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JUDUL : BIOMASS GASIFICATION OF SUGARCANE BAGASSE AND EMPTY FRUIT BUNCH: THE EFFECT OF OPERATING TEMPERATURE AND PARTICLE SIZE ON HYDROGEN PRODUCTION

SESI PENGAJIAN : 2011/2012

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BIOMASS GASIFICATION OF SUGARCANE BAGASSE AND EMPTY FRUIT BUNCH: THE EFFECT OF OPERATING TEMPERATURE AND PARTICLE SIZE ON HYDROGEN PRODUCTION

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
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STUDENT 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.

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Name: Diana Anak Linggang
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Dedicated to my supportive parents.

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ABSTRACT

Depletion of fossil fuel as the source of energy has opened the door to the research of various abundant, potential and valuable sources of energy. Therefore, biomass gasification to produce either liquid or gases fuel has been widely investigated. The production of hydrogen from biomass gasification of agricultural waste which are sugarcane bagasse (SCB) and empty fruit bunch (EFB) has been studied by using small lab scale gasification. There were 12 series of experiments run to investigate the effects of operating temperature at 600˚C, 700˚C, 800˚C and 900˚C and three different particle sizes (0.3 mm, 0.6 mm, and 1.0 mm) of both raw materials. The gasification unit which consists of turbulent furnace and a micro glass reactor were used and nitrogen (N_2) was supplied as the carrier gas and oxygen (O_2) was used as the gasifier agent. Both samples were reduced in the moisture content after drying process. The characteristic of both raw materials was identified using thermo gravimetric analyzer (TGA) to determine volatility, moisture content, thermal stability and the decomposition kinetics of the samples. The fix sample size of 1.0 g and N_2/O_2 ratio of 9:1 was used in the experiment. From the experiment, it was found that the particle size of 0.3 mm and the operating temperature of 800˚C were producing more hydrogen for gasification of EFB and particle size of 0.3 mm with 900˚C for gasification of SCB, compared to other particle size or operating temperature. This is because the smaller particle size gives more surface area to react in partial oxidation process and there is more energy supply at the high operating temperature to break the complex long chain bond of lignincellulosic biomass into the simplest carbon chain of syngas. Amount of ash from the experiment was analyzed to identify the ash content in the raw materials. The study conducted showed the potential of local agricultural waste as a raw material in producing hydrogen via biomass gasification.

ABSTRAK

Susutan bahan api fosil sebagai sumber tenaga telah membuka pintu kepada penyelidikan pelbagai sumber-sumber tenaga yang berpotensi dan bernilai. Oleh itu, gasifikasi biomass untuk menghasilkan sama ada bahan api cecair dan gas telah diselidiki dengan meluas. Pengeluaran syngas dari gasifikasi biomas mengunnakan sisa pertanian seperti hampas tebu (SCB) dan tanda buah kosong kelapa sawit (EFB) telah dikaji dengan menggunakan unit gasifikasi berskala makmal. Terdapat 12 siri ujian yang telah dijalankan untuk menyiasat kesan suhu operasi pada 600˚C, 700˚C, 800˚C dan 900˚C dan tiga saiz zarah yang berbeza (0.3mm, 0.6mm dan 1.0mm) untuk kedua-dua bahan mentah . Unit gasifikasi yang terdiri daripada relau gelora dan reaktor kaca mikro mengunakan nitrogen (N_2) yang dibekalkan sebagai gas pembawa dan oksigen (O_2) telah digunakan sebagai ejen gasifier. Kedua-dua sampel dikurangkan dalam kandungan kelembapan selepas proses pengeringan. Ciri-ciri kedua-dua bahan mentah telah dikenal pasti menggunakan Termo Gravimetrik Analyzer (TGA) untuk menentukan turun naik, kandungan kelembapan, kestabilan terma dan kinetik penguraian sampel. Saiz tetap sampel 1.0 g dan N_2/O_2 nisbah 9:1 digunakan dalam experiment. Eksperimen didapati bahawa saiz zarah 0.3 mm dan suhu operasi sebanyak 800˚C untuk gasifikasi EFB dan saiz zarah 0.3 mm dan suhu 900˚C untuk gasifikasi SCB dikenalpasti telah menghasilkan lebih syngas berbanding dengan lain-lain keadaan. Ini adalah kerana saiz zarah yang lebih kecil memberikan luas permukaan yang lebih untuk bertindak balas dalam proses pengoksidaan separa dan pada suhu operasi yang tinggi membekalkan bekalan tenaga untuk memecahkan rantaian panjang lignincellulosic biomass kepada rantaian yang lebih ringkas seperti hydrogen (H_2). Jumlah abu dari eksperimen dianalisis untuk mengenal pasti kandungan abu dalam bahan-bahan mentah. Kajian yang dijalankan menunjukkan potensi sisa pertanian tempatan (SCB dan EFB) sebagai bahan mentah berharga yang berpotensi dalam menghasilkan syngas melalui pengegasan biomas

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LIST OF SYMBOLS

%	percent
^0C	degree Celsius
^0C/min	degree Celsius per min
C	Carbon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
g	gram
H_2	Hydrogen
KJ/mol	kilo joule per mole
min	minute
MJ/kg	Megajoule per kilogram
ml/min	millilitre per minute
mm	millimetre
MW	Megawatt
N	Nitrogen
O	Oxygen
tone/day	tone per day
wt %	weight percent

LIST OF ABBREVIATIONS

BFB	Bubbling Fluidized Beds
CFB	Circulating Fluidized Beds
FBG	Fluidized Beds Gasifier
FID	Flame Ionized Detector
FTIR	Fourier Transform Infra-red Spectroscopy
GC	Gas Chromatography
LHV	Lower Heating Value
MSW	Municipal Solid Waste
TGA	Thermo gravimetric Analysis
EFB	Empty Fruit Bunch
SCB	Sugarcane Bagasse

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Ever since the first production of oil in 1859, the demand of for crude oil has been increasing throughout the year. Fossil fuel is a non-renewable energy and the source is limited also depleted as years goes by. The increasing in global energy needs, human nation should take consideration on a renewable energy to replace fossil fuel as our main energy sources production. The problem has been going on for a years and perhaps there are no single solution. As stated by the Union of Concerned Scientists, McLamb, "No single solution can meet our society's future energy needs. The solution instead will come from a family of diverse energy technologies that share a common thread and they do not deplete our natural resources or destroy our environment." (Mclamb, 2008-2010).

Despite of the problem, there are many choices of renewable energy for example wind, sun, water, and biomass. These renewable energies are more promising than fossil fuel because of the source availability. However, the renewable energy is depending on the location for example Malaysia; sources like water and biomass are still very available compared to sun and wind which depends on the global weather.

The use of biomass energy has been emphasized in the 9th Malaysian Plan. Supported by the growth of agricultural sector in Malaysia, biomasses from the agricultural waste as the source of energy to replace fossil fuel are reliable. Gasification turns out to be a natural choice for conversion of renewable carbon-neutral biomass into gas which are the gases produce can be used to generate energy. There are many choices of biomass which can be obtained from agricultural waste for example sugarcane bagasse, palm empty fruit bunk, rice husk and other has its own potential.

However, the use of biomass gasification has not widely practice in our nation because of the production cost which did not comply with the gas yield produced. However, the use of biomass which is derived from plants will not only reduce the dependence of fossil fuel but also supporting the agricultural production especially in Malaysia.

As for this research, the study will be concerning on the investigation of the optimum operating temperature and particle size that will help to increase the production of syngas which is mainly hydrogen in gasification of biomass using sugarcane bagasse and palm empty fruit bunch as the feedstock. Therefore, the study will be the seed of hope for the solution to our global energy problem besides promoting the potential of local agricultural waste.

1.2 Problem Statement

Although there are many research has been conducted on biomass gasification, yet, there are still more parameter that has to be investigate to undertake the problem in gas yield production. The problem is what are the parameters that should be considered in order to increase the desirable gas production? Therefore, to produce more desirable hydrogen gas, parameter such as material, operating temperature and raw material are the main concern in this research.

1.3 Objective of Statement

The aims of this research are to investigate the potential of local agricultural waste which are sugarcane bagasse and empty fruit bunch as a feedstock in biomass gasification. Besides that, this research is to identify the optimum operating temperature and the particle size of the feedstock that effect the production of syngas which is maily hydrogen in gasification of biomass.

1.4 Scope of Research

In the research of biomass gasification of local agricultural waste such as sugarcane bagasse and palm empty fruit bunk, the scope will be investigating the optimum temperature at 600°C, 700°C, 800°C and 900°C and the effect of particle size from 0.3mm, 0.6mm and 1.0mm. Therefore, the true potential of sugarcane bagasse and palm empty fruit bunk in syngas production from gasification process will be discovered.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, the depleting of fossil fuels has been a major issue around the globe since the energy consumption is increasing with population and economic developments. Therefore, a reliable affordable and clean energy supply such as biomass as a substitute to fossil fuels has become more promising.

Industrial biomass can be grown from numerous types of plants, including miscanthus, switch grass, hemp, corn, poplar, willow, sorghum, sugarcane, and a variety of tree species, ranging from eucalyptus to oil palm (Volk, 2000).As we can see here, the biomass energy is another reliable renewable energy and it is important for us to undergo a various research to improve the production of energy from biomass.

2.2 Syngas

Syngas is the abbreviation for Synthesis gas. This is a gas mixture that comprises of carbon monoxide, carbon dioxide and hydrogen (Zhe, 2010). The name syngas is derived from the use as an intermediate in generating synthetic natural gas and to create ammonia or methanol. Syngas is also an intermediate in creating synthetic petroleum to use as a lubricant or fuel.

The syngas is produced due to the gasification of a carbon containing fuel to a gaseous product that has some heating value. The use of syngas as a fuel is accomplished by the gasification of coal or municipal waste. In these reactions, carbon combines with water or oxygen to give rise to carbon dioxide. This carbon dioxide combines with carbon to produce carbon monoxide.

2.2.1 Hydrogen to Carbon Monoxide Ratio

The values of hydrogen-to-carbon monoxide ratio are important to evaluate the product over unwanted product according to the favorable product which can be either hydrogen of carbon monoxide. In all types of gasifiers, the carbon dioxide (CO_2) and water vapor (H_2O) are converted or reduced as much as possible to carbon monoxide, hydrogen and methane, which are the main combustible components of producer gas (Wijeyekoon, 2009). This means that the hydrogen-to-carbon monoxide ratio is the key to know the performance of the gasification process.

The parameter such as biomass particle size and temperature of the process will affect the hydrogen-to-carbon monoxide ratio. Therefore, these parameters can be used to control the amounts of hydrogen or methane produced from the gasification process. Controlling the ratio of hydrogen to carbon monoxide in the syngas is crucial since to produce hydrocarbon fuels requires an optimum ratio between hydrogen and carbon monoxide.

2.3 Biomass Gasification to Produce Hydrogen

2.3.1 Biomass

A generally accepted definition of biomass are defined by the United Nation Framework Climate Change which emphasize that biomass is a non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms that also includes products, by-products, residues and waste from agriculture, forestry and related industries (UNFCC, 2005).

Biomass is the organic material from recently living things, including plant matter from trees, grasses, and agricultural crops. The chemical composition of biomass varies among species, but basically consists of high, but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars, and ash. (Turn, 1999).

Common sources of biomass are included agricultural which varies from food grain, bagasse, corn stalks, straw, seed hulls, nutshells and manure from cattle, poultry and hogs. Some other sources are including from forest, and municipal. The broad use of biomass can be best describes by Figure 2.1 below;

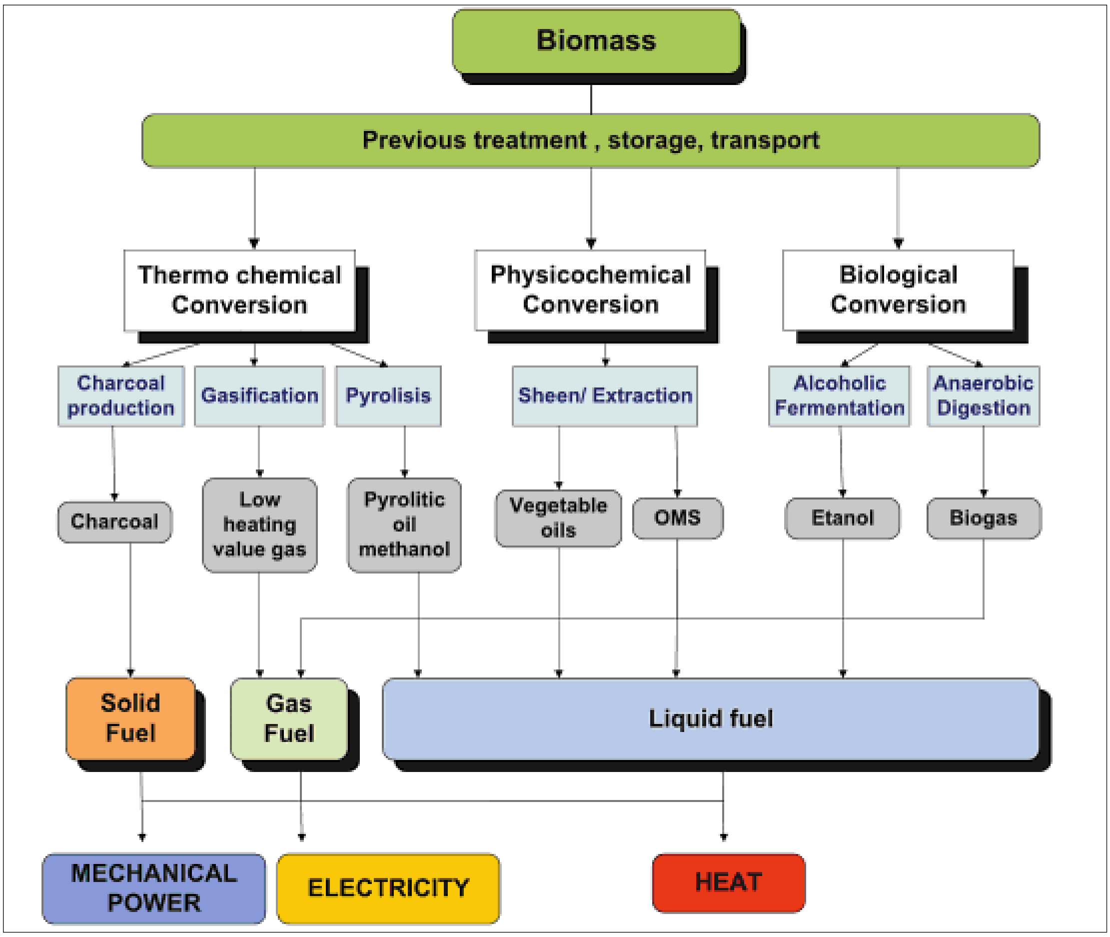

Figure 2.1: Schematic of waste treatment and recycling of biomass

(Source: Luis, 2011)

2.3.2 Types of Biomass

In the book of Biomass Gasification and Pyrolisis by Prabir Basu, he specifically divided biomass into two broad groups which is virgin biomass which includes wood, plants, leaves (lingo-cellulose), crops and vegetables (carbohydrates). The other category is waste includes solid and liquid waste from sewage, animal and human waste.

