

Assessment of Fabric Waste as Fuel in Biomass Gasification System

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. Signed: _____ (TAN PE HAO) Date: _____

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ABSTRAK

Bahan api yang digunakan pada zaman ini kebanyakan adalah bahan api fosil yang semakin berkurangan. Bagi menggantikan sumber bahan api ini, biojisim telah dikenalkan sebagai satu sumber alternatif bagi menghasilkan tenaga.

Objektifnya adalah untuk menentukan kemungkinan suatu sumber biomass, iaitu kain buangan, untuk digunakan dalam proses menghasilkan gas pengeluar dan menentukan nilai pemanasan gas tersebut.

Sisa-sisa kain telah dianalisis nilai pemanasannya menggunakan calorimeter bom, dan seterusnya dijalankan analisis proksim menggunakan penganalisis termogravimetrik. Experimen pengegasan telah dijalankan dengan menggunakan gasifier katil cair. Sampel gas pengeluar telah dianalisis menggunakan kromatografi gas dan sampel tar dikumpul serta dianalisis menggunakan penyejat berputar.

Dari analisis pra sisa-sisa kain, nilai pemanasan sisa kain didapati dalam banjaran 15.69 hingga 17.08 MJ/kg. Dari analisis proksim, telah didapati bahawa sisa-sisa kain secara amnya mengandungi bahan mudah meruap yang tinggi (85.817 hingga 89.015%), diikuti kandungan karbon tetap (7.425 hingga 9.858%), kandungan lembap (3.399 hingga 4.189%), dan juga kandungan abu (0.079 hingga 0.197%). Kandungan gas pengeluar didapati sebagai 0.07% hidrogen, 12.15% oksigen, 30.61% nitrogen, 4.15% karbon monoksida, 0.55% metana dan 52.47% karbon dioksida. Nilai pemanasan gas pengeluar didapati sebagai 0.72 MJ/Sm³ dan kandungan tar dalam gas pengeluar tersebut didapati sebagai 1484 mg/Sm³.

ABSTRACT

The fuel that is used worldwide currently is mostly from fossil fuel which is depleting. In order to replace the fuel, biomass is introduced as an alternative fuel source to generate energy.

The objective of the work are to investigate the possibility of a specific biomass, which is fabric waste, to be used in the gasification process and to determine the heating value of the gas produced.

The fabric waste was analysed its heating value using bomb calorimeter, followed by proximate analysis using thermogravimetric analyzer (TGA). Gasification experiment of fabric waste was done using fluidised bed gasifier. Producer gas sample was then analysed using gas chromatograph and tar sample was collected and analysed using rotary evaporator.

From the pre-analysis of the fabric waste, the heating value of the fabric waste is ranged from 15.69 to 17.08 MJ/kg. From the proximate analysis of the fabric waste, it is found that the fabric generally has high volatile material content (85.817 to 89.015%), followed by fixed carbon content (7.425 to 9.858%), moisture content (3.399 to 4.189%) and ash content (0.079 to 0.197%). The gas composition of the producer gas collected are 0.07% hydrogen, 12.15% oxygen, 30.61% nitrogen, 4.15% carbon monoxide, 0.55% methane and 52.47% carbon dioxide. The heating value of the producer gas is 0.72 MJ/Sm³ and the tar content in the producer gas is 1484 mg/Sm³.

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the fossil fuel we use daily is getting more and more expensive due to its source getting less day by day. The fossil fuel we use are also a big source of greenhouse gases, a leading source towards global warming. Thus, alternative fuel should be researched to overcome this issue.

Biomass is defined as an organic matter while waste is defined as unwanted matter, thus biomass waste can be defined as an organic but unwanted matter. Biomass waste can be classified into four main classes such as wood, fabric waste, crops or garbage.

Gasification has a higher efficiency compared to direct combustion in a smaller scale and in the application of energy generation, gasification plants use less transportation cost compared to combustion as combustion works well in higher scale and in that case, a greater cost is needed for transportation of logs to the plant. Thus, it is more applicable using smaller, standalone systems of gasification plants rather than a large-scale combustion plant.

