PERFORMANCE ANALYSIS OF A DOWNDRAFT AND FLUIDIZED BED BIOMASS GASIFICATION USING THERMODYNAMIC EQUILIBRIUM MODEL

GAN GEK HIAN

BACHELOR OF CHEMICAL ENGINEERING (PURE)
UNIVERSITI MALAYSIA PAHANG

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GAN GEK HIAN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering.

Signature	:
Name of main supervisor	: DR. NOOR ASMA FAZLI ABD SAMAD
Position	: SENIOR LECTURER
Date	: 2 July 2015

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
Name : GAN GEK HIAN
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Dedication

This thesis is made possible through the help and support from everyone including my parents, lecturers, friends and in essence, all sentient beings. I would never have been able to finish my project without the guidance from them. Therefore, I am using this opportunity to express my gratitude to everyone who supported me throughout this final year project.

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ABSTRACT

Gasification is a process of producing fuel gas or synthesis gas from biomass using gasifier. The gas produced through this process particularly hydrogen will be utilized further as an input for power generation in order to produce energy. Due to the environmental concern and sustainability issues, energy from biomass has become one of the most promising renewable sources of energy. Current research points to improve the gasifier performance in order to elevate more economical product from the gasifier. For this purpose, the thermodynamic equilibrium model can be employed to predict the gas composition and to optimize important gasifier parameters for various kinds of gasifiers as well as utilizing various types of biomasses. In this work, the biomasses consisting of wood, rice husk, saw dust and empty fruit brunch are selected considering their low cost and availabilities as an abundant resource in Malaysia. These biomass sources are then served as the inputs for downdraft and fluidized bed gasifier for producing the hydrogen gas and through this study, the performance analysis in terms of the optimal parameters and gas output composition are then carried out. Here the air is used as an input reactant for downdraft gasifier and the fluidized bed gasifier is employing steam for the gasification process. In this work, the model validation is carried out first where the gas composition data obtained from thermodynamic equilibrium model show good agreement with experimental result from Zainal et al. (2001) for downdraft gasifier employing wood and Karmakar and Datta (2011) for fluidized bed gasifier using rice husk. Afterwards the performance analysis is performed to investigate the optimum parameters for downdraft and fluidized bed gasifiers. Based on this analysis, the optimum parameters obtained are at temperature 770^0C with moisture content of 0.2 and steam biomass ratio 1.32, the hydrogen gas produced from wood, rice husk, sawdust and empty fruit bunch in downdraft gasifier is 16.38%, 17.02%, 16.30% and 50.12 % respectively, while in the fluidized bed gasifier is 38.75%, 50.00%, 73.30% and 71.77% respectively. The result of the performance analysis shows that the fluidized bed gasifier is more efficient than downdraft gasifier in term of hydrogen gas production.

ABSTRAK

Pengegasan adalah satu proses untuk menghasilkan gas bahan api atau gas sintesis daripada biomas menggunakan penggas. Gas yang dihasilkan melalui proses ini terutamanya hidrogen akan digunakan lagi sebagai input bagi penjanaan kuasa untuk menghasilkan tenaga. Disebabkan oleh kebimbangan dan kemampanan isu-isu alam sekitar, tenaga daripada biojisim telah menjadi salah satu sumber yang boleh diperbaharui yang paling menjanjikan tenaga. Titik penyelidikan semasa untuk meningkatkan prestasi penggas untuk meningkatkan produk lebih menjimatkan daripada penggas. Untuk tujuan ini, model keseimbangan termodinamik boleh digunakan untuk meramalkan komposisi gas dan untuk mengoptimumkan parameter Penggas penting untuk pelbagai jenis gasifiers serta menggunakan pelbagai jenis biomasses. Dalam karya ini, biomas yang terdiri daripada kayu, sekam padi, habuk papan dan buah tandan kosong dipilih memandangkan cos yang rendah dan sumber didapati di Malaysia. Sumber-sumber biomas kemudiannya bertindak sebagai input untuk penggas downdraft dan fluidized untuk menghasilkan gas hidrogen dan melalui kajian ini, analisis prestasi dari segi parameter optimum dan komposisi pengeluaran gas kemudiannya dijalankan. Di sini udara digunakan sebagai bahan tindak balas input untuk penggas downdraft manakala penggas fluidized menggunakan stim untuk proses pengegasan ini. Dalam projek ini, pengesahan model yang dilakukan dahulu di mana data komposisi gas yang diperolehi daripada model keseimbangan termodinamik menunjukkan persamaan dengan hasil eksperimen dari Zainal et al. (2001) untuk penggas downdraft menggunakan kayu dan Karmakar dan Datta (2011) untuk penggas fluidized menggunakan sekam padi. Selepas itu analisis prestasi dilaksanakan untuk menyiasat parameter optimum untuk penggas downdraft dan fluidized. Berdasarkan analisis ini, parameter optimum diperolehi adalah pada suhu 770^0C dengan kandungan lembapan sebanyak 0.2 dan stim dengan biomas rasio 1.32, gas hidrogen yang dihasilkan daripada kayu, sekam padi, habuk papan dan buah tandan kosong dalam penggas downdraft adalah masing-masing 16,38%, 17,02%, 16.30% dan 50,12% , manakala di penggas fluidized masing-masing adalah 38,75%, 50,00%, 73,24% dan 71,77%. Hasil analisis prestasi menunjukkan bahawa penggas fluidized adalah lebih cekap daripada penggas downdraft dari segi pengeluaran gas hidrogen.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

C	Carbon
CH_4	Ethane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cp	Heat Capacity
EFB	Empty Fruit Bunch
G	Gas phase
H_2	Hydrogen
H_2O	Water
HHV	High Heating Value
L	Liquid phase
LHV	Low Heating Value
MC	Moisture Content
O_2	Oxygen
P	Pressure
R	Universal gas constant
T	Temperature
Tam	Ambient Temperature
ΔH	Enthalpy change

1 INTRODUCTION

1.1 Motivation, problem statement and brief review

Energy is an essential source for application in domestic and industrial activities. However, the energy production and usage can lead to environmental, economic and social impacts. The production of energy through combustion of fuel like coals normally lead to the problem of global warming caused by the rapidly increasing emissions of greenhouse gases such as carbon dioxide (CO_2) and methane.

Previously, one of the approaches to produce energy is by burning coals through combustion or gasification processes (Boqiang and Ouyang, 2014). The combustion and gasification processes utilizing coal leads to the increased carbon dioxide emissions and over ash accumulation which leads to the greenhouse effect (Salleh et al., 2009). The coal is one of the types of fossil fuels which is non-renewable type of fuels. Therefore, the coal can be short-run sometimes in the future and also affecting the environment through the mass production of carbon dioxide. Since some of the electric utilities are consumed of fossil fuels from the coal, therefore an alternative for the energy production is then necessary (Patrik, 2001).

Increasing of global concern on the environmental issues and decreasing the dependence to the fossil fuels leads to the use of renewable energy (Galindo et al., 2014). Renewable energy becomes an alternative energy technologies which use feed stocks like biomass, biogas or, solar to meet the future energy demand (Galindo et al., 2014). It will not give adverse effect on the environment when compare to the fossil fuels (Canbing et al., 2014).

Currently, enormous efforts have been done to recycle waste materials to produce energy where the major proportions of waste materials are the biomass materials. Gasification process is not a new technology but it is quite new technology for most of the peoples and thus, the introduction of the technology requires research to identify the potential benefits, and the potential risks to convince people to use this type of technology. For the analysis, there is a need to consider a detail characteristics and potential of the technology which may include the amount of energy can be produced from the production and the effect of any condition change on the energy production rate.

Biomass becomes one of the most promising renewable energy sources due to its abundance, energy content, and the low emissions of carbon dioxide to the atmosphere (Gao et al., 2008). Usually, the energy from biomass materials may come from plant sources, such as wood from natural forests, waste from agricultural, forestry processes and industrial or human and animal wastes (Twidell, 1998). Biomass gasification produces syngas through thermo chemical conversion of biomass, usually involving partial oxidation of feedstock in the presence of air, oxygen or steam (Li et al., 2004). In Malaysia particularly, the biomass materials such as wood, rice husk, empty fruit bunch and sawdust are cheap abundant resources and therefore can be utilized for energy production using biomass gasification process. Here, the biomass gasification is one of the approaches to convert these biomass materials to energy where it is an attractive solution to solve both waste disposal and energy problems by producing fuel gas like hydrogen (Karmakar and Datta, 2011). Hydrogen is one of the clean energy sources and a potential alternative fuel. The combustion of hydrogen does not negatively affect the environment.

Nowadays, many gasification technologies to exploit biomass abundances such as downdraft and fluidized bed gasifier are used to produce of electricity, heat, chemicals and liquid fuels. Technically, there are two groups of biomass gasification models to represent downdraft or fluidized bed gasifications which are equilibrium approach and kinetic approach. Kinetic models predict the progress and product composition at different positions along a reactor, whereas equilibrium model predicts the maximum achievable yield of a desired product from a reacting system (Li et al., 2004).

Kinetic models concern on the chemical kinetics of the main reactions and the transfer phenomena among phases, estimating the composition of each species on any point of space and time of a system. The kinetics models are specified in general for each process by providing important considerations on the chemical mechanisms and to increase the reaction rates and the overall process performance. However, the kinetic models always contain parameters which make them hardly applicable to different plants (Schuster et al., 2001). An accurate description of the chemical kinetic rate expression is a key issue. The choice of chemical kinetic laws is difficult because there are as many kinetic laws as kinetic studies. A large discrepancy can be observed between them and it is highly hazardous to extrapolate literature results obtained under different operating conditions (Avdhesh, 2008). For example, the steam and carbon dioxide reforming reactions of char are kinetically limited at temperatures lower than 1000 ℃ (Koroneos and Lykidou, 2011).

Although kinetic models provide essential information on mechanisms and rates, equilibrium models are more suitable as it can predict thermodynamic limits to design, evaluation and improve a process. Equilibrium model also provides a useful design aid in evaluating the limiting possible behaviour of a complex reacting system which is difficult or unsafe to reproduce experimentally or in commercial operation. It provides the greatest possible conversion of each species regardless the system size and the time needed to reach equilibrium. These models do not require details of system geometry neither estimate the necessary time to reach that equilibrium (Karmakar and Datta, 2011).

The increase of global concern on environmental issues had led to the finding of alternative ways to produce energy. One of the most promising ways of energy production is through the use of renewable energy like biomass gasification process. Since the gasification models can be divided into two groups that are equilibrium approach and kinetic approach, the comparison between both types of model had been done. Among them the most effective and applicable model is the equilibrium model due to its behaviour and operation system.

1.2 Objectives

The following are the objectives of this research:

i) To investigate and analyse the performance of downdraft biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

ii) To investigate and analyse the performance of fluidized bed biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

iii) To optimize the important parameters in term of gasifier temperature, moisture content, steam biomass ratio and carbon conversion for downdraft and fluidized bed gasification.

iv) To compare the performance of downdraft and fluidized bed biomass gasification under nominal operating condition and optimal condition.

1.3 Scope of this research

The following are the scope of this research:

i) Analysis of the performance downdraft biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

ii) Analysis of the performance fluidized bed biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

iii) Optimization of the parameters in the downdraft and fluidized bed gasification for better and improved performance.

iv) Performance comparison analysis between downdraft and fluidized bed biomass gasification under nominal operating condition and optimal condition.

1.4 Main contribution of this work

The following are the contributions

a) Development a generic equilibrium thermodynamic model that is capable to apply for a wide range of biomasses
b) The optimum condition for biomass gasifier such as downdraft and fluidized bed can be determined to maximize the hydrogen production
c) Performance validation between experimental data from journal and the developed equilibrium model

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a description of the gasification, the type of gasifier, thermodynamic equilibrium model and previous studies on biomass. For gasification part, the process and the product from gasification will be described. The comparison on the gasifier types is made and reviewed to provide the best types of gasifier to be used. Thermodynamic model will be reviewed and the model used to represent the biomass gasification is analysed. A summary of the previous work on various type of biomass give an overview on the type of biomasses used.

Chapter 3 is the explanation on the step by step on how the whole procedures were done in this work. These procedures were implemented in order to analyse the performance of gasification process.

Chapter 4 shows the excel calculation of thermodynamic model and summaries of the work done. Excel is use since it is user friendly where here user can easily make decision on the type of gasifier, type of biomass, and operating condition in order gets the composition of gas produced.

Chapter 5 is the result of performance analysis that had been done in excel sheet. In this chapter, the thermodynamic model validation is made by comparing the model data with the work in Zainal et al., (2001) for downdraft gasifier and Karmakar and Datta.,(2011) for fluidized bed gasifier. The biomass is then tested in downdraft and fluidized bed gasifier at different condition to find out the most optimum condition and most efficient biomass in both gasifier.

Chapter 6 is the conclusion of this final year project includes the overview on the previous work, objective, scope of studies, contribution, the whole procedure on how the work is to be done, the result of this analysis and the summaries of the work.

2 LITERATURE REVIEW

2.1 Overview

This paper presents the review of gasifier using different type of biomasses. The main purpose of this analysis is to review the performance of gasifier in order to facilitate the selection of the gasifier in term of the energy production. The analysis is based on many factors like type of gasifier, the biomasses used and the parameter used to test the performance.

2.2 Gasification Process

The use of the forest biomass, agricultural or animal residues as a source of energy contribute to lower energy dependency on fossil fuels and in such a way reducing greenhouse gases emissions (McKendry, 2002). Gasification is one of the ways to produce energy from the biomass. Typically, gasification is a thermo-chemical conversion technology or partial combustion process to convert biomass materials into energy through partial oxidation where solid fuel are transform into gas product (Bi and Liu, 2010). A limited amount of air that supplied to biomass gasifier will leads to burning of a relatively small part of biomass which generates heat to maintain a series of thermochemical processes. During gasification four main processes occur inside the reactor which is drying, pyrolysis, oxidation and reduction, and each of these processes has certain physical and chemical features (Felipe., 2012). During gasification process, the biomass is heated to a high temperature, which causes a series of physical and chemical changes that result in the production of volatile products and carbonaceous solid residues. The gasification process uses an agent, either air, oxygen, hydrogen or steam to convert carbonaceous materials into gaseous products. Steam may be added from an external source or from the dehydration reactions of crop residues. Compared to air gasification, steam gasification produces a higher energy based on the gas produced. (Sadaka, 2013).

The main gas produced by gasification is the synthesis gas or syngas which is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen (Chen et al., 2007). The composition of this gas depends on several factors such as the type of biomass used in the process, the temperature and the type of gasification agent

(McKendry., 2002). The syngas can be directly used as a gaseous fuel and can be processed further to produce electricity and heat. Usually, this gas is burned to produce heat and steam or used in the gas turbines to produce electricity (Babu and Sheth., 2006). The efficiency of gasification is based on the biomass material, particle size, gas flow rate and design of the gasifier. Gasifier can be grouped based on the direction of gas flow such as updraft, downdraft, cross draft and fluidized bed (Avdhesh., 2008).

2.3 Types of Gasifier

The differences of properties in chemical, physical and morphological of biomass lead to the different methods of gasification or gasification technologies (Karmakar and Datta, 2011). The study of biomass gasification has been conducted extensively by researchers around the world. The selection of gasifier is determined by their different features. Different gasifiers have different operation mechanism. In gasifiers, as air or steam passed through the fuel bed, fairly discrete drying, pyrolysis, gasification and oxidation zones develop along the reactor. The location of these zones in the gasifier depends on the relative movement of the fuel and air (Sadaka., 2013).

Figure 2-1 illustrates the flow of the fuel and gases in the moving bed gasifier. Most of these types of gasifiers are used with oxygen and steam injected into the bottom of the reactor while the biomass material is fed at the top, producing a counter-current flow. The raw fuel gas flows relatively slowly upward through the bed of biomass feed and cools by drying the biomass. This process allows a lower syngas temperature at the output (400 ℃ -500 ℃), avoiding the needing of an expensive cooling system. Ash may be either dry or slag depending on the steam/oxygen ratio and the melting characteristics of the mineral matter. This gasifier produced syngas has a high heating value due to the high methane content and the consumption of oxygen in the reactor is very low. As a result, the thermal efficiency of the process is very high.

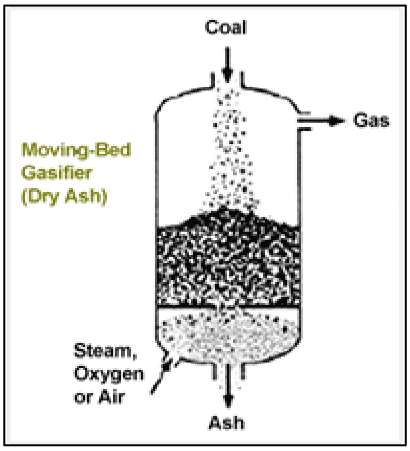


Figure 2-1: Moving Bed Gasifier (adopted from Garcia et al., 2009)

The Figure 2-2 shows the fluidized bed gasifier. There is no specific zone in the fluidized bed gasifier. Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The fluidized bed is externally heated and the feedstock is feed after the bed reaches sufficiently high temperature. The fuel particles like gas or steam are introduced at the bottom of the reactor, very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. This fuel is pyrolysed very fast to make the component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Some ash particles are also carried over the top and have to be removed from the gas stream if the gas is used in engine applications.(Sadaka, 2013).

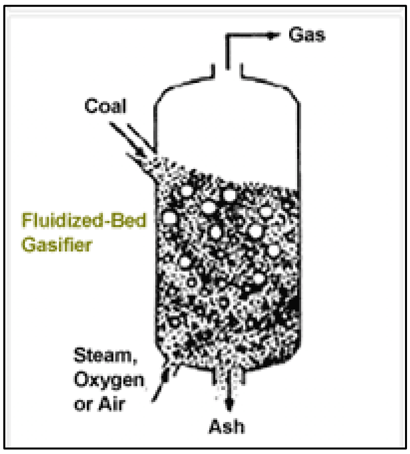


Figure 2-2: Fluidized Bed Gasifier (Adopted from Garcia et al., 2009)

Figure 2-3 illustrates the flow of the fuel and gases in the downdraft gasifier. In the downdraft gasifier, the reduction zone is located at the bottom. The high temperature oxidation zone is located at the above the reduction zone of the gasifier where part of the fuel is burned. The gasifying agent is injected at the bottom of the reactor and ascends from the bottom to the top while the feedstock is introduced at the top of the reactor and descends from the top to the bottom. The fuel descends through three zones which are drying, pyrolysis and oxidation zone of progressively increasing temperatures. The oxidation zone lies at above the injected air of the gasifier and the combustion gas passes through this zone reacting with the char produce heat. The produced gases, tar and other volatiles disperse at the top while ashes are removed at the bottom of the reactor. Part of the fuel is burned in the oxidation zone. The high tar content is not a major problem if the producer gas is used for direct heat applications. However, it requires thorough cleaning for internal combustion engine applications.

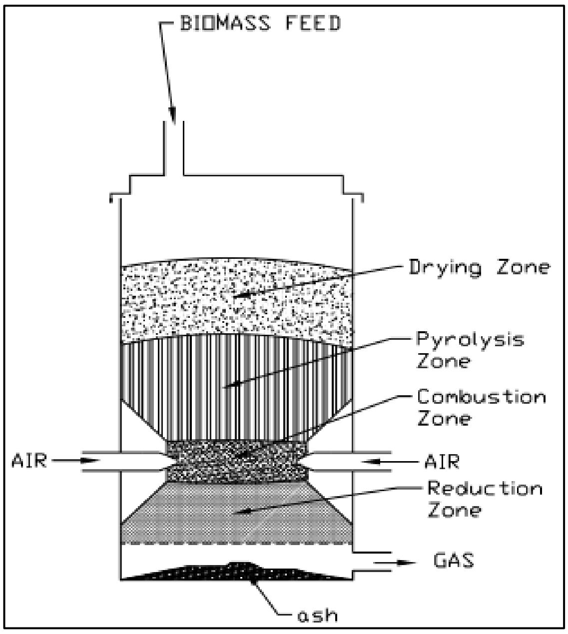


Figure 2-3: Downdraft Gasifier(adopted from Sadaka., 2013)

Table 2-1: Advantage and Disadvantages of Each Type of Gasifier.

Type of Gasifier	Advantages	Disadvantages
Moving-bed Gasifier	• Lower the pressure drop	Suffer from high tar yields inability to maintain uniform radial poor response to load change(Beenackers, 1999; Babu, 1995).
Fluidized beds Gasifier	• High Heating value (HHV) (Schuster et al., 2001). • increase the bunker flow • lower the pressure drop	poor response to load change(Kent.A.J .,

	• lower the slagging • Feedstock steam are flexible • High heat and mass transfer rates(Salleh et al., 2009).	
Downdraft Gasifier	• comparatively cheaper • produces relatively low tar during gasification • can achieve a higher hydrogen content (Giltrap et al., 2003)	High ash content(Sadaka. , 2013)

From the comparison, moving bed had less advantages and more disadvantages compare to the other gasifiers. The fluidized bed gasifier and downdraft gasifier is seems to be more applicable when compare with moving bed gasifier. The fluidized bed had poor response to load change which this problem also faced by the moving bed gasifier so it is better to choose gasifier with more advantages. The high ash content in downdraft will not be a big problem if there are consistent waste management of the remains ash.

Many researchers investigated hydrogen production from biomass gasification in a fluidized bed and only a few studies explore hydrogen-rich gas production in a downdraft gasifier (Pengmei Lva et al., 2007). More studies should be done on the downdraft since both type of gasifier has an ability of hydrogen gas production and a proper comparison between these two types of gasifier should be done to analyse the performance of these gasifier.

2.4 Thermodynamic Equilibrium Model

Traditionally, the simulation of gasifier may be carried out by thermodynamic equilibrium modelling, kinetic modelling, numerical modelling and artificial neural network (Budhathoki et al., 2013). The important parameters such as moisture content, equivalence ratio, producer gas composition and heating value of gas have been analysed in chemical equilibrium approach (Pitchandi, 2012). A mathematical model is developed to predict performance of a biomass gasifier. The model is mostly used to study of process parameters such as reactor temperature, steam biomass ratio and moisture content which generally influence the percentage of hydrogen content in the product gas (Avdhesh, 2008).

Thermodynamic equilibrium never takes place in real gasification process (Chowdhury et al., 1994) but many works demonstrate the use of equilibrium model. Researchers used the equilibrium model based on the minimization of Gibbs free energy to analyses the gasification process and also to solve the optimization and non-linear equation problems based on the gasification process. Equilibrium model can also based on the equilibrium constant. However, equilibrium model based on the minimization of Gibbs free energy and equilibrium constants are of the same concept (Li et al., 2001; Altafini et al., 2003). Some of the models have been developed based on thermodynamic and chemical kinetics to find out the temperature and rate of feedstock consumption in the pyrolysis zone (Sharma, 2008; Kaosol and Sohgrathok, 2013). Schuster et al. (2001) also developed a model for steam gasification of biomass applying thermodynamic equilibrium calculations that combined heat and power station based on a dual fluidized bed steam gasifier.