2.3.3 Ligno-Cellulosic Biomass

A major part of biomass is lingo-cellulose, so this type is described in some detail. Lignocellulosic material is the nonstarch, fibrous part of plant materials. Cellulose, hemicelluloses and lignin are its three major constituents (Robert 2011). Figure 2.2 below shows the long chain chemical structure of lignocellulosic of biomass.

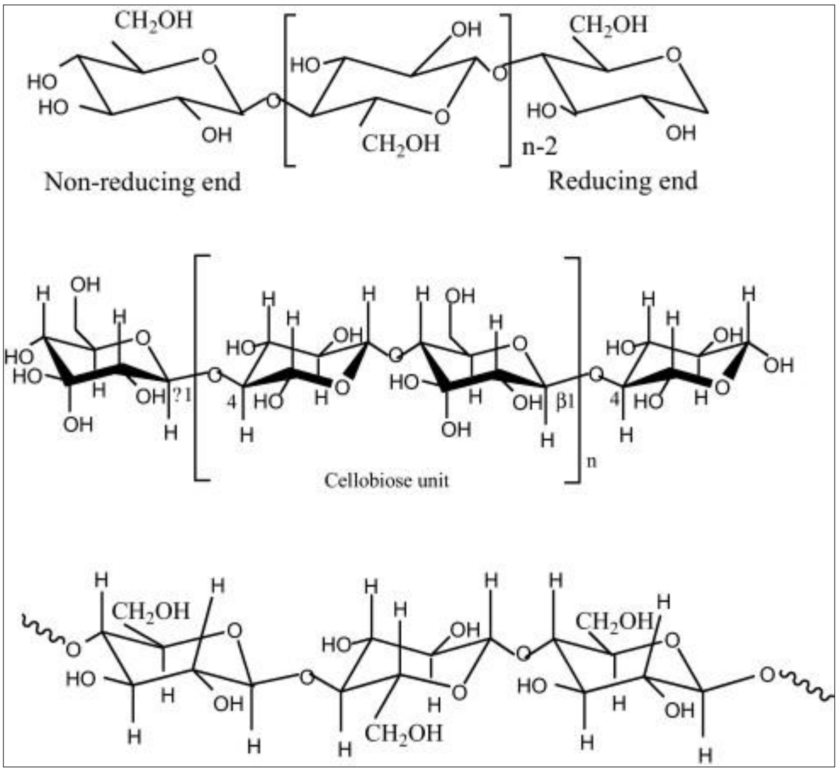

Figure 2.2 Chemical Structural of Ligno-cellulosic of Biomass

(Source: Kittikun 2000)

Thermochemical processes such as gasification convert lignocellulosic biomass into a gas, namely as syngas for further refining to a wide range of products including ethanol, diesel, methane or butanol.

Because of the long chain structure of lignocellulosic of biomass, a great amount of energy is needed to break the chain into a simpler carbon-hydrogen bond. Gasification of biomass is one of thermochemical process that is suitable produce syngas which the process can exceed 1000˚C to supply energy to the chemical reaction in order to break the long chain of lignocellulosic of biomass.

2.3.4 Hydrogen Production from Biomass

Two methods available for hydrogen production from biomass are thermo chemical and biological routes. Syngas can be produced from bio renewable feedstock via thermo chemical conversion processes such as pyrolysis, gasification, steam gasification, steam reforming of bio-oils, and super critical water gasification. While for biological routes, the hydrogen can be produce by anaerobic digestion, fermentation and metabolic processing. From the Figure 2.3 below shows the diagram of pathways of biomass to hydrogen

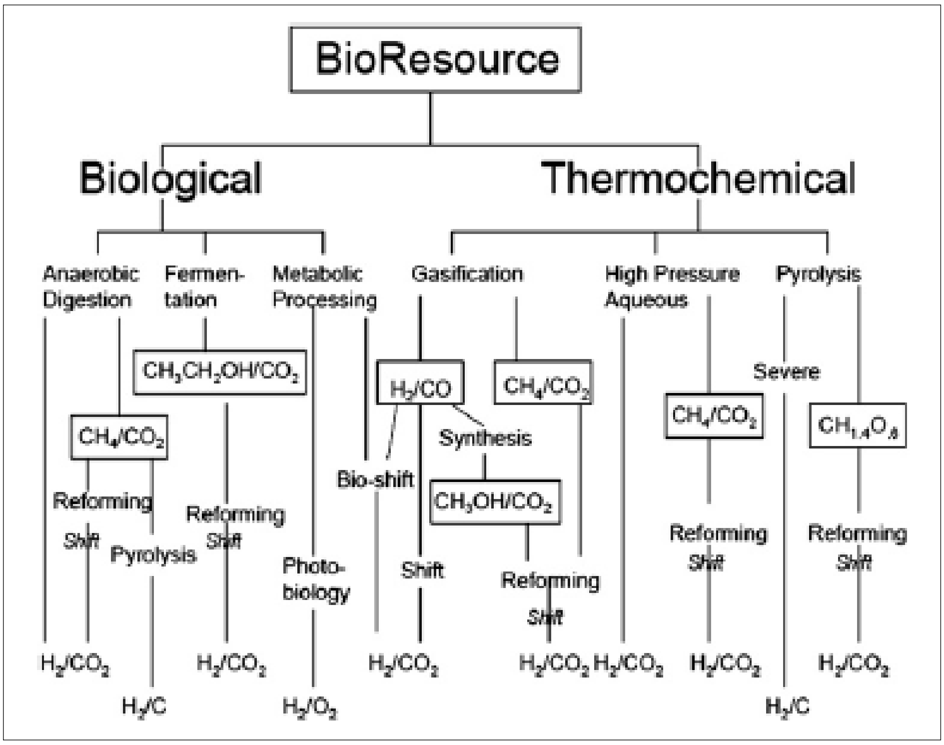

Figure 2.3: Pathways from biomass to hydrogen

Source: (Patel, 2005)

However, the thermo chemical routes are more preferable compared to biological routes. This is because the advantage of the thermo chemical process which is that its overall efficiency which is thermal to hydrogen is higher and production cost is lower (Patel, 2005).

In the pyrolysis and gasification processes, water gas shift is used to convert the reformed gas into hydrogen, and pressure swing adsorption is used to purify the product. Compared to other method, gasification is more preferable than other method because of the lower cost production and higher hydrogen yield. Therefore, this research will concern on using gasification to produce hydrogen using biomass as a feedstock.

2.3.5 Application of Hydrogen as Fuel Cells

A fuel cell by definition is an electrical cell, which unlike storage cells can be continuously fed with a fuel so that the electrical power output is sustained indefinitely (Connihan, 1981). They convert hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water (Brian, 2001).

The other electrochemical device that we are all familiar with is the battery. A battery has all of its chemicals stored inside, and it converts those chemicals into electricity too. This means that a battery eventually "goes dead" and you either throw it away or recharge it. With a fuel cell, chemicals constantly flow into the cell so it never goes dead, as long as there is a flow of chemicals into the cell, the electricity flows out of the cell.

2.3.6 Gasification of Biomass

Gasification is the conversion of solid or liquid feedstock into useful and convenient gaseous fuel or chemical feedstock that can be burned to release energy or used for production of value-added chemicals (Prabir, 2010).

While, biomass gasification is the conversion of an organically derived, carbonaceous feedstock by partial oxidation into a gaseous product, synthesis gas or "syngas," consisting primarily of hydrogen (H_2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO_2), water (H_2O), methane (CH_4), higher hydrocarbons (C_{2+}), and nitrogen (N_2) (Jared P., 2002).

Biomass gasification can be considered as a form of pyrolysis, which takes place in higher temperatures and produces a mixture of gases with hydrogen content. The synthetic gas produced by the gasification of biomass is made up of H_2, CO, CH_4, N_2, CO_2, O_2, and tar. (Demirbas, 2009). Gasification of biomass is generally observed to follow the reaction:

$$Biomass + Heat \xrightarrow{yields} CO, CO_2, H_2O, H_2, CH_4 and\ other CH_s, + ash + char \quad (2.1)$$

The product distribution and gas composition depends on many factors including the gasification temperature, feedstock particle size and the reactor type.

Gasification is an energy process producing a gas that can substitute fossil fuels in high efficiency power generation, heat, and can be used for the production of liquid fuels and chemicals via synthesis gas. Gasification is one of the effective energy conversion methods for the utilization of biomass. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen (Umeki *et al*. 2009).

Most biomass gasification systems utilize air or oxygen in partial oxidation or combustion processes. These processes suffer from low thermal efficiencies and low calorific gas because of the energy required to evaporate the moisture typically inherent in the biomass and the oxidation of a portion of the feedstock to produce this energy. The resulting combustible gas can be burnt to provide energy for cooking and space heating, or create electricity to power other equipment (Demirbas, 2009).

2.4 Types of Gasifier

The simplest gasifier equipment is the fixed bed reactor, which consist of an upright cylindrical container that has an inlet and outlet for the gases and where the feedstock is fed from above and the ashes removed at the base of the container. Some example of fixed bed reactors are the updraft gasifier, the downdraft gasifier, and the cross flow gasifier. The Figure 2.4 below shows the type of gasifier for biomass.

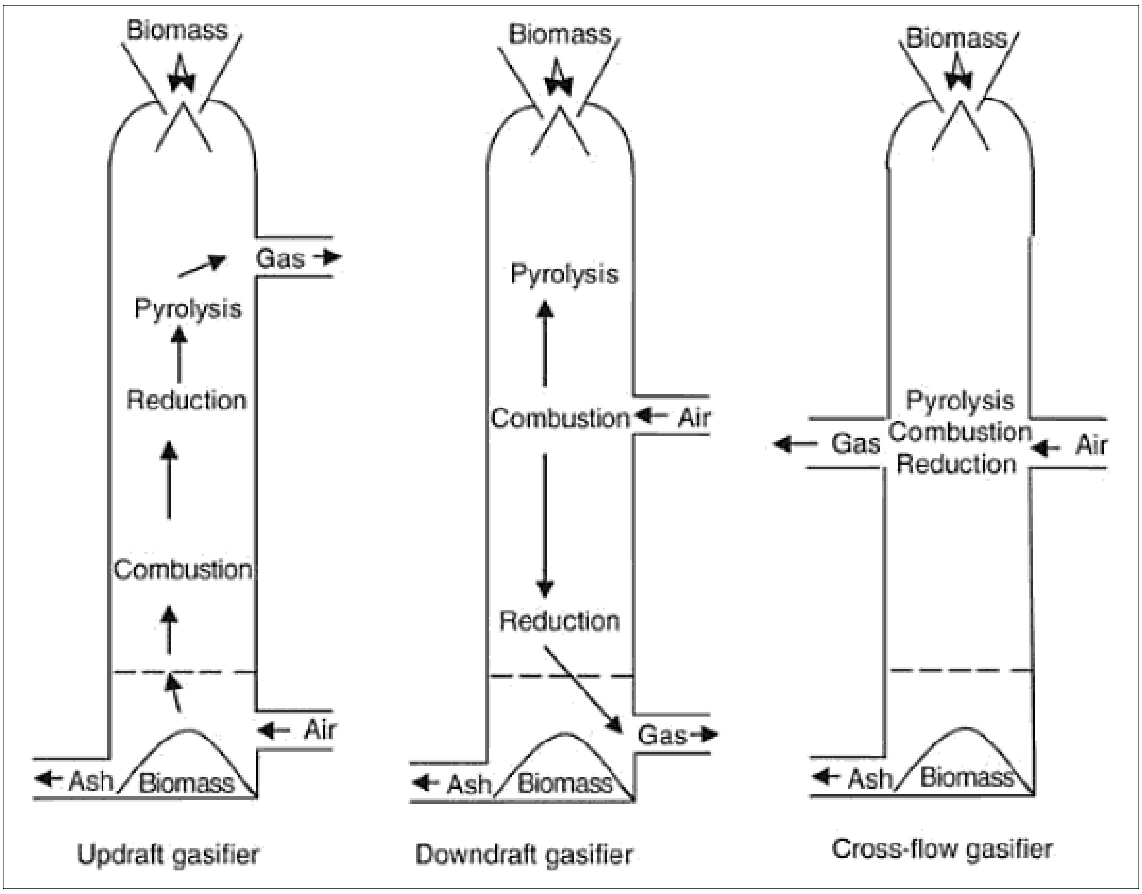

Figure 2.4: Three Different Designs of Fixed Bed Reactor for Gasification

(Source: Clark 2011)

According to Clark J. 2011, the updraft reactor permits the vapor of liquid compounds and tar to distill over, while for the downdraft gasifier the only way out for such materials is through the highest temperature sone, and for the cross flow gasifier, the syngas is drawn off from the opposite side of the incoming gas, this prevents any contact of the reaction products with the fresh feedstock.