In Malaysia, abundant biomass wastes are available, and those wastes have the potential to be used in the form of clean energy. Biomass waste can generate energy that is safe towards the environment and is generally more cost effective. A form of biomass waste is sewage waste. This form of waste is used in aerobic digestion. Another form of biomass waste fabric waste, which is also produced daily. This type of waste is not suitable to be used as compost thus another method is required to use up the waste.

Gasification can be performed on biomasses to produce producer gas, a type of clean energy that is considered a renewable energy. Thus, analysis could be performed on fabric waste to get its heating value to assess whether it is suitable for gasification or not. During gasification, there are a few types of gasifiers including updraft, downdraft and fluidized bed gasifier. Since different types of gasifiers have different properties and mechanisms, it is also required to analyse which gasifier is more suitable depending on the waste used.

1.2 Problem Statement

In Malaysia, there is abundant biomass wastes which are underutilized for power generation, these wastes include fabric waste. The wastes are thrown into dumpsites and landfill, which is not a good solution for biomass wastes. Fossil fuel is a common fuel source at present but comes with some cons including the fact that the source itself is non-renewable and will generate greenhouse gases while we use it. Thus, a better solution will be to gasify the waste into producer gas and to use it as an alternative fuel in internal combustion engines, turbines, and fuel cells. Experiments are to be conducted to determine whether the fabric waste is suitable for gasification by analysing their physical and chemical properties. Fabric waste to be gasified in fluidised bed gasifier. The producer gas quality is also to be determined whether the producer gas is suitable as an alternative fuel source for internal combustion engine or not.

1.3 Objectives

Objectives that are to be achieved in this project, include:

1. To analyse the physical and chemical properties of fabric waste.
2. To perform gasification of this biomass waste in fluidized bed gasifier.
3. To analyse the quality of producer gas produced for possible application for power generation.

1.4 Scope of Work

The project requires pre-analysis of the biomass waste using bomb calorimeter and TGA. The physical and chemical compositions of the waste are to be verified and compared with other biomass sources. Besides, biomass waste will be gasified in fluidized bed gasifier. Producer gas analysis is also required using gas chromatograph to determine its suitability in power production in I.C. engines.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter includes the theoretical and practical information related to the project. Such information includes researches done by other researchers or students previously. These informations are crucial towards the process of carrying out the project.

2.2 Biomass

Biomass is defined as the biodegradable fraction of products, waste and residues from agriculture or any corpse of organisms [1]. Biomass materials are carbon-based and can be combusted to be used as an energy source through various methods such as direct combustion, pyrolysis and gasification.

From Figure 2.1, it can be seen that there are a few types of methods to convert biomass materials into energy sources, each with their own advantages and disadvantages. In this project, the process gasification will be used to convert the biomass (fabric waste) into producer gas which could be used in internal combustion engines for power generation.