Zainal et al. (2001) used the equilibrium constant equilibrium model to predict the performance of gasifier. It was observed that the calorific value of the producer gas decreases with increase in moisture content and the gasification temperature. The amount of oxygen in that model was eliminated by defining it to some components in producer gas. This model can predict the reaction temperature by knowing the amount of oxygen, and vice versa. The coefficients determined from the comparison of the predicted results with the experimental results from other works can be multiplied with the equilibrium constants to improve the model. Equilibrium models convert species regardless of the system size and the time needed to reach equilibrium (Rodrigues et al., 2009).

From Zainal et al. (2001), the equilibrium model assumes that all the reaction are in thermodynamic equilibrium. It is expected that the pyrolysis product burns and achieves equilibrium in the reduction zone before leaving the gasifier, hence an equilibrium model can be used in the downdraft gasifier.

The reaction involve in the gasification process are as follows:

Steam gasification

$C + CO_2 = 2CO$ (1)

Boudouard reaction

$C + H_2O = CO + H2$ (2)

Methanation reaction

$C+2H_2 = CH_4$ (3)

The other important reaction involve is the steam formation reaction.

$CH_4+H_2O=CO+3H_2$ (4)

The shift reaction of

$CO+H_2O=CO_2+H_2$ (5)

The formula of steam formation reaction and shift reaction is then deriving into equilibrium constant for methane formation as follow:

$$K_1 = \frac{P_{CH_4}}{(P_{H_2})^2} \quad (6)$$

$$K_2 = \frac{P_{CH_4}P_{H_2}}{P_{CO}P_{H2O}} \quad (7)$$

The chemical formula is defined in term of $C_nH_aO_b$ which is based on single atom in general to develop the global gasification reaction. In the Zainal et al. (2001) the calculation was given by using the raw material of woody materials. The typical chemical formula of woody materials based on single atom of carbon is $CH_{1.44}O_{0.66}$. Thus the overall chemical reaction is represented as below:

$CH_{1.44}O_{0.66}$ +w H_2O +mO_2 +3.76m N_2 = x_1 H_2 + x_2 CO + x_3 CO_2 + x_4 H_2O + x_5 CH_4 +3.76mN_2 (8)

Where,

w is the amount of water per kmol of material

m is the amount of oxygen per kmol of material

x_1 , x_2 ,x_3 ,x_4 and x_5 is the coefficient of constituents of the products.

Here the w can be determined by using moisture content (MC) formula as shown below:

$$MC = \frac{mass\ of\ water}{mass\ of\ wet\ biomass} \times 100\% = \frac{18w}{24+18w} \times 100\%$$

Therefore,

$$w = \frac{24MC}{18(1-MC)}$$

After the moisture content is known, the value of w becomes a constant. From the global reactions, there are six unknown x_1, x_2, x_3, x_4, x_5 and m, representing the five unknown species of the product and the oxygen content for the reaction. Therefore, six equations are required, which are formulated below:

Carbon balance:

$$1= x_1 + x_2 + x_3 + x_4 + x_5 \tag{9}$$

Hydrogen balance:

$$2w + b= 2x_1 + 2x_4 + 4x_5 \tag{10}$$

Oxygen balance:

$$w + a +2m = x_2 + 2x_3 + x_4 \tag{11}$$

Equilibrium constant from methane formation (Equation (6)):

$$K1=\frac{x_5}{x_1^2} \tag{12}$$

Equilibrium constant from shift reaction (Equation (7)):

$$K2 = \frac{x_1 x_3}{x_2 x_4} \tag{13}$$

In order to find the value for the unknown most of the equation had been derived in term of heat change in term of temperature. The first stage of derivation is to find the value of K_1 and K_2 in term of temperature.

The heat of formation equation for the formation of 1mol of solid biomass ($CH_{1.44}O_{0.66}$) from solid carbon, hydrogen and oxygen is:

$$C_{(sol)} + 0.72\ H_{2\,(g)} + 0.33O_2 \longrightarrow CH_{1.44}O_{0.66} \tag{14}$$

and in the reality, the reaction cannot occur. The formation of $CH_{1.44}O_{0.66}$ is based on the following reactions:

$C + O_2 \longrightarrow CO_2$ ΔH_c= -393509

$0.72\ H_2 + 0.36\ O_2 \longrightarrow 0.72\ H_2O$ ΔH_c= -241818 x(0.72)

$CO_2 + 0.72\ H_2O \longrightarrow CH_{1.44}O_{0.66} + 2.06\ O_2$ ΔH_c= 449568

$C + 0.72\ H_2O + 0.33\ O_2 \longrightarrow CH_{1.44}O_{0.66}$ ΔH_f =-118050 kJ/kmol

Therefore, the heat of formation of materials is -118050kJ/kmol. Hence, the heat of formation for any biomass material can be determined if the ultimate analysis and the heating values of the material are known. The heating value can be determined experimentally by bomb calorimeter, the heat of formation of any biomass material can be calculated with good accuracy from the following:

ΔH_c =HHV (kJ/kmol) =0.2326(146.58 C+56.878 H -51.53 O - 6.58 A + 29.45) (15)

Where C, H, O, and A are the mass fractions of carbon, hydrogen, oxygen and ash, respectively, in the dry biomass. The chemical formula of any biomass material can be determined if the ultimate analysis is known. At constant pressure, the specific heat can be written as:

$$C_p = \left(\frac{\partial H}{\partial T}\right)_P \quad (16)$$

Or

$$dH = C_p dT \quad (17)$$

$$\Delta H = \int_{T_1}^{T_2} C_p dT \quad (18)$$

Where H is the enthalpy and T is the temperature.

Equation (18) can be written as

$$\Delta H = C_{pmh} (T_2 - T_1) \quad (19)$$

Where C_{pmh} is the average specific heat over the temperature change $\Delta T = T_2 - T_1$ with T_2 is the gasification temperature at reduction zone and T_1 is the ambient temperature at the reduction zone.

$$C_{pmh} = \left(\frac{\int_{T_1}^{T_2} C_p dT}{T_2 - T_1} \right) \quad (20)$$

The dependence of specific heat on the temperature is given by an empirical equation and the most simplified version is:

$$C_{pmh} = R \left(A + BT_{am} + C/3\,(4T_{am}^2 - T_1T_2) + \frac{D}{T_1T_2}\right) \quad (21)$$

Where $T_{am} = (T_1 + T_2)/2$ is the arithmetic mean temperature and R is the universal gas constant (8.314 J/mol K).The constant A, B, C and D for Cp is taking from the Smith et al. (2005). The enthalpy changes, ΔH, can be obtained using Equation (19). The equilibrium constant K is a function of temperature only and is written as follows:

$$-RT\ln K = \Delta G^0, \quad (22)$$

Where ΔG^0 is the standard Gibbs function of formation and ΔH^0 is the heat of formation. The dependence of ΔG^0 with temperature T can be written as follows:

$$\frac{d(G^0/RT)}{dT} = \frac{-\Delta H^0}{RT^2} \tag{23}$$

With reference to Equation (22),

$$\frac{\Delta G^0}{RT} = -\ln K \tag{24}$$

Therefore,

$$\frac{d\ln K}{dT} = \frac{-\Delta H^0}{RT^2} \tag{25}$$

The above equation gives the effect of temperature on the equilibrium constant if ΔH^0, is negative, then the reaction is exothermic and the equilibrium constant can be reduced if the temperature increases. On the contrary, K increases with T for an endothermic reaction. Since the heat of formation is a function of T, Equation (25) can be integrated as follows:

$$\ln K = \int \frac{\Delta H^0}{RT^2} dT + I \tag{26}$$

Where I is the constant of integration ΔH^0 is given in the following equation:

$$\frac{\Delta H^0}{R} = \frac{J}{R} + (\Delta A)T + \frac{\Delta B}{2} T^2 + \frac{\Delta C}{3} T^3 - \frac{\Delta D}{T} \tag{27}$$

Where J is a constant. ΔA, ΔB, ΔC and ΔD are the coefficients for determining specific heat. Substitution of Equation (26) into Equation (27) and integrating gives:

$$\ln K = \frac{-J}{RT} + (\Delta A)\ln T + \frac{\Delta B}{2} T + \frac{\Delta C}{3} T^2 + \frac{\Delta D}{2T^2} + I \tag{28}$$

From Equation (23), $-RT\ln K = \Delta G^0$, and multiplying Equation(28) with $-RT$ gives:

$$\Delta G^0 = J - RT\left(\Delta A \ln T + \frac{\Delta B}{2} T + \frac{\Delta C}{3} T^2 + \frac{\Delta D}{2T^2} + I\right) \tag{29}$$

Equations (27) - (29) will be used to find the equilibrium constant for any reaction temperature T. For this purpose, knowledge of the specific heat is sufficient to determine the constants J and K. The constant J can be determined using Equation (27) at the temperature of 298.15 K where the value ΔH^0 is known. Similarly, the constant I is determined using Equation (28) or Equation (29) at the temperature which the value of ln K and ΔG^0 are known, normally at 298.15K.

In this work, two equilibrium equations are required to determine the equilibrium constant K_1 and K_2. K_1 is the equilibrium constant for the reaction of Equation (3) and is solved as follows: ΔA, ΔB, ΔC and ΔD can be obtained from the data of heat capacity. For the reaction from Equation (3),

$C + 2H_2 = CH_4$

$\Delta = CH_4 - C - 2H_2$

The equation to determine the values of ΔA, ΔB, ΔC, and ΔD can be written as:

$\Delta A = A_{CH4} + A_C + 2A_{H2}$

$\Delta B = B_{CH4} + B_C + 2B_{H2}$

$\Delta C = C_{CH4} + C_C + 2C_{H2}$

$\Delta D = D_{CH4} + D_C + 2D_{H2}$

Calculation of the constant J and I at 298.15 K requires the values for ΔH^0_{298} and ΔG^0_{298}. This data is available from the heat of formation data and the Gibbs function of formation.

$\Delta H^0_{298} = (H^0_{298})_{CH4} - (\Delta H^0_{298})_C - 2(\Delta H^0_{298})_{H2}$

$\Delta G^0_{298} = (G^0_{298})_{CH4} - (\Delta G^0_{298})_C - 2(\Delta G^0_{298})_{H2}$

The equilibrium constant K_1 for any temperature T can be obtained by substituting the temperature T. A similar procedure is used to determine the equilibrium constant K_2 for the reaction of Equation (6), that is

$CO + H_2O = CO_2 + H_2$

After going through the calculation steps, the general equation $\ln K_2$ is obtained. Similarly, the equilibrium constant K_2 for any temperature T can be obtained by substituting the temperature T. When temperature is set then the value of K_1 and K_2 can be defined.

Equations (9)-(13) represent six equations with six unknowns. Two of the Equations (12) and (13) are nonlinear equations while the rest are linear equations. The above system of equations can be reduced to three set of equations, one linear and two nonlinear equations.

From Equation (9),

$$x_5 = 1 - x_2 - x_3 \qquad (30)$$

From Equation (10),

$$w = x_1 + x_4 + 2x_5 - 0.72 \qquad (31)$$

Substitution of Equation (30) into Equation (31) gives:

$x_4 = w + 0.72 - x_1 + 2x_2 + 2x_3 - 2(1 - x2 - x3)$

$x_4 = - x1 + 2x2 + 2x3 + w - 1.28$ (32)

From Equation (11),

$m = ½(x_2 + 2x_3 + x_4 - w – 0.66)$ (33)

Substitution of Equation (31) into Equation (33) gives:

$m = ½(x_2 + 2x_3 + w - x_1 + 2x_2 + 2x_3 – 1.28w – 0.66)$

$m = ½(3x_2 + 4x_3 - x_1 - 1.94)$ (34)

From Equation (12),

$x_5 = x_1^2 K_1$ (35)

Substitution of Equation (30) into Equation (35) gives:

$x_1^2 K_1 + x_2 + x_3 - 1 = 0$ (36)

From Equation (13),

$x_1 x_3 = x_4 x_2 K_2$ (37)

Substitution of Equation (31) into Equation (37) gives:

$x_1 x_3 - x_2 (w - x_1 + 2x_2 + 2x_3 - 1.28)K_2 = 0$ (38)

To find the value of these unknown , the equation of heat balance is derived by assumed gasification process to be adiabatic which represented as, is :

$$H^0_{F\,wood} + w(H^0_{F\,H2o(l)} + H_{(vap)}) = x_2 H^0_{F\,CO} + x_3 H^0_{F\,CO2} + x_4 H^0_{F\,H2O(vap)} + x_5 H^0_{F\,CH4} + \Delta T(x_1 C_{p_{H2}} + x_2 C_{p_{CO}} + x_3 C_{p_{CO2}} + x_4 C_{p_{H2O}} + x_5 C_{p_{CH4}} + 3.76\, m\, C_{p_{N2}}) \quad (39)$$

Where,

$H^0_{F\,wood}$ is the heat of formation of wood

$H^0_{F\,H2o(l)}$ is the heat of formation of liquid water

$H_{(vap)}$ is the heat of vaporization of water

$H^0_{F\,H2O(vap)}$ is the heat of formation of water vapor

$H^0_{F\,CO}$, $H^0_{F\,CO2}$ and $H^0_{F\,CH4}$ are heat of formation of gaseous products

$C_{p_{H2}}$,$C_{p_{CO}}$, $C_{p_{CO2}}$, $C_{p_{H2O}}$,$C_{p_{CH4}}$ and $C_{p_{N2}}$ are specific heats of gaseous products

$\Delta T = T_2 – T_1$

T_2 , the gasification temperature at reduction zone

T_1 , the ambient temperature at the reduction zone

This equation can be simplified into

dH_{wood}+ $wdH_{H2O(l)}$ = x_1 dH_{H2} + x_2 dH_{CO}+ x_3 dH_{CO2} + x_4 $dH_{H2O(vap)}$ + x_5 dH_{CH4} +3.76 mdH_{N2} (40)

Where,

$dH_{(for\ any\ gas)}$,is the heat of formation +enthalpy change

$dH_{(for\ any\ gas)}= H_f^0 + \Delta H$, $\Delta H = \Delta T(C_{p_{(g)}})$,

$dH_{H2O(l)} = H^0_{F\,H2o(l)}$ + H $_{(vap)}$,

$dH_{material} = H^0_{F\,wood}$

Substitution of Equations (31), (32) and (34) into Equation (40) gives:

x_1 dH_{H2} + x_2 dH_{CO} + x_3 dH_{CO2} + (w - x_1 + 2x_2 +2 x_3 – (b/2+ 2)) $dH_{H2O(g)}$ + (1- x_2 - x_3) dH_{CH4} + 3.76 ½(3x_2 + 4x_3 - x_1 –(b/2+ 2) – a)dH_{N2} - dH_{wood} – w $dH_{H2O(l)}$ = 0

Which can be simplified as :

(dH_{H2} - $dH_{H2O(g)}$ -1.88 dH_{N2}) x_1+(dH_{CO}+2 $dH_{H2O(g)}$ - dH_{CH4} +5.64 dH_{N2}) x_2 + +(dH_{CO2}+2 $dH_{H2O(g)}$ - dH_{CH4} +7.52 dH_{N2}) x_3 ($dH_{H2O(g)}$ - $dH_{H2O(l)}$)w + dH_{CH4} – (b/2+ 2)$dH_{H2O(g)}$–((b/2+2)–a)dH_{N2}-dH_{wood}=0 (41)

To simplify Equation (41), the unknown constants are simplified as follows:

A= dH_{H2} - $dH_{H2O(g)}$ -1.88 dH_{N2}

B= dH_{CO}+2 $dH_{H2O(g)}$ - dH_{CH4} +5.64 dH_{N2}

C= dH_{CO2}+2 $dH_{H2O(g)}$ - dH_{CH4} +7.52 dH_{N2}

D = $dH_{H2O(g)}$ - $dH_{H2O(l)}$

E = dH_{CH4} – (b/2+ 2)$dH_{H2O(g)}$ –((b/2+ 2) – a)dH_{N2} - dH_{wood}

Therefore, Equation (41) simplifies to:

$Ax_1 + Bx_2 + C\,x_3 + D\,w + E = 0$ (44)

The systems of the remaining equations are 3 which consist of two nonlinear Equations (36) and (38), and one linear Equation (44). The set of equations are solved using the Newton-Raphson method. From the Newton-Raphson method, the values for all unknown and the composition of gas can be analyses by put in all the unknown value into the global general equation.

2.5 Type of Biomasses

In air gasification, the gas quality or the gas composition including tar and quantity varies widely depending on the type of gasifier, chemical composition of the feedstock, moisture content, size, density and equivalence ratio (Sheth and Babu., 2010). Previous studies performed by other researchers determined the type of biomasses suitable for gasification. Singh et al., (2006) presents an experimental study on the gasification of pine wood, eucalyptus wood, rice husk and nut shell. Through the study it has been shown that these residues are suitable for energy production using gasification.

In another study, Mamphweli and Meyer., (2009) study on the residues obtained in sawmill. Yoon et al. (2012) studied experimentally the gasification of rice husk and rice husk pellets which showed the possibility of stable power generation using syngas from rice mills. Jayah et al. (2003) studies on fuels like cashew nut shell, pine wood, wheat straw, kiker wood, waste wood, food waste, card board, paper waste and pellets of palm oil residue in downdraft gasifier. Azzone et al., (2012) also focuses on agriculture residues like corn stalks, sunflower stalks and rapeseed straw by using a downdraft gasifier.

Wood had been used in many studies as one of the main raw materials input during the gasification process. The experimental result for gas composition from wood gasification process in Zainal et al.,(2001) shows the detail calculation of gas produce using thermodynamic equilibrium model. Rice husk was successfully used as a biomass material in a downdraft biomass gasifier by Chowdhury et al., (1994) and in fluidized bed gasifier by Karmakar et al., (2011) which the effect of reactor temperature, steam biomass ratio and carbon conversion were tested. Miskam et al., (2009) had studied on the characteristic of saw dust residues in cyclone gasifier. The result shows that the characteristic of saw dust from Malaysia's furniture industries is comparable with other types of biomass and making it a potential source of fuel for gasification. Sawdust also one of the cheapest fuel and the reuse of it will be the cheapest way to manage the disposed in landfill areas. Gasification of biochar from empty fruit bunch (EFB) in fluidized bed reactor had been studied by Salleh et al. (2009) to determine gas yield, overall carbon conversion, gas quality, and composition as a function of temperature. Hydrogen gas from biochar was also optimized during the experiment. High temperatures favor H2 and CO formation. In their work, it also shown that the EFB has the potential to replace coal as a gasification agent in power plants. Therefore, there are great prospects for the use of EFB as an alternative fuel in power plants, as a renewable energy providing an alternative path to biofuels.

2.6 Summary

In reviewing past literature and experimental/simulation studies in the biomass gasification, it can be concluded that biomass gasification in a fluidized bed and downdraft gasifier shows the potential of hydrogen production from biomass oxygen or steam gasification where their performance can be predicted using the thermodynamic equilibrium model. The studies on wood had been carried out in order to validate the performance of the model by doing the comparison between the model data and the experimental data from journal. There were a lot of studies on the rice husk so the analysis data for rice husk is available which can be used as a reference for future studies in the performance analysis. There were limited studies on feedstock like empty fruit bunch and saw dust which can be a potential fuel for power generation. Therefore, in this work the wood, rice husk, sawdust and empty fruit bunch are selected as a feedstock for the gasifier.

3 METHODOLOGY

3.1 Overview

An overview of the different steps to be taken for performance analysis of a downdraft and fluidized bed biomass gasification using thermodynamic equilibrium model is shown in Figure 3.1. The details of each step are explained below.

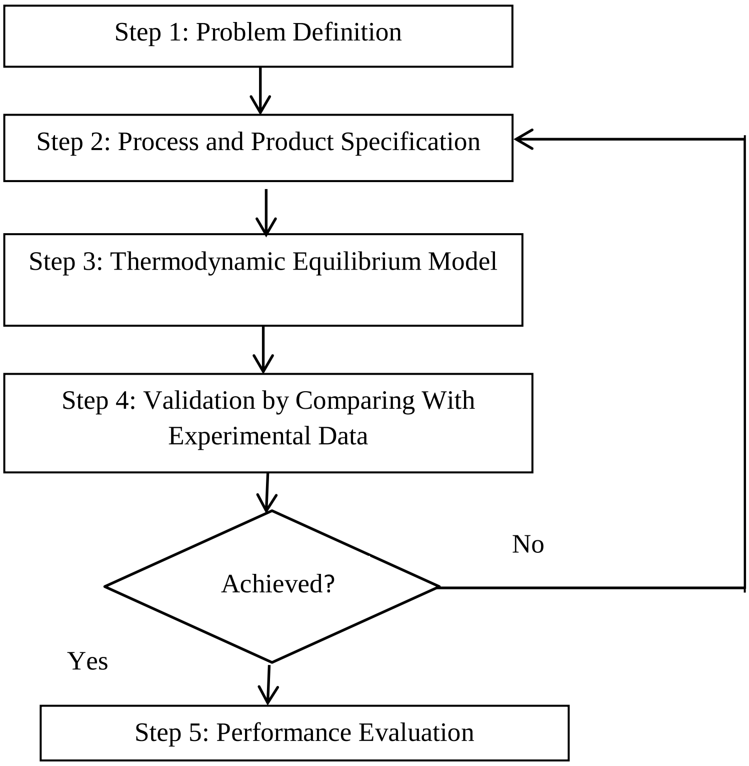


Figure 3-1: Process Flow Diagram for Analysis Gasifier Performance.

3.2 Problem definition (Step 1)

The first step is the problem definition for the performance analysis under study where the overall objective is defined. The main objective of this project includes:

i) To investigate and analyse the performance of downdraft biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

ii) To investigate and analyse the performance of fluidized bed biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

iii) To optimize the important parameters in term of gasifier temperature, moisture content, steam biomass ratio and carbon conversion for downdraft and fluidized bed gasification.

iv) To compare the performance of downdraft and fluidized bed biomass gasification under nominal operating condition and optimal condition.

v) To validate the performance of biomass gasification obtained using thermodynamic model.

3.3 Process and Product Specification (Step 2)

In this step, process and product are specified by the user before the performance analysis is done using Excel. The specification is required to give information for the system that needs to be analyzed based on the desired product or analysis data needed. The user needs to specify process to use either downdraft or fluidized bed gasifier or using both type of gasifier in order to study the performance of the gasifier. This performance analysis can be done using four types of feedstock that is wood, rice husk, empty fruit bunch and sawdust. The users can select either one of the feedstock or can select all of it to compare the gas composition obtained through the gasifier.

In the product specification, the user also needs to specify what conditions need to be achieved in the final product. These conditions may consists of the operating condition of the gasifier such as temperatures, steam biomass ratio, moisture content and gas composition. The user can choose any temperature and can see the performance of the gasifier on different temperature. The steam biomass ratio is specified to analyze how the performance or amount of hydrogen product changes if the ratio of compound or feedstock reacted with the steam change. The main product in this model is hydrogen gas composition and efficiency of the gasifier. The choice of the specification is listed out in the Table 3-1. The range of temperature that can be selected is between 250 ℃-1000 ℃ for both gasifiers. Meanwhile, the moisture content chosen in the result part is between 0% and 40%. It should be noted that the moisture content higher than this range will not be suitable for the gasification process.