2.5 Gasification Feedstock

Biomass is the organic material from recently living things, including plant matter from trees, grasses, and agricultural crops. The chemical composition of biomass varies among species, but basically consists of high, but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars, and ash. (Turn, 1999).

Due to its special properties, it is most suitable to take biomass as a feedstock in the gasification process. However, biomass which is a non-homogeneous in its natural state, therefore, it posses lower heating value compared to coal and it will gasify at lower temperature if compared to coal.

It is important to make sure that the biomass that has been chosen to have several characteristics that related to gasification. As for this research, there are two types of raw material used which are sugarcane bagasse (SCB) and palm empty fruit bunk (EFB).

2.5.1 Sugarcane Bagasse as a Feedstock in Gasification

Sugarcane has been less produce in Malaysia. However the possibilities to use sugarcane as a feedstock in gasification process are highly recommended because this attempt will not also give variety of feedstock for gasification but also gives motivation for sugar production industry. Because of the large availabilities and quantities is sugar cane bagasse, which without densification is very bulky and inhomogeneous, SCB has been the most used in inefficient combustion devices connected to a steam cycle with low steam parameters producing heat and power needed for the sugar process. Figure below shows the pile of SGB disposed in sugarcane plantation field.

Figure 2.5: Dried Sugarcane Bagasse

In addition, sugarcane bagasse has the properties that suitable for gasification for examples a low amount of lignin and ash content. The properties of the sugarcane are shown in the Table 2.1;

Table 2.1: Proximate and Ultimate Analysis of Sugarcane Leaves and Bagasse

			Sugarcane leaves (% w/w; dry)	**Bagasse (% w/w; dry)**
a.		Proximate Analysis		
	1.	Fixed carbon	14.9	20.1
	2.	Volatile matter	77.4	75.8
	3.	Ash content	7.7	4.2
	4.	Volatile matter	17.43	18.11
b.		Ultimate Analysis		
	1.	Carbon	39.8	44.1

2. Hydrogen		5.5	5.26
3. Oxygen		46.8	44.4
Cellulose	46.6		
Hemicelluloses	25.2		
Lignin	20.7		

(Source: Rajvanshi, 1997)

Due to the high moisture content of sugarcane bagasse, it needs to undergo drying process to reduce the amount of moisture so therefore, we can easily increase the heating value in the biomass gasification process.

2.5.2 Palm Empty Fruit Bunch as Feedstock in Gasification

In Malaysia, palm is the dominant agricultural crop. Currently, more than 3.88 million hectares of land in Malaysia are under palm cultivation (Idris, 2010). Although, part of EFB is utilized as solid fuel in the boilers to generate steam and electricity in palm processing mills or used as organic fertilizer (De Souza, 2010), however, still large quantities have no specific use. Therefore, the large amount of EFB generated in Malaysia can be utilized as a potential lignocelluloses biomass source to generate energy and power. Figure 2.6 below shows the dry EFB used in the research.

Figure 2.6: Dry Empty Fruit Bunch

Empty fruit bunches (EFB) of oil palm is one of the major solid wastes from oil palm industry in Malaysia besides fiber and shell. EFB is another valuable source of biomass that can be readily converted into energy. Generally, about 15.8 million tonnes of empty Fruit Bunch (EFB) was generated from fresh fruit bunches process annually in Malaysia. EFB were generally dumped in open areas or disposed by open burning generating pollutant gases harmful to the environment. EFB, with moisture content of 67%, rich in potash and also contain reasonable level of nutrient (Sukiran, 2008).

The potential of empty fruit bunk as a feedstock in gasification has been recognize few years before. The availability of the material especially in Malaysia is very promising. In addition, the special properties of the material also affected in choosing empty fruit bunk as the material in biomass gasification. The properties such as low moisture content and low lignin content made it suitable to undergo gasification process to produce clean syngas. Table 2.2 shows the properties of empty fruit bunk.

Table 2.2 Properties of Palm Empty Fruit Bunch

Component/ property	**Measured**
Cellulose	23.73
Hemicelluloses	21.55
Lignin	29.15
Elemental Analysis	
Carbon	53.10
Hydrogen	4.37
Nitrogen	0.35
Sulphur	0.68
Oxygen	41.50
Proximate Analysis	
Moistures	3.30
Volatiles	83.94
Ash	7.08
Fixed Carbon	5.68
Heating Value	17.02

(Source: Kittikun 2000)

2.5.3 Moisture Content of Biomass

The majority of the gasification technologies reviewed requires feedstock moisture to be below a specified level. Gasification of high moisture content biomass is possible but at the expense of a higher system energy requirement and a dirtier syngas (Bridgwater, 1993).

High moisture content fuels generally decrease reactor-operating temperature and, therefore, may increase methane content and lower hydrogen content. In most fuels there is very little choice in moisture content since it is determined by the type of fuel, its origin and treatment.

It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable and the heat budget of the gasification reaction is impaired. (Rajvanshi, 1986) . For example, for fuel at 25˚C and raw gas exit temperature from gasifier at 300˚C, 2875 KJ/kg moisture must be supplied by fuel to heat and evaporate moisture20.

Besides impairing the gasifier heat budget, high moisture content also puts load on cooling and filtering equipment by increasing the pressure drop across these units because of condensing liquid. Thus in order to reduce the moisture content of fuel some pretreatment of fuel is required. Generally desirable moisture content for fuel should be less than 20%.

2.5.4 Ash Content of Biomass

The mineral content in the feedstock that remains in oxidized from after complete combustion is usually called ash. The ash content of a feedstock and the ash composition has a major impact on trouble free operation of gasifier. (Rajvanshi, 1986)

Ash basically interferes with gasification in two ways which are, if uses together to from slag and this clinker stops or inhibits the downward flow of biomass feed and even if it does not fuse together it shelters the points in fuel where ignition is initiated and thus lowers the fuel's reaction response.

2.6 Factors Affected The Production of Hydrogen in Gasification

2.6.1 Effect of Operating Temperature

The necessary heat for gasification is provided by combustion enthalpy of the biomass, therefore high temperature improves biomass combustion which consequently results in more CO2 and N2 production and low heating value (Wu, 2009).

A similar research has been done by Mohammed and Salmiaton which using air gasification of empty fruit bunch in a fluidized bed reactor. The research also concern on the effect of operating temperature and particle size upon the production of hydrogen rich gas.

From the research, Mohammed and Salmiaton conclude that at high furnace temperature, the gas species generated from biomass at pyrolysis zone could undergo secondary reactions such as tar cracking and shifting reaction, leading to much more incondensable gases including H_2 was generated. Therefore, the total yield of gases products increased significantly as temperature increased from 700 to 1000 ˚C (Salmiaton, 2010). As shown on the Figure 2.7, the hydrogen yield is increasing with the temperature.

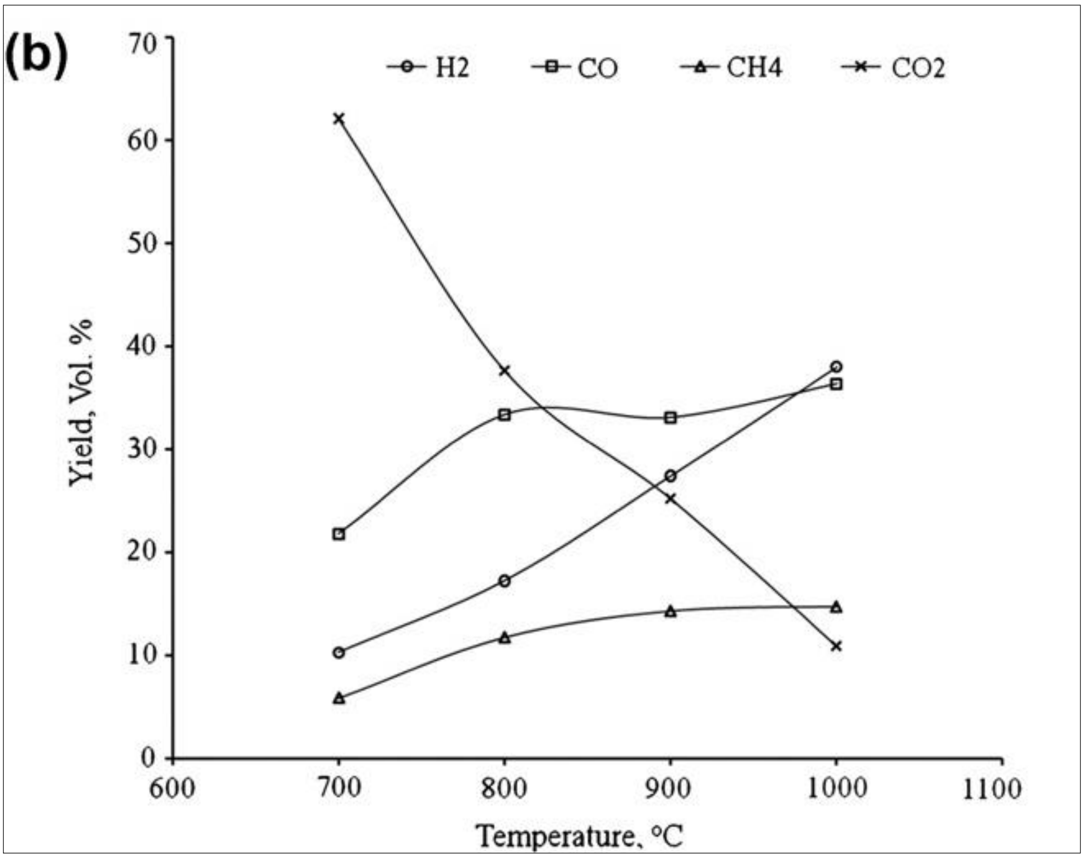

Figure 2.7: Effect of Bed Temperature on Product Gas Composition

(Source: Salmiaton, 2010)

In addition, a research by Kumar in 2009 who has studied the effect of gasification temperature in the range of 650–850ºC shows the same observation (Kumar, 2009). The research obtained maximum carbon conversion of 82% and energy efficiency of 96% at 850 8C. It was also concluded that increasing the bed temperature from 650 to 850˚C improved the hydrogen concentration from 4 to 15%.

In another set of experiment conducted by Pinto 2003, co gasification of coal and biomass in the bed temperature range of 750–890ºC was studied (Pinto, 2003). It was observed that increasing the temperature led to an increase of about 70% in H_2 concentration, whereas a decrease of around 30% was obtained in CH_4 concentration.

2.6.2 Effect of Feedstock's Particle Size

In the terms of heat transfer, smaller particles have larger surface areas per unit mass and larger pore sizes which facilitate faster rates of heat transfer and gasification (Kirubakaran, *et.al*, 2009)

A research also done by Siyi in 2008 has gives the graph profile of particle effect to the production of hydrogen. The graph shows that the production of H_2 is decreased when the size of the particle is increased. The Figures 2.8 shows the effect of particle size to the yield of syngas.

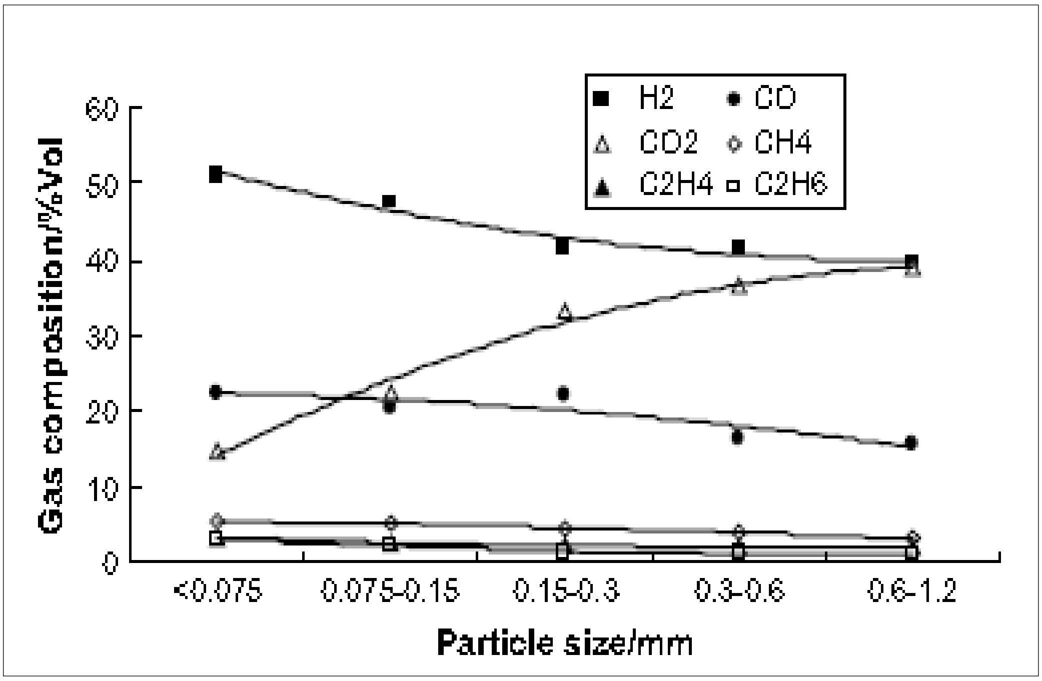

Figure 2.8: Effect of particle size to the Gas Composition in Gasification Process

(Source: Siyi, 2008)

A research which has done by Rapagna in 1997, the research reported that gas yield and gas compositions of CO, CH_4 and CO_2 is increases, when the particle size was reduced from largest which is 1.090 mm to smallest 0.287 mm (Rapagna, 1997).

