stream is fed to a separator that simulates the operation of the CFB gasifier cyclone. The block ‘CYCLONE’ was specified so that it removes 85% of the solid carbon from the gas stream ‘CSEP2’ splits the ‘SOLIDS’ stream into a recycle stream ‘RECYCLE’, that is sent back through the gasifier, and another stream named ‘CLOSS’, which represents the carbon lost from the system in the ash. The stream ‘CLOSS’ is then mixed with the ash in the block ‘ASH-CARB’. The stream ‘SYNGAS’ is fed to a cooler entitled ‘GASCOOL’ that cools the gas to the required gas cleanup temperature.

3.6 Model Validation

The model was validated against the experiments of Li et al. [27], which were conducted on a pilot scale air-blown biomass CFB gasifier. The fuel used for model validation is hemlock wood. The ultimate and proximate analyses for the wood are given in Table 3.

Table3. Simulation Results

Element	Vol%
H_2	0.2
N_2	69.1
CO	13.8
CH_4	Trace
CO_2	14.5
H_2O	2.4

It can be clearly seen from the above table that the simulation result of the developed model (fig3) doesn't satisfy with the literature. The composition of the product gas is not even nearly close to the predicted composition or the experimental results. There can be many reasons explaining the big margin between the expected composition and simulation result composition.We have also tried the data from other wood types but the results won't improve. Seeing the error and checking the chemistry of reactions it can be concluded that there might be some small logical error in the model (or flowsheet).To try working out the error and further improving the complex ASPEN Flowsheet, we consider making it simpler by changing the method of approach and taking some assumptions. Developing a new model in ASPEN is easier than the spotting error in a complex model. So we started with a new approach and tried to develop a better model, a final model that could provide accurate results at par with literature.

3.7 Final Model

Four different stages were considered in ASPEN PLUS simulation are decomposition of the feed, volatile reactions, char gasification, and gas solid separation [10].

3.7.1. Biomass Decomposition

The ASPEN PLUS yield reactor, RYield was made into to simulate the decomposition of the feed. It is used when the Reaction stoichiometry is not known or unimportant, Reaction kinetics is unknown or unimportant but Yield distribution is known. In this stage, biomass is converted into its elemental components including carbon, oxygen, hydrogen, sulfur, nitrogen, and ash by specifying the composition according to its ultimate analysis provided in the literature.

3.7.2. Volatile Reactions

The ASPEN PLUS Gibbs reactor, RGibbs, was used for volatile reactions. RGibbs models single phase chemical equilibrium, or simultaneous phase and chemical equilibrium. This model is used when reaction stoichiometry is not known but reactors temperature and pressure are known. Carbon partly constitutes the gas phase and the remaining carbon comprises part of the solid phase (char) and subsequently undergoes char gasification. A Separation column model was used before the RGIBBS reactor to separate volatiles and solids.

3.7.3 Char Gasification

The ASPEN PLUS CSTR reactor, RCSTR performs char gasification by using reaction kinetics. RCSTR assumes perfect mixing in the reactor, that is, the reactor contents have the same properties and composition as the outlet stream.RCSTR handles kinetic and equilibrium reactions as well as reactions involving solids. So for char gasification it is preferred. The hydrodynamic parameters of the fluidized bed reactor divide the reactor into two regions, bed and freeboard. Each region is simulated by one RCSTR.

Below figure (fig4) shows the ASPEN Plus simulation model of the rectified approach and is likely to to provide satisfactory results. The main model assumptions are: steady state conditions, zero-dimensional model, isothermal (uniform bed temperature), drying and pyrolysis are instantaneous in a CFB char is 100% carbon (graphite), all of the sulfur reacts to form H2S.