Table 3-1: Process and Product Specification.

Process and Product Specifications	Choice
Type of Gasifier	a) Downdraft gasifier b) Fluidized bed gasifier
Biomass	a) Wood b) Rice husk c) Saw dust d) Empty fruit bunch
Temperature	*the user can choose any temperature range of 250^0C-1000^0C
Moisture Content	*the user can choose any moisture content range of (0% -40%)
Reactant	a) Air b) Steam
Product	a) Hydrogen gas composition

3.4 Thermodynamic Equilibrium Model (Step 3)

The equilibrium model assumes that all the reaction is in thermodynamic equilibrium. It is expected that the pyrolysis product burns and achieves equilibrium in the reduction zone before leaving the gasifier, hence an equilibrium model can be used in the gasifier to analyse the performance of the gasifier based on certain parameter. Figure 3-2 shows the step by step of the thermodynamic equilibrium calculation.

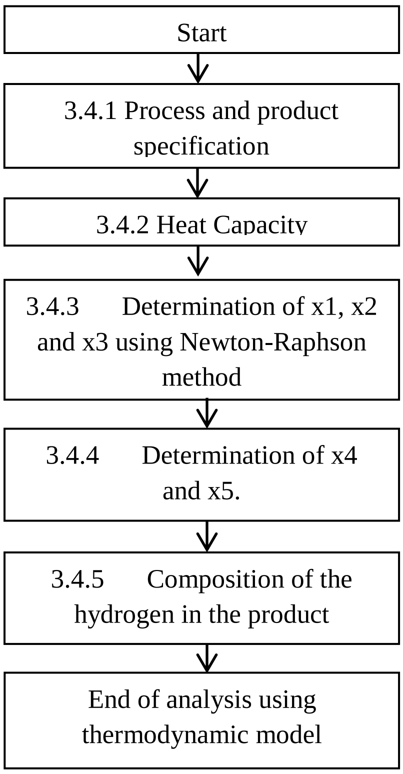


Figure 3-2: Step by Step of the Thermodynamic Equilibrium Calculation.

3.4.1 The process and product specification

In this step, the decision on the process and product need to be set. The product is hydrogen composition. From the decision made the selection of the parameter need to be adjusted to analyze the change of product produce due to the parameter change. The parameter is like the temperature change. All the selection parameter and condition had been shown in Table 3-2. For the type of gasifiers, the user can choose either downdraft or fluidized bed gasifier. The user can choose the biomass feedstock from rice husk, empty fruit bunch and sawdust. The typical chemical formula of each materials have different carbon, hydrogen and oxygen atom with general formula of $C_nH_aO_b$. For the calculation of a and b which is unknown in this chemical formula. The ultimate analysis which is the weight percentage of the dry basis for each material is needed. The ultimate analysis for various biomass materials in use is shown in table 3-2.

Table 3-2: Ultimate Analysis for Various Biomass Material chosen.

Material	C	H	N	S	O	HHV	References
Wood	50.00	6.00	0.00	0.00	44.00	449568.00 kJ/kg	Zainal et.al. (2001)
Rice Husk	38.50	5.70	0.50	0.00	39.80	402133.00 kJ/kmol	Zainal et.al. (2001)
Empty Fruit Bunch	49.50	5.90	0.50	0.10	40.60	30.82 kJ/g	Ahmad et al. (2006)
Sawdust	42.38	5.27	0.14	0.00	42.41	18230.00 kJ/kg	Miskam et al. (2009)

For the calculation of chemical formula for each biomass material the equation from Rajesh et al. (2010) are used. Starting from the ultimate analysis of biomass and mass fractions of all elements, the calculation of fuel formula $C_nH_aO_b$ is calculated by assuming that n equal to 1.0 while unknown a and b is calculated as below:

a = $\frac{mass\ fraction\ (H) x Molecular\ weight\ (C)}{mass\ fraction\ (C) x\ Molecular\ weight (H)}$

b = $\frac{mass\ fraction\ (O) x Molecular\ weight\ (C)}{mass\ fraction\ (C) x\ Molecular\ weight (O)}$

The molecular weight of each components are shown in Table 3-3:

Table 3-3: Molecular Weight of Each Component.

Component	Molecular Weight
C	12
H	1
N	14
O	16

Taking an example of calculation of wood,

a = $\frac{6.0 x 12}{50 x\ 1}$ = 1.44

b = $\frac{39.8 x 12}{38.5 x\ 16}$ = 0.66

The other material also used the same method to calculate the chemical formula. Table 3-4 summarizes the chemical formula for the selected biomass sources used in this work.

Table 3-4: The Chemical Formula for Rice Husk, Empty Fruit Bunch and Sawdust.

Materials	Chemical formula	Reference
Wood	$CH_{1.44}O_{0.66}$	Zainal et al. (2001)
Rice husk	$CH_{1.777}O_{0.775}$	Zainal et al. (2001)
Empty fruit bunch	$CH_{1.430}O_{0.615}$	Ahmad et al. (2006)
Sawdust	$CH_{1.492}O_{0.751}$	Miskam et al.(2009)

The chemical formula of the material is important to analyze the composition of the gas produce in the gasification process. There were two main general reactions that might occur to the feedstock during the gasification process due to the reactant use either using air or steam.

The reactions occur in the downdraft gasifier by using air as reactant:

$C_nH_aO_b$ +wH_2O +mO_2 +3.76m N_2 = x_1H_2 + x_2CO + x_3CO_2 + x_4 H_2O + x_5 CH_4 +3.76 m N_2

The reactions occur in the fluidized bed gasifier by using steam as reactant:

$C_nH_aO_b$ +w H_2O +m H_2O = x_1 H_2 + x_2 CO + x_3 CO_2 + x_4 H_2O + x_5 CH_4

Where,

w is the amout of water per kmol of material m is the amout of oxygen or water reacted per kmol of material

x_1, x_2 ,x_3 ,x_4 and x_5 is the coefficient of constituents of the products.

The derivation of x_1, x_2 , x_3 ,x_4 and x_5 can be seen in chapter 2.

3.4.2 Heat capacity

Since the coefficient of constituents of the products needed to be defined, the value of K_1 and K_2 need to be verify before forming the equation to be solved using Newton-Raphson method.

The K_1 and K_2 is the equilibrium constant for the reactions:

C+2H2 =CH4

$CO + H_2O = CO_2 + H_2$

Since the general equation of K_1 and K_2 is as below:

$$\ln K = \frac{-J}{RT} + (\Delta A)\ln T + \frac{\Delta B}{2} T + \frac{\Delta C}{3} T^2 + \frac{\Delta D}{2T^2} + I$$

The unknowns need to be calculated before the values of K_1 and K_2 can be determined.

The value of constant I and J can be find using the method from Chapter 2 ,while the value of ΔA , ΔB ,ΔC ,and ΔD for K_1 can be determine using the heat capacity as shown below:

$\Delta A = A_{CH4} + A_C + 2A_{H2}$

$\Delta B = B_{CH4} + B_C + 2B_{H2}$

$\Delta C = C_{CH4} + C_C + 2C_{H2}$

$\Delta D = D_{CH4} + D_C + 2D_{H2}$

For K_2 , the value of ΔA , ΔB ,ΔC ,and ΔD can be determine using the equation below:

$\Delta A = A_{CO2} + A_{H2} - A_{H2O} - A_{CO}$

$\Delta B = B_{CO2} + B_{H2} - B_{H2O} - B_{CO}$

$\Delta C = C_{CO2} + C_{H2} - C_{H2O} - C_{CO}$

$\Delta D = D_{CO2} + D_{H2} - D_{H2O} - D_{CO}$

The value of A, B, C, and D for each component is taking from the Table 3-5 below.

Table 3-5: Heat Capacity (constant A, B, C and D)(Smith et al., 2005)

Chemical species	Formula	T_{max}	A	10^3B	10^6C	10^{-5}D
Methane	CH_4	1500	1.702	9.081	- 2.164	-
Hydrogen	H_2	3000	3.249	0.422	-	0.083
Carbon monoxide	CO	2500	3.376	0.557	-	-0.031

Carbon dioxide	CO_2	2000	5.457	1.047	-	-1.157
Nitrogen	N_2	2000	3.280	0.593	-	0.040
Water	H_2O	2000	3.470	1.450	-	0.121
Carbon	C	2000	1.771	0.771	-	-0.867

After all the unknown is known, the temperature is set to certain point and the value of K_1 and K_2 can be calculated.

3.4.3 Determination of x_1, x_2 and x_3 using Newton-Raphson method.

In the determine the value of x_1, x_2 and x_3, the three equations forming from heat capacity is solving using Newton-Raphson method. Since the value of K_1 and K_2 had been determine in the previous step, the value is inserted into the equation below. w is the amount of water per kmol of material which can be decide by user.

$x_1^2 K_1 + x_2 + x_3 - 1 = 0$

$x_1 x_3 - x_2 (w - x_1 + 2x_2 + 2 x_3 - (-a/2 + 2))K2 = 0$

$Ax_1 + Bx_2 + C x_3 + D w + E = 0$

Where,

A, B, C, D and E are the value of heat change for each gas compound form.

K1 and K2 are equilibrium constant at certain temperature.

Value of A, B, C and D is defined using the equation below:

$A = dH_{H2} - dH_{H2O(g)} - 1.88\, dH_{N2}$

$B = dH_{CO} + 2\, dH_{H2O(g)} - dH_{CH4} + 5.64\, dH_{N2}$

$C = dH_{CO2} + 2\, dH_{H2O(g)} - dH_{CH4} + 7.52\, dH_{N2}$

$D = dH_{H2O(g)} - dH_{H2O(l)}$

$E = dH_{CH4} - (-a/2 + 2)dH_{H2O(g)} - ((-a/2 + 2) - n)dH_{N2} - dH_{material}$

The value of dH can be find using the equation:

$dH = \Delta H + \Delta H_{298}$

The value of ΔH_{298} can be found from the Table 3-6 below:

Table 3-6: Heat of Formation at 298K (kJ/kmol)(Smith et al.,2005)

Chemical species	Formula	Phase	$\Delta H^0_{f\ 298}$
Water	H_2O	g	-241818
Water	H_2O	l	-285830

Carbon dioxide	CO_2	g	-393509
Carbon monoxide	CO	g	-110525
Methane	CH_4	g	-74520
Hydrogen	H_2	g	0
Oxygen	O_2	g	0
Nitrogen	N_2	g	0

While the value of ΔH can be calculated using the equation below:

$\Delta H = Cp\ (T_2 - T_1)$

Where,

T_1= ambient temperature

T_2= gasification temperature

$Cp = R\ (A + BT_{am} + C/3\ (4T_{am}^2 - T_1T_2) + \frac{D}{T_1T_2})$

With R=8.314, $T_{am} = (T_1 + T_2)/2$, and constant A,B, C, and D taking from Table 3.3.

After all the values are inserted, user can find the value of x_1, x_2 and x_3. The next step will be determination of the other 2 unknown that is x_4 and x_5.

3.4.4 *Determination of x_4 and x_5.*

From the global reactions, the derivation of each component can be shown below. Here, since all the unknown x_1, x_2 and x_3 were found, now the value is inserted into the equation below to find the value of x_4 and x_5.

Carbon balance:

$1 = x_1 + x_2 + x_3 + x_4 + x_5$

Hydrogen balance:

$2w + a = 2x_1 + 2x_4 + 4x_5$

Oxygen balance:

$w + n + 2m = x_2 + 2x_3 + x_4$

After substitute the value from the previous step, the value for x_4 and x_5 can be identify..

3.4.5 *Composition of the Hydrogen in the Product.*

Since, the entire unknown in the general equation had been defined. The value is inserted into the equations which from here the composition of all gases in the gasification process including the composition of hydrogen gas are defined. For the downdraft gasifier the gas composition is based on the reaction below:

$C_nH_aO_b$ +wH_2O +mO_2 +3.76m N_2 = x_1H_2 + x_2CO + x_3CO_2 + x_4 H_2O + x_5 CH_4 +3.76 m N_2

While for fluidized bed gasifier, the composition is based on the reaction below:

$C_nH_aO_b$ +wH_2O +mH_2O = x_1H_2 + x_2CO + x_3CO_2 + x_4 H_2O + x_5 CH_4

The composition of hydrogen produce during the reactions is calculated using the mole balance by using the inlet mole of the biomass material. After the value of mole for biomass material inlet is known, the mole balance using the stoichiometry calculated from previous step for w, m, x_1, x_2, x_3, x_4 and x_5 is used to determine the composition of each component in the reactions.

3.5 Validation by Comparing with Experimental Data (Step 4)

The validation of the model is done by comparing the data to the experimental data taken from journal which experimental result from Zainal et al. (2001) is for downdraft gasifier and Karmakar and Datta (2011) for fluidized bed gasifier. The comparison is done to ensure that the result and data come out from the model is valid and compatible with real operation process**.**

3.6 Performance Evaluation(Step 5)

The performance evaluation is the steps where the performance of gasifier and biomass is evaluate in different operating condition. The gas composition produce by downdraft and fluidized bed gasifier is calculated by the thermodynamic equilibrium model using biomass like wood, rice husk, sawdust and empty fruit bunch by varying operating condition like temperature, moisture content and steam biomass ratio. The temperature range used in this work is around 650-770^{0}C with moisture content of around 0-40% and steam biomass ratio range 0.60- 1.70. In the last step, the performance of the selected gasifier is analyzed or compared in terms of the effect of gasifier temperature and moisture content to the total gas component produced. Based on this performance, the important parameters for gasifier are identified and optimized in order to further improve the performance of the gasifier.

4 EXCEL CALCULATION OF PERFORMANCE ANALYSIS

In this chapter, step by step calculation of performance analysis that has been done in Excel is shown. The performance analysis using the thermodynamic model has been calculated in the Excel to find the amount of hydrogen gas produced from the gasification process. The result is then validated by comparing it with experimental result from Zainal et al., (2001) for downdraft gasifier and Karmakar and Datta., (2011) for fluidized bed gasifier. The performance of the selected gasifier is analysed or compared in terms of the effect of gasifier temperature and moisture content to the total gas component produced. All the data is then summaries for easier understanding.

4.1 The steps in the performance analysis.

The example of the calculation in excel had been shown here for clear picture on the work done.

4.1.1 Problem definition

The objective here is to validation process where the comparison is implemented between the model results from Excel sheet (thermodynamic equilibrium model) and the experimental result from the literature. The experimental data used in this validation stage are obtained from Zainal et al., (2001) for downdraft gasifier and Karmakar and Datta., (2011) for fluidized bed gasifier. The overall objective also had been defined to analyse the performance of downdraft and fluidized bed gasifier using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust. The analysis also optimizing the important parameters in term of operating condition including gasifier temperature, moisture content and steam biomass ratio.

4.1.2 The process and product specification

In the first step, the decision on the process and product need to be specified. The summaries of process and product specification for the validation process are shown in Table 4-1.

Table 4-1: Process and Product Specification.

Process and product Specification	Chosen	Chosen
Type of Gasifier	Downdraft gasifier	Fluidized Bed gasifier
Biomass	Wood	Rice Husk
Biomass chemical formula	$CH_{1.44}O_{0.66}$	$CH_{1.777}O_{0.775}$
Temperature(^{0} C)	800	690
Moisture Content (%)	20	20
Steam Biomass Ratio	-	1.32
Reactant	Air	Water
Product	Hydrogen gas	Hydrogen gas

After all the process and product are specified, the thermodynamic model can be calculated. The decision on the type of reaction in use is depend on the reactant used. The reaction used in this the performance analysis is the reactions occur in the downdraft gasifier by using air as reactant and the reactions occur in the fluidized bed gasifier by using steam as reactant. For the downdraft gasifier the gas composition is based on the reaction below:

CnHaOb +wH2O +mO2 +3.76m N2 = x1H2 + x2CO + x3CO2 + x4 H2O + x5 CH4 +3.76 m N2

While for fluidized bed gasifier, the composition is based on the reaction below:

CnHaOb +wH2O +mH2O = x1H2 + x2CO + x3CO2 + x4 H2O + x5 CH4

Where,
w is the amout of water per kmol of material
m is the amout of oxygen or water reacted per kmol of material
x_1, x_2 ,x_3 ,x_4 and x_5 is the coefficient of constituents of the products.

The specification of type of biomass leads to the ultimate analysis of each type of biomass which here as long as user can get the composition of each type of biomass from journal they can calculate any chemical formula and can continues with calculation to calculate gas composition produce from gasification process. The calculation of ultimate analysis was done in the Excel. Figure 4-1 shows the ultimate analysis of biomass materials of wood, rice husk, empty fruit bunch, sawdust, paper, municipal waste and oil-palm fronts.

CALCULATION OF ULTIMATE ANALYSIS

$C_nH_aO_b$

SPECIES	Atomic mass
C	12
H	1
N	14
O	16

Material	C	H	N	S	O	Reference
Wood	50	6	0	0	44	Zainal et. al. ,2001
Rice husk	38.43	2.97	0.5	0	36.36	Karmakar and Datta. ,2001
Empty fruit bunch	49.5	5.9	0.5	0.1	40.6	Ahmad et al. ,2006
Sawdust	42.38	5.27	0.14	0	42.41	Miskam et al. ,2009
Paper	43.4	5.8	0.3	0.2	44.3	Zainal et. al. ,2001
Municiple Waste	47.6	6	1.2	0.3	32.9	Zainal et. al. ,2001
Oil-Palm Fronds	42.55	5.48	2.18	0.11	45.5	Atnaw et al. ,2011

Taking n=1

$$a = \frac{mass\ fraction\ (H) x Molecular\ weight\ (C)}{mass\ fraction\ (C) x\ Molecular\ weight\ (H)}$$

$$b = \frac{mass\ fraction\ (O) x Molecular\ weight\ (C)}{mass\ fraction\ (C) x\ Molecular\ weight\ (O)}$$

Material	C	H	O
Wood	1	1.44	0.66
Ricehusk	1	0.927400468	0.709601874
Emptyfruitbunch	1	1.43030303	0.615151515
Sawdust	1	1.492213308	0.750530911
Paper	1	1.603686636	0.765552995
Municiple Waste	1	1.512605042	0.518382353
Oil-Palm Fronds	1	1.545475911	0.80199765

Materials	Chemical formula	Molecular Weight
Wood	$CH_{1.44}O_{0.66}$	24
Rice husk	$CH_{0.93}O_{0.71}$	24.28103044
Empty fruit bunch	$CH_{1.430}O_{0.615}$	23.27272727
Sawdust	$CH_{1.492}O_{0.751}$	25.50070788
Paper	$CH_{1.604}O_{0.766}$	25.85253456
Municiple Waste	$CH_{1.513}O_{0.518}$	21.80672269
Oil-Palm Fronds	$CH_{1.545}O_{0.802}$	26.37743831

Figure 4-1: Ultimate Analysis of Biomass Materials.

4.1.3 *Heat capacity*

For the heat capacity calculation, the value of K_1 and K_2 are defined before forming the equation to be solving using Newton-Raphson method. To obtain the values of K_1 and K_2, the first thing to do is the calculation of energy conversion. The calculation of energy conversion includes the heat capacity and enthalpy change which is calculated through the use of formula and constant from Smith et al., (2005) .The calculation step is shown in step 3.4.2 taking the value of A, B, C and D from table 3-5. The energy conversion calculation in Excel is shown in Figure 4-2.

Heat Capacity (constant A,B,C and D.)

Chemical species	Formula	Tmax	A	(10^3)B	(10^6)C	(10^-5)D
Methane	CH4	1500	1.702	9.081	-2.164	0
Hydrogen	H2	3000	3.249	0.422	0	0.083
Carbon monoxide	CO	2500	3.376	0.557	0	-0.031
Carbon dioxide	CO2	2000	5.457	1.047	0	-1.157
Nitrogen	N2	2000	3.28	0.593	0	0.04
Water	H2O	2000	3.47	1.45	0	0.121
Carbon	C	2000	1.771	0.771	0	-0.867

Universal Gas Constant

R	8.314	J/molK	
Specify Temperature			
T1	298	K	Ambient Temperature
T2	1043	K	Gasification Temperature
Arithmetic Mean Temperature			
Tam	670.5	K	

Specific Heat Capacity	Cp	kJ/kmolK
Enthalpy Change	ΔH	kJ/kmolK

Moisture content 0.2

Chemical species	Formula	Cp(kJ/kmolK)	ΔH(kJ/kmol)
Methane	CH4	55.85221297	41609.89866
Hydrogen	H2	29.36464061	21876.65726
Carbon monoxide	CO	31.17308111	23223.94543
Carbon dioxide	CO2	51.20603824	38148.49849
Nitrogen	N2	30.57562044	22778.83723
Water	H2O	36.93265865	27514.83069
Carbon	C	19.02206203	14171.43621

Figure 4-2: Energy Conversion Calculation for Downdraft Gasifier.

After the heat capacity is being calculated the value here is used to find the values of K_1 and K_2.Values of K_1 and K_2 is being derived from the general equation:

$$\ln K = \frac{-J}{RT} + (\Delta A)\ln T + \frac{\Delta B}{2}T + \frac{\Delta C}{3}T^2 + \frac{\Delta D}{2T^2} + I$$

Before the calculation the derive the value of K_1 and K_2, the unknown I, J, ΔA, ΔB, ΔC and ΔD are being calculated. Figure 4-3 shows the derivation of equation K_1 in term of temperature for downdraft gasifier. The derivation of equation K_1 in term of temperature is based on the calculation step in step 3.4.2. From the Excel ,the value of K_1 at the temperature is set to 800^{0}C or 1073K can be defined which the value obtained is 0.04675. The K_1 equation is as below:

$$\ln K_1 = \frac{-7082.828}{T} + (-6.567)\ln T + \frac{7.466x10^{-3}}{2}\,T + \frac{-2.164x10^{-6}}{3}\,T^2 + \frac{0.701x10^{-5}}{2T^2} + 32.541$$

When the temperature change the K_1 value also change.

Heat Capacity (constant A,B,C and D.)