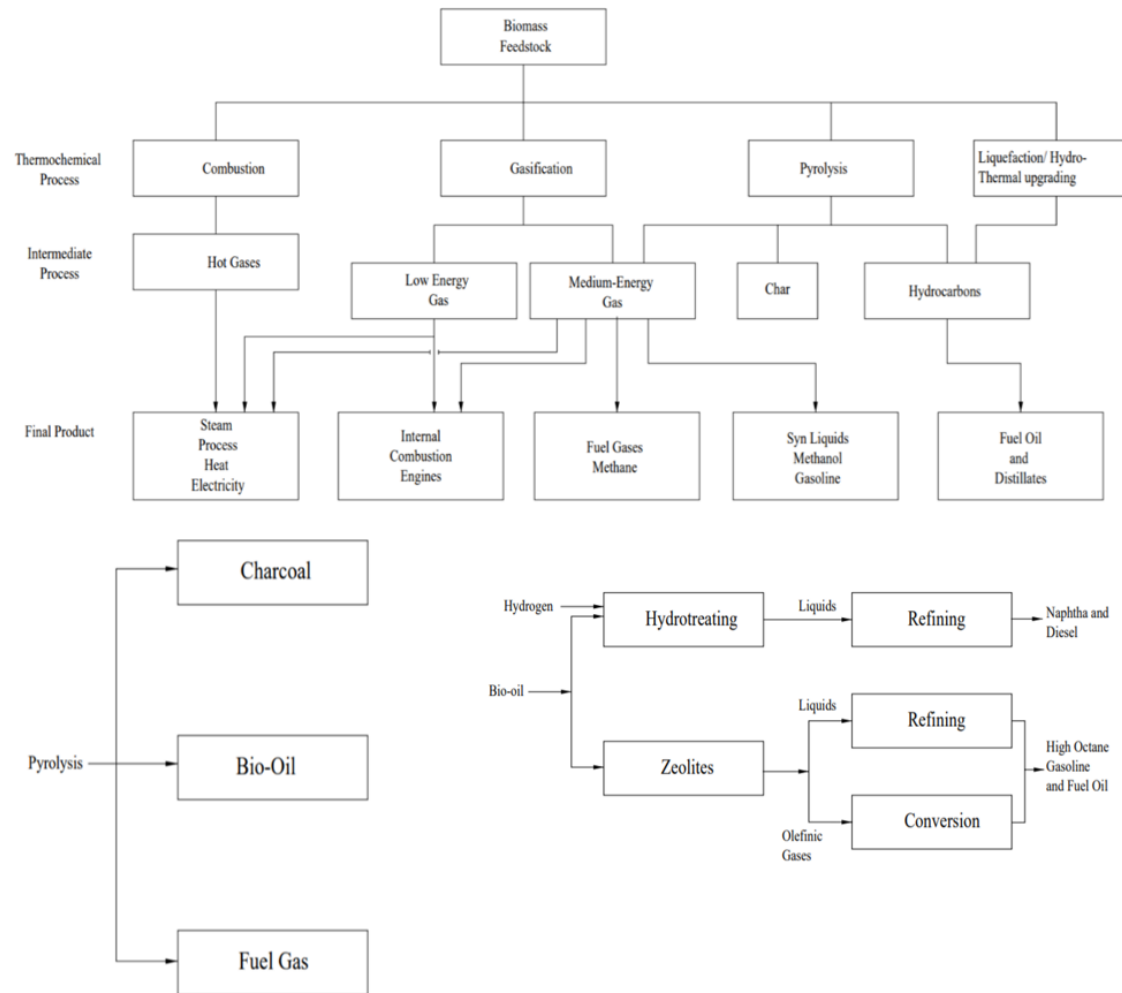


Figure 2.1: Methods of using biomass as energy source [2]

2.3 Gasification

Gasification is the process of turning biomass into producer gas, a mixture of flammable gases, principally carbon monoxide (CO), methane (CH₄) and hydrogen gas (H₂), and non-flammable gases, mainly nitrogen (N₂) and carbon dioxide (CO₂). The process is carried out in a gasifier with less water content. The difference of this process with combustion and pyrolysis is stated in Table 2.1 below.

Table 2.1: Comparison of gasification, combustion and pyrolysis [3]

	Gasification	Combustion	Pyrolysis
Presence of oxygen	Yes (insufficient)	Yes (sufficient)	No
Main product	Producer gas (or synthesis gas)	Carbon dioxide and water	- Slow pyrolysis produces char or charcoal - Fast pyrolysis produces bio-oil
Temperature condition	800°C-1200°C	No specific condition	350°C-600°C

From Table 2.1, it can be seen that the different processes have different conditions, such as combustion requires sufficient oxygen presence while gasification requires high temperature. The products by each process also differs from one another.

2.4 Biomass materials

An ideal energy crop should have high yield, low energy input to produce, low cost, composition with least contaminants as well as low nutrient requirements [4]. Proximate and ultimate analysis of some biomass materials are shown in Table 2.2 and 2.3 below:

Table 2.2: Proximate analysis for some biomass feedstock (wt%)

Biomass	Moisture (%)	Volatile Material (%)	Fixed Carbon (%)	Ash (%)	LHV (MJ/kg)
Wood	20	82	17	1	18.6
Wheat straw	16	59	21	4	17.3
Barley straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.8
Bituminous coal	11	35	45	9	34.0

Table 2.3: Ultimate analysis for typical biomass materials (wt%)