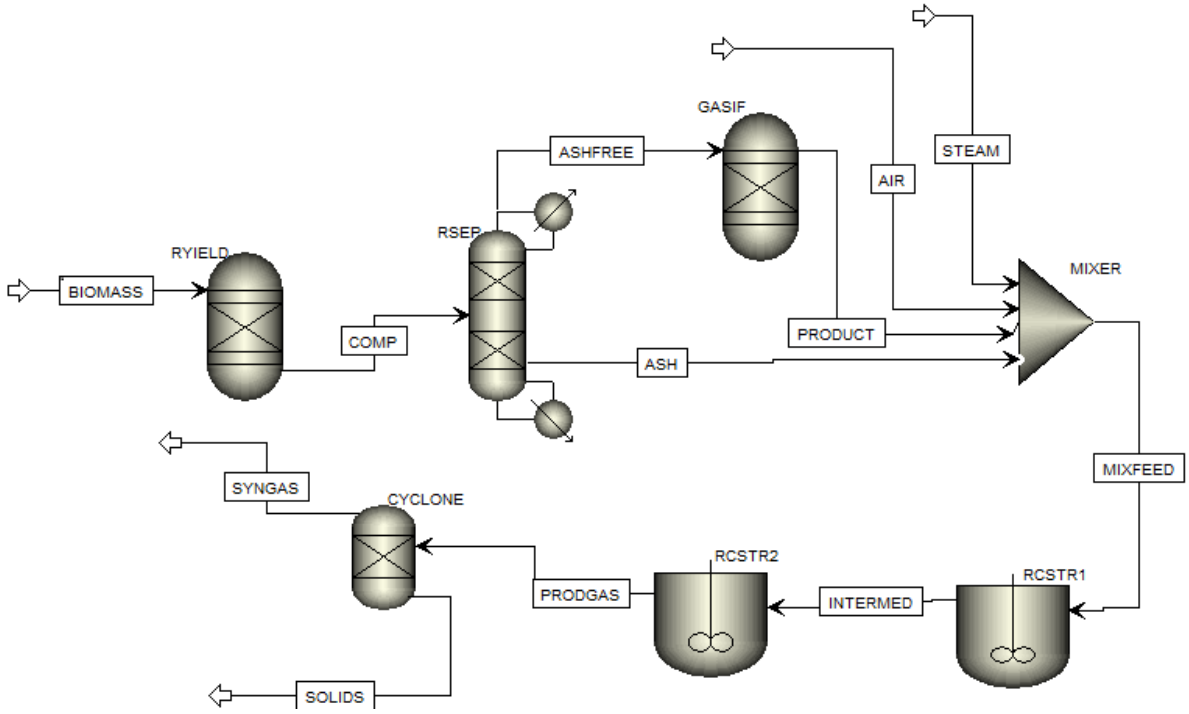

Figure4: Flow-sheet of ASPEN PLUS Simulation for rectified fluidized bed gasification process.

3.8 Model Validation

The model was validated against the experiments of Li et al. [27], which were conducted on a pilot scale air-blown biomass CFB gasifier. The fuel used for model validation is hemlock wood. The ultimate and proximate analyses for the wood are given in Tables 4&5.

Tables 4 & 5, Experimental results versus model predictions

Gas composition*	Experimental (Run 5): Hemlock Wood	ASPEN Model
H_2	4.0	4.2
N_2	61.8	60.5
CO	14.7	14.9
CH_4	2.9	4.5
CO_2	16.5	15.9

*** Volume %, dry basis**

Gas composition*	Experimental (Run 7): Average	ASPEN Model
H_2	7.3	7.1
N_2	55.4	55.5
CO	17.9	16.95
CH_4	3.2	4.1
CO_2	16.3	16.4

*** Volume %, dry basis**

Li et al. reports results for six experimental runs using hemlock wood as input fuel. The input data for three of these runs (run 5 and 7) were entered into the model and the predictions were found to be in good agreement with the reported results. For example for run number 7 the model predicts the following syn-gas composition: 7.1% H_2, 55.5% N_2, 16.95% CO, 16.4% CO_2 and 4.1% CH_4 and for the same input data Li et al. reports 7.3% H_2, 55.4% N_2, 17.9% CO, 16.3%

CO_2 and 3.2% CH_4. The input data for run number 7 are as follows: input fuel stream mass flow - 33.626 kg h-1, gasification temperature - 991 K, and gasification pressure - 1.05 bar.

The model predictions are in good agreement with the experimental data. For example H_2, CO and CO_2 are predicted within 2.5% and N_2 is under-predicted by 6.8%. However the CH_4 is over-predicted. The under or over-prediction of methane is quite a common problem for modelers; the product gas of fluidized bed gasifiers generally contains tar, which is not considered in equilibrium models, and much more hydrocarbons (especially methane) than predicted.

