PRELIMINARY DESIGN OF PALM OIL FROND GASIFIER

by

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CERTIFICATION OF APPROVAL

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Approved by,

29/05/08.

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Azrul Amin B Kimin

ABSTRACT

This report is emphasizing on designing a gasifier that utilizes the palm oil frond as the carbonaceous feed material. Gasifier is the reactor where the gasification process occurs to produce combustible gas for power generation application.

Malaysia is one of the largest palm oil producing countries in the world and there are large amounts of palm oil tree waste especially the frond and leaves produced Currently, the waste such as the frond are not been managed well and disposed in uncontrolled manner. To treat this tremendous biomass waste, gasification can be the way to convert the waste to be an alternative energy, in the form of combustible gas called producer gas or syngas.

The methodology of the project is to plan and clarify the task to be done, followed by research on the project through literature review, determine the characteristic and thermal behavior of palm oil frond through material testing and lastly design the gasifier based on the characteristics of the frond. The gasifier with feed consumption of 150 kg/h is designed since the gasifier is required to produce medium scale of power generation in the range of 50 to 200 kW.

The palm oil frond gasifier has total dimension of 0.8 m in diameter and 2.5 m in height. The construction material for the gasifier is 5mm thick stainless steel and the insulation is made of rock wool. The producer gas produced is approximately 531.62 m^3h^{-1}.The gasifier can generate power capacity of 166.32 kW with 70% of gasification efficiency and has total gasifier system efficiency of 20.9%.

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CHAPTER 1

INTRODUCTION

Over the last few decades, the Malaysian palm oil industry has grown to become very important agriculture-based industry oil and the oil palm has been domesticated from the wilderness and transformed to become a plantation-based industry [2]. These palm residues contain high nutrient value as the wastes contain high-energy value. The estimated calorific value for CPO and palm kernel oil is 40 GJ/ton and the oils from 3.45 tons of FFB (22% of CPO and 6% palm kernel oil) will produce 38.6 GJ of energy [3]. However, the market value for both oils has not been used for commercial energy generation. Research in methyl esters converted from palm oil, as a diesel substitute is very promising and direct burning of palm oil waste to generate electricity has also been tested recently in Malaysia. This situation will need to develop more research on the residue of the palm oil which is potentially can be used for alternative renewable energy resource in Malaysia. Besides, other palm oil residue such as empty fruit brunch (EFB) and the frond are can be potentially be used to generate energy and the wastes are largely available in Malaysia.

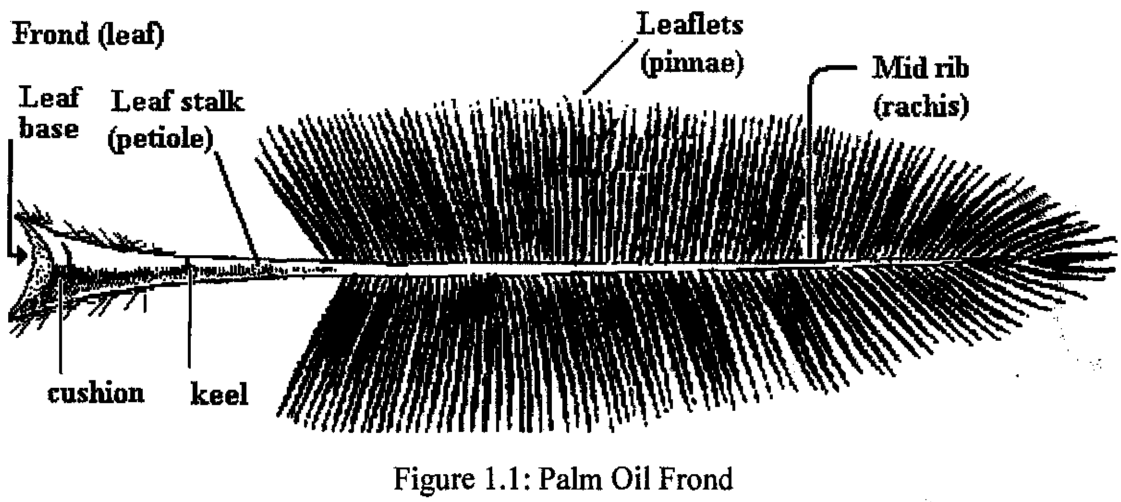


Figure 1.1: Palm Oil Frond

1.1 Background of Study

Biomass fuel is defined as any gaseous, liquid or solid phase derived from biological or organic matters [4]. The raw material is mainly originated from the organic resources such as the plant, agricultural residues and animal waste. These residues contains high amount of energy that can be converted into energy and can be used for various applications such as for heating, cooling and power application. In Malaysia, biomass resources are mainly come from the agricultural residues and the palm oil plantation in Malaysia contribute large amount of residues over the years. The residues such as the palm oil frond and leaves is potentially to be the hydrocarbon material for alternative energy and the material can be develop to make the biomass fuel.

1.2 Problem Statement

Malaysia is one of the largest palm oil producing countries in the world and there are large amounts of palm oil tree waste especially the frond and leaves produced. The waste is increasing at with the rapidly expanding of food and manufacturing palm oil based industries. There is no particular ways to manage the waste and they are also being disposed in an uncontrolled manner presently. To treat this tremendous amount of wastes, technologies with improved efficiencies and reduced environmental impacts need to be established. Alternatively, the palm oil's frond and leaves are the biomass that can be used to produce energy by controlled combustion system or gasification process. This process produces producer gas that could generate electrical or mechanical energy for other application. Thus, the biomass from the leaves and frond can be an alternative energy to be developed for the future.

1.3 Objectives and Scope of study

1.3.1 Objective

The objective of this project is to design and produce the technical drawing of gasifier which can utilizes the palm oil frond as the carbonaceous material and the producer gas is used for power generation application.

1.3.2 Scope of Study

The scope of study for this project is to design a gasifier that can process the palm oil frond to produce producer gas for power or heat generation application. The characteristic and thermal properties of palm oil frond have to determine through some material testing method. The gasifier will be design based on the material testing results with operating capacity of 150 kg h^{-1} feed material consumption to provide sufficient energy for medium scale power generation. The gasifier will be designed in small scale size since it is only a prototype.

CHAPTER 2
LITERITURE REVIEW

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, petroleum coke or biomass, into carbon monoxide, hydrogen and carbon dioxide [5]. The material gasification process will undergo 4 main reactions explained as below:

2.1 Gasification of Material

The material at the upper side of the gasifier will be heated up by the heat from the hearth zone. The process will eliminate the moisture content of the feed up to 160 ^{0}C. The pyrolysis occur at the bottom of drying zone where volatile gases are released from the dry biomass at temperatures ranging up to about 700°C. These gases are non-condensable vapors (e.g. methane, carbon-monoxide) and condensable vapors (various tar compounds) and the residuum from this process will be mainly activated.

The combustion or oxidation process occur where the remaining char is combusted (reaction with oxygen) to provide heat, carbon dioxide, carbon monoxide and water vapor. The general reaction of the process is described as below [6]:

$C + O_2 \Leftrightarrow CO_2$ - 401.9 kJ/mol

$H + 1/2O_2 \Leftrightarrow H_2O$ - 241.1 kJ/mol

The heat produced from the combustion process will be transported by convection and radiation to heat up the feed at the upper side.

The process of reduction is the simultaneous reaction of char, carbon dioxide and water vapor from the combustion process to produce producer gas that mainly composed of carbon monoxide and hydrogen. The chemical process is described as below [6]:

$C + CO_2 = 2CO$ 164.9 kJ/kmol

$C + H_2O = CO + H_2$ 122.3 kJ/kmol

$CO + H_2 = CO + H_2O$ 42.3 kJ/kmol

$C + 2H_2 = CH_4$ 0

$CO + 3H_2 = CH_4 + H_2O$ -205.9 kJ/kmol

Equations (a) and (b), which are the main reactions of reduction, show that reduction requires heat. Therefore the gas temperature will decrease during reduction.

2.2 Gasifier

A gasifier is equipment to converts solid fuel such as coal, wood and agro-residues into the producer gas through a thermo-chemical process and the gas produced can be used for heat or power generation applications. The overall thermal efficiency of this process is more than 75% and the producer gas normally contains carbon monoxide, hydrogen, nitrogen, carbon dioxide and methane [6]. Gasifier technology also can be used in any application where diesel or any petrol-fuel is used. There are four main types of gasifier available for commercial uses which are the updraft, downdraft, cross draft and fluidized bed gasifier. The types of gasifier are explained as below:

2.2.1 Updraft / counter-current bed gasifier

This is the simplest gasifier among the other types of gasifier. The material will be feed at the top of the gasifier and will moves down due to gasification and ash removal process. The air will be supplied from the bottom and the gas will leaves at the top. The movement of the feed relatively to gas produced explains the term of counter current used for this kind of gasifier. The zones inside the gasifier from the top to bottom are the drying zone, pyrolysis zone, reduction zone and the combustion zone, placed at the bottom part of the reactor.

Major advantages of updraft gasifier are its simplicity, high char burn, high efficiencies and low gas exit temperature. The variation of fuel also can be tolerated and small size particle can be used. The major drawback is that the amount of tar and pyrolysis product is high since the gas is not combusted. This has been major concern to environmental issue as the tar content can bring effects on environment and good purification system is required to overcome the problem.

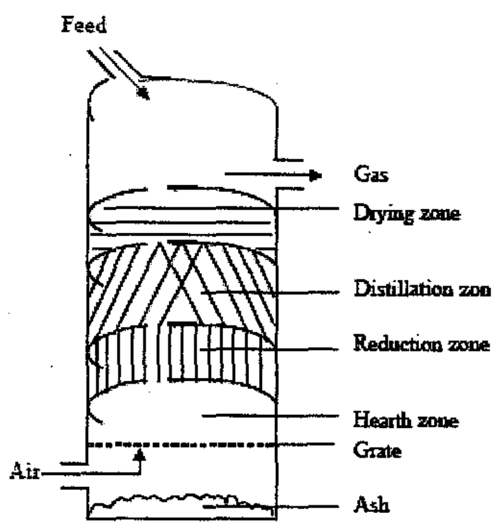


Figure 2.1: Sketch of Typical Updraft Gasifier

2.2.2 Down draft / co-current bed gasifier

The gasifier is applicable for medium and large scale of power generation ranging from 80 up to 500kW or more. The feedstock is fed at the top and the air for the combustion is either from the top or side. The gas leaves at the bottom with same direction as material movement.

The zones are slightly differ from the up draft type as the reduction zone is occur at the bottom of the gasifier, and the combustion occur at the top of the zone.