Material	C	H	O	N	S	Ash
Cypress	55.0	6.5	38.1	-	-	0.4
Ash	49.7	6.9	43.0	-	-	0.3
Beech	51.6	6.3	41.4	-	-	-
Wood (average)	51.6	6.3	41.5	0.0	0.1	1.0
Miscanthus	48.1	5.4	42.2	0.5	<0.1	2.8
Wheat straw	48.5	5.5	3.9	0.3	0.1	4.0
Barley straw	45.7	6.1	38.3	0.4	0.1	6.0
Rice straw	41.4	5.0	39.9	0.7	0.1	-
Bituminous coal	73.1	5.5	8.7	1.4	1.7	9.0
Lignite	56.4	4.2	18.4	1.6	-	5.0

Another study by Chun-Yang Yin [5] shows some data in higher heating values of various biomass materials in the form of tabulates data as shown in Table 2.4 below:

Table 2.4: Properties of various biomass materials

Type	Proximate analysis (wt.%) ^a			Ultimate analysis (wt.%) ^a					Experimental HHV (MJ/kg)
	VM	FC	Ash	C	H	N	O	S	
Rice husk	61.81	16.95	21.24	38.50	5.20	0.45	34.61	–	14.69
Cotton stalk	76.10	18.80	5.10	47.07	4.58	1.15	42.10	–	17.40
Dried grains – solubles	82.50	12.84	3.89	50.24	6.89	4.79	33.42	0.77	21.75
Corn stover	66.58	26.65	6.73	45.48	5.52	0.69	41.52	0.04	17.93
Oil palm fruit bunch	78.20	16.46	4.53	45.90	5.80	1.20	40.10	–	16.96
Olive kernel	63.90	32.80	1.70	54.60	6.80	0.80	36.10	–	22.40
Cotton residue	72.80	20.59	6.61	47.03	5.96	1.79	38.42	0.19	16.90
Rice straw	65.47	15.86	18.67	38.24	5.20	0.87	36.26	0.18	15.09
Corn straw	73.15	19.19	7.65	44.73	5.87	0.60	40.44	0.07	17.68
Rice husk ^b	61.20	16.30	22.50	38.20	5.60	–	33.70	–	16.47

2.5 Types of gasifiers

Gasification is a process of biomass being oxidised where only part of the biomass is completely combusted while the other part is partially combusted. There are a few types of gasifiers, including fixed bed gasifiers (updraft gasifier, downdraft gasifier and also cross-flow gasifier), and fluidized bed gasifiers (circulating fluidized bed gasifier and bubbling bed gasifier). Table 2.5 shows the advantages and disadvantages of these types of gasifiers.

Table 2.5: Properties of gasifiers

Type of Gasifier	Advantages	Disadvantages
Fixed/ moving bed, updraft	<ul style="list-style-type: none"> • Simple, inexpensive process • Exit gas temperature about 250°C • Operates satisfactorily under pressure • High carbon conversion efficiency • Low dust levels in gas • High thermal efficiency 	<ul style="list-style-type: none"> • Large tar production • Potential channeling • Potential bridging • Small feed size • Potential clinkering
Fixed/ moving bed, downdraft	<ul style="list-style-type: none"> • Simple process • Only traces of tar in product gas 	<ul style="list-style-type: none"> • Minimum feed size • Limited ash content allowable in feed • Limits to scale up capacity • Potential for bridging and clinkering
Fluidised bed	<ul style="list-style-type: none"> • Flexible feed rate and composition • High ash fuels acceptable • Able to pressurize • High CH₄ in product gas • High volumetric capacity • Easy temperature control 	<ul style="list-style-type: none"> • Operating temperature limited by ash clinkering • High product gas temperature • High tar and fines content in gas • Possibility of high C content in fly ash
Circulating fluidised bed	<ul style="list-style-type: none"> • Flexible process • Up to 850°C operating temperature 	<ul style="list-style-type: none"> • Corrosion and attrition problems • Poor operational control using biomass
Double fluidised bed	<ul style="list-style-type: none"> • Oxygen not required • High CH₄ due to low bed temperature • Temperature limit in the oxidiser 	<ul style="list-style-type: none"> • More tar due to lower bed temperature • Difficult to operate under pressure
Entrained bed	<ul style="list-style-type: none"> • Very low in tar and CO₂ • Flexible to feedstock • Exit gas temperature 	<ul style="list-style-type: none"> • Low in CH₄ • Extreme feedstock size reduction required • Complex operational control • Carbon loss with ash • Ash slagging

Fixed bed gasifiers have beds of solid fuel particles through that gasifies the media gas move either up or down and are generally the simplest type of gasifiers consisting of a cylindrical fuel feeding unit, ash removal unit and a gas outlet unit. The common problem of these gasifiers is tar removing and thus, external tar removing process is needed. This classification of gasifier includes updraft, downdraft and also cross-flow gasifiers.