Also reported by Luo in 2009, by decreasing the particle size from 1.2 mm to 0.075 mm, it was observed that H_2 and CO contents as well as gas yield and carbon conversion efficiencies increased whereas the CO_2 decreased (Luo, *et. al*, 2009). Therefore, higher gas yields and energy efficiencies were attributed to the increased heat transfer in smaller size particles due to the larger surface area.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In the research, there are total 12 sets of experiments with different operating temperature and particle size. The gasification process are using two types of feedstock which are EFB and SCB, three different particle size and four sets of operating temperature. Then, the experiments are repeated twice to get the average amount of hydrogen in the product of gasification process.

3.2 Gasification Unit

In this research, the type of gasifier use is a turbulence heating with batch type reactor. A macro glass reactor with the outer diameter of 10mm and the length of 50mm long is place in the turbulence furnace. The glass reactor has a three opening, which are one for gas mixture inlet, one for temperature probe and one for product outlet. Furthermore, the glass reactor will feed in with 1 g of biomass feedstock for every batch. Gas is flowing to the tubing and connected to portable gas chromatograph to analyze the gas contain.

Figure 3.1 Turbulence Furnace

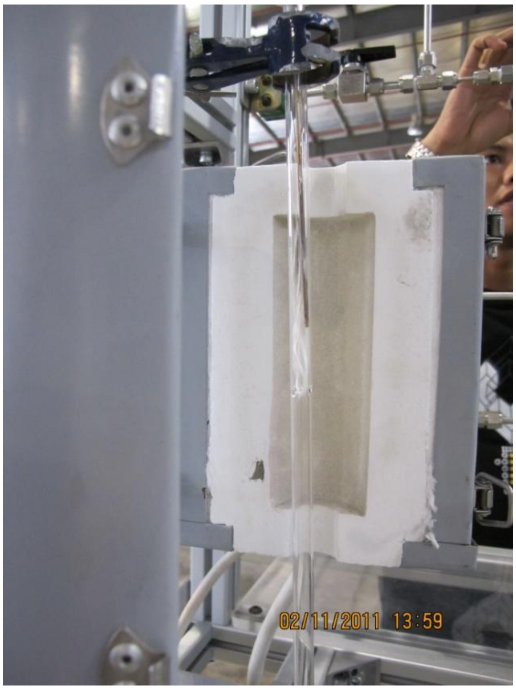

Figure 3.2 Micro Glass Reactor

3.3 Sample Preparation

3.3.1 Empty Fruit Bunch (EFB)

The empty fruit bunches are collected from the nearest oil palm mill (Lepar Hilir) that is located near Gambang area. The empty fruit bunch that was obtained is relatively containing 60% of moisture contain. Therefore, the EFB must undergo a pretreatment by drying process to increase the heating value. The drying processes are done before the grinding process to various particle sizes. The moisture content of the fruit bunch is reduced until below than 10% by drying process using the furnace at 105˚C for an hour. The raw material undergoes grinding then sieving process using sieve shaker at amplitude of 1.0 for 10 minutes for every 500g of sample. Three particle sizes chosen are 0.3, 0.6, and 1.0 mm with average of 100g for every size. All three figure below shows the particle size of EFB use in the research

Figure 3.3: Empty Fruit Bunch with Size Particle of 0.3 mm

Figure 3.4: Empty Fruit Bunch with Size Particle of 0.6 mm

Figure 3.5: Empty Fruit Bunch with Size Particle of 0.1 mm

3.3.2 Sugarcane Bagasse (SCB)

The sugarcane bagasses are collected from the stall at the Wednesday Night Market of University Malaysia Pahang that selling sugarcane juice. The SCB that was obtained is relatively containing 75% of moisture contain which is more than EFB. Therefore, the SCB must undergo a pretreatment by drying process to increase the heating value. The drying processes are done before the grinding process to various particle sizes. The moisture content of the bagasse is reduced until below than 10% by drying process using the furnace at 105˚C for an hour. The raw material undergoes grinding then sieving process using sieve shaker at amplitude of 1.0 for 10 minutes for every 500g of sample. Three particle sizes chosen are 0.3, 0.6, and 1.0 mm with average of 100g for every size. All three figures below show the particle size of SCB use in the research.

Figure 3.6: Sugarcane Bagasse with Size Particle of 0.3 mm

Figure 3.7: Sugarcane Bagasse with Size Particle of 0.6 mm

Figure 3.8: Sugarcane Bagasse with Size Particle of 0.1 mm

3.4 Experimental Procedure

The type of gasifier used was the turbulence furnace with a macro glass reactor with the outer diameter of 10 mm and the length of 50 mm long. There is one inlet for gas which is using mixture of nitrogen and oxygen supply during the gasification process. 95% of nitrogen is use as the product carrier gas and 5% of oxygen is the gasifier agent.

3.4.1 Effect of Different Particle Size

To study on the effect of different type of feedstock, the dried EFB and SCB sample is grinded into small pieces. After the grinding process, the sample is sort into 3 different particle sizes. For the first experiment is using EFB with size of 1.0 mm weighing of 1.0 g were feed into the macro reactor. The EFB is gasified for total of 80 minutes with the ramping temperature set as what shown in the Figure 3.11. The gas produce is directly analyzed by using portable gas chromatograph. The procedure is repeated for different particle size of 0.3 mm and 0.6 mm. The same experiment procedure is also repeated for SCB. Figure 3.9 shows the Sieve Shaker and Figure 3.10 used in the research.

Figure 3.9 Sieve Shaker

Figure 3.10 Grinder

3.4.2 Effect of Operating Temperature

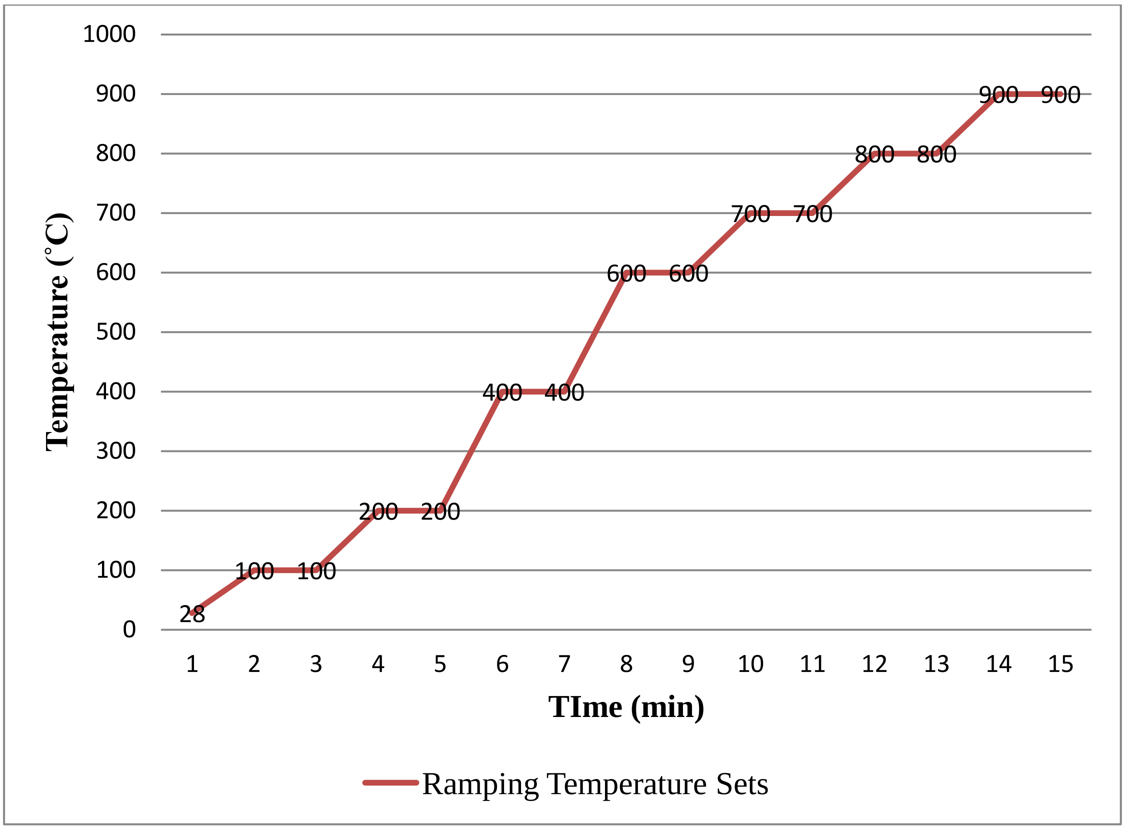

Figure 3.11 Ramping Temperature Sets

The gas chromatography will detect the hydrogen produce at every 100˚C, 200˚C, 400˚C, 600˚C, 700˚C, 800˚C and 900˚C. The flow rate of the oxygen is set to 25 ml/min and the nitrogen is 475 ml/min. The Portable Gas Chromatography is connected to the bottom of the reactor to analyze the hydrogen production.

The time taken for one experiment is approximately one and a half hour including the ramping time taken for the temperature to reach from the surrounding temperature to the desired operating temperature. The experiment is repeated for particle size of 0.6 mm and 1.0 mm for both sugarcane bagasse and empty fruit bunch. All three different particle sizes will undergo four different operating temperatures which are 600, 700, 800 and 900˚C.

After the termination of the gasification process, the residue from the biomass feedstock is weigh to record the weight of ash for every different type of feedstock and particle size.

3.5 Determination of Gas Yield

The conversion of biomass to gas is determined by using Portable Gas Chromatograph. The gas yield is shown in the weight percentage.

3.6 Flow Diagram of Experimental Procedure

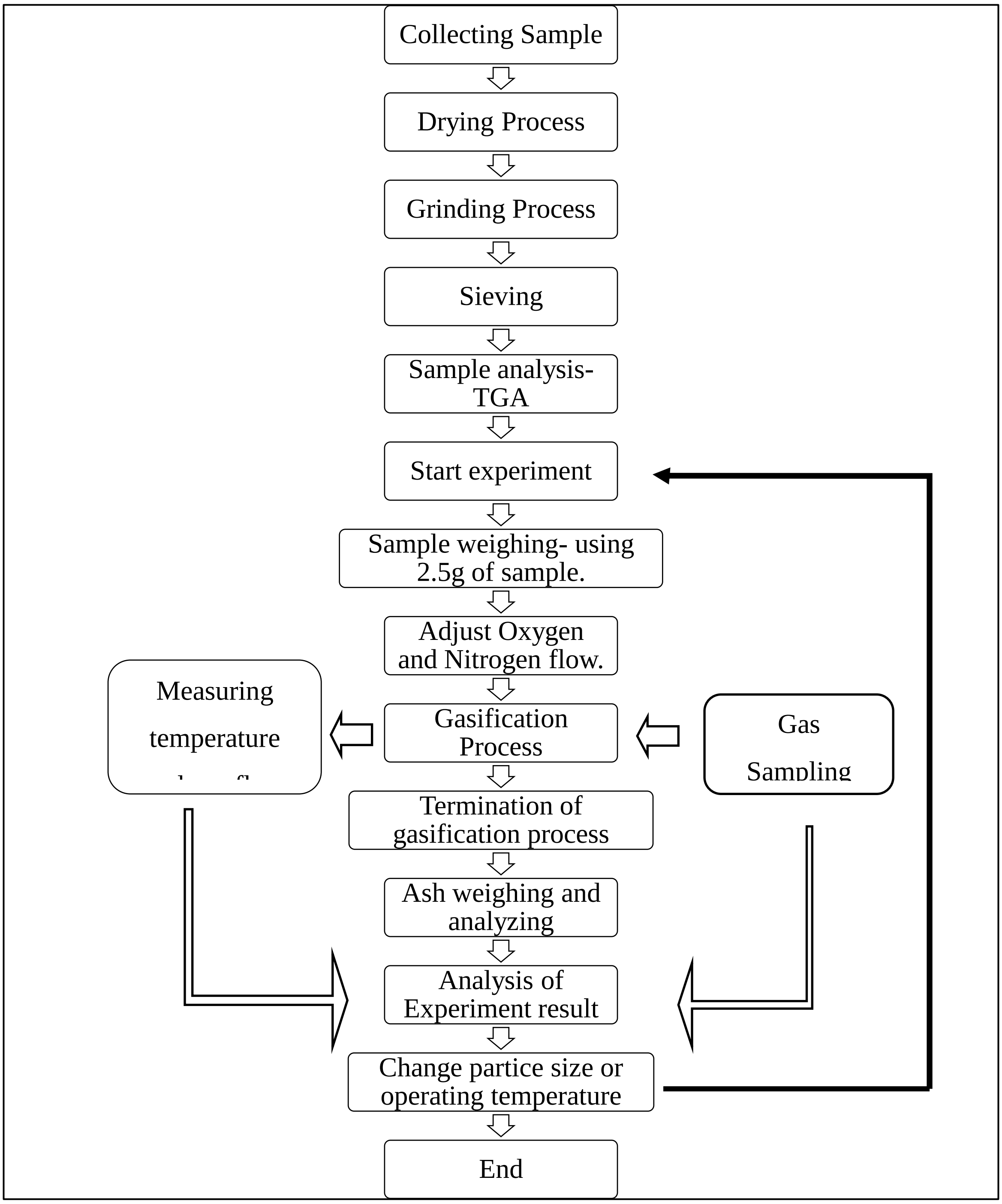

Figure 3.12 Process Diagram of the Experiment Procedures

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The products obtained from the gasification of Empty Fruit Bunches and Sugarcane Bagasse was consisting of bio-oil, char and gaseous materials. However, in this study, only the gaseous product was analyzed. The yields are highly influenced on various parameters. In this study, the effect of temperature, and particle size of different biomass to the conversion of syngas was studied. The material and methodology employed in the experiments were described in Chapter 3.