Chemical species	Formula	Tmax	A	(10^3)B	(10^6)C	(10^-5)D
Methane	CH4	1500	1.702	9.081	-2.164	0
Hydrogen	H2	3000	3.249	0.422	0	0.083
Carbon monoxide	CO	2500	3.376	0.557	0	-0.031
Carbon dioxide	CO2	2000	5.457	1.047	0	-1.157
Nitrogen	N2	2000	3.28	0.593	0	0.04
Water	H2O	2000	3.47	1.45	0	0.121
Carbon	C	2000	1.771	0.771	0	-0.867

Gibbs functions of formation ((kJ/kmol) and Heats of formation (kJ/kmol) at 298.15 K

Chemical species	Formula	Phase	ΔH0f 298	ΔG0f 298
Water	H2O	g	-241818	-228572
Water	H2O	l	-285830	-237129
Carbon dioxide	CO2	g	-393509	-394359
Carbon monoxide	CO	g	-110525	-137169
Methane	CH4	g	-74520	-50460
Hydrogen	H2	g	0	0
Oxygen	O2	g	0	0
Nitrogen	N2	g	0	0

Coefficient for Determining Specific Heat

$A_{CH4}-A_C-2A_{H2}$	ΔA	-6.567
$B_{CH4}-B_C-2B_{H2}$	ΔB	0.007466
$C_{CH4}-C_C.2C_{H2}$	ΔC	-2.164E-06
$D_{CH4}-D_C-2D_{H2}$	ΔD	70100

Heats of formation (kJ/kmol)

ΔH0f 298 -74520

Gibbs functions of formation ((kJ/kmol)

ΔG0f 298 -50460

The temperature of formation is fixed and used to find the constant J and I

Temperature of Formation

T 298.15 K

Universal Gas Constant

R 8.314 J/molK

Constant J

J/R -7082.85

J -58886.8

Constan I (constant of Integration)

I 32.54137

$$\ln K1 = \frac{-7082.828}{T} + (-6.567)\ln T + \frac{7.466x10^{-3}}{2}\,T + \frac{-2.164x10^{-6}}{3}\,T^2 + \frac{0.701x10^{-5}}{2T^2} + 32.541$$

The temperature here can be set to find the new value of K

Set Temperature (can be change)

T 1073 K

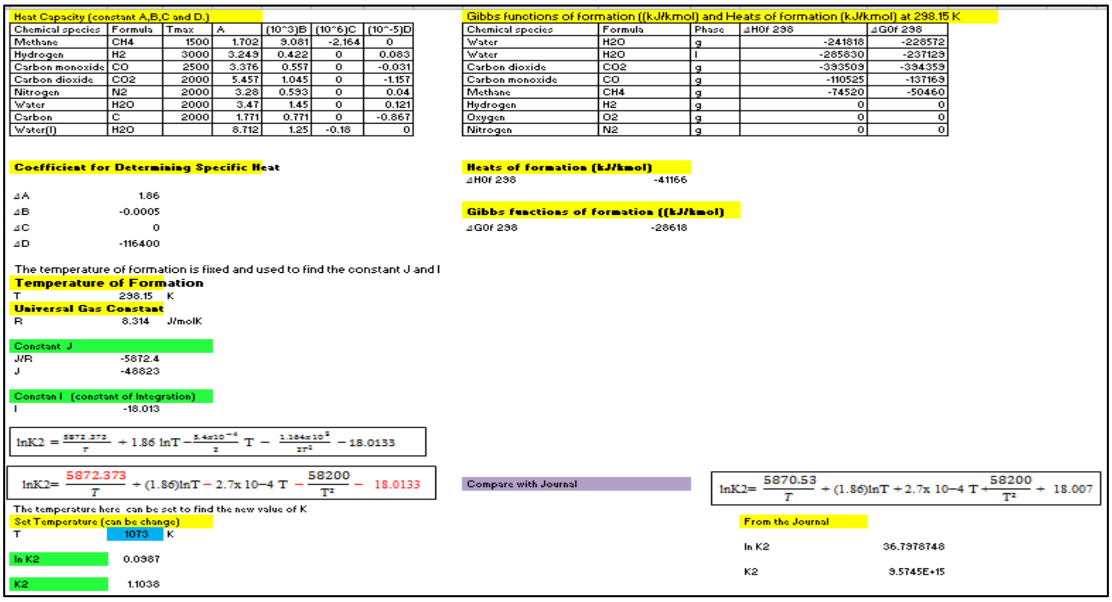
ln K -3.06288

K 0.046753

Figure 4-3: The Derivation of Equation K_1 in term of Temperature for Downdraft Gasifier.

The derivation of equation K_2 in term of temperature is based on the calculation step in step 3.4.2. Figure 4-3 shows the derivation of equation K_2 in term of temperature for downdraft gasifier. From the excel the value of K_2 at the temperature 800^{0}C or 1073K is 1.10378. The K_2 equation is as below:

$$\ln K_2 = \frac{5872.373}{T} + (1.86)\ln T - 2.7x\,10^{-4}T - \frac{58200}{T^2} - 18.0133$$



Heat Capacity (constant A,B,C and D.)

Chemical species	Formula	Tmax	A	(10^3)B	(10^6)C	(10^-5)D
Methane	CH4	1500	1.702	9.081	-2.164	0
Hydrogen	H2	3000	3.249	0.422	0	0.083
Carbon monoxide	CO	2500	3.376	0.557	0	-0.031
Carbon dioxide	CO2	2000	5.457	1.045	0	-1.157
Nitrogen	N2	2000	3.28	0.593	0	0.04
Water	H2O	2000	3.47	1.45	0	0.121
Carbon	C	2000	1.771	0.771	0	-0.867
Water(l)	H2O		8.712	1.25	-0.18	0

Gibbs functions of formation ((kJ/kmol) and Heats of formation (kJ/kmol) at 298.15 K

Chemical species	Formula	Phase	ΔH0f 298	ΔG0f 298
Water	H2O	g	-241818	-228572
Water	H2O	l	-285830	-237129
Carbon dioxide	CO2	g	-393509	-394359
Carbon monoxide	CO	g	-110525	-137169
Methane	CH4	g	-74520	-50460
Hydrogen	H2	g	0	0
Oxygen	O2	g	0	0
Nitrogen	N2	g	0	0

Coefficient for Determining Specific Heat

ΔA 1.86
ΔB -0.0005
ΔC 0
ΔD -116400

Heats of formation (kJ/kmol)
ΔH0f 298 -41166

Gibbs functions of formation ((kJ/kmol)
ΔG0f 298 -28618

The temperature of formation is fixed and used to find the constant J and I

Temperature of Formation
T 298.15 K

Universal Gas Constant
R 8.314 J/molK

Constant J
J/R -5872.4
J -48823

Constan I (constant of Integration)
I -18.013

$$\ln K2 = \frac{5872.373}{T} + 1.86 \ln T - \frac{5.4x10^{-4}}{2} T - \frac{1.164x10^{5}}{2T^2} - 18.0133$$

$$\ln K2 = \frac{5872.373}{T} + (1.86)\ln T - 2.7x\ 10{-}4\ T - \frac{58200}{T^2} - 18.0133$$

The temperature here can be set to find the new value of K

Set Temperature (can be change)
T 1073 K

ln K2 0.0987
K2 1.1038

Compare with Journal

$$\ln K2 = \frac{5870.53}{T} + (1.86)\ln T + 2.7x\ 10{-}4\ T + \frac{58200}{T^2} + 18.007$$

From the Journal
ln K2 36.7978748
K2 9.5745E+15

Figure 4-4: The Derivation of Equation K_2 in term of Temperature in Downdraft Gasifier.

The same steps of determining K1 and K2 value is done for fluidized bed gasifier with the difference in coefficient for determining heat capacity which in the coefficient is derive from the reaction in fluidized bed gasifier.

4.1.4 Determination of x_1, x_2 and x_3 using Newton-Raphson method.

To determine the value of x_1, x_2 and x_3, the three equations forming from heat capacity is solving using Newton-Raphson method. Since the values of K_1 and K_2 have been determined in the previous step, the value is inserted into the derived equation.

The equation for newton rapsons in downdraft gasifier is as below:

$x_1^2 K_1 + x_2 + x_3 - 1 = 0$

$x_1 x_3 - x_2 (w - x_1 + 2x_2 + 2 x_3 - (b/2 + 2))K2 = 0$

$A x_1 - Bx_2 - C x_3 + Dw + E = 0$

For fluidized bed gasifier, the equation use in Newton-Rapson is as below:

$x_1^2 K_1 + x_2 + x_3 - 1 = 0$

$x_1 x_3 + K_2 x_2 x_1 + 2 K_2 x_2 x_5 - a/2K_2 x_2 - w K_2 x_2 - m K_2 x_2 = 0$

$Ax_1 + Bx_2 + C x_3 + D w + E m + F = 0$

Where,

A, B, C, D E and F are the value of heat change for each gas compound form.

K1 and K2 are equilibrium constant at certain temperature.

x_1, x_2 ,x_3 are the coefficient or mole balance for hydrogen, carbon monoxide and carbon dioxide gas produced.

m is the steam biomass ratio.

w is the moisture content.

For the calculation in excel, the value for the unknown A, B, C, D, E and F can be defined by refer to the step in 3.4.3 first before insert in to the three equations stated above. Figure 4-5 shows the calculation of A, B, C, D and E of wood in downdraft gasifier. The values of A, B, C, D, E and F is different with temperature change and different biomass.

Taking from Journal For one value of moisture and Temperature

For wood

Amount of water per kmol wood

Hf of Wood -118050 kJ.kmol

Taking value from previous calculation(Cp and H)

$$dH_{(\text{for any gas})} = H_f^0 + \Delta H$$

Chemical species	Formula	Phase	Cp(kJ/kmolK)	ΔH(kJ/kmol)	ΔH0f 298	dH
Methane	CH4	g	56.55038977	43826.55207	-74520	-30693.44793
Hydrogen	H2	g	29.41726823	22798.38288	0	22798.38288
Carbon monoxide	CO	g	31.24254458	24212.97205	-110525	-86312.02795
Carbon dioxide	CO2	g	51.33660961	39785.87245	-393509	-353723.1276
Nitrogen	N2	g	30.64957347	23753.41944	0	23753.41944
Water	H2O	l	37.11348815	28762.95332	-285830	-257067.0467
Water	H2O	g	37.11348815	28762.95332	-241818	-213055.0467
Carbon	C		19.11821344	14816.61541		14816.61541

Simplified the constant

$A = dHH_2 - dHH_{2O(g)} - 1.88\ dHN_2$

$B = dHCO + 2\ dHH_{2O(g)} - dHCH_4 + 5.64\ dHN_2$

$C = dHCO_2 + 2\ dHH_{2O(g)} - dHCH_4 + 7.52\ dHN_2$

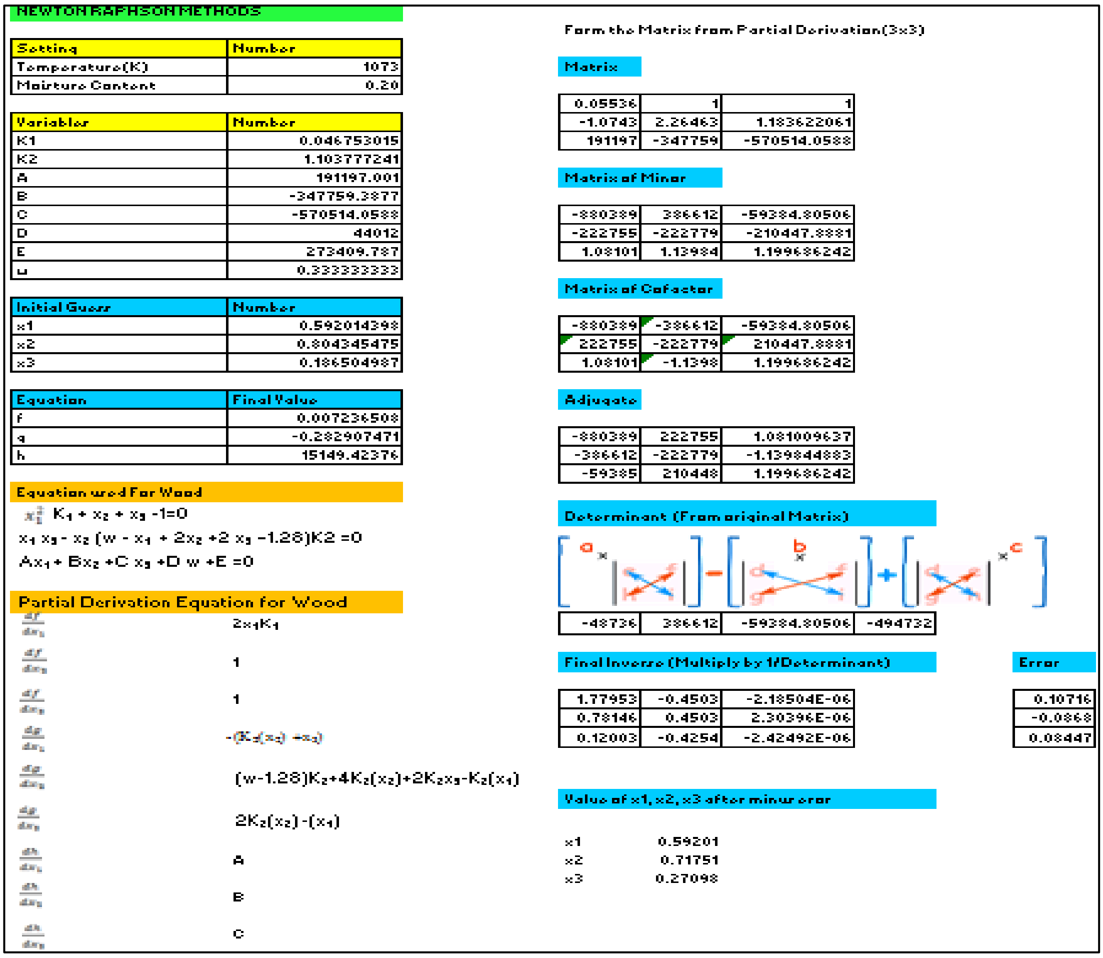
$D = dHH_{2O(g)} - dHH_{2O(l)}$

$E = dHCH_4 - (b/2 + 2)dHH_{2O(g)} - ((b/2 + 2) - a)dHN_2 - dHmaterial$

Value of Constant	
A	191197.001
B	-347759.3877
C	-570514.0588
D	44012
E	273409.787

Figure 4-5: Calculation of A, B, C, D and E of Wood in Downdraft Gasifier.

After all the value inserted, the value of x_1, x_2 and x_3 is calculated using the iteration of Newton Raphson. Figure 4-6 shows the Newton Raphson calculation of wood in excel sheet in order to get the value of x1, x2 and x3 with least error.



NEWTON RAPHSON METHODS

Setting	Number
Temperature(K)	1073
Moisture Content	0.20

Variables	Number
K1	0.046753015
K2	1.103777241
A	191197.001
B	-347759.3877
C	-570514.0588
D	44012
E	273409.787
w	0.333333333

Initial Guess	Number
x1	0.592014398
x2	0.804345475
x3	0.186504987

Equation	Final Value
f	0.007236508
g	-0.282907471
h	15149.42376

Equation used For Wood

$x_1^2 K_1 + x_2 + x_3 - 1 = 0$

$x_1 x_3 - x_2 (w - x_1 + 2x_2 + 2x_3 - 1.28) K2 = 0$

$Ax_1 + Bx_2 + C x_3 + D w + E = 0$

Partial Derivation Equation for Wood

$2x_1K_1$

1

1

$-(K_2(x_2) + x_3)$

$(w-1.28)K_2+4K_2(x_2)+2K_2x_3-K_2(x_1)$

$2K_2(x_2)-(x_1)$

A

B

C

Form the Matrix from Partial Derivation(3x3)

Matrix

0.05536	1	1
-1.0743	2.26463	1.183622061
191197	-347759	-570514.0588

Matrix of Minor

-880389	386612	-59384.80506
-222755	-222779	-210447.8881
1.08101	1.13984	1.199686242

Matrix of Cofactor

-880389	-386612	-59384.80506
222755	-222779	210447.8881
1.08101	-1.1398	1.199686242

Adjugate

-880389	222755	1.081009637
-386612	-222779	-1.139844883
-59385	210448	1.199686242

Determinant (From original Matrix)

-48736	386612	-59384.80506	-494732

Final Inverse (Multiply by 1/Determinant)

1.77953	-0.4503	-2.18504E-06
0.78146	0.4503	2.30396E-06
0.12003	-0.4254	-2.42492E-06

Error

0.10716
-0.0868
0.08447

Value of x1, x2, x3 after minus eror

x1	0.59201
x2	0.71751
x3	0.27098

Figure 4-6 : The Newton Raphson Calculation for Wood in Downdraft Gasifier.

4.1.5 Composition of the Hydrogen in the Product

The last step in this work is the calculation of gas composition produced during gasification process. The calculation is done by calculating the x_4 and x_5 from the equation derived from the Zainal et al. (2001). The value of x_1, x_2, x_3, x_4 and x_5 are inserted as the number of mole for each gas composition and the percentage outlet is calculated from the number of mole of gas produce. This final percentage of gas outlet will be the final result of performance analysis. Figure 4-7 shows the gas composition produced by wood in downdraft gasifier. The same steps are applied to calculate the composition of gas in other type of biomass in the downdraft and fluidized bed gasifier.

Equation to find value of x_4 and x_5

Wood $CH_{1.44}O_{0.66}$ $CHaO_b$

Carbon balance:

$1 = x2 + x3 + x5$

Hydrogen balance:

$2w + a = 2x1 + 2x4 + 4x5$

Oxygen balance:

$w + b + 2m = x_2 + 2x_3 + x_4$

Variables	Number
x1	0.592014398
x2	0.804345475
x3	0.186504987
w	0.333333333

Calculation of x4 and x5

Variables	Number
x4	0.443019861
x5	0.009149537
m	0.313520989

Composition of Gas

$CH_{1.44}O_{0.66} + w\,H_2O + mO_2 + 3.76m\,N_2 = x1\,H_2 + x2CO + x3\,CO_2 + x4H_2O + x5\,CH_4 + 3.76m\,N_2$

Taking w= 0.2 and temperature of 800^0C

Assume 100 mol biomass inlet

Component	Outlet mol	Percentage of outlet(%)
H2	59.20143977	21.36577907
CO	80.43454753	29.02880029
CO2	18.65049873	6.73095852
CH4	0.914953738	0.330206487
N2	117.8838918	42.54425563
Total	277.0853315	100

Figure 4-7: The Gas Composition produced by Wood in Downdraft Gasifier.

4.2 Summary of Performance Analysis

The summary of performance analysis is the formation of a few simpler understanding sheets in excels to summarize the steps and result of the performance analysis for better understanding and give overall view on the analysis.

4.2.1 Overall Steps in Performance Analysis

For the first page of the summaries, the overview of the steps in the methodology are shows for the user can get the preview or get clearer picture on the procedure in the summaries. Figure 4-8 shows the step by step performance analysis of biomass gasification processes.

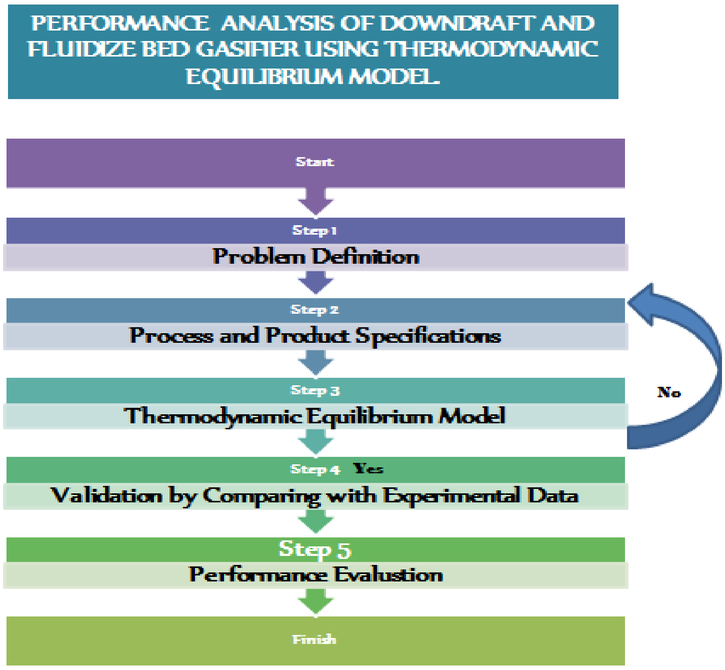


Figure 4-8: The methodology in the first page of the summaries.

4.2.2 Problem Definition (Step 1)

In the problem definition, it consist 2 main parts which the right hand side part is the overall review of problem definition and left hand side part for the selection of problem definition from drop down box. The user can choose and view any problem definition here:

i) To investigate and analyse the performance of downdraft biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

ii) To investigate and analyse the performance of fluidized bed biomass gasification using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust.

iii) To optimize the important parameters in term of gasifier temperature, moisture content, steam biomass ratio and carbon conversion for downdraft and fluidized bed gasification.

iv) To compare the performance of downdraft and fluidized bed biomass gasification under nominal operating condition and optimal condition.

v) To validate the performance of biomass gasification obtained using thermodynamic model.

Figure 4-9 shows the summaries of problem definition in the performance analysis of biomass gasification.

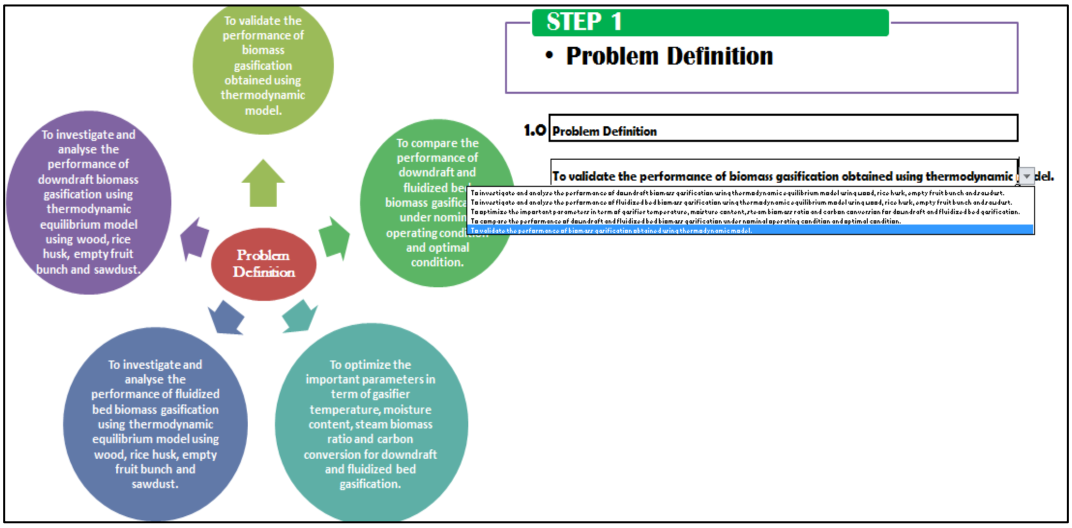


Figure 4-9: Problem Definition in Performance Analysis of Biomass Gasification Process.

4.2.3 *Process and Product Specification (Step 2)*

In the process and product specification, user can choose the process and product from the drop down box list by refer to the block flow of process and products at the right hand side. Figure 4-10 shows the process and product specification in performance analysis which here user can choose and specified any desired process and products based on the flow figure on the right hand sides.