‘

CHAPTER- 4

SENSITIVITY ANALYSIS

The model described was used to perform sensitivity analyses. The effects of varying ER, level of air preheating, and steam to biomass ratio on product gas composition, gas heating value, were investigated. During the sensitivity analyses the model input data was kept the same as for model validation (run 7 input data), with one parameter being varied at any given time.

4.1. Effect of equivalence ratio (ER)

The influence of ER on product gas composition is illustrated in Fig. 4. *Tg* depends on the amount of air fed to the gasifier, i.e. it is controlled by the ER. As a result, varying ER or *Tg* will have the same effect on product gas composition, heating value, and CGE. For this reason only ER is plotted against product gas composition

The equivalence ratio shows two opposing effects on the gasification process. Increasing the amount of air favors gasification by increasing the temperature but, at the same time, produces more carbon dioxide. Gasification with a better level of efficiency produces more carbon monoxide and less carbon dioxide.

Table6. Effect of Varying ER on product gas composition.

ER	H_2	CO	CO_2	CH_4
0.29	2.5	12.5	18.5	10.1
0.3	3.7	13.5	17.5	9
0.33	8	20	8.2	3.2
0.35	14.5	24.7	7.3	0.8
0.38	13	24	7.7	0
0.4	11.5	23.5	8	0
0.43	10	22.5	8.1	0
0.45	9	22	8.3	0

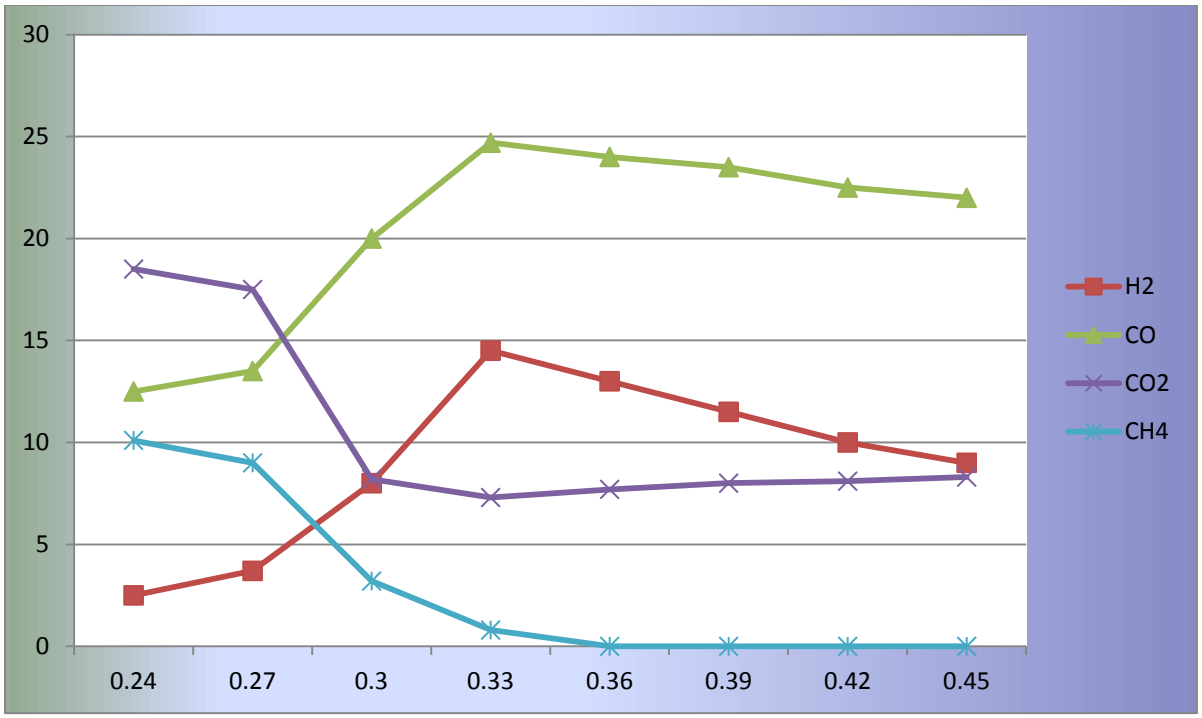

Fig 5. Plot of ER vs. Vol% of the product gas components.