The main difference between the three types of gasifiers are the feed inlet. Updraft gasifiers have a feeding unit at the top and air intake at the bottom as shown in Figure 2.2a while downdraft gasifiers have the air intake at a higher level compares to the previous type as shown in Figure 2.2b. For cross-flow gasifiers, the feed, or biomass, moves downwards and air inlets are at the side of the gasifiers.

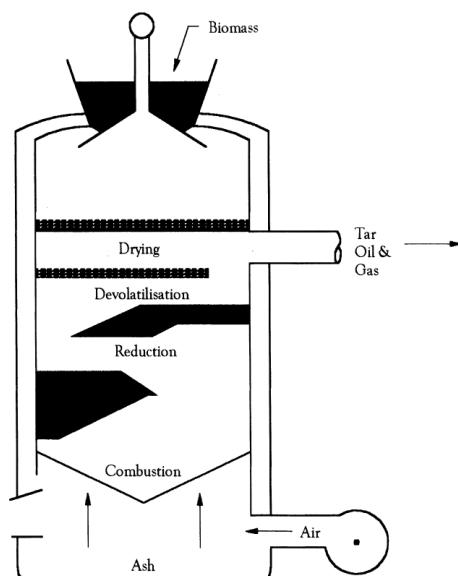


Figure 2.2a: Updraft Gasifier[6]

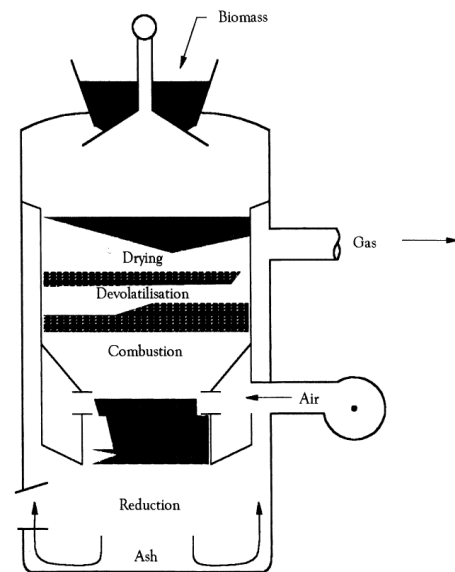


Figure 2.2b: Downdraft gasifier[6]

Fluidised bed gasifiers have two main types, circulating fluidised bed and bubbling bed gasifiers. Circulating fluidised bed gasifiers operate by circulating the bed material between the reaction vessel and cyclone separator. Ash is removed in the

process while the bed material and char return to the reaction vessel. On the other hand, the bubbling bed fluidised bed gasifier consist of a vessel with a grate at the bottom as an air inlet. The moving bed, which is above the air inlet, consists of fine-grained material is also where the feed is introduced.

2.6 Producer gas

Based on a study conducted by K.G. Mansaray and et. al. [7], gasification was performed on rice husks and the mole fractions of the combustible components has a composition of 4% hydrogen gas, 5% hydrocarbon (CH₄, C₂H₂, C₂H₄ and C₂H₆), 15% carbon dioxide gas, 20% carbon monoxide gas and 57% nitrogen gas. The higher heating value of the producer gas was determined in a range of 3.09–5.03 MJ Nm⁻³. The gas yield and carbon conversion were in the range of 1.30 to 1.98 Nm³ kg⁻¹ and 55.0 to 81.0%, respectively.

2.7 Tar in producer gas

As a sub-product, tar is also produced during the gasification process. The amount of tar in a producer gas can affect the quality of the fuel. Tar is known as the hydrocarbon-containing mixture that can be formed as a liquid or solid deposit by cooling gaseous phase matters such as fuels to ambient temperature [8]. Organic linked elements (such as carbon, hydrogen and oxygen) can often be found in tar. Table 2.6 shows the tar classes and their properties.