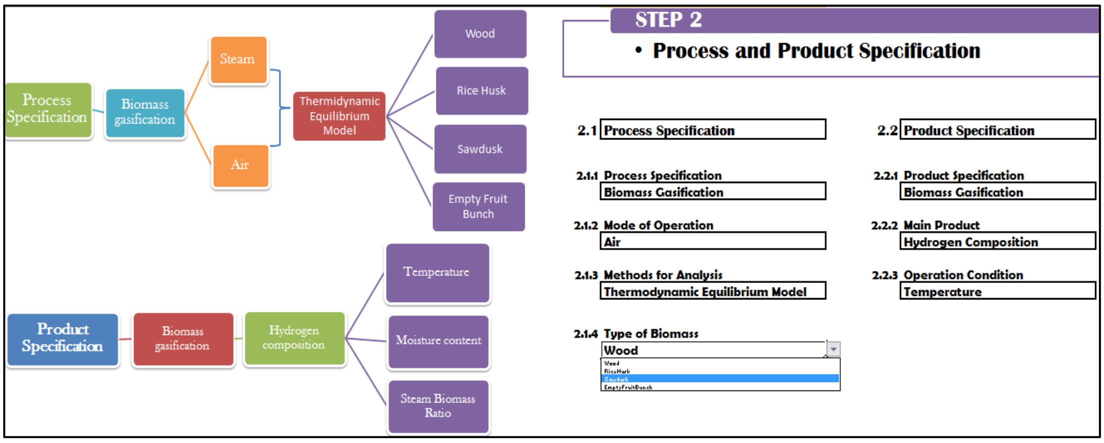


Figure 4-10: Process and Product Specification in Performance Analysis of Biomass Gasification.

4.2.4 Model Evaluation (Step 3)

The composition of gas produced is shown here together with the type of biomass material used and operating condition. The comparison data also had been shown in the table form in this step. Figure 4-11 shows overall process and product specification in performance analysis. Figure 4-12 shows comparison of the gas produce in the model with experimental data in Zainal et al.,(2001). Figure 4-13 and 4.14 shows comparison of gas produce in model with experimental data in Karmakar and Datta et al., 2011 at different temperature and steam biomass ratio.

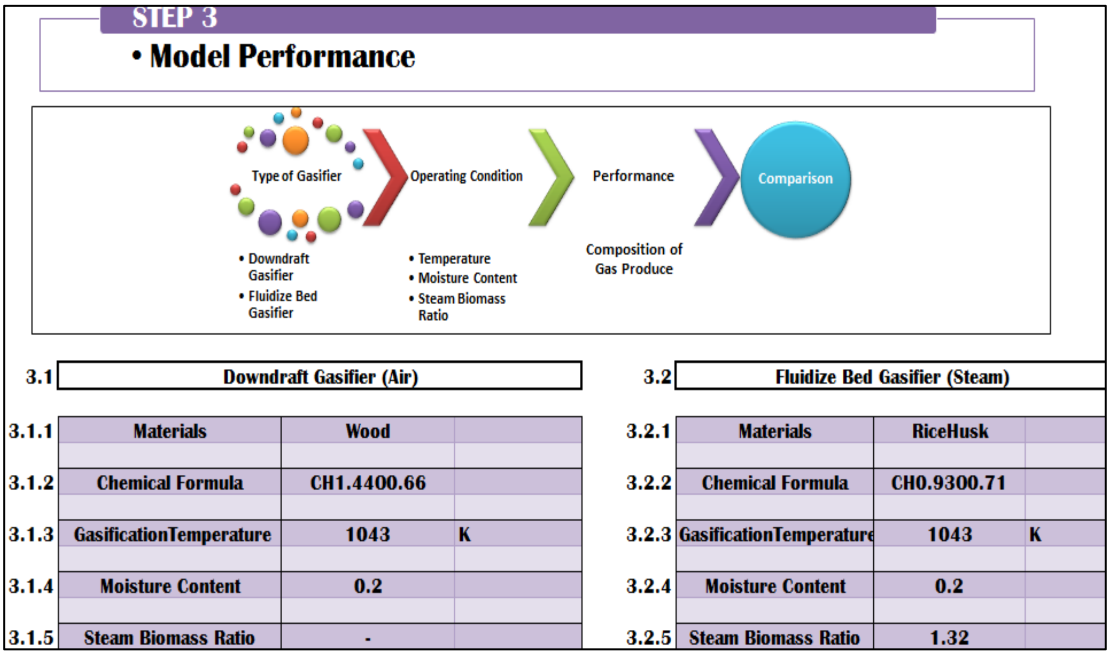


Figure 4-11: Overall Process and Product Specification from Downdraft and Fluidized Bed Gasifier.

Comparison of gas produce in the Model with Experiment Data in Zainal et al.,2001 for Wood at 1073 K and 20% Moisture Content

Components	Experimental Data	Model Data	Mean square eror
H2	15.23	15.23	0
CO	23.04	27.71	0.04108363
CO2	1.58	6.43	9.422568499
CH4	16.42	0.32	0.961402941
O2	1.42	0.00	1.000000000
N2	42.31	50.32	0.035840906
Total	100	100.00	1.910149329

Figure 4-12: Comparison of Gas Produce in the Model with Experimental Data in Zainal et al.,2001.

Comparison of gas produce from experiment in Karmakar and Datta for rice husk at Different Temperature and Steam Biomass Ratio

Model Validation by Comparing Gas composition at different Temperature (SBR=1.32,MC=0.2)

Model

Component	Temperature			
	650	690	730	770
H2	47.25	50.00	50.00	50.00
CO	11.24	12.83	15.93	17.85
CO2	31.91	28.45	25.65	23.95
CH4	9.59	8.71	8.42	8.20
H2O	0.00	0.00	0.00	0.00
Total	100	100	100	100.00

Experimental

Component	Temperature			
	650	690	730	770
H2	47.25	50.50	52.20	53.08
CO	11.25	12.83	15.90	17.85
CO2	31.90	28.51	25.65	23.90
CH4	9.60	8.16	6.25	5.17
H2O	0.00	0.00	0.00	0.00
Total	100	100	100	100

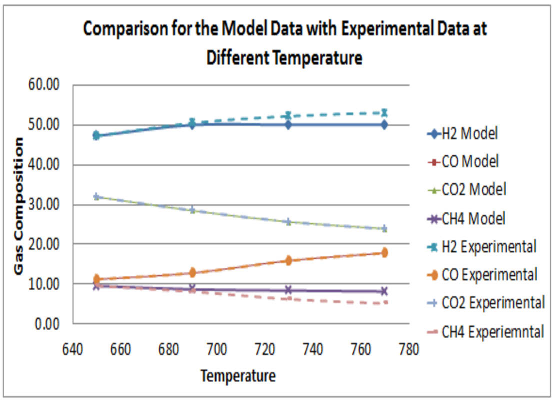


Figure 4-13: Comparison of Gas Produce in Model with Experimental Data in Karmakar and Datta et al., 2011at different Temperature.

Model Validation by Comparing Gas composition at different Steam Biomass Ratio (T=1023,MC=0.2)

Model

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	47.81	48.87	50.00	50.00
CO	27.48	27.69	16.65	17.38
CO2	18.09	22.22	23.14	23.99
CH4	6.62	1.22	10.21	8.63
H2O	0.00	0.00	0.00	0.00
Total	100	100	100	100

Experimental

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	47.81	48.88	51.17	51.89
CO	27.48	22.70	16.65	17.38
CO2	18.09	22.20	23.15	24.81
CH4	6.62	6.22	9.03	5.92
H2O	0.00	0.00	0.00	0.00
Total	100	100	100.00	100

Mean Square Error for T=690 ,SBR=1.32,MC=0.2

Components	Experimental Data	Model Data	Mean square eror
H2	50.50	50.00	0.000098
CO	12.83	12.83	0.000000
CO2	28.51	28.45	0.000004
CH4	8.16	8.71	0.004566
O2	0.00	0.00	0.000000
N2	0.00	0.00	0.000000
Total	100	100.00	0.000778

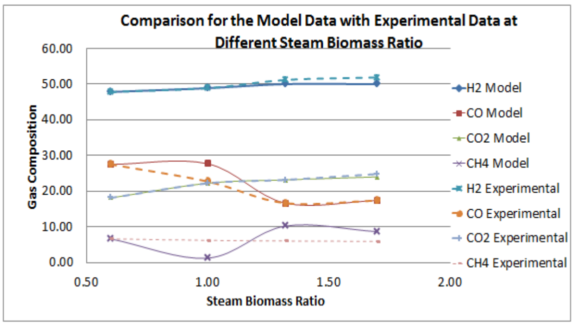
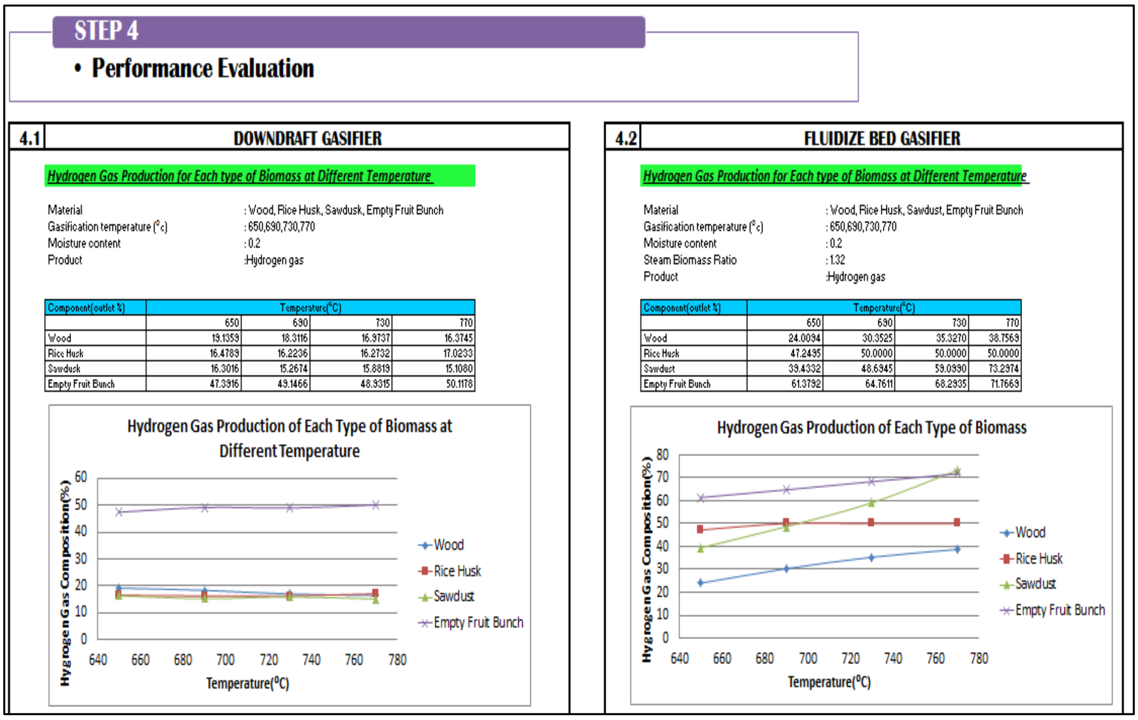


Figure 4-14: Comparison of Gas Produce in Model with Experimental Data in Karmakar and Datta et al., 2011at different Steam Biomass Ratio.

4.2.5 Performance Analysis (Step 4)

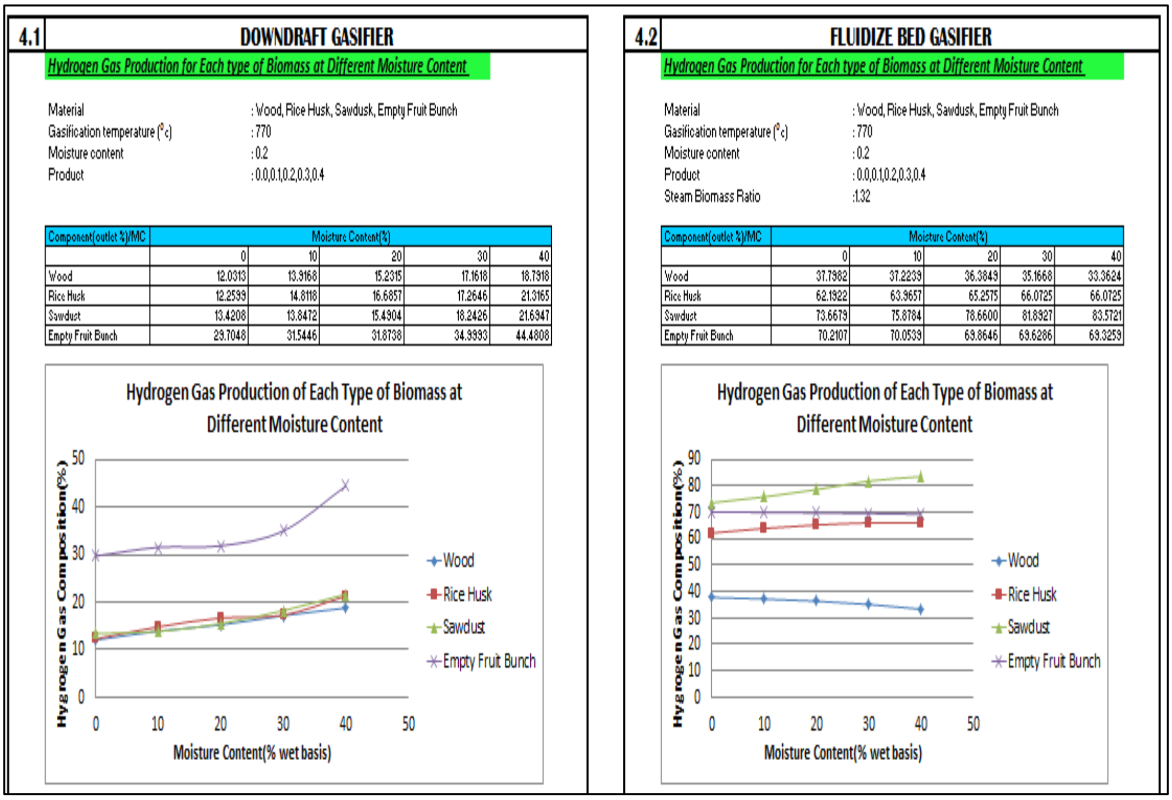
In this step, the final result of the gas composition produced are shows in table and graph form .Figure 4-15 and Figure 4-16 shows the summaries of performance analysis in downdraft and fluidized bed gasifier at different temperature and moisture content. Figure 4-17 shows summaries of comparison of performance analysis in downdraft and fluidized bed gasifier at different temperature and moisture content.



Component(outlet %)	Temperature(°C)			
	650	690	730	770
Wood	19.1359	18.3116	16.9737	16.3745
Rice Husk	16.4789	16.2236	16.2732	17.0233
Sawdusk	16.3016	15.2674	15.8819	15.1080
Empty Fruit Bunch	47.3916	49.1466	48.9315	50.1178

Component(outlet %)	Temperature(°C)			
	650	690	730	770
Wood	24.0094	30.3525	35.3270	38.7569
Rice Husk	47.2495	50.0000	50.0000	50.0000
Sawdust	39.4332	48.6945	59.0990	73.2974
Empty Fruit Bunch	61.3792	64.7611	68.2935	71.7669

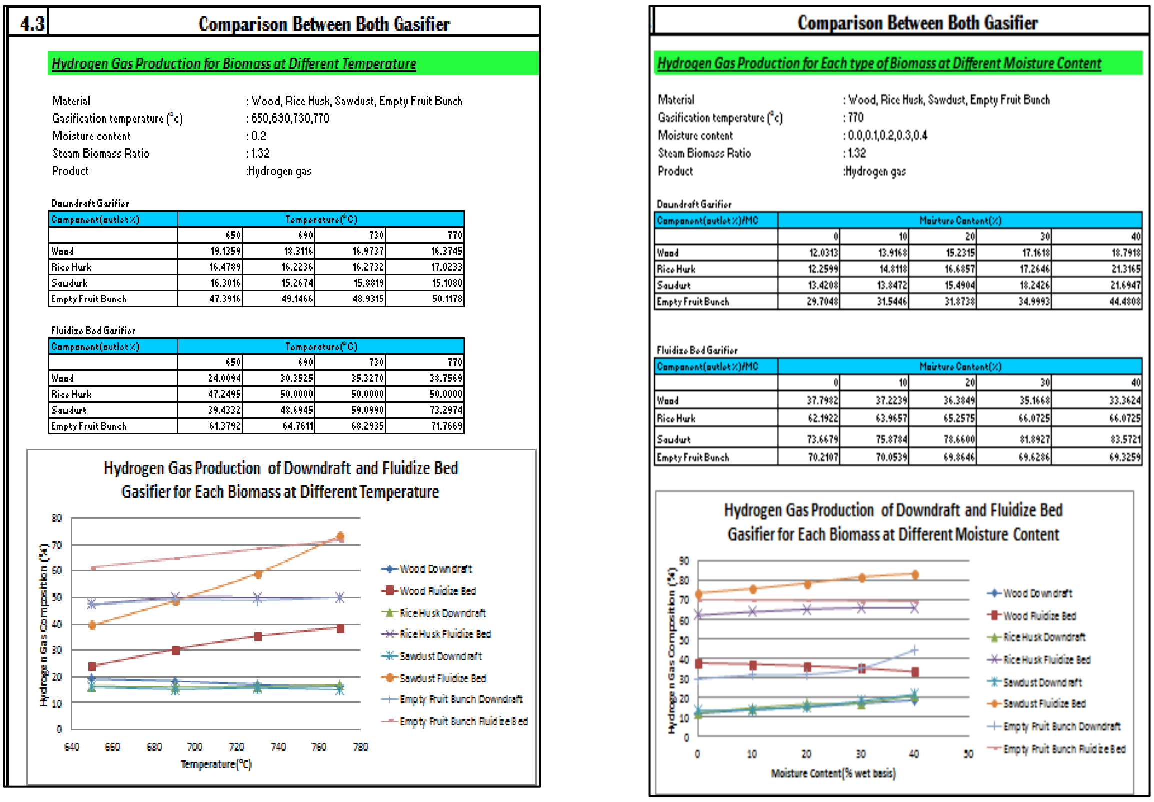
Figure 4-15: Summaries of Performance Analysis in Downdraft and Fluidized Bed Gasifier at different Temperature.



Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
Wood	12.0313	13.9168	15.2315	17.1618	18.7918
Rice Husk	12.2599	14.8118	16.6857	17.2646	21.3165
Sawdust	13.4208	13.8472	15.4904	18.2426	21.6947
Empty Fruit Bunch	29.7048	31.5446	31.8738	34.9993	44.4808

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
Wood	37.7982	37.2239	36.3849	35.1668	33.3624
Rice Husk	62.1922	63.9657	65.2575	66.0725	66.0725
Sawdust	73.6679	75.8784	78.6600	81.8927	83.5721
Empty Fruit Bunch	70.2107	70.0539	69.8646	69.6286	69.3259

Figure 4-16: Summaries of Performance Analysis in Downdraft and Fluidized Bed Gasifier at different Moisture Content.



4.3 Comparison Between Both Gasifier

Hydrogen Gas Production for Biomass at Different Temperature

Material	: Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (°c)	: 650,690,730,770
Moisture content	: 0.2
Steam Biomass Ratio	: 1.32
Product	:Hydrogen gas

Downdraft Gasifier

Component(outlet %)	Temperature(°C)			
	650	690	730	770
Wood	19.1359	18.3116	16.9737	16.3745
Rice Husk	16.4789	16.2236	16.2732	17.0233
Sawdust	16.3016	15.2674	15.8819	15.1080
Empty Fruit Bunch	47.3916	49.1466	48.9315	50.1178

Fluidize Bed Gasifier

Component(outlet %)	Temperature(°C)			
	650	690	730	770
Wood	24.0094	30.3525	35.3270	38.7569
Rice Husk	47.2495	50.0000	50.0000	50.0000
Sawdust	39.4332	48.6945	59.0990	73.2974
Empty Fruit Bunch	61.3792	64.7611	68.2935	71.7669

Comparison Between Both Gasifier

Hydrogen Gas Production for Each type of Biomass at Different Moisture Content

Material	: Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (°c)	: 770
Moisture content	: 0.0,0.1,0.2,0.3,0.4
Steam Biomass Ratio	: 1.32
Product	:Hydrogen gas

Downdraft Gasifier

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
Wood	12.0313	13.9168	15.2315	17.1618	18.7918
Rice Husk	12.2599	14.8118	16.6857	17.2646	21.3165
Sawdust	13.4208	13.8472	15.4904	18.2426	21.6947
Empty Fruit Bunch	29.7048	31.5446	31.8738	34.9993	44.4808

Fluidize Bed Gasifier

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
Wood	37.7982	37.2239	36.3849	35.1668	33.3624
Rice Husk	62.1922	63.9657	65.2575	66.0725	66.0725
Sawdust	73.6679	75.8784	78.6600	81.8927	83.5721
Empty Fruit Bunch	70.2107	70.0539	69.8646	69.6286	69.3259

Figure 4-17: Summaries of Comparison of Performance Analysis in Downdraft and Fluidized Bed Gasifier at different Temperature and Moisture Content.

4.2.6 Overall Summary of Performance Analysis

The last part of the summaries of performance analysis is the overall summaries which gave an overall view of the performance analysis start from 4.2.2 until 4.2.5. The overall summaries also can be considered as the overall conclusion of the performance analysis work.

5 PERFORMANCE ANALYSIS OF BIOMASS GASIFICATION

5.1 Overview

The thermodynamic model had been used to find the amount the gas composition produce during the gasification process. In this chapter, the detail discussion on the result was done. The validation process is done to make sure the literature in use or equation of thermodynamic that will be used later is valid and applicable in further studies. The validation of thermodynamic model in downdraft gasifier is based on the comparison on the propose model result with the work in Zainal et al. (2001) where similar condition of the operation is applied from the literature ,while the validation of fluidized bed gasifier is based on the Karmakar and Datta (2011). The types of biomass used during the analysis process are wood, rice husk, empty fruit bunch and sawdust. The performance evaluation is performed by varying operation condition like gasifier temperature, moisture content and steam biomass ratio for both gasifiers. Gas composition produce by each of the biomass at certain operation condition had been calculated and the detailed results are shown in Appendix.

5.2 Model Evaluation of Downdraft Gasifier

The model evaluation is to validate the thermodynamic equilibrium model by comparing the model data with the literature data from Zainal et al. (2011) for downdraft gasifier. The validation optimizing the error in calculation of gas produces during the gasification process. The decision on the process and product need to be specified. The summaries of process and product specification are shown in Table 5-1.

Table 5-1: Process and Product Specification of Downdraft Gasifier for Model Evaluation.

Process and product Specification	Chosen
Type of Gasifier	Downdraft gasifier
Biomass	Wood
Biomass chemical formula	$CH_{1.44}O_{0.66}$
Temperature	800^0 C
Moisture Content (wet basis)	20%
Reactant	Air
Product	Hydrogen gas composition

After all the specification is made, the step by step calculation had been done in excel sheet as shown in chapter 4 until the final value of gas composition produce from the specified biomass at certain operating condition is defined. The last step in this work is the comparison of the result obtain from the calculation with the experimental result from Zainal et al.,(2001). Table 5-2 shows the comparison of the model data and experimental data where the MSE value is the mean square error between experimental data and model data.

Table 5-2: Comparison of Experimental Value in the Zainal et al.,(2011) with the Model Data.