4.2 Effect of Effect of Air Preheating

Table7 show the simulation results compared with experimental data for product gas composition versus nine different temperatures in the range of 25–825^{0}C. Fig.6 shows better agreement between simulation prediction and experimental data for hydrogen production in the temperatures higher than 600^{0}C. Simulation results for carbon monoxide in Fig.6 display good qualitative prediction of experimental data in the whole range, and carbon dioxide production is underestimated before. Also, simulation results in Fig.6 show good accuracy for methane production.

Gases with a CnHm formula are the result of non-equilibrium processes. Thus, because of the assumption in this study that homogeneous reactions follow Gibbs equilibrium, methane is the only possible hydrocarbon in the gasification products.

Table7. Effect of Air Pre-heating on product gas composition.

Temp.	H_2	CO	CO_2	CH_4
25	0.28	12.4	18.2	11
125	4.3	14.6	16.9	9.1
225	6.8	17.45	14.7	8.3
325	8.6	20.1	12.3	7
425	11.7	24.5	9.5	4.6
525	14.2	26.3	7.5	2.2
625	17.1	28	7	0.65
725	17.45	28.6	6.8	0.18
825	17.51	29	6.5	0

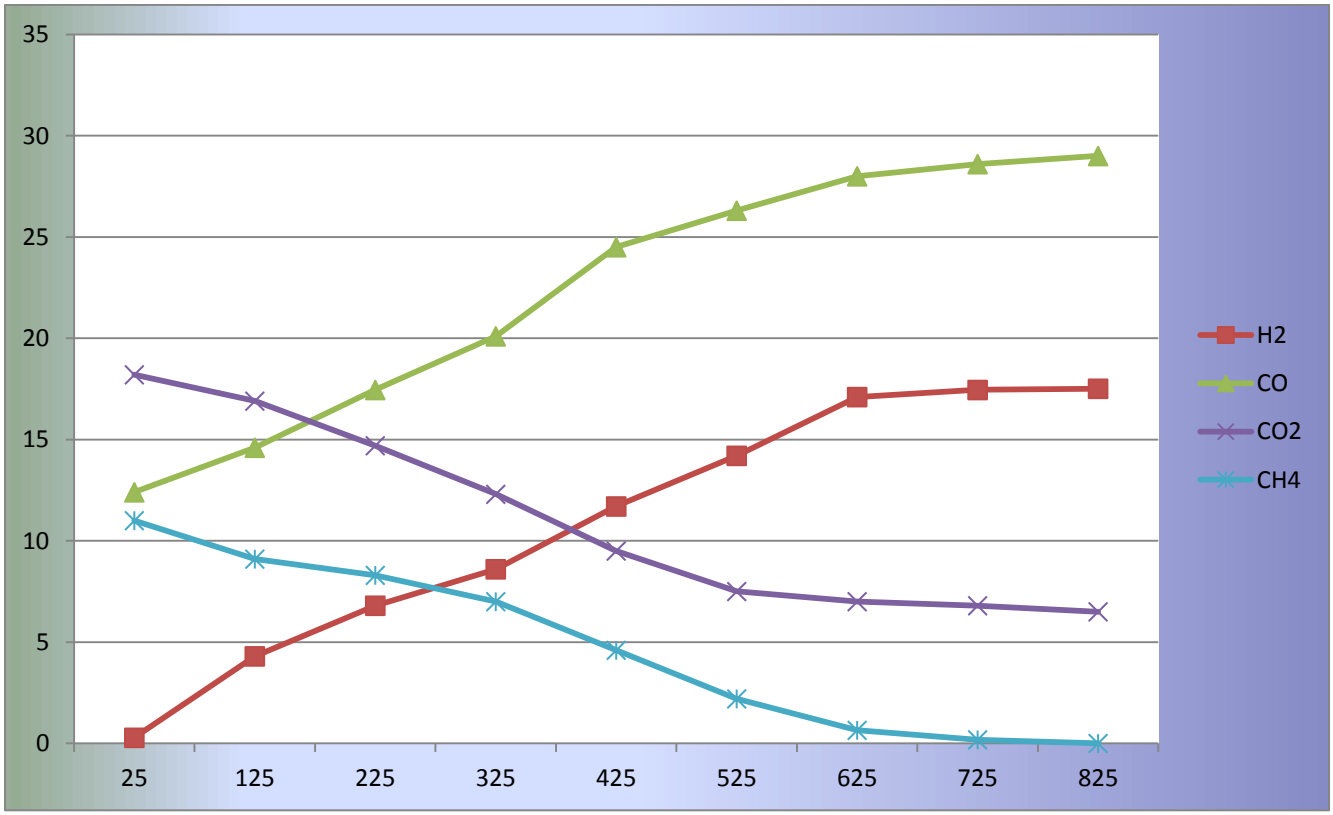

Fig 6. Plot of Air Pre-heating temperature vs Vol% of the product gas components.

4.3 Effect of steam-to-biomass ratio (S/B)

Comparisons of simulation predictions with experimental results of gas composition versus steam-to-biomass ratio in five points in the range of 0.5 – 1.5 are shown in Table 8. Introducing low-temperature steam to the gasification process reduces the temperature of the process and increases the amount of tar. Simulation (Fig.7) predicts the percentage of hydrogen in product gas with the best precision for gasification without steam because of the low amount of tar in the process.

As seen in Fig a higher flow rate of steam decreases carbon monoxide and increases carbon dioxide in the product gas. However, simulation cannot predict the real trends because the effect of varying temperature resulting from the entering steam is ignored. Also, overestimation of the amount of methane is caused when there is no steam in the process.

Table 8. Effect of Steam to Biomass (S/B) Ratio on product gas composition.

S/B	H_2	CO	CO_2	CH_4
0.5	15.28	27.68	7.75	4.29
0.75	15.89	27.32	7.72	4.07
1	16.42	27.19	7.7	3.69
1.25	16.86	27.08	7.69	3.37
1.5	17.34	27.01	7.69	3.08