The main advantage of down draft is the producer gas will content low amount of tar as the gas will flow through combustion and reduction zone prior exit at the outlet. However, the residence time is the important factor to consider ensuring the tar is combusted through the hottest zone. In each particular design, other features are includes to realize a high conversion rate of the pyrolysis gas.

The drawbacks are the high ash content in the gas due that the gas has to pass the reduction zone and collecting small ash particles. The uniform size of material is important to ensure no blocking in the throat and enough space for gas flow downward and allow transportation of heat from the oxidation zone upward. The relatively high temperature will lead to lower gasification efficiency furthermore; the moisture content of the feedstock must be less than 25 %. [6]

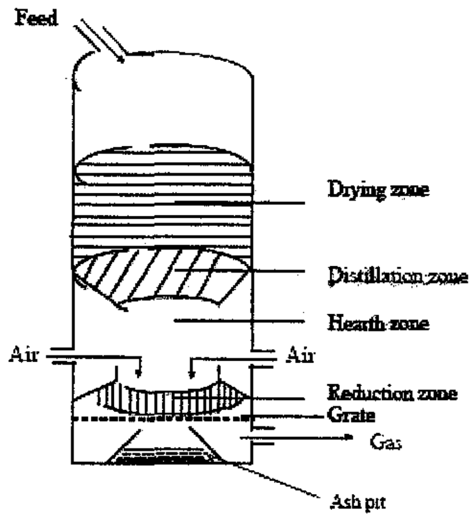


Figure 2.2: Sketch of Typical Downdraft Gasifier

2.2.3 Crossdraft gasifier

It is adapted for use of charcoal. The gasification results in very high temperature (1500 ^{0}C and higher) in the hearth zone which can lead to material problems. Advantages of the system lie in the very small scale at which it can be operated due to very high gas cleaning train. A drawback is the minimal tar-converting capability, resulting in the need for high charcoal.

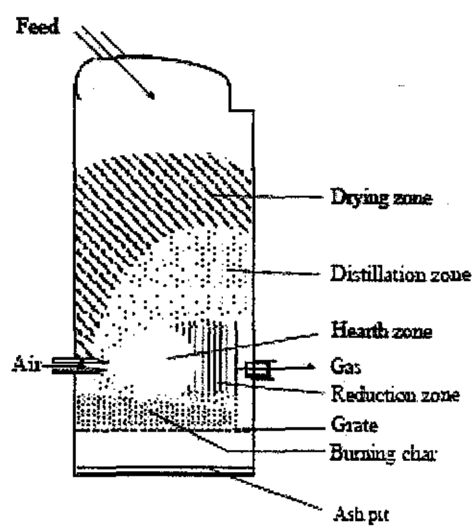


Figure 2.3: Sketch of Typical Cross draft Gasifier

2.2.4 Fluidized bed gasifier

The gasifier is designed to overcome the operational problem of high ash content and it is suitable for larger capacity. The gasification temperature is lower compared to fixed bed gasifier around 750 to 900^{0}C . The fuel is fed into hot sand which is instate of suspension or circulating. The bed behaves more or less like a fluid and it is characterized by high turbulence. Fuel particles mix quickly with the bed material creates fast pyrolysis and large amount of pyrolysis gas. Due to the lower temperature, the tar conversion is not high.

The advantages of the gasifier are the ability to changes in fuel characteristic and deal with fine grained material with high as content or low bulk density. Relatively low ash melting pointes are allowed due to the low reaction temperature.

The drawbacks are formation of high content of tar and dust in producer gas and incomplete carbon burn out. The high producer gas temperature containing alkali metal in the vapor state and there is complex gasifier operation because of the need to control the supply of both air supply and solid fuel. Power consumption is needed for the compression of the gas stream.

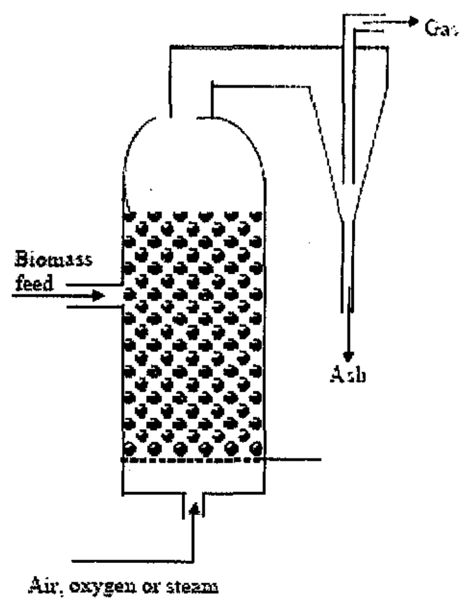


Figure 2.4: Sketch of Typical Fluidized bed Gasifier

2.3 The Criteria to Select Type of Gasifier

To select the best type of gasifier for the palm oil frond gasifier, several main factors are considered such as the less bad effect on the environmental issues related to tar content produced, the gasifier general efficiency, the gasifier operation simplicity, commercially available gasifier, and the ability to produce medium scale of power generation. The decision to select the type of gasifier which considering the updraft, downdraft and fluidized bed type gasifies are shown in Table 2.1:

Table 2.1: Gasifier Types Decision Factor- Rating

Decision Factors	Weight	Score (out of 100)			Weighted score		
		U	D	F	U	D	F
Environmental issues	4	50	75	80	200	300	320
Gasifier Efficiency	5	80	70	85	400	350	425
Operation Simplicity	2	85	70	40	170	140	80
Commercialized	4	50	80	70	200	320	280
Medium scale power generation	4	80	85	40	320	340	160
Total weighted score					1290	1550	1265

Notes: U = Updraft Gasifier

D = Downdraft Gasifier

F = Fluidized bed Gasifier

From the Table 2.1, the downdraft gasifier has the highest weighted scores among the updraft and fluidized bed gasifier, thus, downdraft type is selected for the design of palm oil frond gasifier.

CHAPTER 3
METHODOLOGY

3.1 Methodology

Research methodology for this project mostly involve on the literature review, determine the palm oil frond properties through testing and design the gasifier based on the data obtained from the testing results. The methodology is shown as figure 3.1:

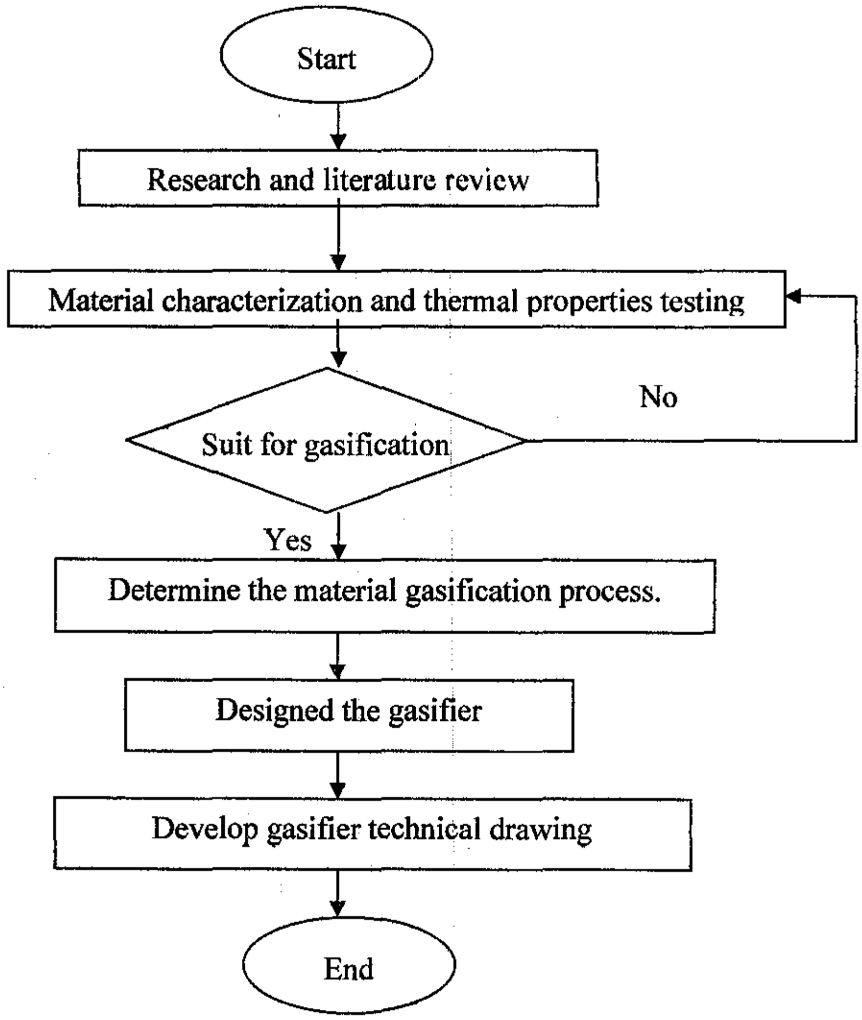


Figure 3.1: Project Methodology Flow chart

3.2 Material Testing

To determine the characteristic and thermal behavior of the palm oil frond, ultimate and proximate analysis were done as well the bomb calorimeter. The methodology of each testing are explained as follow:

3.2.1 Ultimate Analysis

Ultimate analysis was conducted to determine the chemical composition of material in percentage of carbon, hydrogen, nitrogen, and sulfur. The equipment for the testing is LECO CHNS 932 machine. In the combustion process, a nominal 2 mg sample is encapsulated in a tin or silver capsule. The sample is placed in the sample loading chamber and held until a dose of oxygen has been released. The sample is then dropped into the furnace at the same time the oxygen arrives. The sample is combusted by the heated oxygen-rich environment.