Components	Experimental Data	Model Data	Mean Square Error
H2	15.23	15.23	0.00
CO	23.04	27.71	0.04
CO2	1.58	6.43	9.42
CH4	16.42	0.32	0.96
O2	1.42	0.00	1.00
N2	42.31	50.32	0.04
Total	100.00	100.00	1.91

From the comparison in table 5-2 shows that the model data is quite compatible with the experimental data especially for the hydrogen gas production with zero mean square error. The other types of gas are a bit different from experimental data except for CH4 gas composition where the difference is a bit too high with about 1.00 mean square error but it do not effect much since our main product is hydrogen gas. The validation shows that the model is applicable and valid to be used to analyze the hydrogen gas produce in downdraft gasifier.

5.3 Model Evaluation of Fluidized Bed Gasifier.

The model evaluation is to validate the thermodynamic equilibrium model in fluidized bed gasifier by comparing the model data with the literature data from Karmakar and Datta (2011). The decision on the process and product need to be specified. The summaries of process and product specification are shown in Table 5-3.

Table 5-3: Process and Product Specification of Fluidized Bed Gasifier for Model Evaluation.

Process and product Specification	Chosen
Type of Gasifier	Fluidized Bed gasifier
Biomass	Rice Husk

Biomass chemical formula	$CH_{1.777}O_{0.775}$
Temperature	650,690,730,770
Moisture Content	0.2
Steam Biomass Ratio	0.60,1.00,1.32,1.70
Reactant	Water
Product	Hydrogen gas composition

After all the specification is made, the step by step calculation had been done in Excel sheet. In fluidized bed gasifier the results obtained from the calculation had been compared with the experimental result from Karmakar and Datta (2011). Table 5-4 shows the gas composition produce calculated by the thermodynamic model for rice husk at different temperature and steam biomass ratio, while table 5-5 shows the experimental data for gas composition produce by rice husk at different temperature and different steam biomass ratio which is taken from the Karmakar and Datta (2011).

Table 5-4: Composition of Gas taken from Model Calculation.

Component	Temperature				Steam Biomass Ratio			
	650	690	730	770	0.60	1.00	1.32	1.70
H2	47.25	50.00	50.00	50.00	47.81	48.87	50.00	50.00
CO	11.24	12.83	15.93	17.85	27.48	27.69	16.65	17.38
CO2	31.91	28.45	25.65	23.95	18.09	22.22	23.14	23.99
CH4	9.59	8.71	8.42	8.20	6.62	1.22	10.21	8.63
H2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100	100	100	100

Table 5-5: Experimental Value from Karmakar and Datta., (2011).

Component	Temperature				Steam Biomass Ratio			
	650	690	730	770	0.60	1.00	1.32	1.70
H2	47.25	50.50	52.20	53.08	47.81	48.88	51.17	51.89
CO	11.25	12.83	15.90	17.85	27.48	22.70	16.65	17.38
CO2	31.90	28.51	25.65	23.90	18.09	22.20	23.15	24.81
CH4	9.60	8.16	6.25	5.17	6.62	6.22	9.03	5.92
H2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100	100	100.00	100

The comparison of composition of gas produce is more clearly show in graph form. Figure 5-1 shows the comparison of result from model calculated in excel with the experimental data taken from Karmakar and Datta., (2011) at different temperature, while figure 5-2 shows the comparison of result from model calculated in excel with the experimental data taken from Karmakar and Datta (2011) at different steam biomass ratio.

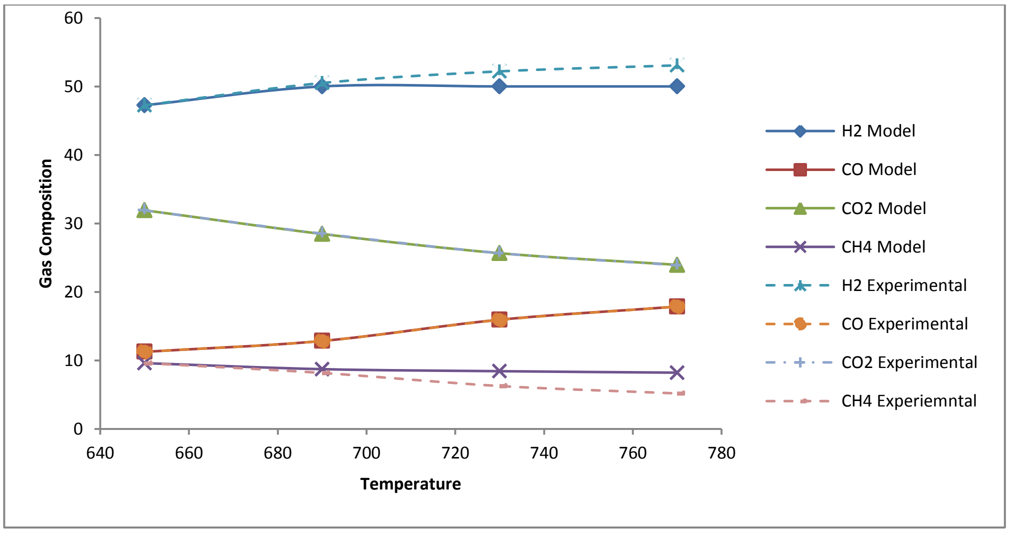


Figure 5-1: Comparison of Model Data with the Experimantal Data taken from Kamarkar and Datta(2011) at different temperature.

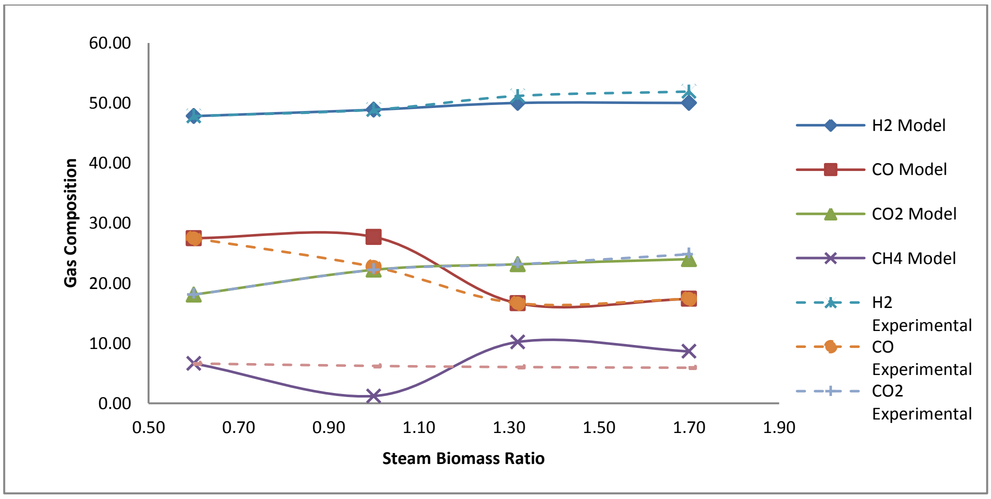


Figure 5-2: Comparison of Model Data with the Experimantal Data taken from Kamarkar and Datta(2011) at different Steam Biomass Ratio.

Figures 5-1 and 5-2 show there is only a minor different between model data and experimental data as the temperature and steam biomass ratio change where from here it can be conclude that the model data is valid to be used. For further conformation, the comparison for the gas composition produces is compare by selected one of the data from certain condition to see the mean square error between the both data. Table 5-6 shows the comparison of model data and experimental data of gas composition produce from rice husk in fluidized bed gasifier at temperature 690^{0}C with moisture content of 20% and steam biomass ratio 1.32.

Table 5-6: The Comparison of Model Data and Experimental Data of Gas Composition Produce from Rice Husk in Fluidized Bed Gasifier.

Components	Experiment Data	Model Data	Mean Square Error
H2	50.50	50.00	0.00
CO	12.83	12.83	0.00
CO2	28.51	28.45	0.00
CH4	8.16	8.71	0.00
O2	0.00	0.00	0.00
N2	0.00	0.00	0.00
Total	100.00	100.00	0.00

From the comparison, the mean square error is zero so this means the model is totally compatible with the experimental data. The validation for both gasifier shows that the model is applicable for analysis of the hydrogen gas produced in the downdraft and fluidized bed gasifier. Since the result for both type of gasifiers was in good agreement and only a slight error occur during comparison means the thermodynamic model in used is valid and applicable for further studies.

5.4 Performance Analysis for Downdraft Gasifier.

In this step, the performance evaluation is performed on wood, rice husk, sawdust and empty fruit bunch by varying gasifier temperature and moisture content for downdraft gasifiers. The detail result on the performance analysis for different operating condition in downdraft gasifier using different types of biomasses is show in appendix.

5.4.1 Performance Analysis by Varying Temperature in Downdraft Gasifier.

The performance analysis for gasifier is done by changing the operating condition which one of the most important parameter which affects the performance of gasifier is gasification temperature. The performance analysis of downdraft gasifier at different temperature range 650-770 ^{0}C is perform using wood, rice husk , sawdust and empty fruit bunch. The summaries of process and product specification for temperature different in downdraft gasifier are shown in Table 5-7.

Table 5-7 : Process and Product Specification for Temperature Different in Downdraft Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	650,690,730,770
Moisture content	0.2

Product	Hydrogen gas

After all the specification is made, the step by step calculation had been done in excel sheet and the final result of the composition of hydrogen gas produced by each types of biomass is present in table and graph form. Table 5-8 and figure 5-3 shows the composition of hydrogen gas produced by each types of biomass at different temperature.

Table 5-8: Composition of Hydrogen Gas Produced by each types of Biomass at Different Temperature.

Composition of Hydrogen (outlet %)	Temperature(^{0}C)			
Types of Biomass	650	690	730	770
Wood	19.14	18.31	16.97	16.37
Rice Husk	16.18	16.22	16.27	17.02
Sawdust	15.11	15.27	15.88	16.30
Empty Fruit Bunch	47.39	48.15	49.93	50.12

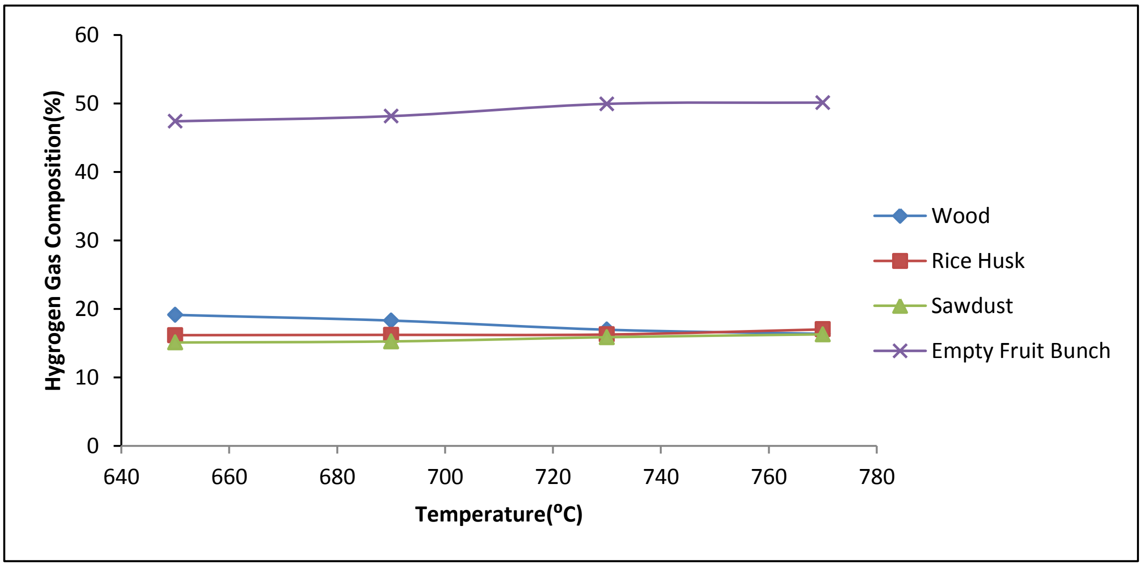


Figure 5-3 : Hydrogen Gas Composition Produced by Each Types of Biomass at Different Temperature.

From the composition of hydrogen gas produced by each types of biomass, empty fruit bunch is the biomass which produce the highest amount of hydrogen when compare to other types of biomass. This is because of the highest HHV value of empty fruit bunch makes it react better with air when compare to other types of biomass. When temperature increase, the composition of hydrogen gas produce for most of the biomass will increase accept for wood and temperature 770^{0}C can said to be the most optimum temperature for gasification processes.

5.4.2 Performance Analysis by Varying Moisture Content in Downdraft Gasifier.

One of the important parameter which affects the performance of gasifier is biomass moisture content. Based on the previous analysis, it has been found that the optimum temperature is 770^{0}C. Next the analysis is performed at varying moisture content at the optimum temperature. The performance analysis of downdraft gasifier at different moisture content range 0-40% is perform using wood, rice husk , sawdust and empty fruit bunch. It should be noted that the moisture content higher than this range will not be suitable for the gasification process. The summaries of process and product specification for moisture content different in downdraft gasifier are shown in Table 5-9.

Table 5-9: Process and Product Specification for Moisture Content Different in Downdraft Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	770
Moisture content(%)	0,10,20,30,40
Product	Hydrogen gas

After all the specification is made, the step by step calculation had been done in excel sheet and the final result of the composition of hydrogen gas produced by each types of biomass is present in table and graph form. Table 5-10 and figure 5-4 shows the composition of hydrogen gas produced by each types of biomass at different moisture content.

Table 5-10: Composition of Hydrogen Gas Produced by each types of Biomass at Different Moisture Content.

Component(outlet %)	Moisture Content(%)				
	0	10	20	30	40
Wood	12.03	13.92	15.23	17.16	18.79
Rice Husk	12.26	14.81	16.69	17.26	21.32
Sawdust	13.42	13.85	15.49	18.24	21.69
Empty Fruit Bunch	29.70	31.54	31.87	35.00	44.48

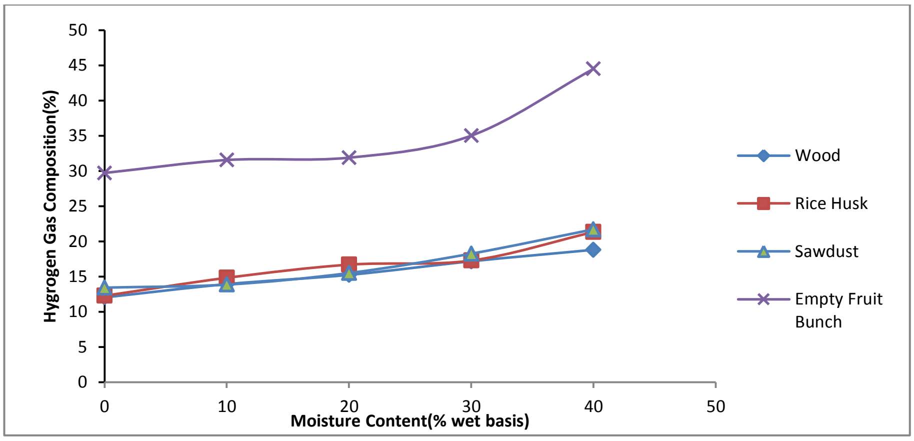


Figure 5-4: Hydrogen Gas Composition Produced by Each Types of Biomass at Different Temperature.

From the composition of hydrogen gas produced by each types of biomass, empty fruit bunch is the biomass which produce the highest amount of hydrogen when compare to other types of biomass. When the moisture content increases, the composition of hydrogen gas produce will increase.

5.5 *Performance Analysis for Fluidized bed Gasifier.*

The performance evaluation is performed on wood, rice husk, sawdust and empty fruit bunch by varying gasifier temperature, moisture content and steam biomass ratio for fluidized bed gasifiers. The detail result on the performance analysis for different operating condition in fluidized bed gasifier using different types of biomasses is show in appendix.

5.5.1 *Performance Analysis by Varying Temperature in Fluidized Bed Gasifier.*

The performance analysis of fluidized bed gasifier at different temperature range 650-770 ^{0}C is perform using wood, rice husk , sawdust and empty fruit bunch. The summaries of process and product specification for temperature different in fluidized bed gasifier are shown in Table 5-11.

Table 5-11: Process and Product Specification for Temperature Different in Fluidized Bed Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch

Gasification temperature (^{0}C)	650,690,730,770
Moisture content	0.2
Steam Biomass Ratio	1.32
Product	Hydrogen gas

After all the specification is made, the step by step calculation had been done in excel sheet and the final result of the composition of hydrogen gas produced by each types of biomass is present in table and graph form. Table 5-12 and figure 5-5 shows the composition of hydrogen gas produced by each types of biomass at different temperature.

Table 5-12: Composition of Hydrogen Gas Produced by each types of Biomass at Different Temperature.

Component (outlet %)	Temperature(^{0}C)			
	650	690	730	770
Wood	24.01	30.35	35.33	38.76
Rice Husk	47.25	50.00	50.00	50.00
Sawdust	39.43	48.69	59.10	73.30
Empty Fruit Bunch	61.38	64.76	68.29	71.77

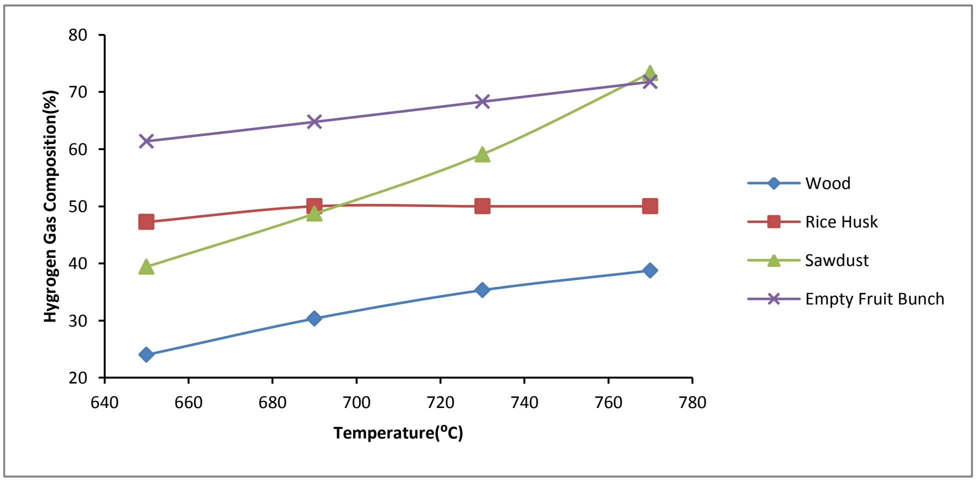


Figure 5-5: Hydrogen Gas Composition Produced by Each Types of Biomass at Different Temperature.

From the composition of hydrogen gas produced by each types of biomass, when the temperature is increased, the hydrogen gases produced by sawdust will gradually increasing until it is exceeding the amount of hydrogen gas produced by empty fruit bunch. Therefore for fluidized bed gasifier, the sawdust will be the biomass that produced the highest amount of hydrogen gas at high temperature. At low temperature, the steam inlet will not react well with biomass which here the reaction shifted to the empty fruit bunch with highest HHV value but when temperature increase, the steam contain hydrogen gas compound will tend to react and activated the hydrogen component in sawdust which have highest hydrogen component compare to other type of biomass. Temperature 770^{0}C can said to be the most optimum temperature for gasification processes which here highest amount of hydrogen gas composition is produced.

5.5.2 Performance analysis by Varying Moisture Content in Fluidized Bed Gasifier.

One of the important parameter which affects the performance of gasifier is biomass moisture content. Based on the previous analysis, it has been found that the optimum temperature is 770^{0}C. Next the analysis is performed at varying moisture content at the optimum temperature. The performance analysis of fluidized bed gasifier at different moisture content range 0-40% is perform using wood, rice husk , sawdust and empty fruit bunch. It should be noted that the moisture content higher than this range will not be suitable for the gasification process. The summaries of process and product specification for moisture content different in fluidized bed gasifier are shown in Table 5-13.

Table 5-13: Process and Product Specification for Moisture Content Different in Fluidized Bed Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	770
Moisture content (%)	0,10,20,30,40
Steam Biomass Ratio	1.32
Product	Hydrogen gas

After all the specification is made, the step by step calculation had been done in excel sheet and the final result of the composition of hydrogen gas produced by each types of biomass is present in table and graph form. Table 5-14 and figure 5-6 shows the composition of hydrogen gas produced by each types of biomass at different moisture content.

Table 5-14: Composition of Hydrogen Gas Produced by each types of Biomass at Different Moisture Content.

Component(outlet %)	Moisture Content (%)				
	0	10	20	30	40
Wood	37.80	37.22	36.38	35.17	33.36
Rice Husk	62.19	63.97	65.26	66.07	66.07
Sawdust	73.67	75.88	78.66	81.89	83.57
Empty Fruit Bunch	70.21	70.05	69.86	69.63	69.33

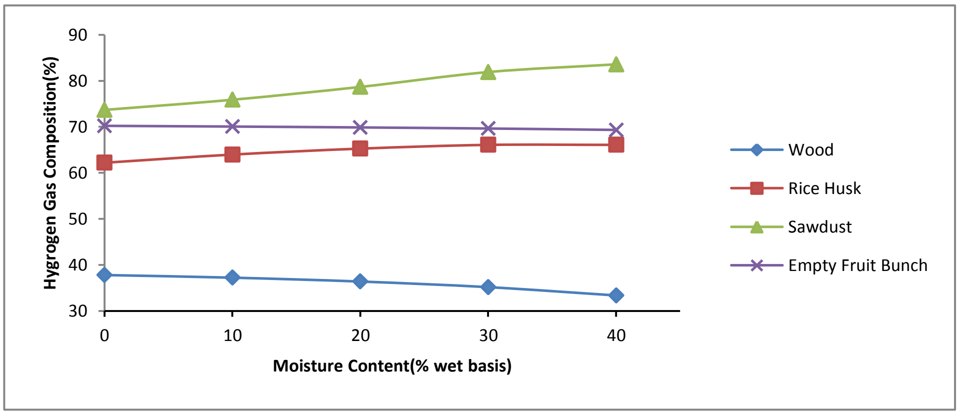


Figure 5-6 : Hydrogen Gas Composition Produced by Each Types of Biomass at Different Moisture Content.

From the composition of hydrogen gas produced by each types of biomass, sawdust is the biomass which produce the highest amount of hydrogen when compare to other types of biomass. When the moisture content increases, the composition of hydrogen gas produce will increase accept for wood and empty fruit bunch which will decrease when moisture content increase.

5.5.3 Performance Analysis by Varying Steam Biomass Ratio

Another important parameter which affects the performance of fluidized bed gasifier is steam biomass ratio. The performance analysis of fluidized bed gasifier at different steam biomass ratio range 0.60-1.70 is perform using wood, rice husk , sawdust and empty fruit bunch. The summaries of process and product specification for steam biomass ratio different in fluidized bed gasifier are shown in Table 5-15.

Table 5-15: Process and Product Specification for Steam Biomass Ratio Different in Fluidized Bed Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	770
Moisture content	0.2
Steam Biomass Ratio	0.60,1.00, 1.32,1.70

Product	Hydrogen gas

After all the specification is made, the step by step calculation had been done in excel sheet and the final result of the composition of hydrogen gas produced by each types of biomass is present in table and graph form. Table 5-16 and figure 5-7 shows the composition of hydrogen gas produced by each types of biomass at different steam biomass ratio.