Table 2.6: Classification of tar [8]

Tar Class	Class name	Property	Representative Compounds
1	GC-undetectable	<ul style="list-style-type: none"> - Very heavy tars - Cannot be detected by GC 	None
2	Heterocyclic aromatics	<ul style="list-style-type: none"> - Tars containing hetero atoms - Highly water soluble compounds 	<ul style="list-style-type: none"> - Pyridine - Phenol - Cresols - Quinoline - Isoquinoline - Dibenzophenol
3	Light aromatic (one ring)	<ul style="list-style-type: none"> - Usually light hydrocarbons with single rings - Do not pose a problem regarding condensability and solubility 	<ul style="list-style-type: none"> - Toluene - Ethylbenzene - Xylenes - Styrene
4	Light PAH (two or three rings)	<ul style="list-style-type: none"> - Two to three ring compounds - Condense at low temperature even at very low concentration 	<ul style="list-style-type: none"> - Indene - Naphthalene - Methyl-naphthalene - Biphenyl - Acenaphthalene - Fluorene - Phenanthrene - Anthracene
5	Heavy PAH compounds (four to seven rings)	<ul style="list-style-type: none"> - Larger than three rings - Condense at high-temperature at low concentration 	<ul style="list-style-type: none"> - Fluoranthene - Pyrene - Chrysene - Perylene - Coronene

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the experimental methods and procedures of each stage of the project is described as well as the theoretical equations used in calculations and analyses are described to ensure the objectives are met.

The experiments and tests done includes calorific value test using bomb calorimeter, proximate analysis test using thermogravimetric analyzer, gasification experiment using fluidised bed gasifier, tar analysis using tar sampling tram and rotary evaporator, and producer gas heating value analysis using gas chromatograph.

3.2 Preparation of fabric waste

The biomass material was supplied by Espquel Sdn. Bhd. in packings of 1kg as shown in Figure 3.1 and the fabric was supplied in shredded state as shown in Figure 3.2.



Figure 3.1: Fabric sent from industry



Figure 3.2: The shredded fabric

3.3 Physiochemical characterization of fabric waste

This section describes the experimental methods used before the gasification experiment takes place. The analyses includes bomb calorimeter test and also thermogravimetric analysis (TGA).

3.3.1 Energy content

The apparatus used in the test is the bomb calorimeter, which is located at the Heat Transfer Lab of School of Mechanical Engineering, Engineering Campus, USM, as shown in Figure 3.3.

The sample is first made into a “bomb”, as shown in Figure 3.4, with around 1 gram of fabric being wrapped in a piece of tracing paper and tied with fuse wire of length 10 centimeters. Exactly 2.1 litres of water is also poured into the apparatus. The sample bomb is inserted into the shell by fixing the fuse wire onto the set location as shown in Figure 3.5, and the shell is locked before it is being inserted with oxygen gas. The shell is then placed into the apparatus and ignition wires are fixed onto the shell as shown in Figure 3.6. The water temperature is set by heating the water bit-by-bit until there are readings on the two thermometers. After setting up the apparatus, the stirrer is switched on to ensure the temperature is at equilibrium. The temperature was observed and recorded for 5 minutes at 1 minute intervals. After 5 minutes the bomb is set off by pressing the ignition button. The temperature

is recorded at 30 seconds intervals for another 5 minutes. After 5 minutes the temperature is recorded at 1 minute intervals until the temperature reaches equilibrium, which is determined when the temperature remains constant for 3 minutes.

The equations used in this test are as shown below:

$$\begin{aligned}\Delta T &= T_f - T_i \\ Q_w &= C\Delta T(m_w + m_{ew}) \\ \Delta L &= 10 - L \\ m_f Q_{nett_{fuel}} + m_{paper} Q_{nett_{paper}} + \Delta L Q_{nett_{fuse\ wire}} &= Q_w\end{aligned}$$

Where,

ΔT is the total temperature difference,

T_f is the final water temperature,

T_i is the initial water temperature,

Q_w is the heat absorbed by water,

C_p is the specific heat capacity of water (4.1868 J/g•K),

m_w is the mass of water used (2100 g),

m_{ew} is the mass of water equivalent (604 g),

ΔL is the length of fuse wire burnt,

L is the length of fuse wire left,

m_f is the mass of fuel (fabric),

$Q_{nett_{fuel}}$ is the high heating value of fuel (fabric),

m_{paper} is the mass of tracing paper (0.02 g),

$Q_{nett_{paper}}$ is the heating value of tracing paper (16190 J/g),

$Q_{nett_{fuse\ wire}}$ is the heating value of fuse wire (9.625 J/cm).