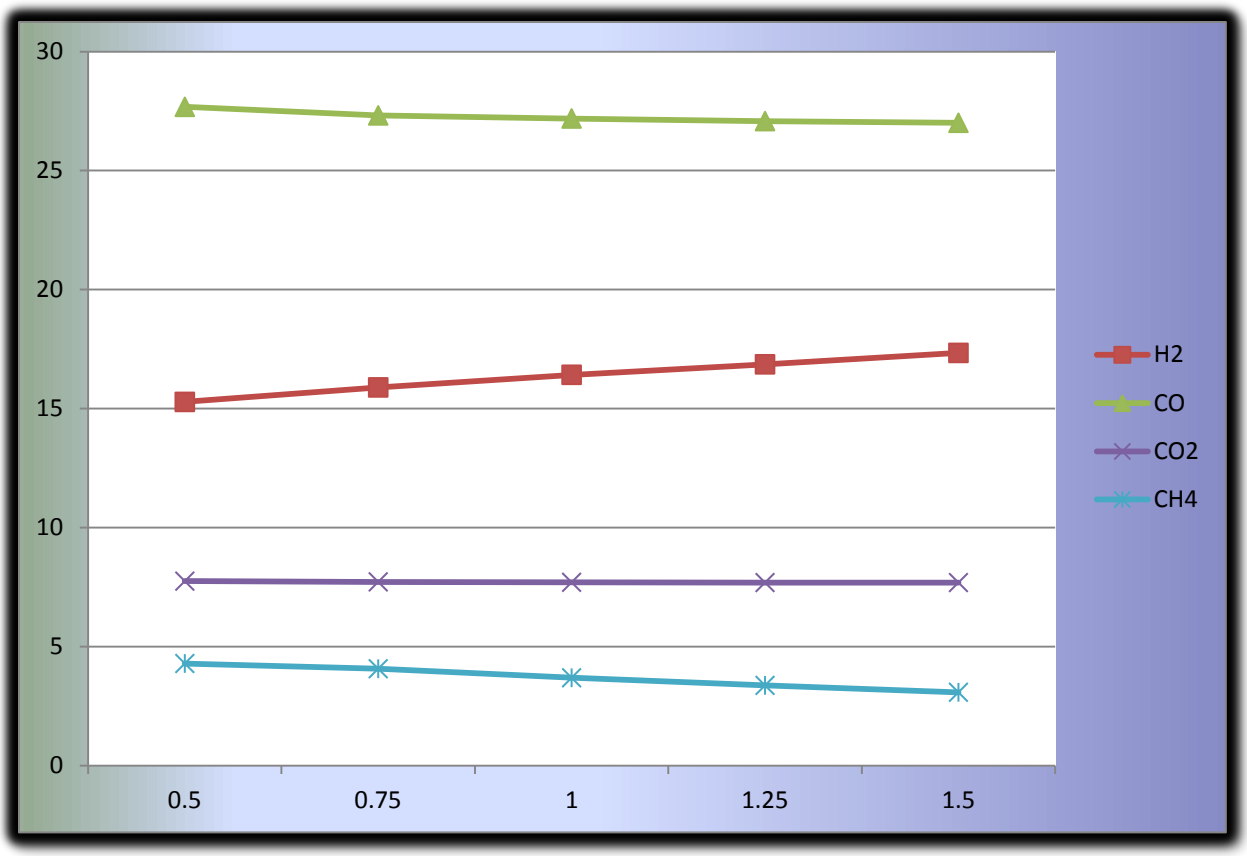

Fig 7. Plot of Steam to biomass ratio vs Vol% of the product gas components.

CHAPTER- 5

DISCUSSION AND CONCLUSION

DISCUSSION

An ASPEN Plus simulation model of circulating fluidized bed biomass gasifier was developed. The developed model was then calibrated against the experimental data provided in the literature. The effect of different operating parameters viz. equivalence ratio, air preheating temperature and steam to biomass ratio was studied by performing sensitivity analysis after obtaining satisfactory results and results obtained from the sensitivity analyses are in good agreement with published work but the concentrations were different because of some simplified assumptions were considered for simulation model. Also studying the effect of changes in the parameter over product gas composition, an optimum value to all the three main parameters has been found out which provides the best possible result of the simulation model.

As we know the gasification reaction is an endothermic reaction, the product as composition is sensitive towards the temperature changes. Changing the temperature of the pre heated gas also increases/decreases the bed temperature which in turn results in the change in the composition of product gas. It can be clearly noticed from the graphs generated that the concentration of almost all the main components changes over a wide range of temperature (25-625C). Further details can be observed from the data tables.

The most important parameter of any gasification process is its equivalence ratio. The effect of equivalence ratio on the product gas composition was studied over a varying equivalence ratio in the range of 0.25-0.45. ER values higher than 0.3 have to be used to get tar contents below 2 g m-3 [40]. Taking these points into consideration the authors recommend operation at ER = 0.34 to 0.35 or Tg = 837 to 874 °C. It can be seen from fig 5 that the Carbon dioxide concentration is inversely proportional to the ER and decreases over slight change in the ER value so we can say that carbon dioxide concentration is sensitive towards the ER.