Table 5-16: Composition of Hydrogen Gas Produced by each types of Biomass at Different Steam Biomass Ratio.

Component(outlet %)	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
Wood	36.00	36.49	36.38	36.08
Rice Husk	47.81	48.87	50.00	50.00
Sawdust	70.72	74.45	78.68	66.66
Empty Fruit Bunch	70.47	70.10	69.86	69.62

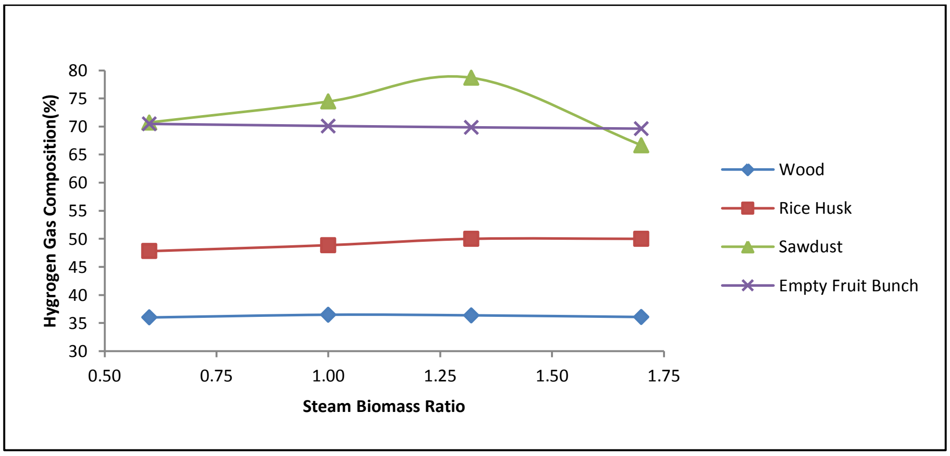


Figure 5-7: Hydrogen Gas Composition Produced by Each Types of Biomass at Different Steam Biomass Ratio.

From the composition of hydrogen gas produced by each types of biomass, sawdust is the biomass which produce the highest amount of hydrogen when compare to other types of biomass. However, after sawdust reach its optimum steam biomass ratio of 1.32, the composition of hydrogen gas produced by the sawdust will decrease which after that empty fruit bunch will become the biomass that produce highest amount of hydrogen gas. When steam biomass ratio changes, the composition of hydrogen gas produce will fluctuate according to the changes.

5.6 *Comparison of Performance Analysis of both types of gasifier.*

In comparison of both gasifier, the performance evaluation is performed on wood, rice husk, sawdust and empty fruit bunch by varying gasifier temperature and moisture content for both gasifiers. Table 5-17 shows the specification for the comparison of downdraft and fluidized bed gasifier at different temperature. After the specification is made, the thermodynamic model is used to predict the amount of hydrogen gas produced by both type of gasifiers. Table 5-18 and 5-19 show the hydrogen gas composition produced by each types of biomass at different temperature in downdraft gasifier and fluidized bed gasifier. The hydrogen gas produced at different temperature is shown in Figure 5-8 for downdraft and fluidized bed gasifiers.

Table 5-17: The specification for the comparison of downdraft and fluidized bed gasifiers at different temperature.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch(EFB)
Temperature (^{0}C)	650,690,730,770
Moisture content	0.2
Steam Biomass Ratio	1.32
Product	Hydrogen gas

Table 5-18: Hydrogen gas composition produced by each type of biomasses at different temperature in downdraft gasifier.

Component (outlet %)	Temperature(^{0}C)			
	650	690	730	770
Wood	19.14	18.31	16.97	16.37
Rice Husk	16.18	16.22	16.27	17.02
Sawdust	15.11	15.27	15.88	16.30
Empty Fruit Bunch	47.39	48.15	49.93	50.12

Table 5-19: Hydrogen gas composition produced by each type of biomasses at different temperature in fluidized bed gasifier.

Component (outlet %)	Temperature(^{0}C)			
	650	690	730	770
Wood	24.01	30.35	35.33	38.76
Rice Husk	47.25	50.00	50.00	50.00
Sawdust	39.43	48.69	59.10	73.30

Empty Fruit Bunch	61.38	64.76	68.29	71.77

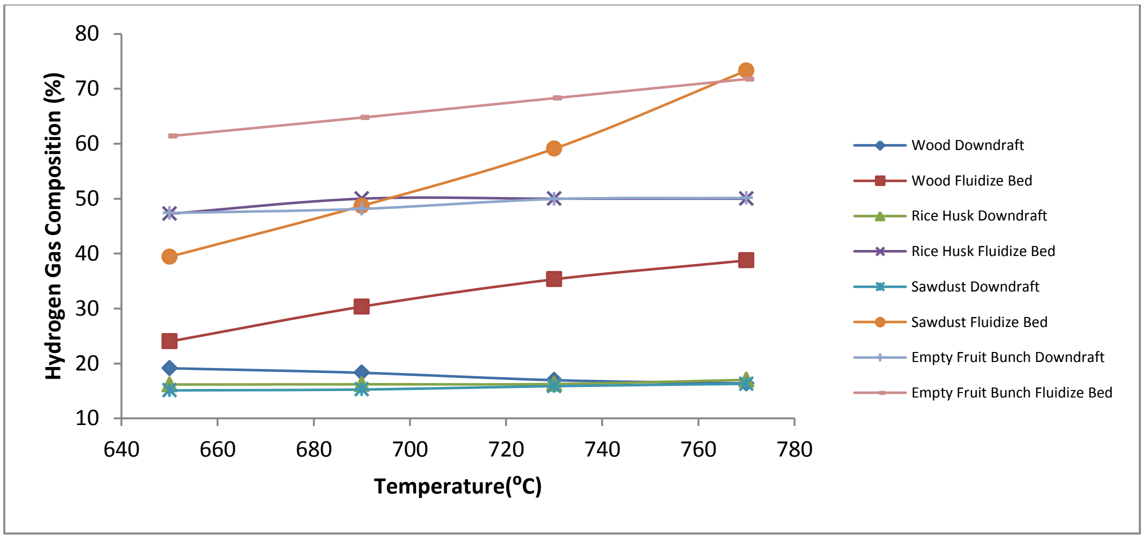


Figure 5-8: The comparison of downdraft and fluidized bed gasifier at different temperature.

Figure 5-8 shows that as the temperature increase, the hydrogen gas composition produced will be increased. The fluidized bed gasifier was more efficient than downdraft gasifier in terms of hydrogen gas production for all types of biomass tested. Fluidized bed gasifier was more efficient due to the biomass tend to react with steam better than air especially in hydrogen gas production since steam contain hydrogen compound. The empty fruit bunch is the types of biomasses which produce the highest amount of hydrogen gas in downdraft gasifier since empty fruit bunch undergo partial combustion process faster due to high heating value (HHV) in this biomass which tend to react with air in more efficient way. However, in the fluidized bed gasifier, when the temperature is increased, the hydrogen gases produced by sawdust will gradually increasing until it is exceeding the amount of hydrogen gas produced by empty fruit bunch. Therefore for fluidized bed gasifier, the sawdust will be the biomass that produced the highest amount of hydrogen gas at high temperature. At low temperature, the steam inlet will not react well with biomass which here the reaction shifted to the empty fruit bunch with highest HHV value but when temperature increase, the steam contain hydrogen gas compound will tend to react and activated the hydrogen component in sawdust which have highest hydrogen component compare to other type of biomass.

Based on the previous analysis, it has been found that the optimum temperature is 770^{0}C. Next the analysis is performed at varying moisture content at the optimum temperature. Tables 5-20 show the specification and the hydrogen gas produced for downdraft and fluidized bed gasifier at different moisture content. Table 5-21 and 5-22 show the hydrogen gas composition produced by each types of biomass at different moisture content in downdraft gasifier and fluidized bed gasifier. The hydrogen gas produced at different moisture content in both gasifier is shown in Figure 5-9 for downdraft and fluidized bed gasifiers.

Table 5-20: Process and Product Specification for Moisture Content Different in Fluidized Bed Gasifier.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	770
Moisture content	0,10,20,30,40
Steam Biomass Ratio	1.32
Product	Hydrogen gas

Table 5-21: Hydrogen gas composition produced by each type of biomasses at different moisture content in downdraft gasifier.

Component(outlet %)/MC	Moisture Content (%)				
	0	10	20	30	40
Wood	12.03	13.92	15.23	17.16	18.79
Rice Husk	12.26	14.81	16.69	17.26	21.31
Sawdust	13.42	13.85	15.49	18.24	21.69
Empty Fruit Bunch	29.70	31.54	31.87	35.00	44.48

Table 5-22: Hydrogen gas composition produced by each type of biomasses at different moisture content in fluidized bed gasifier.

Component (outlet %)	Moisture Content (%)				
Moisture Content	0	10	20	30	40
Wood	37.79	37.22	36.38	35.16	33.36
Rice Husk	62.19	63.96	65.25	66.07	66.07
Sawdust	73.66	75.87	78.66	81.89	83.57
Empty Fruit Bunch	70.21	70.05	69.86	69.63	69.32

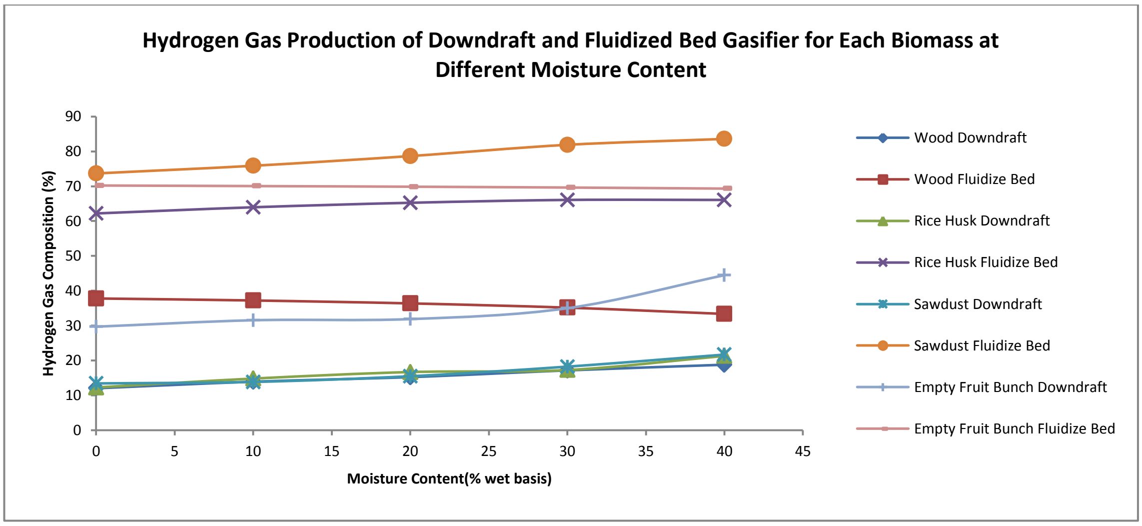


Figure 5-9: Downdraft and fluidized bed gasifiers comparison at different moisture content.

Figure 5-9 shows that as the moisture content of biomass increase, the hydrogen gas composition produce will slight increase except for wood and empty fruit bunch in fluidized bed gasifier where here when moisture content increase the hydrogen gas produce decrease. The fluidized bed gasifier was more efficient than downdraft gasifier in hydrogen gas production for all types of biomass tested. The empty fruit bunch is the types of biomass which produce highest amount of hydrogen gas in downdraft gasifier, while sawdust is the biomass produce highest amount of hydrogen in fluidized bed gasifier as the temperature for the operating condition here was quite high.

6 CONCLUSION

6.1 Conclusion

This project focuses on using thermodynamic model to analyse the performance of downdraft and fluidized bed gasifier. In the first chapter, the problem statement and motivation is defined. The use of coal as fuels leads to the problem like the depletion of resource and environmental issues like greenhouse effect from the emission of carbon dioxide during the energy production process. These problems lead to the finding of alternative methods to produce energy that is through the use of biomass and one of the effective technologies to produce energy from biomass is through gasification process. The gasification process leads to the further problem of the choice of model for gasification process which is either kinetics or equilibrium model. After the comparison between both types of model, the best model to be used is equilibrium model.

The second chapter is the review of the past literature and studies. From the overall review of the types of gasifiers shows that fluidized bed and downdraft are suitable for hydrogen production compare to other types of gasifier. The performance analysis of the gasifier can be done by using the thermodynamic equilibrium model. The previous studies on the biomass used leads to the decision on biomass material to be used in this work which are of wood, rice husk, empty fruit bunch and saw dust.

The third chapter is the methodology of the process. Here the step by step of how work is done is clearly stated. The step is clearly stated to act as a guideline to the user on how the performance analysis of the gasification process has been done. As stated in the chapter 3, the procedure of this project starts from the problem definition followed by the decision on the type of equipment, feedstock, measured parameter or condition and the final product. The third step is about the thermodynamic model and calculation is done in Excel. In here, part by part calculation in Excel has been done to find the value of gas composition. All the performance analysis will be calculated in Excel and verified by comparing the result with the experimental data. At the end of this analysis, result comparisons for performance analysis of both type of gasifier were done and ultimately the optimal condition to produce the desired hydrogen will be analysed through this work.

Chapter 4 shows the summary of all the excel calculation which is shown in excel sheet. This summary will be more users friendly since user can choose the type of gasifier, materials and condition accordingly in order to get the result of gas composition produced instead of go through the long calculation procedures. The summaries can be improved in future in order for the user to make easier prediction on gas composition

Chapter 5 is about the result of gas composition produce during gasification process calculated in Excel sheet using the thermodynamic equilibrium model. The calculation is then will be validate by comparing the value with experimental values obtained from the work of Zainal et Al. (2011) and Karmakar and Datta (2011) where good agreement is achieved. Based on the performance analysis, fluidized bed gasifier is more efficient compare to downdraft gasifier since at temperature 770 ℃ with moisture content of 0.2 and steam biomass ratio 1.32, the hydrogen gas produced from wood, rice husk, sawdust and empty fruit bunch in downdraft gasifier is 16.38%, 17.02%, 16.30% and 50.12 % respectively, while in the fluidized bed gasifier is 38.75%, 50.00%, 73.30% and 71.77% respectively. In addition it has been concluded that hydrogen gas production in most of the biomass are increased when the moisture content is increased except wood and empty fruit bunch in fluidized bed gasifier where the value is decreasing. The biomass that produce the highest amount of hydrogen in downdraft gasifier is empty fruit bunch, while in the fluidized bed gasifier, empty fruit bunch is the highest hydrogen gas production at low temperature but as the temperature increase the sawdust become the biomass that produce the highest amount of hydrogen.

As a conclusion, the proposed model is applicable for modelling of gasification process and can be used for preanalysis in determining the hydrogen gas production for any new biomass without the need to perform the full scale experiment. The performance analysis of gasifier is important to analyse the best type of gasifier to be used in industries to get highest energy production and to find the optimum condition for the gasifier to functioning to give highest performance. Since for techno-economical evaluation, actual construction of a gasifier is not always feasible and economically sound because experimentation usually involves much greater time, effort, and cost. Thus, a mathematical model for such analysis is more useful. The equilibrium model has been used by many researchers for the analysis of the gasification process. The development of the user friendly software in analysis needs to be detailed and easy to understand so that this kind of software can be widely used and being one of the useful tools in the energy production later.

6.2 Future Works

Development of the performance analysis is considerably meticulous task, yet its application brings various positive impacts in industry. The endless effort to achieve operational efficiencies in energy production will place modelling at an utmost important position in process engineering. However, performance analysis of biomass gasification should not be limited to industry but should be equally exploited in academic institution. Gasification could be an effective tool where the interrelationships among a multitude of engineering concepts such as mass balance, chemical formula analysis, energy production and thermodynamic could be demonstrated. Performance analysis of gasification process will becomes an important model in gas and energy production industrial. It is no longer considered only as an added benefit to be able to model and thereby predict, modify and adapt proactively to changing conditions, but this competitive advantage is actually a attribute to operational excellence of sustainability in the energy production.

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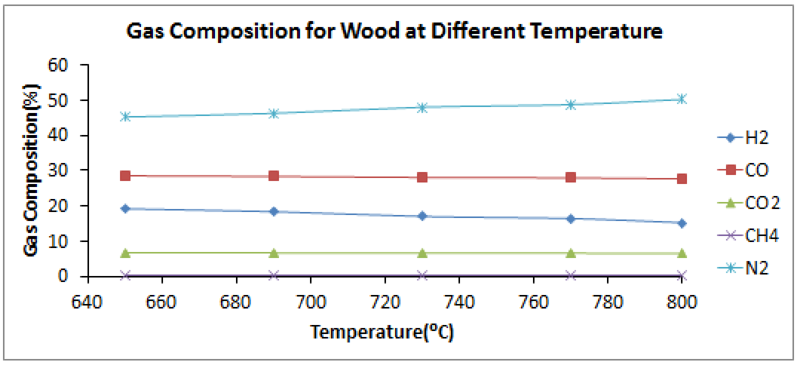
APPENDIX

Performance Analysis of Downdraft Gasifier at Different temperature for each types of Biomass

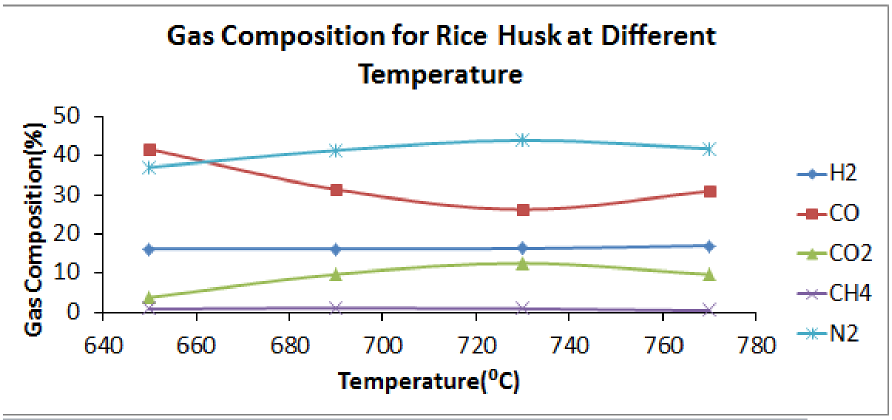
Material	: Wood
Chemical formula	$CH_{1.44}O_{0.66}$
Gasification temperature (°C)	: 650,690,730,770
Moisture content	: 0.2

Component(outlet %)	Temperature(°C)				
	650	690	730	770	800
H2	19.14	18.31	16.97	16.37	15.23
CO	28.55	28.37	28.08	27.96	27.71
CO2	6.62	6.58	6.51	6.48	6.43
CH4	0.32	0.32	0.32	0.32	0.32
N2	45.37	46.41	48.11	48.87	50.32
Total	100.00	100.00	100.00	100.00	100.00



Material	: Rice Husk
Chemical formula	$CH_{0.93}O_{0.71}$
Gasification temperature (°C)	: 650,690,730,770
Moisture content	: 0.2

Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	16.18	16.22	16.27	17.02
CO	41.78	31.43	26.28	30.96
CO2	3.79	9.75	12.53	9.68
CH4	0.86	1.13	0.95	0.46
N2	37.09	41.47	43.98	41.87
Total	99.70	100.00	100.00	100.00



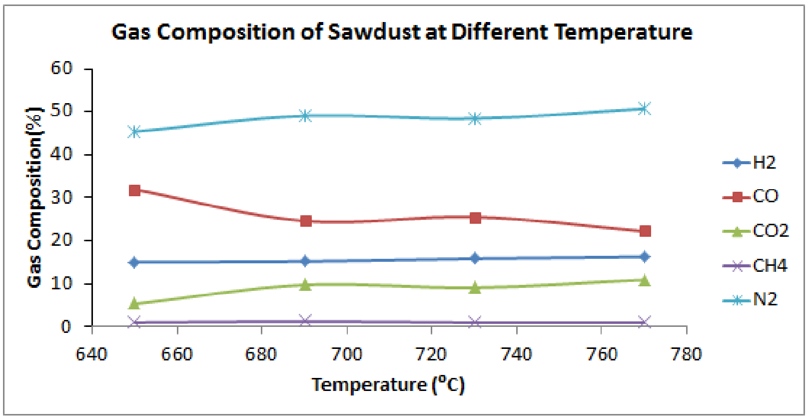
Material : Sawdusk

Chemical formula $CH_{1.492}O_{0.751}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	15.11	15.27	15.88	16.30
CO	31.92	24.61	25.58	22.26
CO2	5.38	9.77	9.12	10.97
CH4	1.04	1.32	1.02	0.99
N2	45.37	49.03	48.40	50.67
Total	98.81	100.00	100.00	101.19



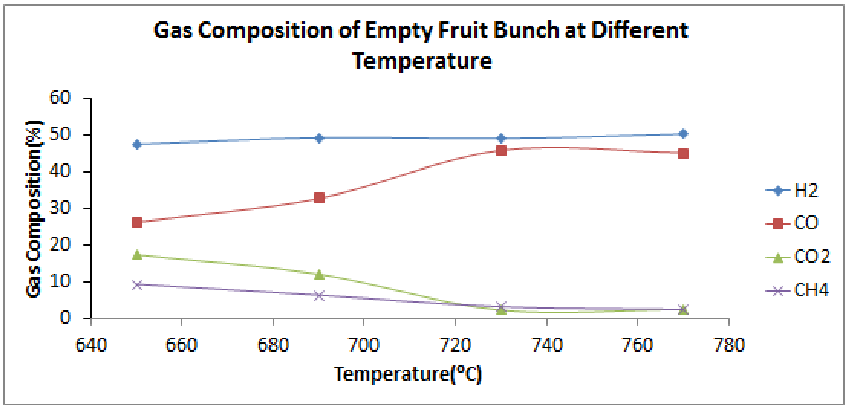
Material : Empty Fruit Bunch

Chemical formula $CH_{1.430}O_{0.615}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

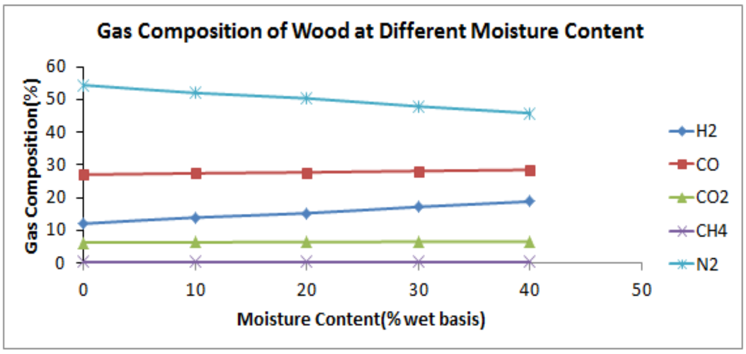
Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	47.39	49.15	48.93	50.12
CO	26.12	32.61	45.76	45.04
CO2	17.25	11.98	2.17	2.44
CH4	9.24	6.26	3.14	2.40
N2	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Performance Analysis of Downdraft Gasifier at Different moisture content for each types of Biomass