Figure 3.3: Bomb calorimeter



Figure 3.4: The fabric being wrapped into a “bomb”



Figure 3.5: The “bomb” being placed onto the “shell”



Figure 3.6: The “shell” being placed into the apparatus

3.3.2 Properties of fabric waste

The TGA analyser is located at the Nanofabrication and Functional Materials Lab, School of Mechanical Engineering, Engineering Campus, USM.

The apparatus was warmed up for 30 minutes before the test, and the furnace was brought up and the sample pan as well as the hangdown wire was given some time to stabilize. The sample pan weight was then tared by using the tare weight button. The furnace was then brought down and the platform was turned in and brought to the bottom of the sample pan gently. Sample was loaded gently until half the height of sample pan and the platform was brought down and turned out. Stabilization time was given about 3 minutes. The weight of the sample was taken. The test was then taken by starting the apparatus.

The apparatus used is as shown in Figure 3.7.



Figure 3.7: The TGA analyser used

3.4 Gasification experiment

The gasification experiment was done in several stages to ensure the smoothness when used upon the fabric waste. In this project the fluidised bed gasifier as shown in Figure 3.8 was used.



Figure 3.8: The fluidised bed gasifier used in experiment

3.4.1 Gasification system components and configurations

The gasifier used in the experiment is an air-blown bubbling fluidized bed gasifier. Its dimension includes height of 1050 millimeters, internal diameter of 150 millimeters in the bed zone, and 270 millimeters of freeboard length. The bed material was silica sand of 1620 kg/m^3 bulk density with mean size of 600 micrometers. The inlet hole was positioned at 12 centimeters above the distributor cap. Cooling water jacket was also attached, surrounding the screw feeder to cool down the biomass before entering the gasifier, as well as preventing pyrolysis.

3.4.2 Experimental procedure

Before any material was being inserted into the gasifier, a test run was run by turning on the components one-by-one to ensure all the components are working perfectly. The gasifier used is the fluidised bed gasifier located at the Biomass Lab of School of Mechanical Engineering, Engineering Campus, USM.

Before testing the components, the wiring of each components, including the combustor, water pump, air blower and also the feeder driver motor, was checked. Then, the components was switched on one by one to ensure all the components are working. When the blower was turned on, the rotameter was checked to ensure there was a reading and there is no blockage. The gasifier was also opened from the top to check the sand level as it needs to be below the feeder outlet to ensure the biomass flow to the gasifier is not blocked. Figures 3.9 to 3.12 shows some of the apparatus used in the experiment.



Figure 3.9: The interior of gasifier



Figure 3.10: Water pump used to keep temperature at screw feeder low

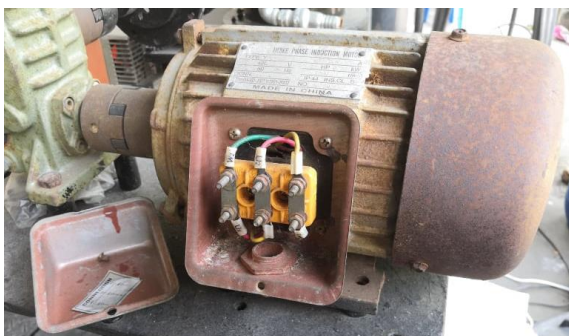


Figure 3.11: Motor for screw feeder



Figure 3.12: Combustor and fuel tank

Before experimenting the gasification of fabric waste, rice husk is used in the gasifier to ensure the apparatus are all in working condition and to familiarise with the standard operating procedure of the gasifier.

First, the combustor and water pump were turned on simultaneously to heat up the sand in the gasifier while keeping the temperature in the screw feeder low. After heating the sand for 5 minutes, the screw feeder driver motor was turned on and the rice husk was fed slowly into the feeder. After another 5 minutes, the blower was turned on and the exhaust was observed for any smoke. Once there is smoke at the exhaust, the gas was tested its combustability by lighting it with a lighter while liquefied petroleum gas (LPG) was supplied. Presence of flare was

observed to identify the combustability of the gas. Figure 3.13 shows the rice husk being inserted into the feeder.