The products of combustion in the CHNS analysis are CO2, H2O, N2, and SOX. The gases, which are carried through the system by the helium carrier, are swept through the oxidation tube packed with either tungsten trioxide (which adds oxygen) or copper sticks (which removes oxygen), to complete the conversion to SO2. The H2O is swept through the non-dispersive infrared absorption detection system where it is measured, Anhydrone then removes the H2O and the remaining gases are swept through the SO2 and CO2. Lecosorb and Anhydrone leaving the helium carrier gas and N2 remove the CO2 and the H2O. The N2 is measured by thermal conductivity. Adjustments for blank, calibration, and weights are applied to the final integrated signal and the answers are displayed as weight percent carbon, hydrogen, nitrogen and sulfur. In the project, less than 2 mg of pulverized material was loaded into the capsule and flatten. A few capsules were loaded into the machine each time and the machine would automaticlly capture a capsule at one time to be analyzed. The CHNS Leco equipment is shown in Figure 3.2:

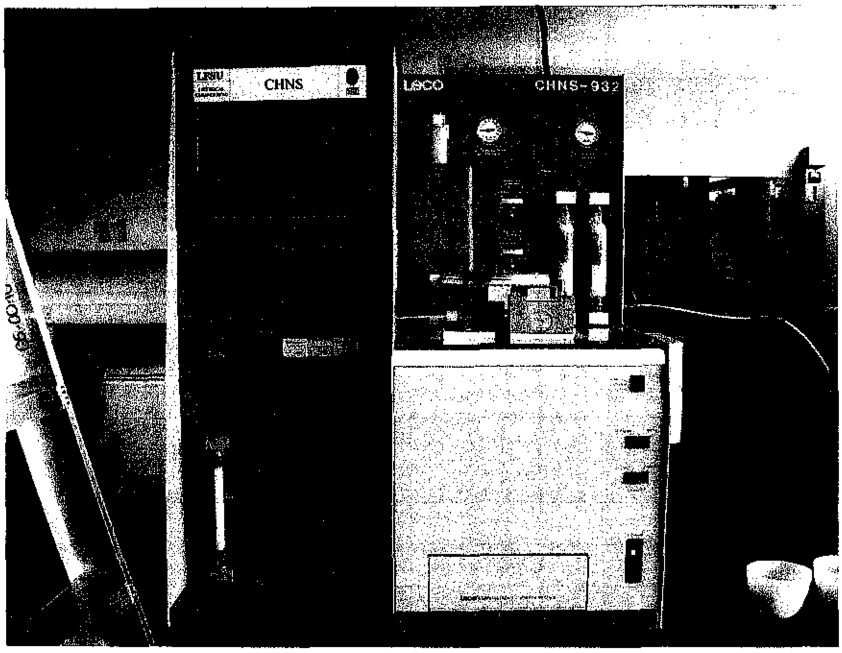


Figure 3.2: CHNS Leco

3.2.4 Experiment of Palm Oil Frond Density

The density of palm oil frond is obtained by conducted the experiment of water displacement for particular volume of material submerged into the water. One liter of water displaced is equivalent to one cubic meter of the submerged material. The density of the frond is calculated by the following equation:

$$\rho = \frac{M}{V}$$

Where ρ = Density of palm oil frond [Kgm^{-3}]

M= total mass of palm oil frond [Kg]

V = volume of displace water [m^3]

3.2.2 Proximate Analysis

Proximate analysis was carried out to determine the weight percentage of moisture, volatile matter, fixed carbon and ashes in the oil palm fronds. The test was done using a Perkin Elmer TGA7 Analyzer, shown in Figure 3.3. Software used for the test was PYRIS 2003. A set of 3 runs were conducted to obtain the averaged value for the desired parameters. TGA analyzer requirement of sample weight is between 10.00mg to 15.00 mg. The parameter of TGA analysis were set based on ASTM E 1131-98, Standard Test Method for Compositional Analysis by Thermogravimetry. The testing procedures are as below:

1) Hold the material for 1 min at 500 ^{0}C
2) Heat from 50 ^{0}C to 110 ^{0}C at 60 ^{0}C/min
3) Hold for 5 min at 110 ^{0}C
4) Heat from 110 to 800 at 100 ^{0}C/min
5) Hold for 3 min at 800^{0}C
6) Heat from 800 C to 900 ^{0}C at 20 ^{0}C/min
7) Hold for 5 min at 900 ^{0}C

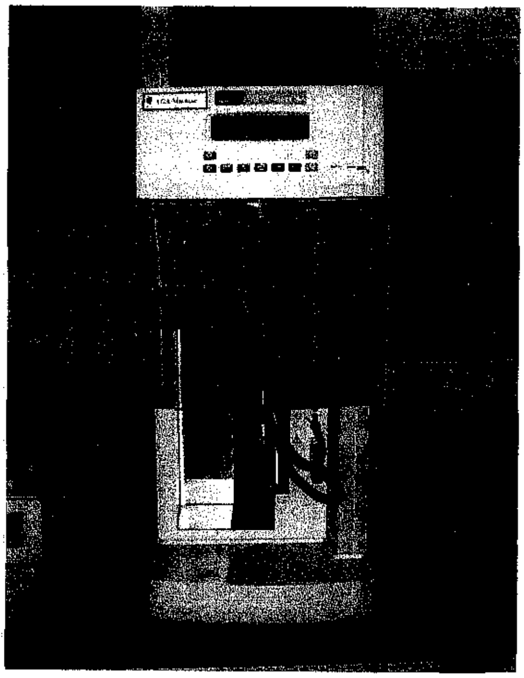


Figure 3.3: Perkin Elmer TGA7 Analyzer

3.2.3 Bomb Calorimeter Testing

The bomb calorimeter is the most common device for measuring the heat of combustion or calorific value of a material. The basic principles behind bomb calorimeter are:

1) Supply oxygen to the sample to ensure it burns completely
2) Burn the sample quickly so that the heat produced has little time to diffuse into the surrounding environment before measuring the total change in the water temperature
3) Enclose the reaction inside a strong chamber to contain the high pressure of the rapidly-burning sample.

The equipment for bomb calorimeter testing is shown in Figure 3.4.

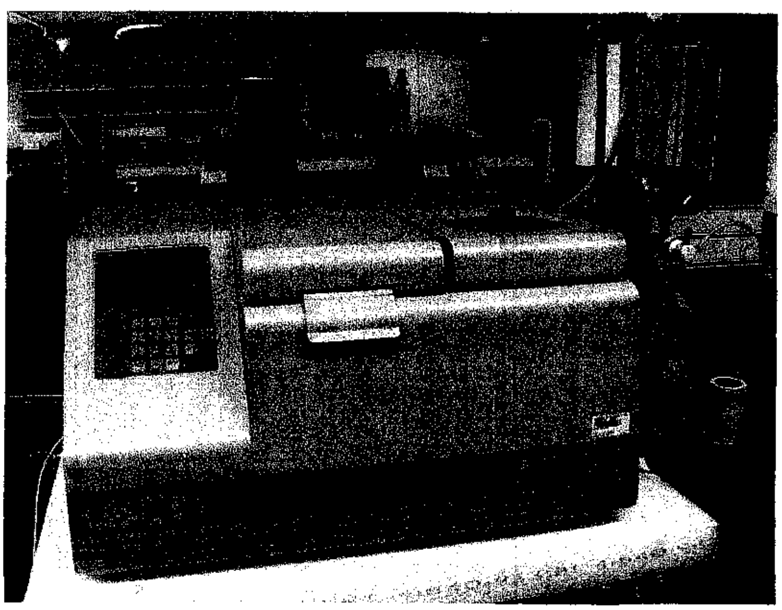


Figure 3.4: Bomb Calorimeter

3.3 Gasifier Design

The gasifier was design based on palm oil frond characteristic as the feed material. Methodology used for the detail calculation of the gasifier dimension was obtained from the papers and journal in the internet. The process in gasifier, superficial velocity and the volume of material capacity are those methodology used in designing the gasifier.

3.3.1 The Gasifier Process

Four main processes in gasifier are the drying, pyrolysis, combustion and reduction process. The reactions in combustion and reduction zone are been emphasized to obtain the production rate of the producer gas per hour. First, the chemical formula of the palm oil frond to be obtained to determine the moles of composition yield for each process. The chemical formula is formulated by determine the composition of carbon, hydrogen, and oxygen of the material through ultimate analysis.

In the combustion process, the biomass reacts with air from surrounding to produce the carbon monoxide, water vapor and nitrogen. Since the frond undergo pyrolysis and drying process, only the fixed carbon of the frond will react with the air to produce carbon dioxide and water vapor. The air fuel ratio can be determined in this process. The reaction occurs in the combustion zones are given as below [6]:

(a) $C + O_2 \Leftrightarrow CO_2$ -401.9 kJ/kmol

(b) $H + \frac{1}{2} O_2 \Leftrightarrow H_2O$ -241.1 kJ/kmol

In the reduction zone, the carbon dioxide and water vapor will be reduced to carbon monoxide and hydrogen due to reaction with high temperature of char. The reactions occur in the reduction zone of gasifier are given as below [26]:

(a) $C + CO_2 \Leftrightarrow 2CO$ 164.9 kJ/kmol

(b) $C + H_2O \Leftrightarrow CO + H_2$ 122.3 kJ/kmol

(c) $CO + H_2 \Leftrightarrow CO + H_2O$ 42.3 kJ/kmol

(d) $C + 2H_2 \Leftrightarrow CH_4$ 0

(e) $CO + 3H_2 \Leftrightarrow CH_4 + H_2O$ -205.9 kJ/kmol

Only equation (a) and (b) are considered in this project since the reactions are the main reduction process [6]. Gas production rate is obtained by determine the volume of carbon monoxide and hydrogen and compare with the general volume content of the particular composition from the literature study.

3.3.1 Gasifier Dimension

Dimensioning gasifier is closely related to superficial velocity (hearth load) concept. Superficial velocity control the performance, gas production rate, gas energy content, fuel consumption rate, power output, char and tar production rate.[8] The superficial velocity, SV of gasifier is defined as:

SV = Gas production Rate /Cross sectional area = (m^3/s) (m^2) = m/s

The dimension of combustion and pyrolysis zone of gasifier can be obtain by dividing the amount of producer gas produce from the reduction process with the range value of SV for the particular gasifier zones. The value of SV is shown from the Table 3.1 below:

Table 3.1: Superficial Velocity for Various Gasifiers [8]

Gasifier type	Pyrolysis Zone SV m/s	Char Zone SV m/s
Imbert	0.63	2.5
Biomass	0.24	0.95
SERI Air	0.28	0.28
SERI Oxygen	0.24	0.24
Syn-Gas air	1.71	1.71
Syn-gas oxygen	1.07	1.07
Buck Rogers (Chern)	0.23	0.23
Buck Rogers (Wallawender)	0.13	0.13

The height of the combustion zone is determined from Table 3.2 where the diameter of the narrowest constriction of the zones is needed to be determined first.