Steam to biomass ratio also plays an important role in gasification of biomass. The effect of steam to biomass ratio on product gas composition was studied over the range 0.5-1.5 at 800-820C with equivalence ratio 0.35. Higher steam to biomass ratio favors more conversion of CO

to CO_2 and H_2 through water gas shift reaction. So with increase in steam to biomass ratio H_2 and CO_2 concentration increases and CO concentration decreases in the product gas. Also higher steam to biomass provides more favorable condition for steam reforming of methane. So methane concentration decreases with increase in steam to biomass ratio.

CONCLUSION

Using ASPEN PLUS simulator, a model for biomass gasification in an atmospheric fluidized bed was simulated using different kind of wood chips as feed material. Also the sensitivity analysis of biomass gasification model was conducted. A series of experiments and simulations were performed to investigate the effect of air preheating temperature, equivalence ratio and steam to biomass ratio. The volume percentages of H_2, CO, CH_4 and CO_2 were calculated on dry, inert free basis neglecting other gases of very low concentrations. The concentration profiles of these main components were developed on varying the different parameters. Moreover the optimum value of these parameters for the above study has been found out and reported in the table below:

Table9. Optimum value of the Process Parameters found out during sensitivity analysis.

Parameters	**Optimum Value**
Equivalence Ratio	0.35
Operating Temperature	800-875 ºC
Steam to Biomass ratio	~1.25

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