Figure 3.13: Rice husk being inserted into the feeder

3.4.3 Testing of feeder

Due to some issues during the gasification experiment using fabric waste, a modification has been made to allow the experiment to proceed.

As the gasification experiment goes on, it was noticed that the screw feeder gets stuck eventually, thus the feeder was removed and tested separately. After cleaning the screw feeder, the hopper of the feeder was removed for better view towards the inside of the feeder. Fabric waste was prepared in packings of approximately 100 grams each for one kilogram in total. The screw was fixed back into the feeder after cleaning. The feeder was then tested by feeding fabric slowly with the water pump to prevent the feeder from heating up from absorbing the heat from the driver motor. After each 100 grams the condition at the feeder outlet was observed and recorded until the feeder gets stucked.

3.4.4 Gasification experiment on fabric waste

The experiment was done by gasifying the fabric waste and collecting the sample on the producer gas. The combustor was turned on for 5 minutes to heat up the sand. Then, fabric was inserted through the screw feeder to allow continuous feeding. The blower was then switched on and LPG was supplied to check the presence of producer gas. Once flare is observed at the exhaust of the gasifier, the valve near the exhaust was closed partially to force the producer gas to flow to the tar sampling tram and the gas sampling bag.

3.5 Producer gas composition analysis

After getting the samples, the gas sample, as shown in Figure 3.14, was sent for composition analysis by using the gas chromatograph. The analysis was done at the Engine Lab at School of Mechanical Engineering, Engineering Campus, USM.

The analysis was started by ensuring the Helium supply pressure of 80 psi. The gas chromatograph and computer was then turned on. Then, the apparatus was set as shown in Table 3.1 below

Table 3.1: Parameters of gas chromatograph

Parameter	Value
Valve	All off
Front injector temperature	120°C
Oven initial temperature	30°C
Oven equilibrium time	30 seconds
Oven maximum temperature	200°C
Oven initial-hold time	5 minutes
Oven temperature increase	10°C per minute until 120°C (hold for 5 minutes after reaching)
Front detector temperature	150°C (should be higher than oven temperature)
Detector TCD sensitivity	High, positive polarity

Heater aux temperature	120°C
Configuration parameter	Sample injection source, manual

After setting the apparatus, 100 millimeters of sample was taken from the sampling bag using a syringe and the syringe was placed at the injector. The apparatus was started and the gas was injected simultaneously. The result was then printed.



Figure 3.14: Gas sample

3.6 Tar sampling and analysis

3.6.1 Tar sampling

The tar sampling tram, with four bottles, was prepared before the experiment by pouring 30 ml of isopropanol solution into each of the bottles, leaving only one empty bottle. Then, ice is put into the insulation box with the bottles and salt was added to slow down the melting of the ice. The tar sampling tram was then connected to the gasifier after the cooling coil. During the sampling of producer gas, the gas was directed to a tar sampling tram as shown in Figure 3.15. The gas was directed for 5 minutes and the flow was observed and recorded for tar amount calculation.



Figure 3.15: Tar sampling tram used for the tar analysis of producer gas

3.6.2 Tar analysis

The solution in the bottles of the tar sampling tram was all transferred into a conical flask, as shown in Figure 3.16, and was sent to Central Analytical Lab of School of Chemical Engineering, Engineering Campus, USM. The solution was then evaporated to determine the amount of tar in it by using the rotary evaporator in the lab, as shown in Figure 3.17. Silicon grease was applied to the inner wall of the socket of the conical flask before attaching it to the apparatus. After fixing the conical flask, the flask was lowered into the glycerin, which was heated to 100°C. The rotational speed of the flask was set to 60 rpm and vacuum pump was also turned on to speed up the process. The solution was observed and the evaporating process continued until the solution in the flask remains at the same volume for at least 5 minutes, indicating all isopropanol and water are evaporated. The flask was then weighted. Calculations was done to determine the weight of the tar per litre of producer gas using the formulas below:

$$W_T = W_2 - W_1$$
$$V = \dot{V} \times t$$