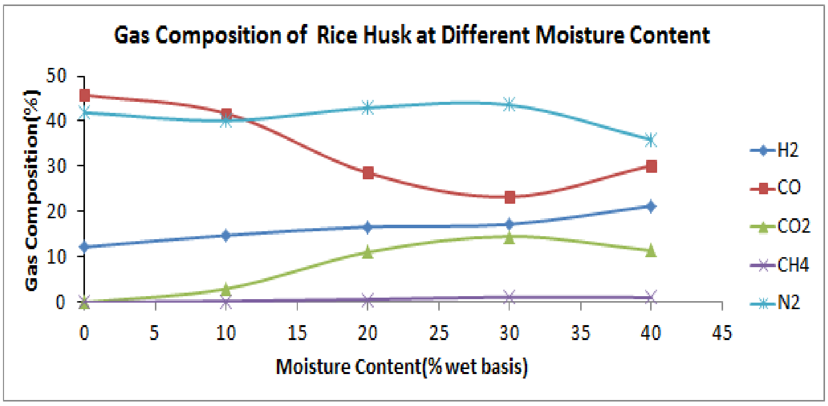
Material	: Wood
Chemical formula	$CH_{1.44}O_{0.66}$
Gasification temperature (°C)	: 750
Moisture content	: 0.0,0.1,0.2,0.3,0.4

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	12.73	15.16	16.87	18.79	21.37
CO	27.17	27.69	28.06	28.48	29.03
CO2	6.30	6.42	6.51	6.60	6.73
CH4	0.31	0.32	0.32	0.32	0.33
N2	53.49	50.41	48.24	45.80	42.54
Total	100.00	100.00	100.00	100.00	100.00



Material	: Rice Husk
Chemical formula	$CH_{0.93}O_{0.71}$
Gasification temperature (°C)	: 750
Moisture content	: 0.0,0.1,0.2,0.3,0.4

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	12.26	14.81	16.69	17.26	21.32
CO	45.82	41.75	28.60	23.32	30.20
CO2	0.00	3.03	11.10	14.59	11.46
CH4	0.01	0.28	0.67	1.21	1.09
N2	41.91	40.13	42.94	43.61	35.93
Total	100.00	100.00	100.00	100.00	100.00



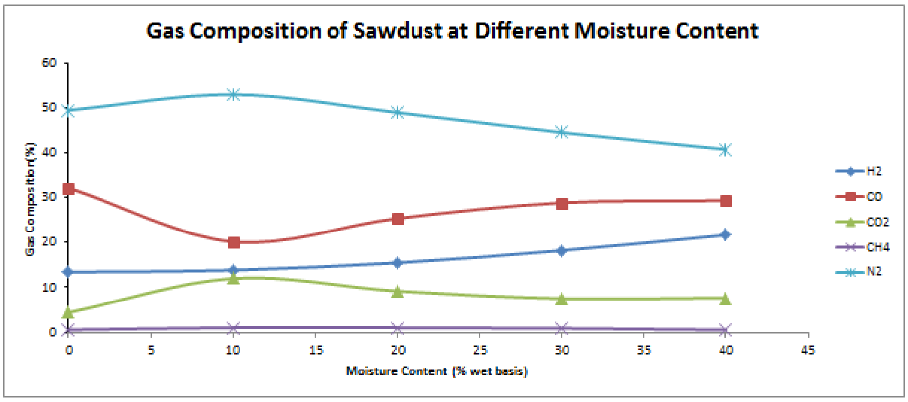
Material : Sawdusk

Chemical formula $CH_{1.492}O_{0.751}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	13.42	13.85	15.49	18.24	21.69
CO	32.16	20.20	25.38	28.86	29.33
CO2	4.43	12.00	9.17	7.50	7.66
CH4	0.57	1.02	1.03	0.88	0.56
N2	49.43	52.93	48.93	44.52	40.76
Total	100.00	100.00	100.00	100.00	100.00



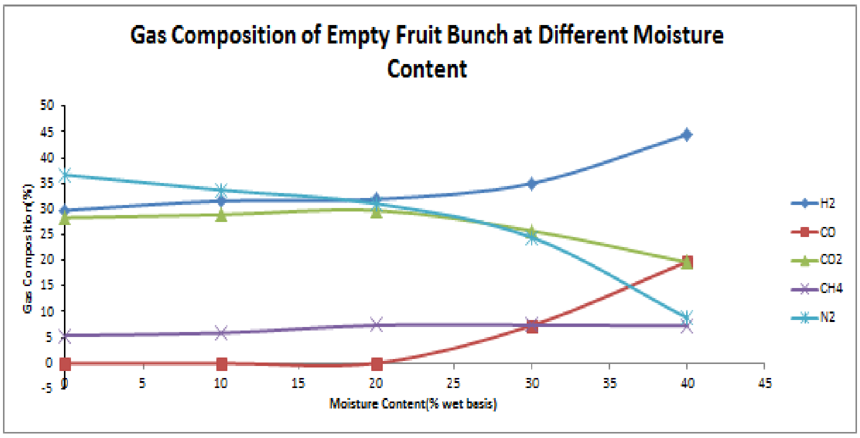
Material : Empty Fruit Bunch

Chemical formula $CH_{1.430}O_{0.615}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	29.70	31.54	31.87	35.00	44.48
CO	0.00	0.00	0.00	7.33	19.79
CO2	28.29	28.88	29.71	25.76	19.65
CH4	5.39	5.89	7.38	7.43	7.30
N2	36.62	33.69	31.03	24.49	8.79
Total	100.00	100.00	100.00	100.00	100.00



Performance Analysis of Fluidized Bed Gasifier at Different Temperature for each types of Biomass

Material : Wood

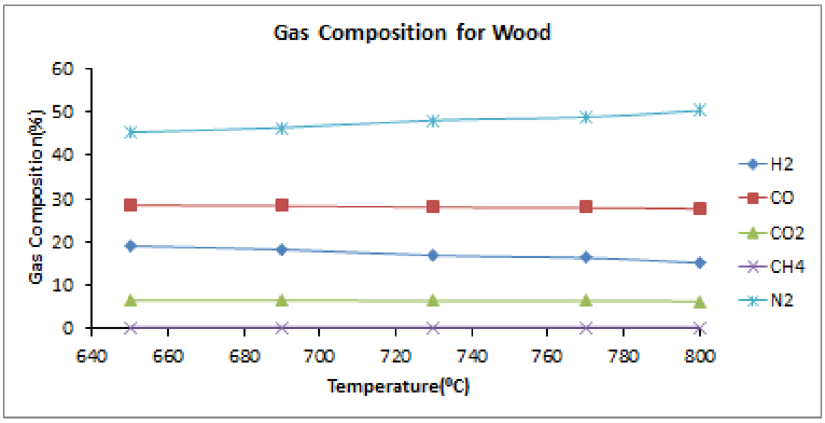
Chemical formula $CH_{1.44}O_{0.66}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

Steam Biomass Ratio :1.32

Component(outlet %)	Temperature(°C)				
	650	690	730	770	800
H2	24.01	30.35	35.33	38.76	15.23
CO	32.89	30.63	29.64	29.75	27.71
CO2	27.44	26.64	25.67	24.60	6.43
CH4	15.66	12.38	9.37	6.90	0.32
N2	0.00	0.00	0.00	0.00	50.32
Total	100.00	100.00	100.00	100.00	100.00



Material : Rice Husk

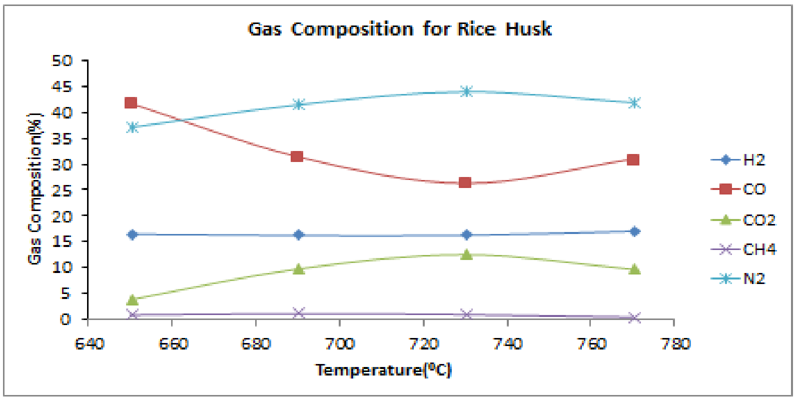
Chemical formula $CH_{0.93}O_{0.71}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

Steam Biomass Ratio :1.32

Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	47.25	50.00	50.00	50.00
CO	11.24	12.83	15.93	17.85
CO2	31.91	28.45	25.65	23.95
CH4	9.59	8.71	8.42	8.20
N2	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Material : Sawdust

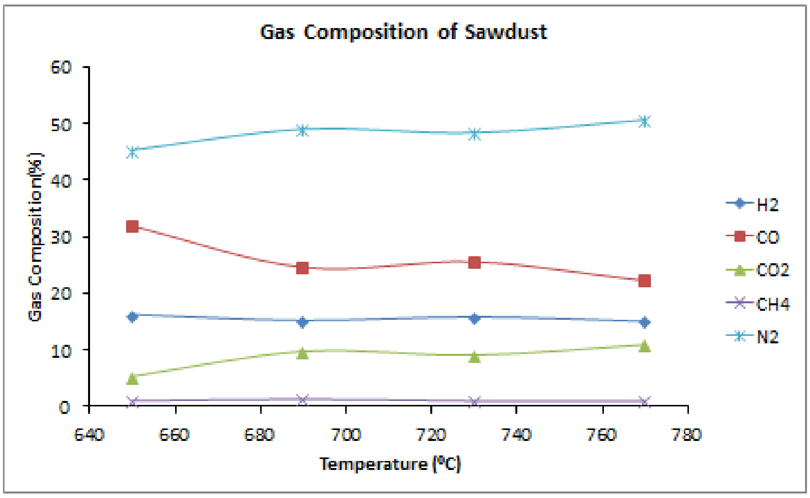
Chemical formula $CH_{1.492}O_{0.751}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

Steam Biomass Ratio : 1.32

Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	39.43	48.69	59.10	73.30
CO	16.41	13.78	10.56	6.12
CO2	24.26	22.71	20.15	16.03
CH4	19.90	14.81	10.19	4.55
N2	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Material : Empty Fruit Bunch

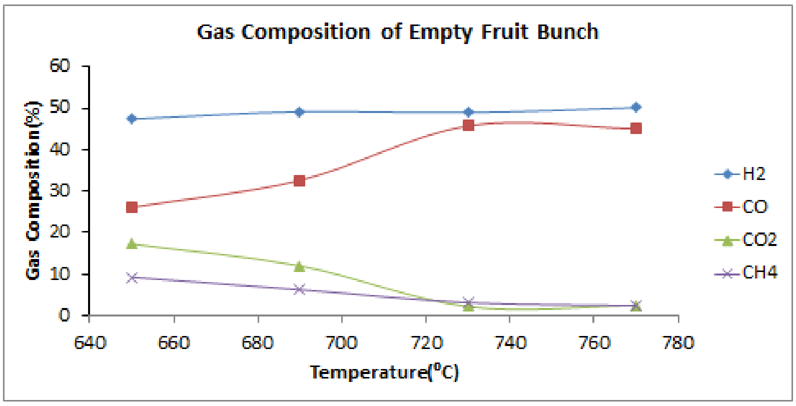
Chemical formula $CH_{1.430}O_{0.615}$

Gasification temperature (°C) : 650,690,730,770

Moisture content : 0.2

Steam Biomass Ratio : 1.32

Component(outlet %)	Temperature(°C)			
	650	690	730	770
H2	61.38	64.76	68.29	75.50
CO	3.13	4.05	4.06	5.57
CO2	33.47	27.86	24.67	15.20
CH4	2.01	3.32	2.99	3.73
N2	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Performance Analysis of Fluidized Bed Gasifier at Different Moisture Content for each types of Biomass

Material : Wood

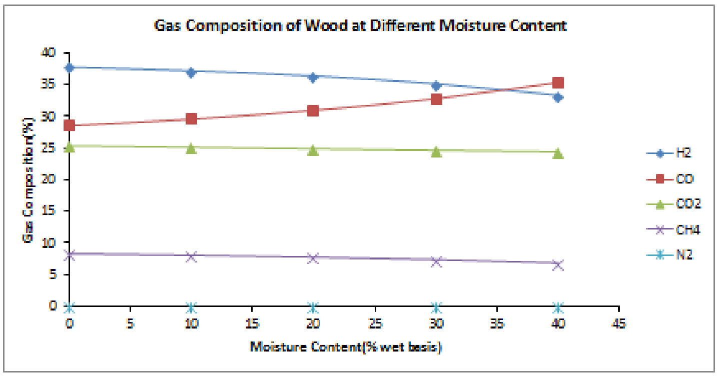
Chemical formula $CH_{1.44}O_{0.66}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Steam Biomass Ratio :1.32

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	37.80	37.22	36.38	35.17	33.36
CO	28.52	29.58	30.97	32.82	35.37
CO2	25.39	25.14	24.89	24.65	24.44
CH4	8.29	8.06	7.76	7.36	6.83
N2	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00



Material : Rice Husk

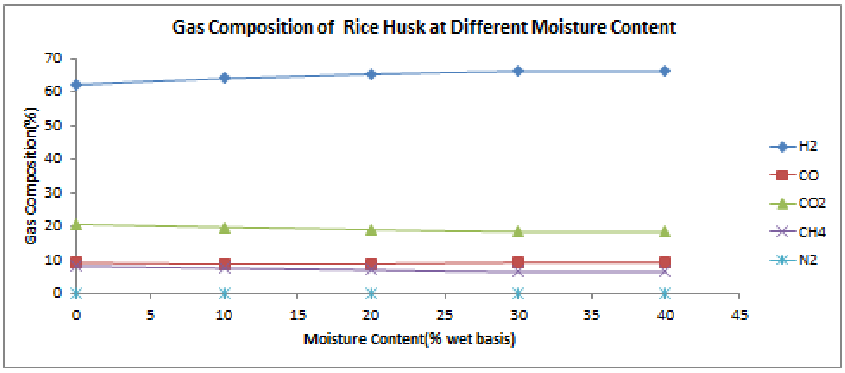
Chemical formula $CH_{0.93}O_{0.71}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Steam Biomass Ratio :1.32

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	62.19	63.97	65.26	66.07	66.07
CO	9.08	8.76	8.78	9.16	9.16
CO2	20.64	19.75	18.98	18.34	18.34
CH4	8.09	7.53	6.98	6.43	6.43
N2	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00



Material : Sawdusk

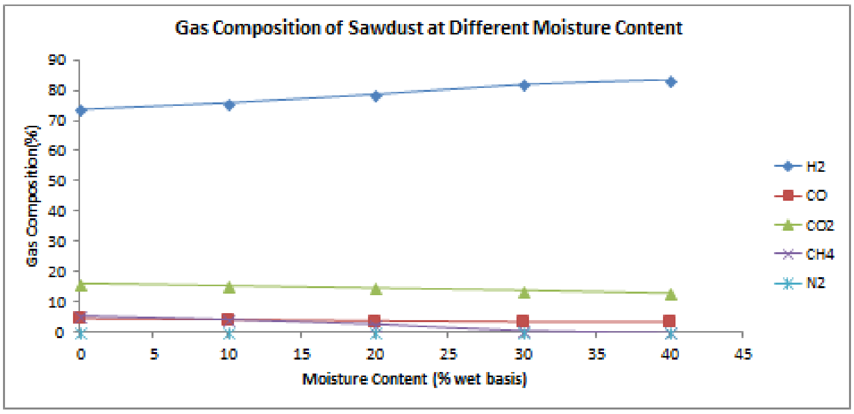
Chemical formula $CH_{1.492}O_{0.751}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Steam Biomass Ratio :1.32

Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	73.67	75.88	78.66	81.89	83.57
CO	4.61	4.30	3.91	3.51	3.45
CO2	16.24	15.50	14.70	13.97	12.98
CH4	5.48	4.33	2.73	0.63	0.00
N2	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00



Material : Empty Fruit Bunch

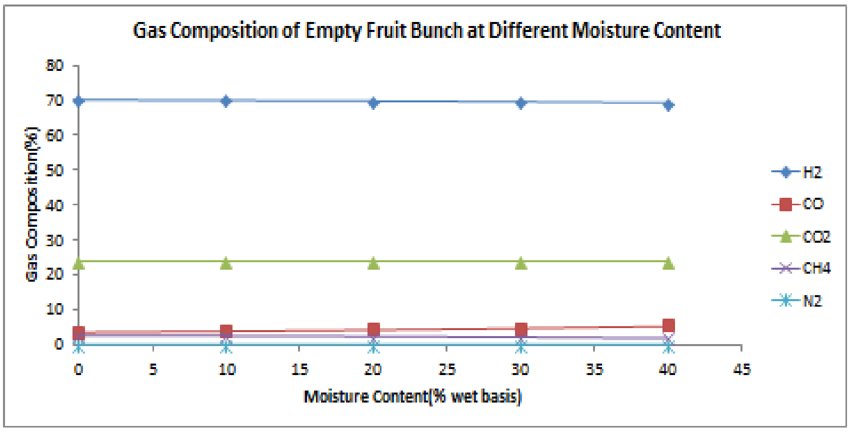
Chemical formula $CH_{1.430}O_{0.615}$

Gasification temperature (°C) : 750

Moisture content : 0.0,0.1,0.2,0.3,0.4

Steam Biomass Ratio :1.32

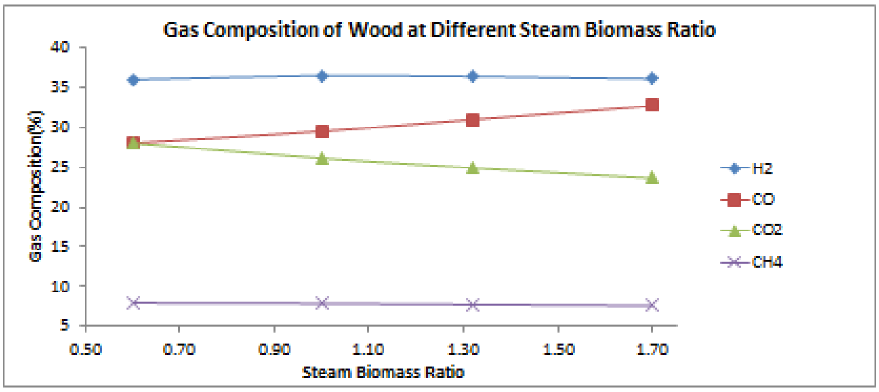
Component(outlet %)/MC	Moisture Content(%)				
	0	10	20	30	40
H2	70.21	70.05	69.86	69.63	69.33
CO	3.38	3.67	4.04	4.49	5.08
CO2	23.83	23.83	23.83	23.84	23.86
CH4	2.58	2.44	2.27	2.04	1.74
N2	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00



Performance Analysis of Fluidized Bed Gasifier at Different Steam Biomass Ratio for each types of Biomass

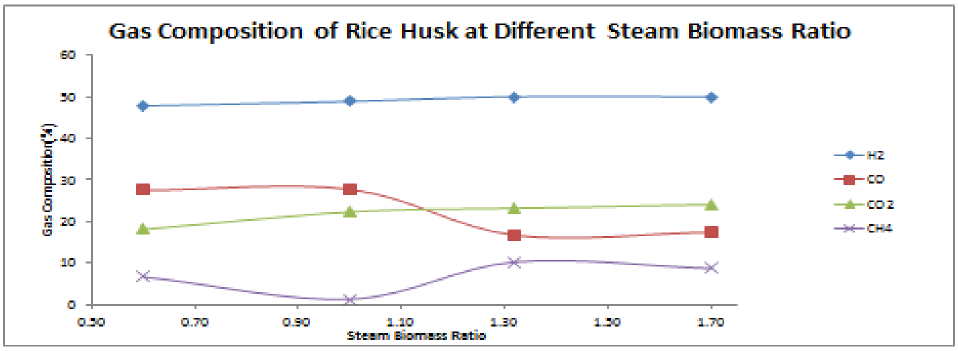
Material	: Wood
Chemical formula	$CH_{1.44}O_{0.66}$
Gasification temperature (°C)	: 750
Moisture content	: 0.2
Steam Biomass Ratio	:0.6,1.00,1.32,1.70

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	36.00	36.49	36.38	36.08
CO	28.02	29.50	30.97	32.70
CO2	28.01	26.13	24.89	23.61
CH4	7.97	7.88	7.76	7.61
H2O	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



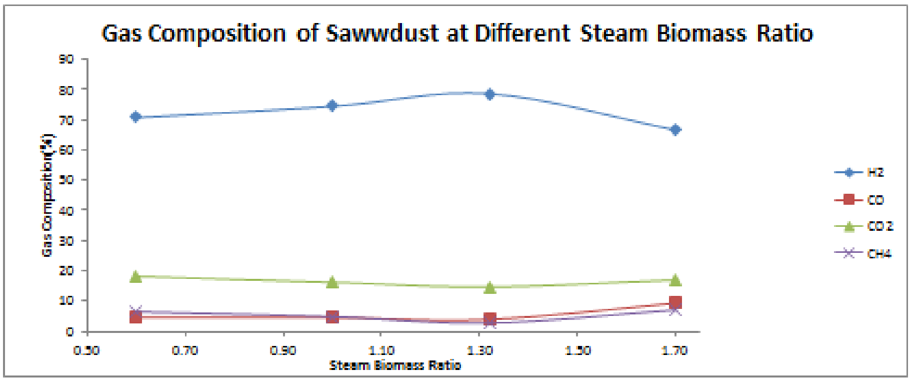
Material	: Rice Husk
Chemical formula	$CH_{0.93}O_{0.71}$
Gasification temperature (°C)	: 750
Moisture content	: 0.2
Steam Biomass Ratio	:0.6,1.00,1.32,1.70

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	47.81	48.87	50.00	50.00
CO	27.48	27.69	16.65	17.38
CO2	18.09	22.22	23.14	23.99
CH4	6.62	1.22	10.21	8.63
H2O	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Material	: Sawdusk
Chemical formula	$CH_{1.492}O_{0.751}$
Gasification temperature (°C)	: 750
Moisture content	: 0.2
Steam Biomass Ratio	:0.6,1.00,1.32,1.70

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	70.72	74.45	78.68	66.66
CO	4.64	4.50	3.93	9.28
CO2	18.19	16.21	14.68	16.99
CH4	6.45	4.84	2.71	7.07
H2O	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00



Material	: Empty Fruit Bunch
Chemical formula	$CH_{1.430}O_{0.615}$
Gasification temperature (°C)	: 750
Moisture content	: 0.2
Steam Biomass Ratio	:0.6,1.00,1.32,1.70

Component	Steam Biomass Ratio			
	0.60	1.00	1.32	1.70
H2	70.47	70.10	69.86	69.62
CO	2.46	3.37	4.07	4.87
CO2	24.70	24.21	23.80	23.31
CH4	2.37	2.32	2.27	2.19
H2O	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00