Table 3.2: Dimension of combustion zone [11]

Inside diameter (m)	**Minimum length (m)**	**Engine power (kilowatt)**	**Typical engine displacement $(10^{-3} m^3)$**
0.05	0.41	3.73	1.64
0.10	0.41	11.19	4.92
0.15	0.41	22.37	9.83
0.18	0.46	29.83	1.31
0.20	0.51	37.28	1.64
0.23	0.56	48.47	2.13
0.25	0.61	59.66	2.62
0.27	0.66	74.57	3.28
0.30	0.71	89.48	3.93
0.33	0.76	104.40	4.59
0.36	0.81	119.31	5.24

The air inlet for combustion is an important part in gasifier design. The size and the height of the air nozzle will affect the air flow for the combustion process, thus the composition of the producer gas. The size and amount of air nozzle is determined from Table 3.3 and the height of air inlet nozzle is determined by figure 3.1 as follow:

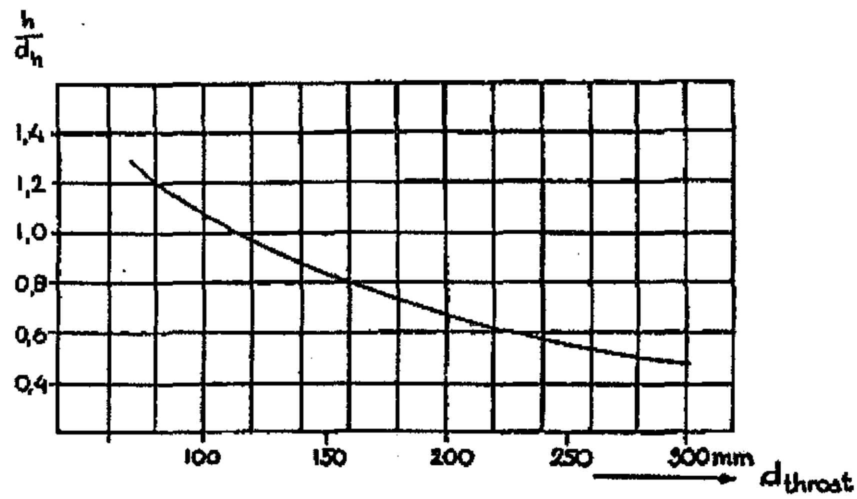
Table 3.3: Dimension of air nozzle [10]

Dt (mm)	Dn (mm)	N
130	13.5	5
150	15	5
170	14.3	7
190	16	7
220	18	7
270	22	7
300	24	7

Notes: Dt = Diameter of narrowest constriction of combustion zone

Dn = Diameter of air nozzle

N = Number of air nozzles



Notes: h = Height of air nozzle

d_n = Diameter of air nozzle

Figure 3.5: Height of air inlet nozzle [10]

The dimensions of hopper and reduction zone are determined by the volume capacity of palm oil frond to be feed into the gasifier in one operation. Palm oil frond volume is determined by the following equation:

$$\text{Volume } [m^3] = \frac{\text{Mass [kg]}}{\text{Density [kg/m3]}}$$

Drying zone is design accommodate the maximum load of gasifier while the reduction zone is dimensioned to provide area for volume of palm oil frond after gasification process.

3.3.2 Construction Material

The material for the gasifier body is determine to withstand the high temperature inside the gasifier due to the heat generate from the processes. Material is selected based on literature review and the wall thickness are determined using the excel software application.

The insulation is important in gasifier design to prevent excessive heat loss to the surrounding. The heat generate from the combustion process is used for drying, pyrolysis and reduction process. The material is select based on literature study and the wall thickness is determined to apply with the palm oil frond gasifier application.

3.4 Gasifier Technical Drawing

The technical drawing is based on gasifier design from the calculation of design parameter of the gasifier. The software used for drawing the technical drawing is AutoCAD 2007 software. The technical drawing of the palm oil frond gasifier is shown in Appendix C.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Material Testing

The results for the material testing and design of palm oil frond gasifier are shown in this chapter. The characteristics of palm oil frond are determined from ultimate and proximate analysis, bomb calorimeter testing shown as follow:

4.1.1 Proximate Analysis

The moisture content, volatile matter, fixed carbon content and ash content of pal oil frond is shown in Figure 4.1 below:

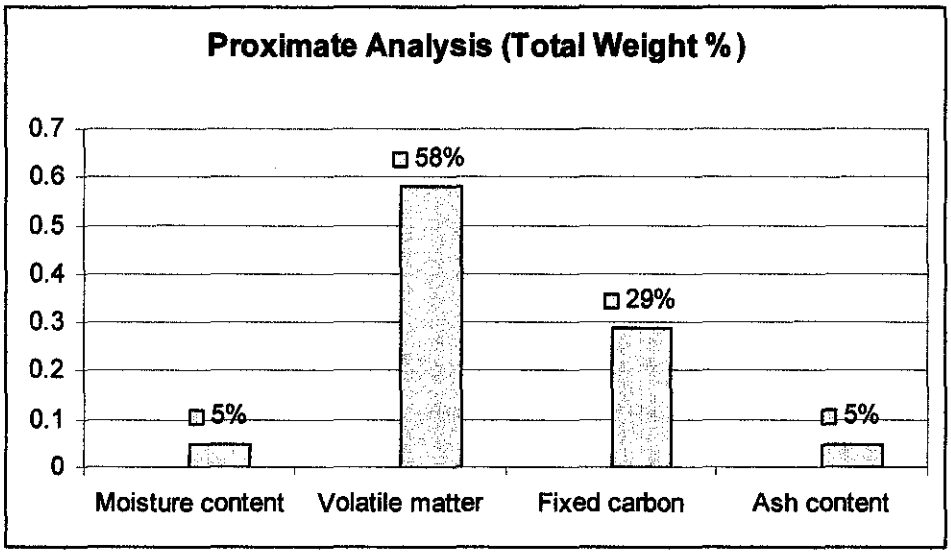


Figure 4.1: Proximate Analysis Results

4.1.2 Ultimate Analysis

The result of ultimate analysis is shown as in Figure 4.2 in the percentage of carbon, hydrogen, nitrogen and sulphur content of the oil palm's frond and leaves.

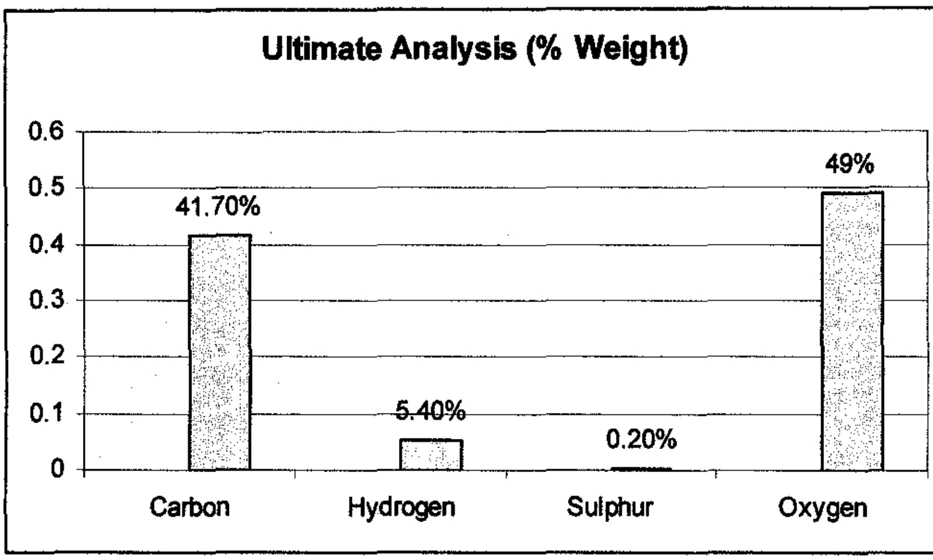


Figure 4.2: Ultimate Analysis Results

4.1.3 Palm Oil Frond Density

The result of palm oil density experiment is shown as in Table 4.1:

Table 4.1: Palm oil density experiment results

	Test 1	Test 2
Mass of the material, kg	7.638	4.212
Volume of displaces water, L	10.8	5.85
Material density, kg/m^3	702	702
Average density, kg/m^3	702	

4.1.4 Calorific Value

From the testing, 3 run of experiment was done and the weight of each sample is 1.4, 1.6 and 1.8 gram. The average calorific value obtained is 4558.23 cal/g.

4.2 Gasifier Design

4.2.1 Gasifier technical drawing

The design and dimension of palm oil frond gasifier is shown as in technical drawing, Figure C-1. The detail calculation and design of the gasifier are shown in Appendix C.

4.2.2 Gasifier Technical Specification

The specification of the palm oil frond gasifier is shown as in Table 4.3. The detail calculation of the specification is shown in Appendix B.

Table 4.2: Gasifier Technical Specification

Type	Double throat down draft gasifier
Fuel consumption	150 kg h^{-1}
Capacity	166 kWh^{-1}
Gas produced	531.62 m^3/h
Outer diameter	0.8 m
Total height	2.5 m
Hopper capacity	450 kg
Material construction	Stainless steel
Ash removal unit	Rotating type made of cast iron

4.3 Gasifier Auxiliary System

The system function as to purify the gas produced from the reactor (gasifier) before used in the engine application. The gasifier auxiliary system consists of heat exchanger, gas filter, control and safety valves and the air blower. The schematic of the gasifier auxiliary system is shown in Figure 4.3.The detail description of auxiliary system is described in Appendix D:

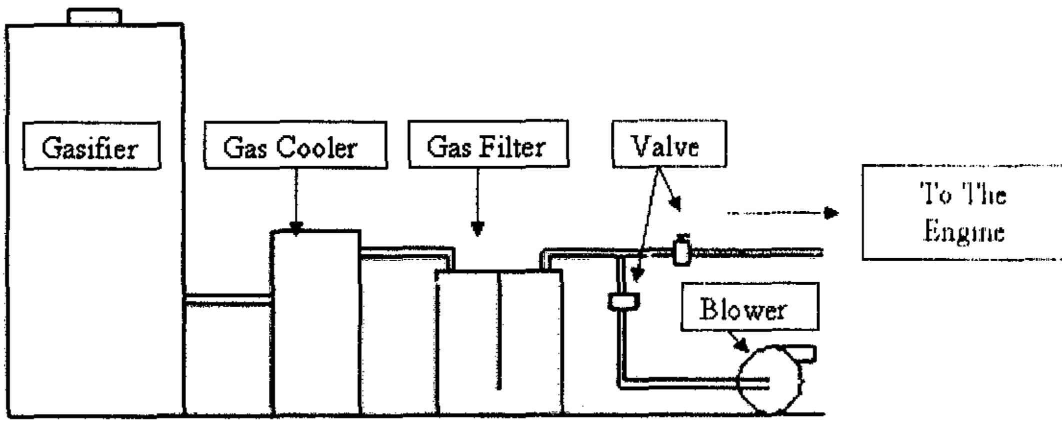


Figure 4.3: Schematic of Gasifier Auxiliary System

4.4 Energy Balance

The power generation of the gasifier system is obtained by considering the efficiency of the gasifier of 70% and the gas produced of 30% for mechanical work. The overall gasifier power generation is shown in Figure 4.4:

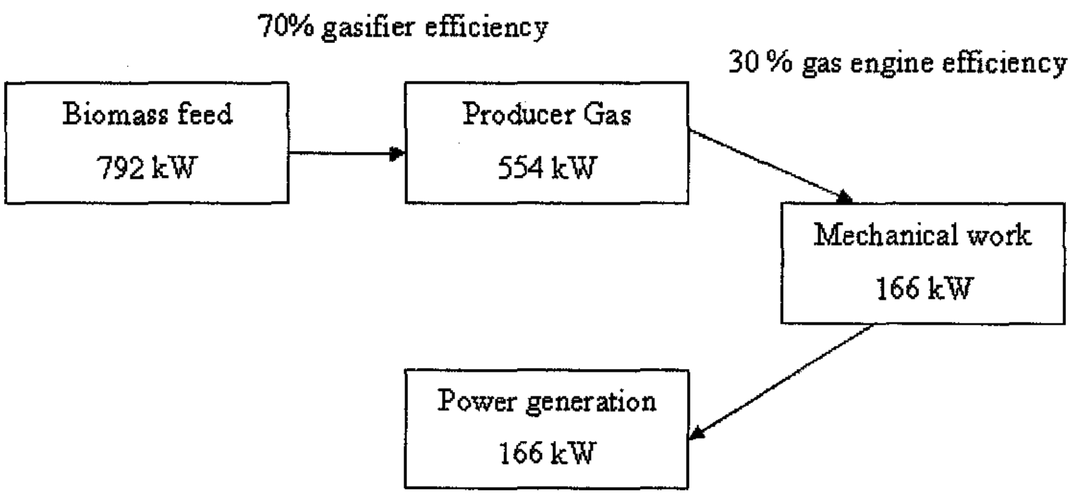


Figure 4.4: Energy Balance

4.3 Discussions

From the results of proximate analysis, the palm oil frond is potentially to be used as the feed material since the moisture content is lower than 25%, the volatile matters is exceed 30 %, and the ash content is in acceptable range of 5-6% [10]. The chemical formula of palm oil frond is $CH_{1.55}O_{0.88}$, determined from the result of ultimate analysis. The palm oil has density of 702 kg/m^3 and calorific value of 19 MJ/kg, which are suitable for gasification process.

The volume of producer gas calculated through the stoichiometric reaction is 531.62 m^3/h which state from the literature review that as the temperature increases from 700 to 800 ^{0}C, the gas yield increases from 3.2 to 3.5 m^3/kg. [3]. The stoichiometric reaction shown in Appendix B is assumed that all the carbon dioxide and water vapor reacted with char to produce carbon monoxide and hydrogen at the optimal temperature and conditions.

The maximum weight of palm oil gasified in one hour is set to be 150 kg as the power generated is sufficient for power generation application and the availability of reference and guidance on how to design the gasifier with the respective specification. The overall power generate from the gasifier system is 166 kW and the engine with 200 kW load can be used in the gasifier auxiliary system as shown in Figure to generate the power.

The height of gasifier is 2.5 m and has the outer diameter of 0.77m. The detail dimension for each gasifier zones is shown in Appendix B. The dimension of the gasifier is likely similar to the wood gasifier for respective medium scale power generation. For the safety purpose, the gas seal is installed at each of opening port to avoid the leakage of poisonous carbon monoxide. From the economic analysis of the gasifier shown in appendix E, the profit will be gained starting at the 5th year. Thus, the gasifier system can be commercialized as one of power generating system.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

As the conclusion, the palm oil frond can be used as feed material in gasifier by conducting the proximate, ultimate analysis and bomb calorimeter testing. The results of proximate analysis show the palm oil frond has moisture content of 5%, volatile matter of 59%, ash content of 5%, and fixed carbon content 29%. The bomb calorimeter show the material has 19 MJ/kg of energy content. A downdraft type gasifier is designed based on Imbert gasifier principle. The gasifier has the capacity of 150 kg material per hour and the producer gas produced from the thermodynamic reaction is 531.62 m^3/h. The power generated is 166 kW per hour with 70% of gasifier efficiency. Dimension of the gasifier is based on the practical superficial velocity for updraft gasifier which is 2.5 and 0.6 m/s respectively for combustion and pyrolysis zones. The gasifier has 4 main parts which are the reduction, combustion, pyrolysis and drying zones. The gasifier also has two main throats, for the pyrolysis zones and the combustion zone. The main function of the throat is to enhance the heat concentration on the combustion and pyrolysis zone area. The total height of the gasifier is 2.5 m and the outer diameter is 0.8m. The construction material for the gasifier's body is stainless steel 310 to withstand the high temperature of gasifier operating temperature and rock wool for the insulation material.

5.2 Recommendation

This project is meeting the objectives, but there are some improvements can be made for further development which are:

1) Simulation on the air and producer gas flow inside the gasifier which effects the composition of producer gas.
2) Study on palm oil frond preparation for updraft gasifier such as the particle size and size distribution to obtain the optimum gasification process.
3) Simulation on the heat condition inside the gasifier to ensure the optimal value of producer gas in various heat temperatures.
4) Small scale of gasifier prototype should be fabricated to determine experiment result of volume and composition of producer gas produced and the gasifier efficiency.
5) Determine the detail dimension and requirements of gasifier auxiliary system to enable the producer gas to be used for power generation.

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me: Mohd Azuan B. Mohamad Nor (019-441 5401)

erial : oil palm fronds and leaves

timate analysis

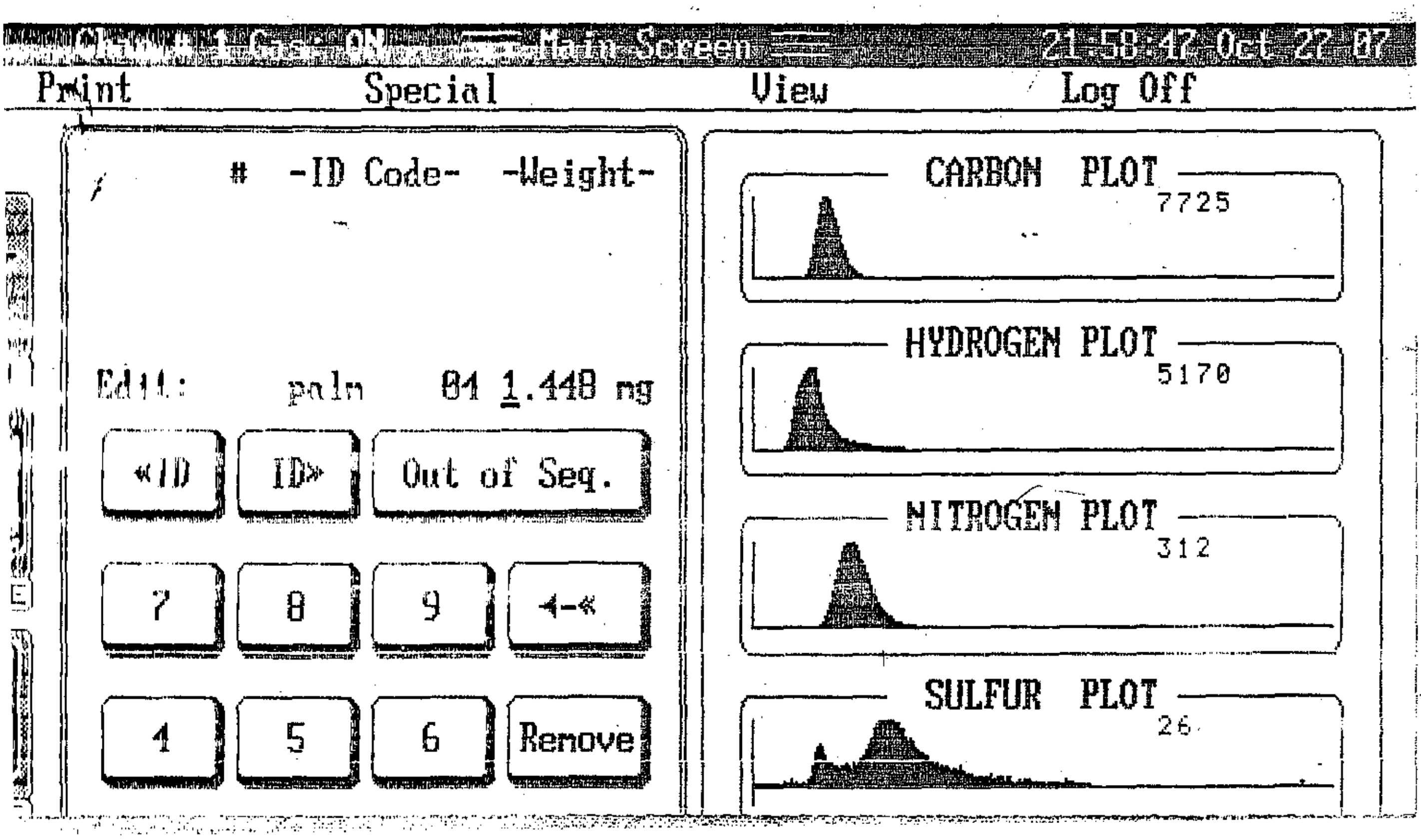
```
alm     01  Blank System Check  [redacted] mg Mst.=0.00     Chan # 1    20:59 Oct-27-07
 42.92%  H =     5.650%  N =     0.738%  S =    -0.079%
.00  Peak= 8314   Time =   150  Peak= 5459   Time =   100  Peak=  382   Time =   150  Peak=  108
95  Blk =0.001   Calib=0.7748  Blk =0.086   Calib=1.3247  Blk =0.036   Calib=0.9257  Blk =0.002

                        Change  Crucible
alm     02  Blank System Check  [redacted] mg Mst.=0.00     Chan # 1    21:01 Oct-27-07
 41.76%  H =     5.463%  N =     0.718%  S =     0.178%
00  Peak= 8078   Time =   150  Peak= 5338   Time =   100  Peak=  355   Time =   150  Peak=   40
95  Blk =0.001   Calib=0.7748  Blk =0.086   Calib=1.3247  Blk =0.036   Calib=0.9257  Blk =0.002

                        Change  Crucible
alm     03  Blank System Check  [redacted] mg Mst.=0.00     Chan # 1    21:04 Oct-27-07
 41.61%  H =     5.276%  N =     0.640%  S =     0.131%
00  Peak= 7725   Time =   150  Peak= 5170   Time =   100  Peak=  312   Time =   150  Peak=   26
95  Blk =0.001   Calib=0.7748  Blk =0.086   Calib=1.3247  Blk =0.036   Calib=0.9257  Blk =0.002

                        Change  Crucible
```

$O_2 = 51.881\%$ (handwritten beside run 02)