4.2 Effect of Particle Size to the Hydrogen Production

In this study, the experiments were conducted by using three different feedstock particle sizes, which are 0.3 mm, 0.6 mm and 1.0 mm with constant reactor temperature of 900˚C. As shown in Figure 4.1, the smallest particle size of 0.3 mm produced a hydrogen gas yield of 34.1wt% for gasification of EFB while 29.5wt% for gasification of SGB. It is about 15% higher than larger particle size of 0.6 mm, which produced a hydrogen gas yield of 18.71wt% for gasification of EFB and 16.3wt% for gasification of SGB, while particles size of 1.0 produced a hydrogen gas yield of 12.3wt% and 11.5wt% for gasification of EFB and SGB.

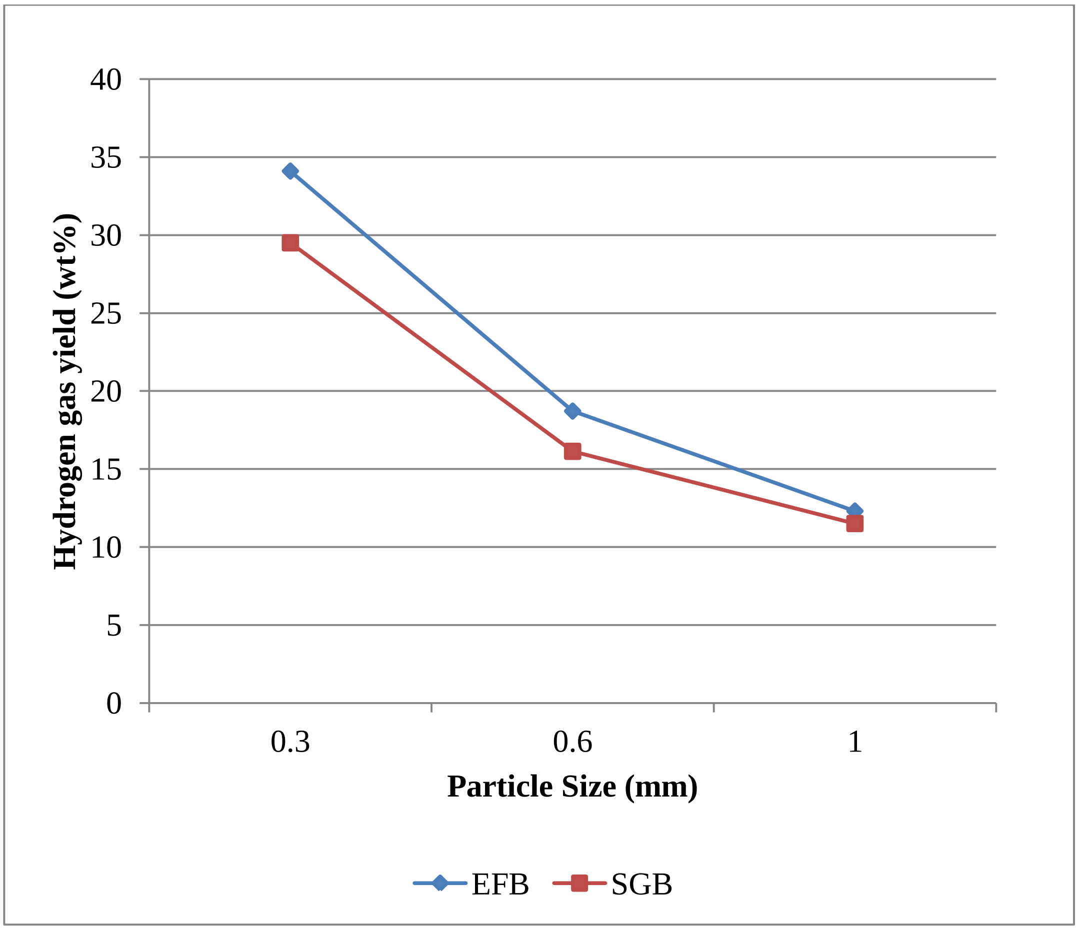

Figure 4.1: Effect of Particle Size to the Hydrogen Gas Yield at 900˚C

The total gas yield decreased with feedstock particle size increased. An increase in feedstock particle size causes greater temperature gradient inside the particle so that at a given time the core temperature is lower than of the surface (Encinar JM). Therefore, in this study it was observed that the smallest feedstock particle size of 0.3 mm obtained maximum yield of gas product.

4.3 Effect of Temperature to the Hydrogen Gas Yield

4.3.1 Effect of Temperature to the Hydrogen Gas Yield for Gasification of EFB

Operating temperature is one of the most important operation parameters which affect both the heating value and gas yield composition. Based on Le Chatelier's principle, the effect of temperature on producer gas composition depends on the thermodynamic behavior of the reactions whereas high temperatures improve product formation in endothermic reactions whereas they favor reactants in exothermic reactions. (Li K, Zhang R). Figure 4.3 below shows the effect of temperature to the hydrogen gas yield for the gasification of EFB.

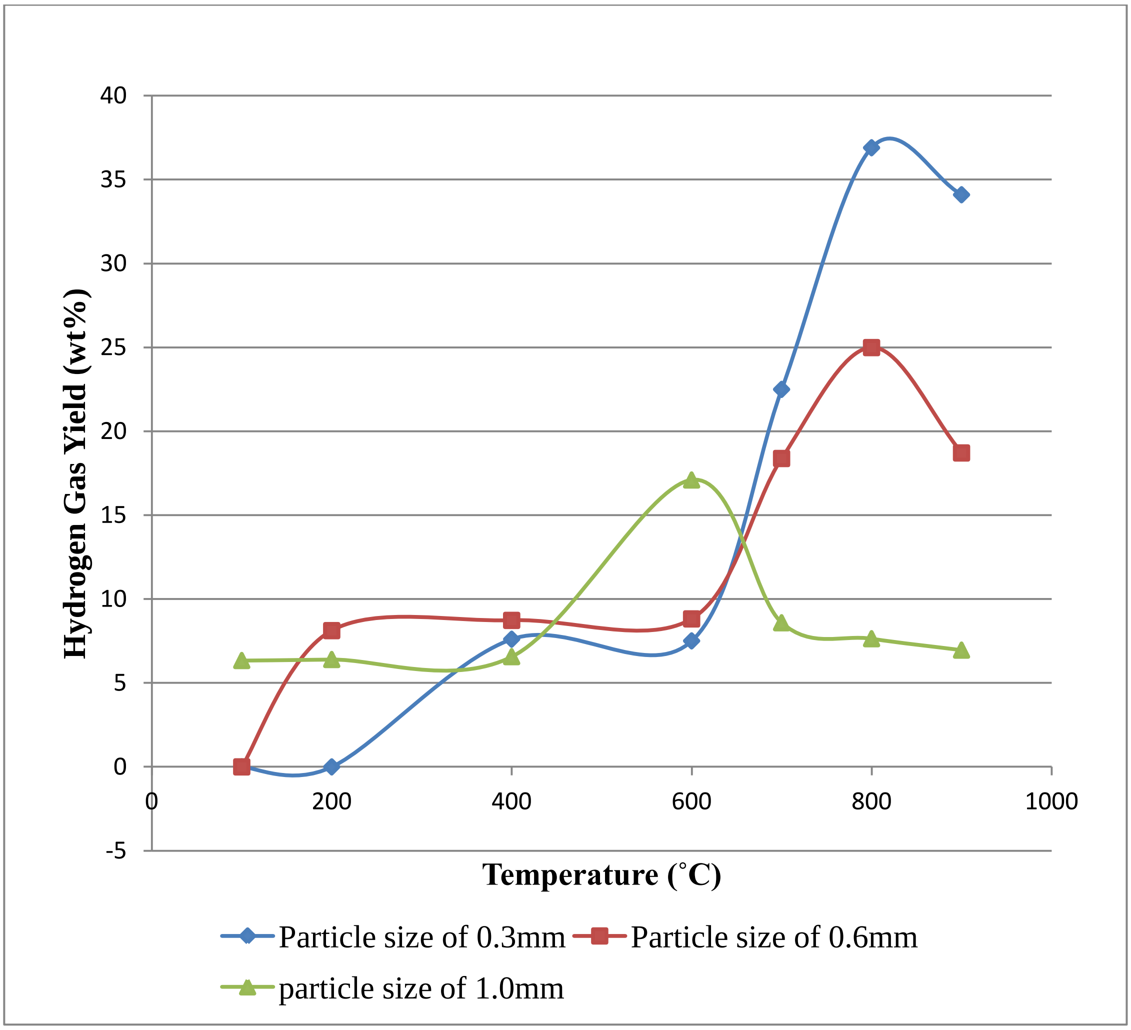

Figure 4.2: Effect of Temperature to the Hydrogen Yield for Gasification of EFB

As shown in Figure 4.2, with temperature increasing from 400 to 800˚C, the total gas yields were increased. As for the smallest particle size which is 0.3mm gives the highest hydrogen yield at 800˚C with 36.9wt% of gas hydrogen. The particle size of 0.6mm also resulted to the highest hydrogen yield at 800˚C with 24.99wt% of gas hydrogen. While for the particle size of 1.0mm the highest hydrogen yield is 17.1wt% of gas hydrogen at 600˚C.

However, as shown in the figure, the production of gas hydrogen are gradually decreased as the temperature increased from 800˚C to 900˚C, which concluded that the best condition for gasification of EFB is at 800˚C with the particle size of 0.3mm.

4.3.2 Effect of Temperature to the Hydrogen Yield for Gasification of SGB

The yields of final products from EFB gasification under different temperatures are shown in Fig 4.3.From the figure, it is shown the almost same pattern with the gasification of EFB with the highest hydrogen yield at 900˚C with 29.5wt% of hydrogen gas for the smallest particle size of 0.3mm. As for the particle size of 0.6mm and 1.0mm indicates the highest hydrogen yield also at 900˚C with 20.44wt% and 19.02wt% of hydrogen yield respectively.

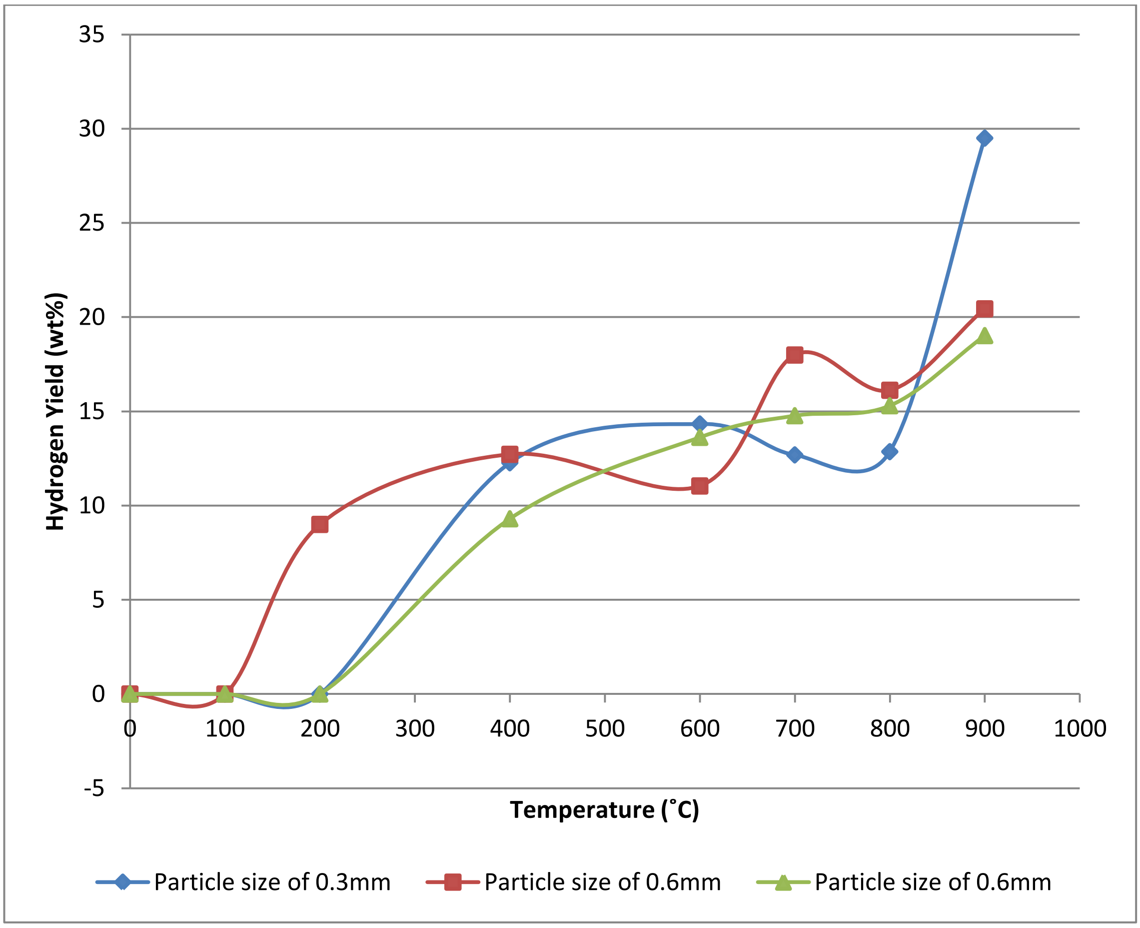

Figure 4.3: Effect of Temperature to the Hydrogen Yield for Gasification of SGB

It is suggested that the gas composition is directly related to the reactivity of the biomass sorts, which in turn affects the temperature levels in the gasification reactor which is, a more reactive fuel gives higher temperature levels and a richer gas, meanwhile a less reactive fuel results in more nitrogen diluted product gas and lower temperature levels in the reactor (T.H. Fransson). Therefore, for the gasification of SGB, the best condition is at 0.3mm with the temperature of 900˚C

4.4 Comparison Between Gasification of Sugarcane Bagasse and Empty Fruit Bunches

Biomass in general consists of three different component, cellulose, hemicelluloses and lignin. The compositions of these components are strongly influencing the composition of the product at the end of a gasification process. From the Figure 4.4, it shows the gasification of EFB is higher in hydrogen gas yield compare to the SCB. At 900˚C, gasification of EFB yield 34.1wt% of hydrogen while gasification of SCB yield 29.5wt% of hydrogen gas.