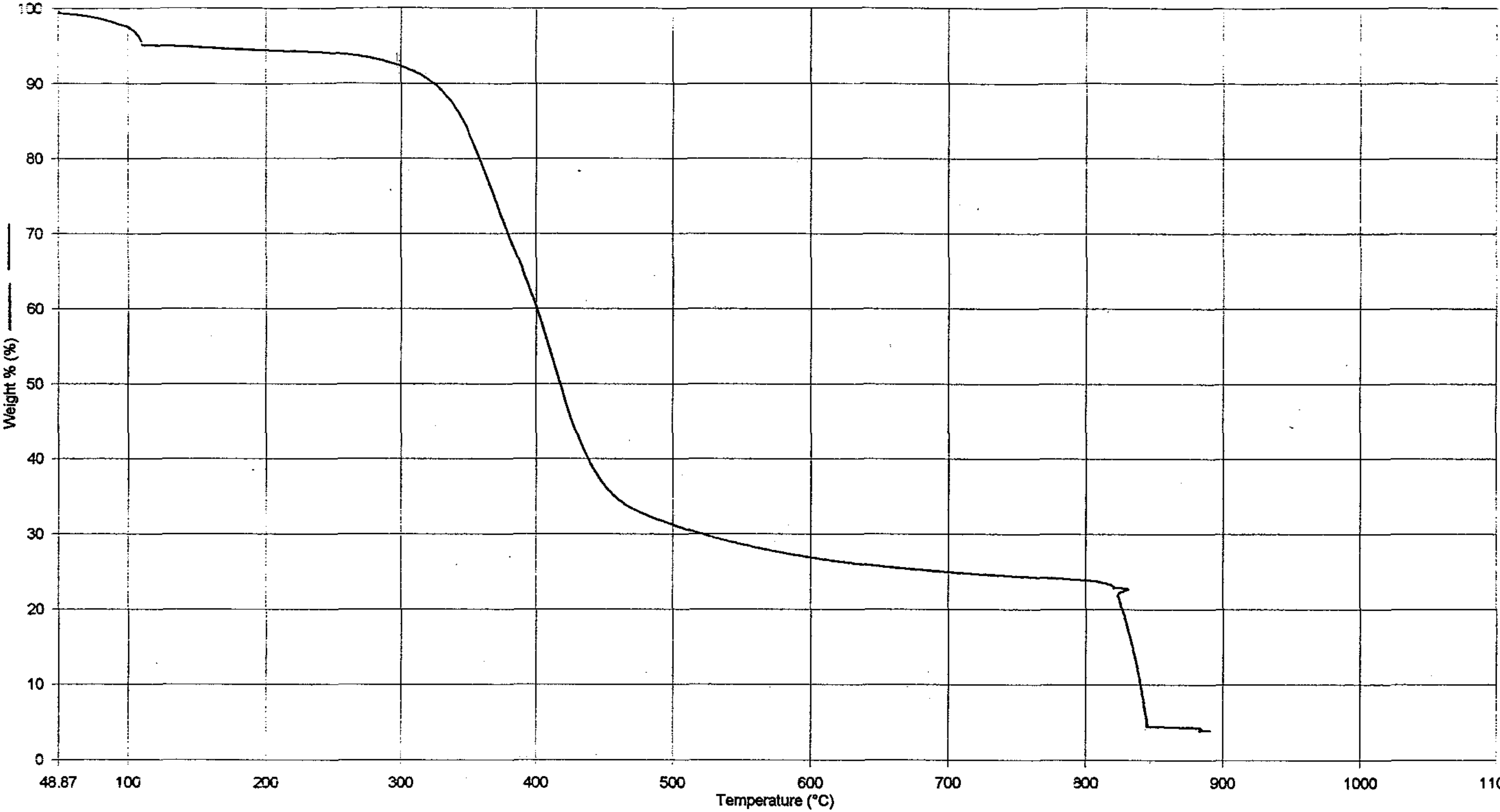
$O_2 = 52.343\%$ (handwritten beside run 03)

erage

41.7 H = 5.4 N = 0.7 S = 0.2 O_2 = ~~51.88~~ ≈ 52 %



Sample Weight: [illegible] mg
Initial Purge Gas: Nitrogen



1) Hold for 1.0 min at 50.00°C
2) Heat from 50.00°C to 110.00°C at 60.00°C/min
3) Hold for 5.0 min at 110.00°C
4) Heat from 110.00°C to 800.00°C at 100.00°C/min
5) Hold for 3.0 min at 800.00°C
6) Heat from 800.00°C to 900.00°C at 20.00°C/min
7) Hold for 5.0 min at 900.00°C

08:49:13 Nov 05, 2007
Q = 5578.3 cal/g
GCV(ad) = 5565.3 cal/g
ID Code : PM1
Operator : LAB
Method : METHOD 1
Weight = 1.40000 g
Bomb = 1
Calib = 4339.6
Fuse = 8.00 cm
Nitrogen = 0.00 ml
Sulfur = 0.00 ml
Hydrogen = 0.00 %
Total H2O = 0.00 %
Moisture = 0.00 %
Ash = 0.00 %
Initial Temp = 24.20 C
Delta T = 1.7996 C

09:07:53 Nov 05, 2007
Q = 4137.7 cal/g
GCV(ad) = 4127.6 cal/g
ID Code : PM2
Operator : LAB
Method : METHOD 1
Weight = 1.80000 g
Bomb = 1
Calib = 4339.6
Fuse = 8.00 cm
Nitrogen = 0.00 ml
Sulfur = 0.00 ml
Hydrogen = 0.00 %
Total H2O = 0.00 %
Moisture = 0.00 %
Ash = 0.00 %
Initial Temp = 25.68 C
Delta T = 1.7163 C

09:37:17 Nov 05, 2007
Q = 3993.2 cal/g
GCV(ad) = 3981.8 cal/g
ID Code : PM3
Operator : LAB
Method : METHOD 1
Weight = 1.60000 g
Bomb = 1
Calib = 4339.6
Fuse = 8.00 cm
Nitrogen = 0.00 ml
Sulfur = 0.00 ml
Hydrogen = 0.00 %
Total H2O = 0.00 %
Moisture = 0.00 %
Ash = 0.00 %
Initial Temp = 26.37 C
Delta T = 1.4723 C

Appendix B: Calculation of Gasifier Design

Palm Oil Chemical Formula

Total sample weight = 1.462 g

No. moles, n = mass/ molecular weight = $\frac{kg}{kg/kmol}$

Moles C = 5.1 x 10^{-5} kmol

Moles H = 7.9 x 10^{-5} kmol

Moles of O = 4.5 x 10^{-5} kmol

Chemical formula of palm oil frond = $CH_{1.55}O_{0.88}$

Oxidation Reaction

Moles of 150 kg of palm oil frond = 5.43 kmol

Moles of carbon for combustion = moles of 150 kg palm oil x fixed carbon content

= 5.43 x 0.29

= 1.57 kmol

Combustion Reaction of palm oil frond:

$$1.57\ CH_{1.55}O_{0.88} + a\,(O_2 + 3.76\,N_2) = b\,CO_2 + c\,H_2O + d\,N_2$$

C	1.57 = b	a = 1.49
H	1.55 x 1.57 = 2c	b = 1.57
O	0.88 x 1.57 + 2a = 2b + c	c = 1.22
N	3.76 a = d	d =5.60

$$1.57\ CH_{1.55}O_{0.88} + 1.49\,(O2 + 3.76\,N2) = 1.57\ CO2 + 1.22\ H2O + 5.60\ N2$$

Moles of carbon dioxide (CO_2) = 1.57 kmol
Moles of water vapor (H_2O) = 1.22 kmol
Air fuel ratio on molar basis, AF

AF = moles of air / moles of fuel

$$= \frac{1.49 + 5.60}{1.57}$$
$$= 4.52$$

The air fuel ratio on mass basis, $\bar{AF}$

$$\bar{AF} = 4.52 \left[\frac{kmol(air)}{kmol(fuel)} \right] \left[\frac{28.97 \frac{kg(air)}{kmol(air)}}{27.63 \frac{kg(fuel)}{kmol(fuel)}} \right]$$
$$= 4.74$$

Reduction Process

Reduction reaction occurs when the carbon dioxide CO_2 and H_2O will react with the char from combustion zone.

General reaction reduction process
$C + CO_2 = 2CO$
$C + H_2O = CO + H_2$

Reduction zone

$1.57.\ C + 1.57\ CO_2 = 3.14\ CO$
$1.22\ C + 1.22\ H_2O = 1.22\ CO + 1.22\ H_2$

Moles of carbon monoxide produce, CO = 3.14 + 1.22
= 4.36 kmol

Mass of CO = kmol of CO x Molecular Weight
= 4.36 x 28
= 122.08 kg

Density of CO at 500 $^0C = 0.5741\ kg / m^3$

Volume of CO = 122.08 / 0.5741
= 212.65 m^3

Average content of CO = 40 %
Total volume of producer gas = 531.62 m3/h @ 0.15 m3/s

Gasifier Dimension

Combustion Zone

Superficial Velocity, SV= Gas Production rate/ Cross Sectional = $(m^3/s)/(m^2)$

Ideal SV in char zone = 2.5 m / s [8]

$2.5 = 0.15\ m^3/s$ / area

Area of narrowest constriction = 0.06 m

Diameter of constriction = $\sqrt{\dfrac{areax4}{\eta}}$

Diameter of bottom side = 0.27 m

The length of inclination of frustum shaped combustion zone is defined as:

$$s = \sqrt{(R_1 - R_2)^2 + h^2}$$

Where h = the high of combustion tube = 0.7 m

R_1 = diameter of upper side

s = the length of inclination

Set the inclination of 60^0

$\sin 60^0 = 0.7$ m/ s

s = 0.81 m

Solve for above equation, R_1 is 0.647 m

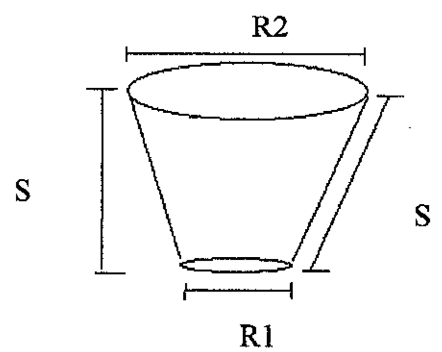


Figure B1: Sketch of combustion zone

Air Nozzle

From the Table 3.3, the gasifier is required to have 7 air nozzles with diameter of 22 mm each. The air nozzle height, determined from the figure 10 is 12 cm. The height of the air inlet nozzle plane should be 10 cm above the narrowest constriction

The height of air inlet is determined by taking the minimum hearth diameter at inlet is 0.2 m larger than the narrowest constriction in case of double throat design.

$$s = \sqrt{(R_1 - R_2)^2 + h^2}$$

Set the value of $R_2 = 0.27$ m
$R_1 = 0.47$ m
$s = 0.67$ m

The combustion wall is inclined with the inclination of 60 °.

The height of air inlet, h = 0.571 m
Air blast velocity

Volumetric flow rate / area of nozzle = velocity of air at outlet nozzle

Volumetric flow rate = 0.033 m3/s

Area of nozzle = 0.0027 m2

Velocity = 15 m/s

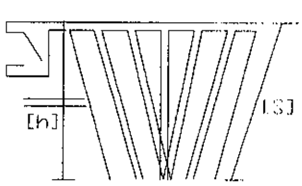


Figure B2: Sketch of air nozzle

Reduction Zone

The reduction zone is design to cater the volume of 150 kg of palm oil frond gasify for an hour operation. The height of the reduction zone should be more than 20 cm.

Volume of gasified material = mass / density

= 150 kg / 702 kg/m ^{3}

= 0.21 m ^{3}

The volume of reduction zone is defined as:

Volume = η d ^{2} h

0.21 m ^{3} = η 0.385 ^{2} h

Height of reduction zone, h = 0.45 m

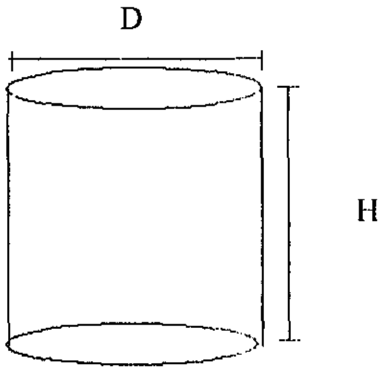


Figure B3: Sketch of reduction zone

Pyrolysis Zone

Superficial velocity for pyrolysis zone is 0.63 m/s [8]

Area of bottom side of pyrolysis zone, m ^{2} $= \dfrac{0.15m^3/s}{0.63m/s}$

$= 0.23$ m ^{2}

The diameter of bottom side of pyrolysis zone is determined as below:

Area of bottom side of pyrolysis zone, m ^{2} = η D ^{2} / 4

D = 0.55 m

Set the height of the zone is 0.4 m and inclination of 60 ^{0} for better feeding rate

Using equation of inclination length of frustum shaped pyrolysis zones

s = $\sqrt{(R_1 - R_2)^2 + h}^2$

Where s = 0,465 m

$h = 0.4$ m

$R_2 = D = 0.54$ m

Solve for above equation, the diameter of upper side of pyrolysis zone, R_1 is:

$R_1 = 0.77$ m

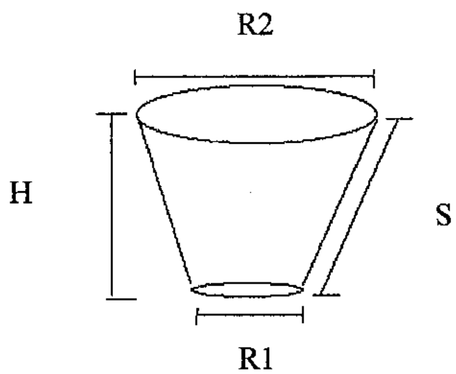


Figure B4: Sketch of pyrolysis zone

Drying Zone

The dimension of drying is determined to cater the maximum load of material for one gasifier operation. The mass of palm oil frond for maximum gasifier load is 450 kg. The volume of 450 kg of palm oil frond is obtained as below:

Volume, m^3 = Mass / Volume

$= 450 \text{ kg} / 702 \text{ kg/m}^3$

$= 0.64 \text{ m}^3$

The volume of drying zone is determined as below:

Volume of drying zone = Maximum load volume – (volume of combustion zone + volume of pyrolysis zone)

Volume of material occupy in combustion zone is determined from below equation:

$$V_c = \frac{\pi h}{12}(R_1 + R_1 R_2 + R_2)$$

Where height of zone, h $= 0.7$ m

Upper diameter, R_1 $= 0.26$ m

Bottom diameter, R_2 = 0.647 m

Solve the equation, gives the volume of combustion zone, V:

$V_c = 0.197\ m^3$

The volume of frond occupy in pyrolysis zone is obtained as below:

$$V_p = \frac{\pi h}{12}(R_1 + R_1 R_2 + R_2)$$

Where The height of zone, h = 0.4 m

Upper diameter, R_1 = 0.77 m

Bottom diameter, R_2 = 0.54 m

By solving the equation, the volume of material in pyrolysis zone is

$V_p = 0.18\ m^3$

The volume of drying zone, $V_d = [0.64 - (0.197 + 0.18)]\ m^3$

$= 0.263\ m^3$

To determine the height of the zone, h use the below equation:

$$h = \frac{\eta d^2}{4V}$$

∴ Height of hopper, h = 0.56 m

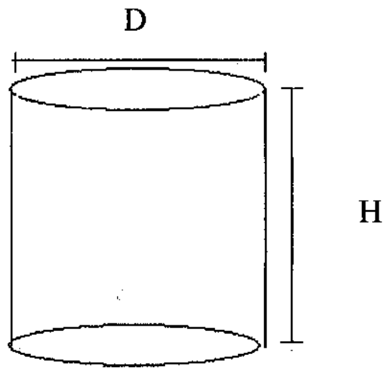


Figure B5: Sketch of drying zone

Insulation

The insulation material is rock wool since the material is a good insulator.

The thickness of the insulation is determined by the following equation:

$$w = \frac{\lambda(T_1 - T_0)}{q}$$

Where w = insulator wall thickness

λ = thermal conductivity through wall = 0.0036 $Wm^{-1}K^{-1}$

q = heat flux through wall =103.5 watts

T_1 = final temperature = 298 K

T_0 = initial temperature = 873 K

The wall thickness of rock wool is = 0.02m

Construction Material

The construction materials are stainless steel SX 310. The metal finds wide application in all high-temperature environments where scaling and corrosion resistance, as well as high temperature strength and good creep resistance, are required.

The wall thickness of stainless steel and mild steel is determined as follow:

$$W = \frac{P_D D_I}{2(\sigma_D x J) - \sigma_D} + e$$

Where; w = material wall thickness

P_D = Design pressure = 1.6 bar / 160560 Pa

D_I = inner diameter = 0.77 m

σ_D = Design stress

J= Full radiograph

e = corrosion allowance

The operating parameter for stainless steel sheet is described as below:

Design Stress (N/m^2): 2.08^8

Full Radiograph: 1

Corrosion allowance (m) 0002

The wall thickness of the stainless steel determined by solving the equation:

W_S = 0.002297m
= 3mm

Power Generation

The energy released by gasification of palm oil frond is determined by multiply calorific value of frond with the weight of material gasify in hour. The calorific value is obtained by material testing done during the project. From the bomb calorimeter testing result, the calorific value of palm oil frond is 4569.73 cal/ g, equivalent to 19 MJ/kg. The weight of palm oil frond been gasified in one hour is 150 kg. Thus the power generate from the designed gasifier is:

Conversion factor calories (cal) to Joule (J)

0.252 kcal = 1055 J

For 4.56973 kcal/g

4.56973/ 0.252 = 18.13

18.13 x 1055 J = 19,131.21 J/g

19,131.21 J/g = 0.019 MJ/g

Calorific value per kg

$$0.019\ \text{MJ/g} \times \frac{1000g}{1kg} = \frac{19MJ}{kg}$$

For 150 kg per hour, Power generate, MJ/h

$$\frac{19MJ}{kg} \times \frac{150kg}{1hour} = 2850\ \text{MJ/h}$$

To convert Mega Joule (MJ) to Kilowatt hour (kWh), divide value of MJ/h with 3.6:

3.6 MJ = 1 kWh

$$\text{Thus, power generate is} = \frac{2850}{3.6}$$

$$= 792\ \text{kWh}$$

792 x 1 kWh = 792 kWh

Biomass Feed = 792 kW

Producer Gas of 70% gasifier efficiency = 792 x 0.7 = 554.4 kWh

Mechanical work of 30% engine efficiency = 554.4 x 0.3 = 166.32 kW

Power generation = 166.32 kW

792kwh = 2.7 x 10^6 BTU / hr

Hheat generate for power generation is shown as below:

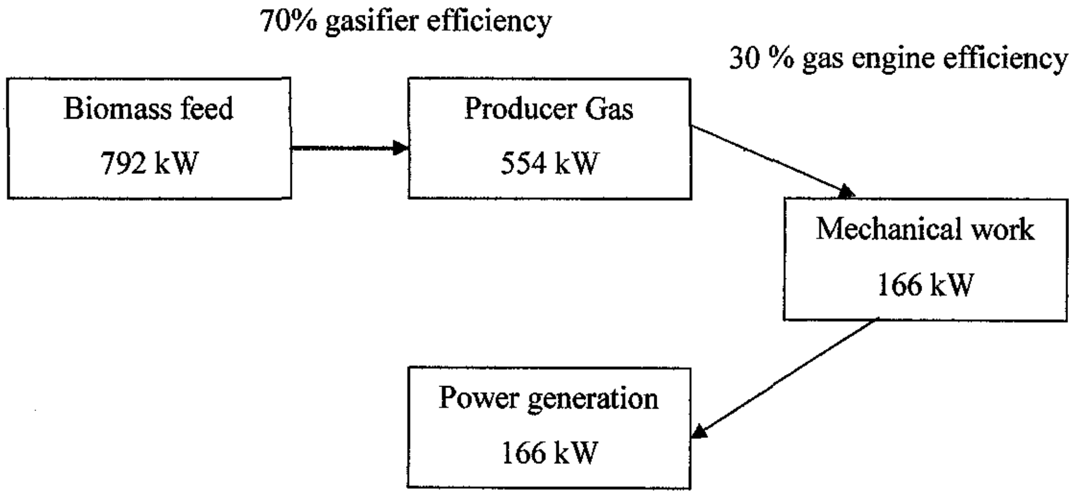


Figure B1: Energy Balance

Appendix C: Palm Oil Frond Technical Drawing

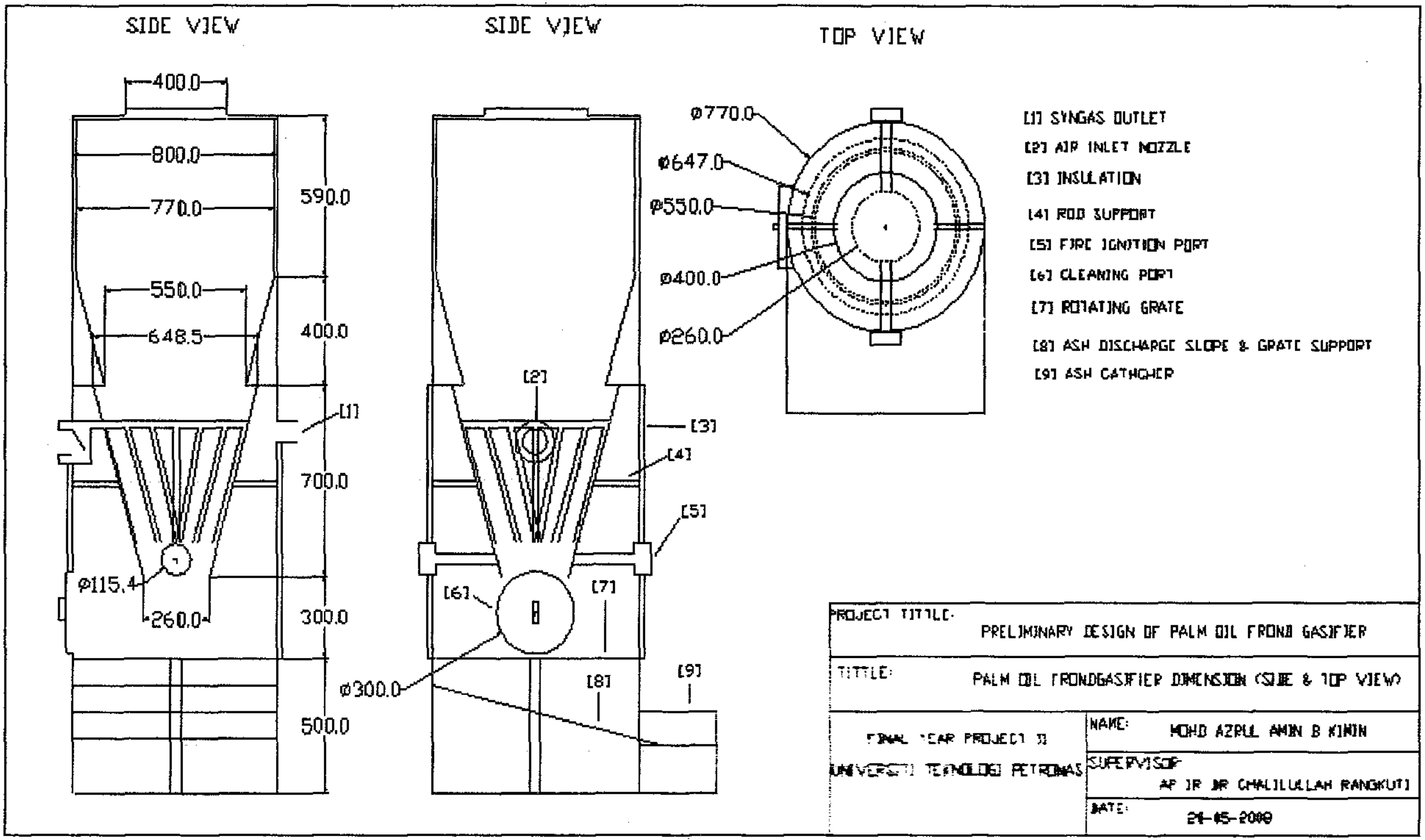


Figure C1: Palm Oil Gasifier Technical Drawing

Appendix D: Gasifier Auxiliary System

The gasifier auxiliary system consists of heat exchanger, gas filter, control and safety valves and the air blower. The system function as to purify the gas produced from the reactor (gasifier) before used in the engine application. The gas produced in down draft type gasifier has relatively high amount of ash contaminant since the gas flows through bed of char and ashes prior exit at the gasifier gas outlet. The schematic and the description of the equipments of the auxiliary system are described as below:

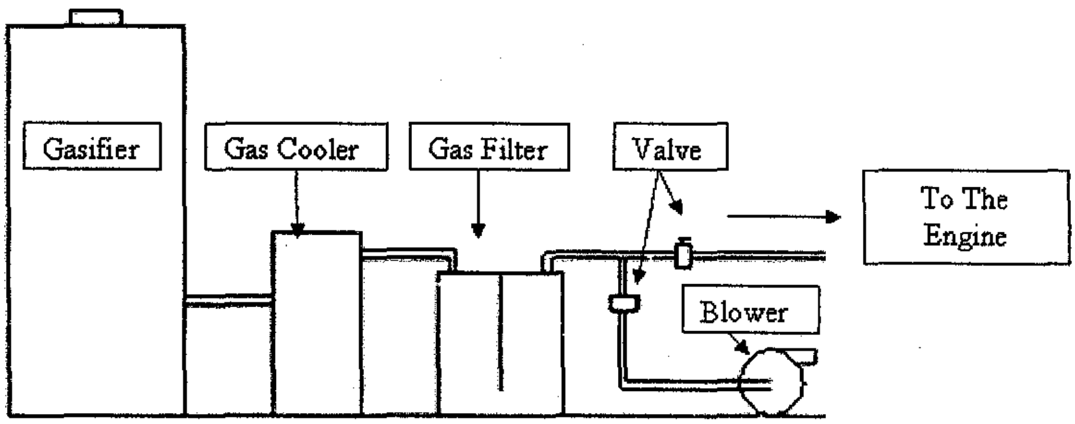


Figure D1: Schematic of Auxiliary system

i) Gas Cooler

A typical gas cooler is designed with the hot waste gas flowing vertically down over the outside of horizontal tubes, while cooling air passes inside the tubes. A large volume of cooling air is usually provided by multiple vanes axial or panel fans mounted on the side of the cooler. A complete system is normally supplied including tube bundles, outer shells, cooling fans, ducts, hoppers, structural supports, walkways, etc [1]. The piping is consider to be the necessary part of cooling system

ii) **Gas filter unit**

If a fire tube diameter of more than 10 in. is required, and then a 20-gal garbage can or a 30-gal oil drum should be used. The Filter unit could be fabricated in any shape or form as long as air tightness and unobstructed flow of gas are provided. The filter is filled on both side of the divider plate with the same material used for fuel in the gasifier unit. After carefully packing and leveling the material, place the lid on the filter container and close the latches tightly

Suitable dimension of gas filter is obtained according to the required volume, stated from the above paragraph.

The volume of the filter = 30 gallons / 0.1136 m3

$$0.1136 \text{ m3} = \frac{\eta D^2}{4} \text{ x h}$$

Set height, h = 1 m

The diameter, D = 0.38 m

iii) Valves

Gate valves, butterfly valves, check valves, gate and plug valves van be used in the piping system to control or block the gas flow from the gasifier into the auxiliary equipments. The valve must be design according to API 6D or API 6FD.

iv) Blower

The blower is used to supply air at the combustion zone particular during the gasifier start up process. After the start up sequence, the function of blower will be taken by the engine manifold. The engine will suck the producer gas, creating vacuum area in combustion zone. The air from the surrounding will flow to the vacuum space, provide air for combustion process. The suitable horsepower (Bhp) of the blower for the specific gasifier capacity is determined as follow:

$$\text{Bhp} = [\frac{WRT}{550} \text{ x } 0.283 \text{ x e}] [(P_2/P_1)^{0.283} - 1]$$

Where

W= air weight per second, lb/s

P_2 = pressure outlet = 100 mbar

P_1= pressure inlet

R = gas constant

T = temperature = $80^0 C$

e = blower efficiency

Assume the blower inlet and outlet pressure is 14 and 15.45 Psi respectively and the inlet temperature is 80^0C.

The value of W is calculated from the moles of air required in complete combustion of 150 kg palm oil frond per hour.

Weight of air = Moles of air x Molecular Weight of air

= 5.145 kmol x 28.9

= 148.69 kg @ 327.81 lb

To obtain the weight of air per second, divide with ($\frac{1hour}{3600s}$), thus the W = 0.091 lb/s

$$Bhp = \frac{636x53.5x0.091}{550x0.283x0.6}\left[\left(\frac{15.45}{14}\right)^{0.283} - 1\right]$$

= 0.94 @ 1 hp

Appendix E: Gasifier Economic Analysis

A) Capital cost = cost of gasifier system + civil construction cost = RM 1200000

(i) Gasifier system cost = RM 1, 150,000

(ii) Civil construction cost = RM 50, 000

B) Annual fixed Cost = Maintenance cost + Worker Salaries + Electricity = RM 100000

(i) Maintenance cost = RM 38, 000

(ii) Workers Salaries = $\frac{2 \text{ workers}}{\text{shift}} \times \frac{3 \text{ shift}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{\text{RM } 24}{\frac{\text{worker}}{\text{day}}}$ = RM 52560

(iii) Electricity = 6kW x $\frac{\text{RM } 0.18}{kWh^{-1}}$ x 8760 h = RM 9600

C) Annual Revenue = 166 kW x $\frac{\text{RM } 0.26}{kWh^{-1}}$ x 8760 = RM 378082

Table E1: Gasifier Economic Analysis

Year	1	2	3	4	5	6	7	8
Capital Cost	1200000	0	0	0	0	0	0	0
Fixed Cost	0	100000	100000	100000	100000	100000	100000	100000
Annual Revenue	0	378100	378100	378100	378100	378100	378100	378100
Cash In	-1200000	308100	308100	308100	308100	308100	308100	289800
Cumulative Cash In	-1200000	-891900	-583800	-294000	14100	322200	630300	920100

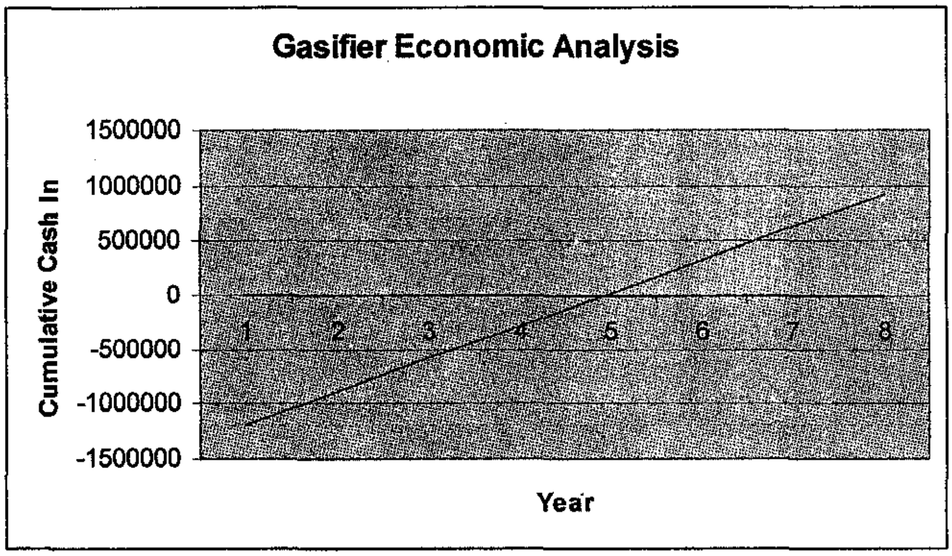


Figure E 1: Gasifier economic Analysis

From the above graph, the gasifier system will contribute profit at 5th year with annual profit of RM 14100.