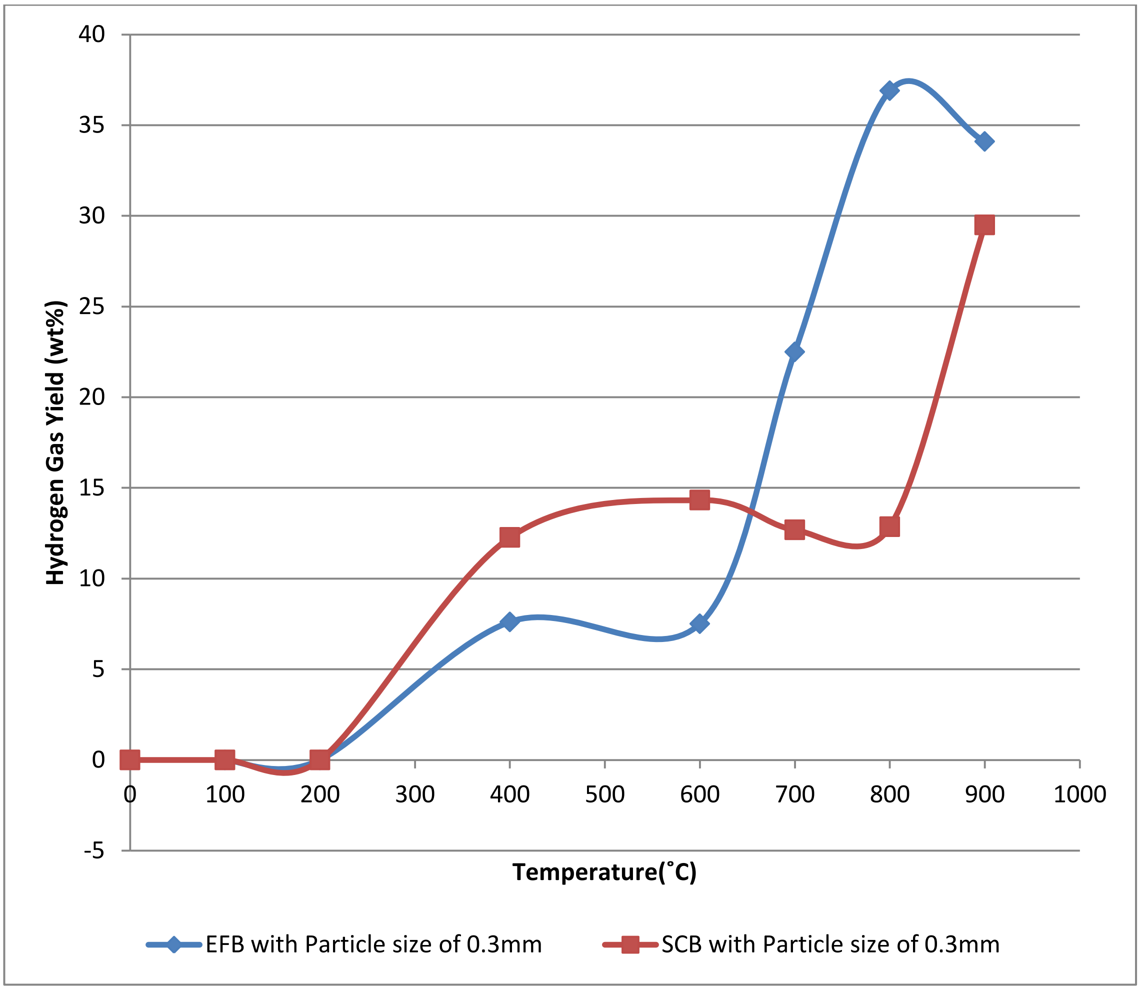

Figure 4.4: Comparisons between Gasification of EFB and SCB in Hydrogen Gas Yield

The compositions of these components are strongly influencing the composition of the product at the end of a pyrolysis process. Sukiran, 2008 pyrolyzed the different sample of palm oil waste, EFB, trunks, fronds and fibers. It was concluded that the cellulose and hemicellulose content in biomass causes an increase in the release of volatiles yield. In addition, an increase in the lignin composition results the increment in the char yield.

Table 3.1 Comparison of composition in EFB and SCB

Sample Feedstock	Cellulose	Hemicellulose	Lignin
Palm Empty Fruit Bunch	46.6	25.5	23.73
Sugarcan Bagasse	23.73	21.55	29.15

(Source: Rajvansh, 1997 & Kittikun, 2000)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this study, the experiments on gasification of different biomass samples, Empty Fruit Bunches and Sugarcane Baggase, the different temperature and heating rate both biomass sample were conducted using a micro batch glass reactor in the turbulence furnance. Generally, there are three main products obtained from the gasification of SGB and EFB that were bio-oil, char and gas. However, only the production of gas hydrogen is analyzed.

The study of the effect of different biomass on the gas yield showed that the maximum gas hydrogen yield was obtained by using EFB sample rather than SGB. Therefore, EFB is the better selection for the raw material for the system used in this study compared with SGB since the higher conversion of hydrogen gas.

The study of the effect of reactor temperature on the gas hydrogen yield showed that the maximum gas yield was obtained at a moderate temperature of 800˚C for gasification of EFB and 900˚C for gasification of SGB. However, to meet the optimum operating condition, particle size of 0.6mm and temperature at 700˚C are the most preferable, because to operate under this condition will not only gain a moderate amount of hydrogen contain but also reducing the economic cost since lower temperature needed to be supply to the system. Therefore, less energy consumption to produce the high temperature beside to gain the moderate particle size.

Furthermore, the smallest particle size at 0.3mm is the most suitable condition to achieve the highest conversion of gas hydrogen yield compared to particle size at 0.6mm and 1.0mm.

5.2 Recommendation

The weakness of this research is that the other product such as bio-oil and char was not able to analyze since. This is because, the design of the reactor that was not able to collect the remaining bio-oil from the gasification process. Therefore, it is strongly recommended to re-design the reactor so that the liquid can be collected. In addition, it is compulsory to determine the composition of each one of the sample by perform proximate and ultimate analysis.

Besides, the other types of gases such as carbon dioxide and methane were not able to be detected by Portable Gas Chromatography. Therefore, other method should be considered in order to analyze other potential gas product.

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APPENDIX A1: SERIES OF GAS CHROMATOGRAPH RESULT ON GASIFICATION OF SUGARCANE BAGASSE

Sample name:	Diana 18112011 SCB0.3 600
Sample note:	18 November 2011 13:25:05
Operator:	
Injection date:	18 November 2011 13:25:05
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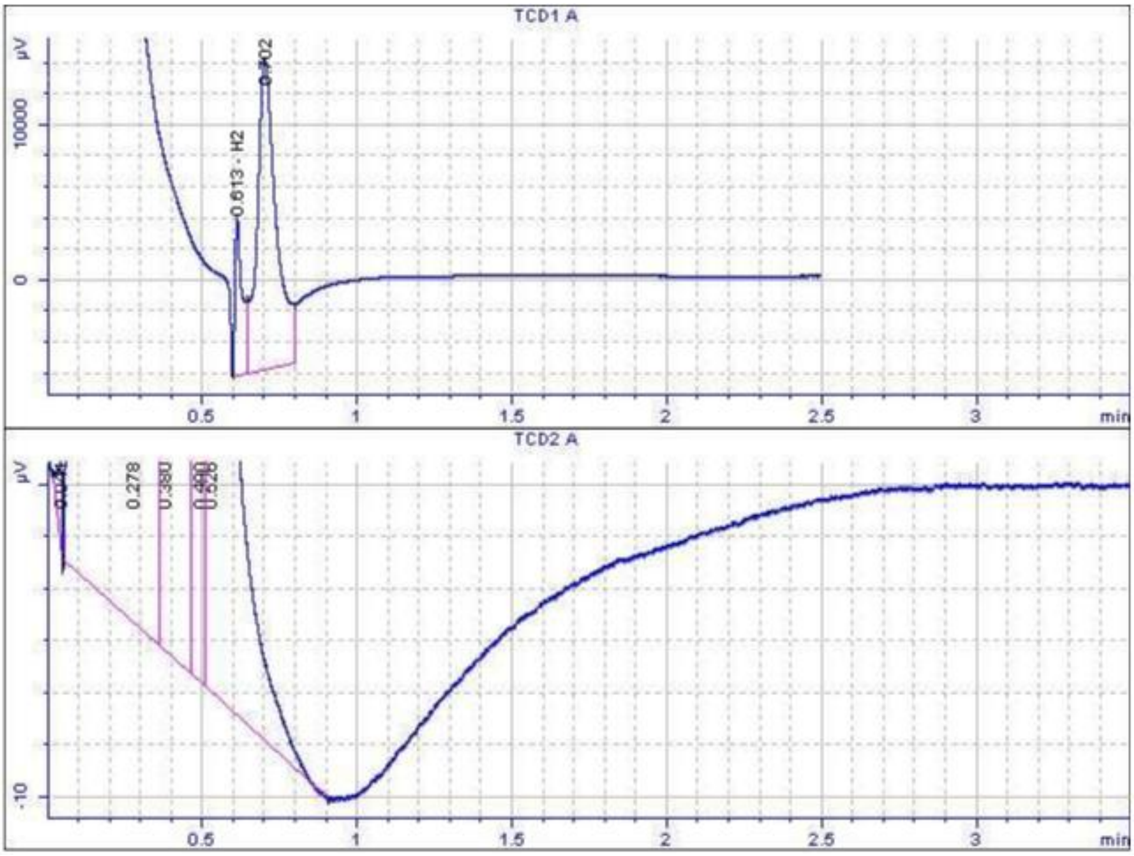
Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
Method last saved:	14 September 2010 13:39:20



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Multiplier:	1.0000
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Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.613	BV	0.022	1.6021e+004	14.33383	H2
1	0.702	VV	0.063	8.7834e+004	78.58603	
1	0.759		0.000	0.00000	0.00000	O2
1	0.919		0.000	0.00000	0.00000	N2
2	0.041	BP	0.018	12.59147	0.01127	
2	0.278	VV	0.168	4116.06808	3.68268	
2	0.380	VV	0.068	1714.64307	1.53410	
2	0.490	VV	0.035	775.40511	0.69376	
2	0.526	VP	0.060	1294.64966	1.15833	

Sample name:	Diana 18112011 SCB0.3 700
Sample note:	18 November 2011 13:29:23
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Injection date:	18 November 2011 13:34:57
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Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
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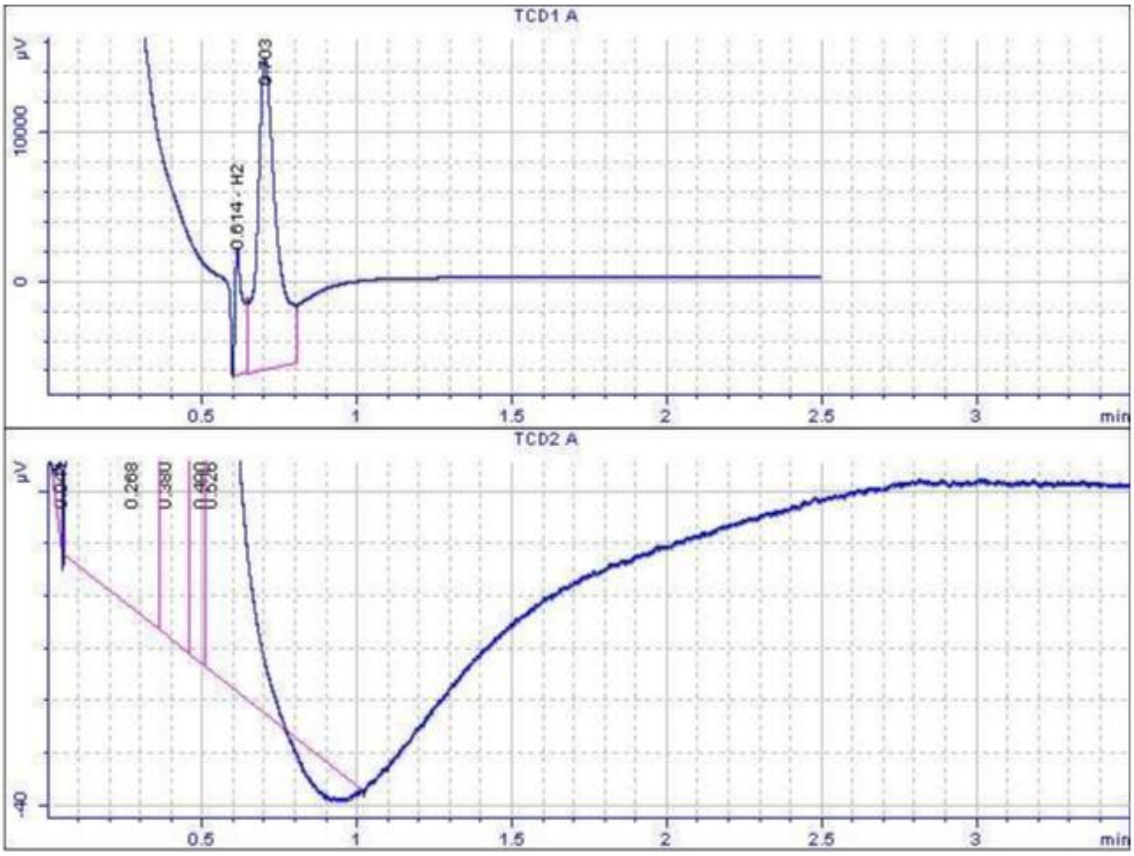

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Dilution:	1.0000
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Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.614	BV	0.024	1.4439e+004	12.69264	H2
1	0.703	VV	0.063	9.1792e+004	80.68990	
1	0.759		0.000	0.00000	0.00000	O2
1	0.919		0.000	0.00000	0.00000	N2
2	0.041	PP	0.018	14.61246	0.01285	
2	0.268	VV	0.170	4008.26620	3.52346	
2	0.380	VV	0.066	1611.17707	1.41630	
2	0.490	VV	0.036	761.94287	0.66978	
2	0.526	VP	0.055	1131.98684	0.99507	

Sample name:	Diana 18112011 SCB0.3 800
Sample note:	18 November 2011 13:42:38
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Injection date:	18 November 2011 13:45:10
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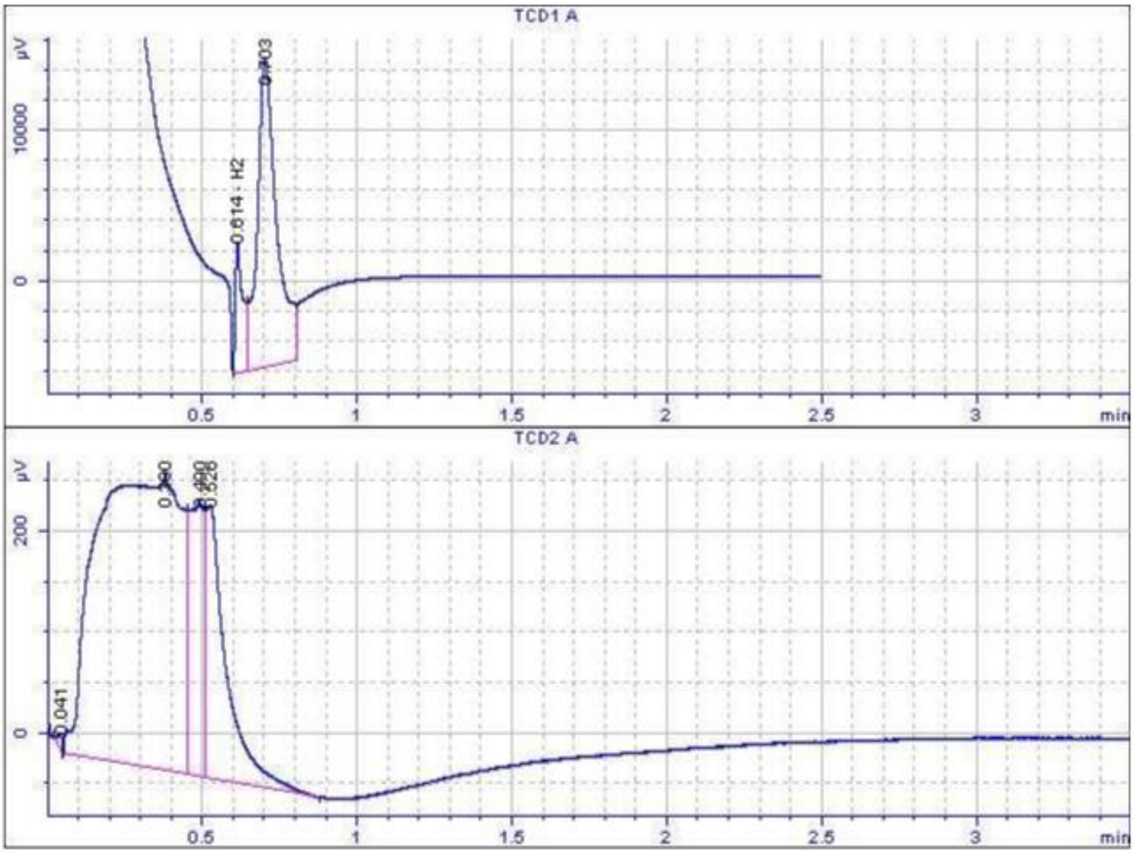

Calibration last saved:	14 September 2010 13:19:15
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Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.614	BV	0.024	1.4435e+004	12.85707	H2
1	0.703	VV	0.062	9.0228e+004	80.36239	
1	0.759		0.000	0.00000	0.00000	O2
1	0.919		0.000	0.00000	0.00000	N2
2	0.041	BP	0.017	10.94010	0.00974	
2	0.380	VV	0.219	5476.83329	4.87799	
2	0.490	VV	0.040	851.51795	0.75841	
2	0.526	VP	0.061	1273.65570	1.13439	

Sample name:	Diana 18112011 SCB0.3 900
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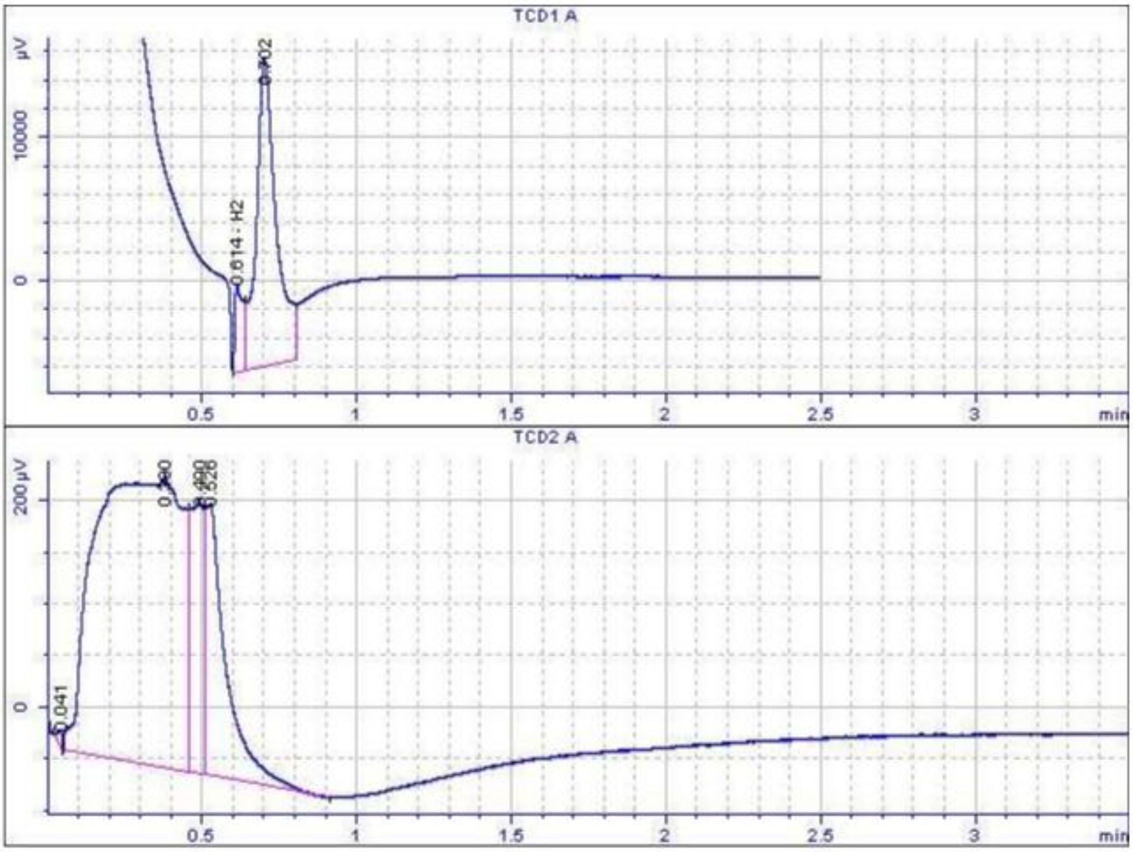

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Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
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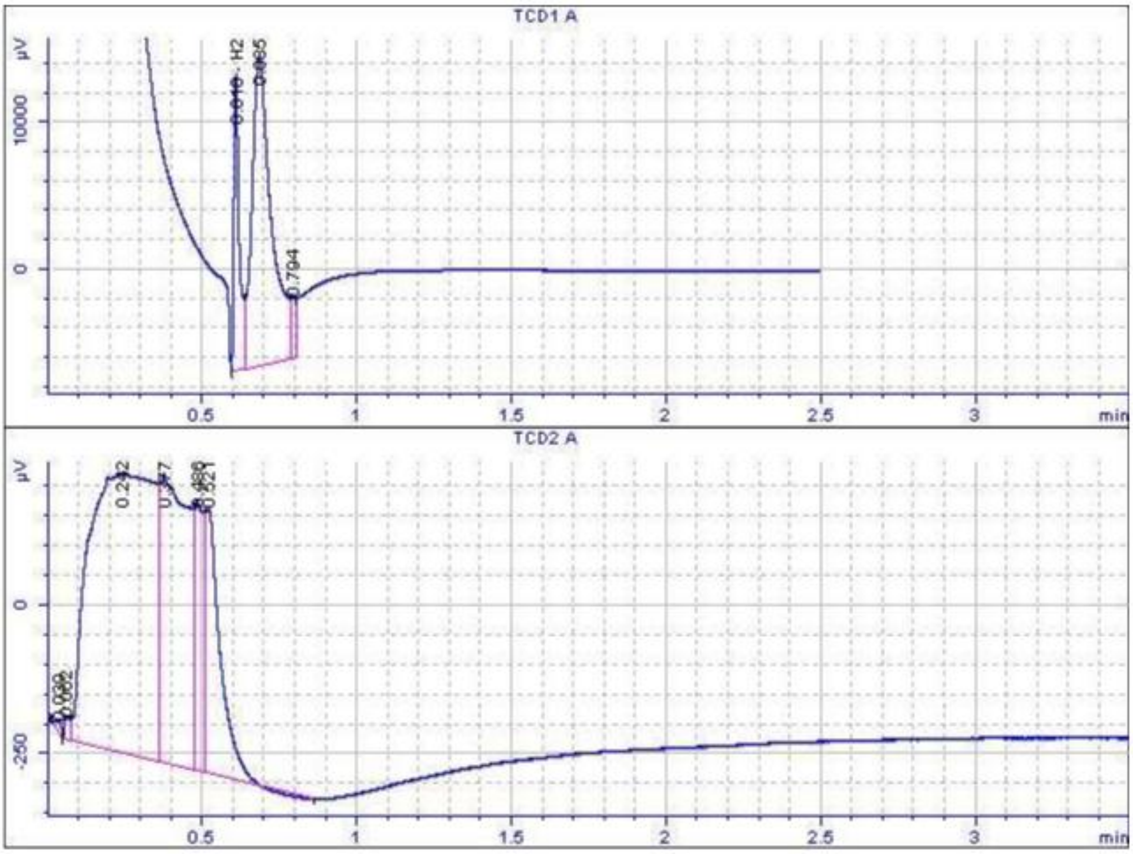
1	0.614	BV	0.027	1.1869e+004	10.22718	H2
1	0.702	VV	0.064	9.6763e+004	83.38037	
1	0.759		0.000	0.00000	0.00000	O2
1	0.919		0.000	0.00000	0.00000	N2
2	0.041	PP	0.016	12.10634	0.01043	
2	0.380	VV	0.223	5423.28715	4.67321	
2	0.490	VV	0.036	743.99006	0.64109	
2	0.526	VP	0.061	1239.09766	1.06772	

APPENDIX A2: SERIES OF GAS CHROMATOGRAPH RESULT ON GASIFICATION OF EMPTY FRUIT BUNCHES.

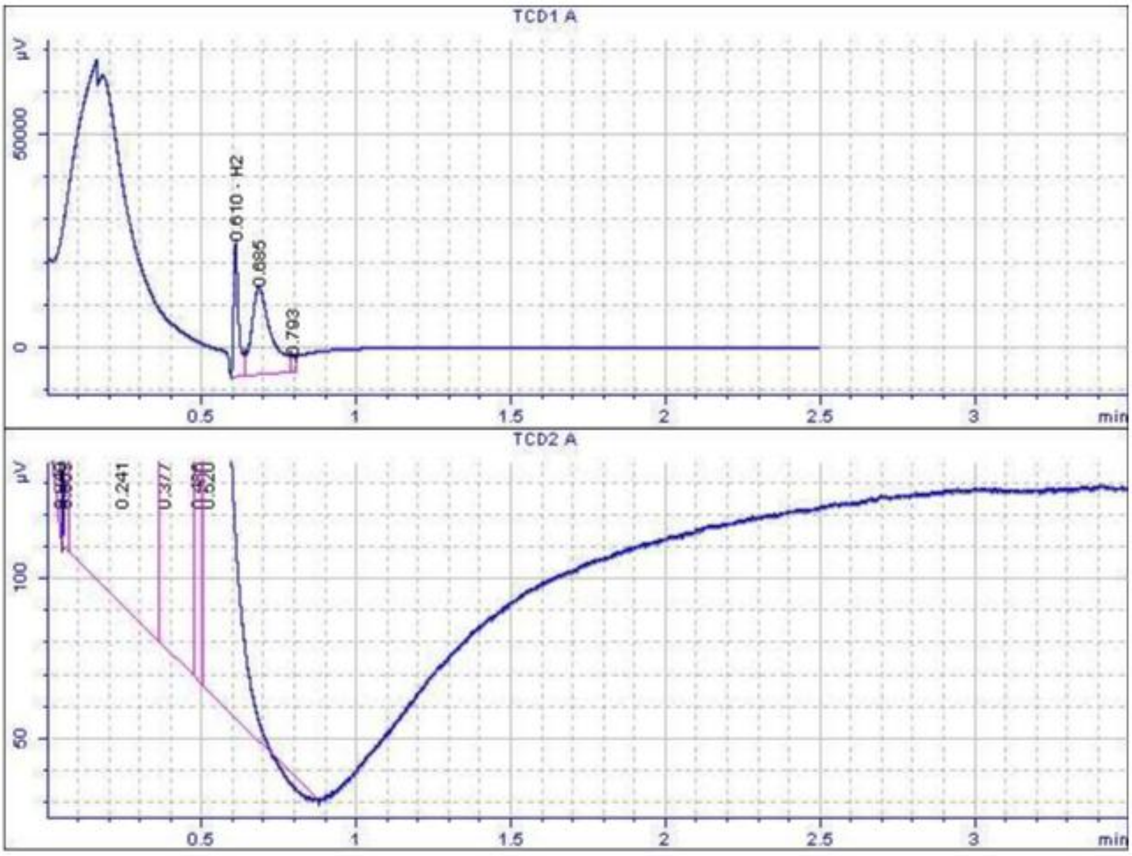
Sample name:	Diana 01122011 EFB0.6 600
Sample note:	01 December 2011 17:10:55
Operator:	
Injection date:	01 December 2011 17:11:17
GC Description:	Micro GC
Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
Method last saved:	14 September 2010 13:39:20



Calibration last saved:	14 September 2010 13:19:15
Multiplier:	1.0000
Dilution:	1.0000
Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.610	BV	0.018	2.4518e+004	18.37872	H2
1	0.685	VV	0.064	9.2488e+004	69.32970	
1	0.759		0.000	0.00000	0.00000	O2
1	0.794	VV	0.014	4064.73881	3.04694	
1	0.919		0.000	0.00000	0.00000	N2
2	0.039	BP	0.018	25.73438	0.01929	
2	0.062	VV	0.018	46.79722	0.03508	
2	0.242	VV	0.178	6765.51296	5.07145	
2	0.377	VV	0.077	3097.34649	2.32178	
2	0.486	VV	0.026	903.73601	0.67744	
2	0.521	VP	0.046	1493.56952	1.11959	

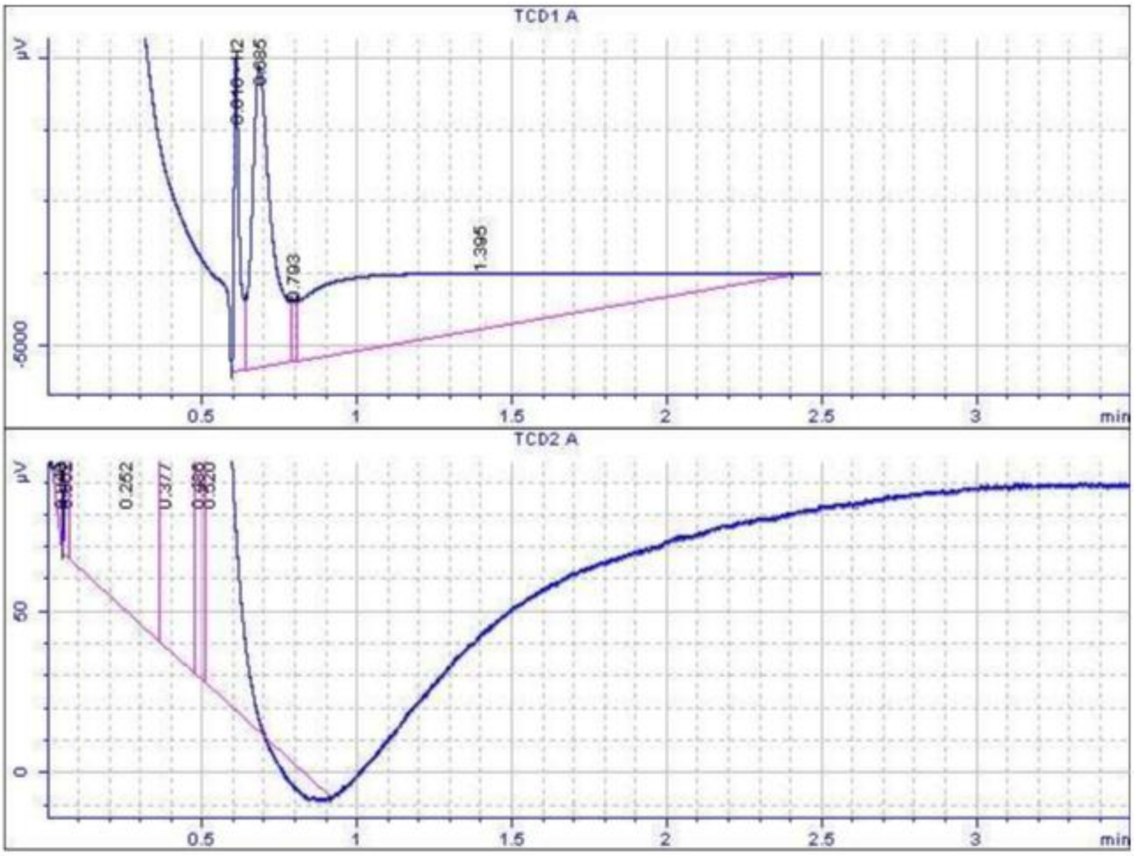
Sample name:	Diana 01122011 EFB0.6 700
Sample note:	01 December 2011 17:15:03
Operator:	
Injection date:	01 December 2011 17:15:25
GC Description:	Micro GC
Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
Method last saved:	14 September 2010 13:39:20



Calibration last saved:	14 September 2010 13:19:15
Multiplier:	1.0000
Dilution:	1.0000
Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.610	BV	0.017	3.5696e+004	24.99970	H2
1	0.685	VV	0.063	9.0868e+004	63.63963	
1	0.759		0.000	0.00000	0.00000	O2
1	0.793	VV	0.014	4016.39622	2.81289	
1	0.919		0.000	0.00000	0.00000	N2
2	0.040	BP	0.015	23.73914	0.01663	
2	0.063	VV	0.017	37.78307	0.02646	
2	0.241	VV	0.173	6701.22855	4.69322	
2	0.377	VV	0.075	3031.24075	2.12294	
2	0.486	VV	0.024	842.57780	0.59010	
2	0.520	VP	0.048	1568.39046	1.09843	

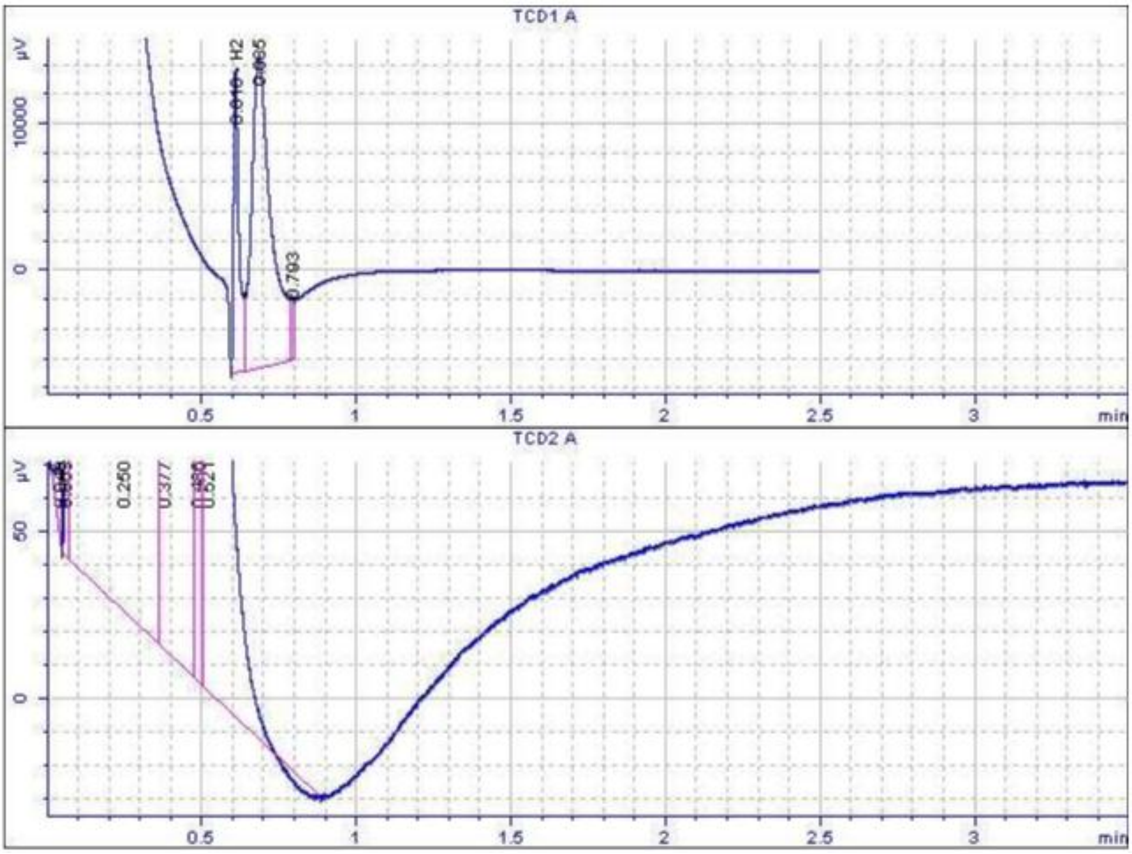
Sample name:	Diana 01122011 EFB0.6 800
Sample note:	01 December 2011 17:20:08
Operator:	
Injection date:	01 December 2011 17:26:16
GC Description:	Micro GC
Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
Method last saved:	14 September 2010 13:39:20



Calibration last saved:	14 September 2010 13:19:15
Multiplier:	1.0000
Dilution:	1.0000
Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.610	BV	0.018	2.5982e+004	6.18388	H2
1	0.685	VV	0.064	9.2773e+004	22.08016	
1	0.759		0.000	0.00000	0.00000	O2
1	0.793	VV	0.014	4163.65299	0.99096	
1	0.919		0.000	0.00000	0.00000	N2
1	1.395	VB	0.860	2.8548e+005	67.94531	
2	0.040	BP	0.015	23.42771	0.00558	
2	0.062	VV	0.016	35.53906	0.00846	
2	0.252	VV	0.177	6460.20805	1.53754	
2	0.377	VV	0.076	2924.81790	0.69611	
2	0.486	VV	0.025	846.92387	0.20157	
2	0.520	VP	0.047	1472.39411	0.35043	

Sample name:	Diana 01122011 EFB0.6 900
Sample note:	01 December 2011 17:30:09
Operator:	
Injection date:	01 December 2011 17:35:05
GC Description:	Micro GC
Signal description:	TCD1 A; TCD2 A
Method:	ARCARRIERGAS
Method last saved:	14 September 2010 13:39:20



Calibration last saved:	14 September 2010 13:19:15
Multiplier:	1.0000
Dilution:	1.0000
Sample amount:	0.0000µL
Sample type:	Sample
Sampling source:	Inlet

Signal	Retention Time [min]	Type	Width [min]	Area [µV*s]	Area %	Name
1	0.581		0.000	0.00000	0.00000	HE
1	0.610	BV	0.018	2.5083e+004	18.71250	H2
1	0.685	VV	0.064	9.3528e+004	69.77531	
1	0.759		0.000	0.00000	0.00000	O2
1	0.793	VV	0.014	4060.91937	3.02959	
1	0.919		0.000	0.00000	0.00000	N2
2	0.040	PP	0.016	24.12004	0.01799	
2	0.063	VV	0.016	37.26404	0.02780	
2	0.250	VV	0.173	6182.18579	4.61212	
2	0.377	VV	0.076	2836.86775	2.11640	
2	0.486	VV	0.022	712.23595	0.53135	
2	0.521	VP	0.052	1577.58610	1.17693	