CERTIFICATION OF APPROVAL

Experimental Study of Oil Palm Biomass Waste Mixture for Energy Potential

by

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Approved by,

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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.

KEE LIAN SOON

ABSTRACT

Malaysia is one of the largest producer and exporter of palm oil country. Oil palm industry plays a major role in the economic development of the country. As a result, palm oil waste generated is increased. Among the waste generated, palm oil mill effluent (POME) is considered the most harmful waste to the environment if discharged untreated. The sludge from POME is a source of pollutant and results in bad odours. At the same time, the oil palm fronds are pruned regularly but have little use and left on the ground in a huge quantity for natural decomposition which is a slow and uneconomical process. Considering their large and consistent supply, oil palm fronds and POME sludge mixture as an alternative biomass fuel could be a promising source of energy. In this research, an attempt has been made to convert these residues into biomass fuel. The feasibility of POME sludge and oil palm fronds mixture as an alternative biomass fuel is studied. The study is conducted by developing experimental testing for the biomass fuel in briquette form and the performance of each sample with different weight percentage is investigated via standard tests. These biomasses are converted into a compressed form of briquette through a simple briquetting process. The experiments conducted on the briquettes are ultimate analysis, calorific value test, burning characteristics test, dimensional stability test, crack analysis and durability test. Ultimate analysis is carried out to determine the contents of carbon, hydrogen, nitrogen and sulfur. The energy content in the biomass fuel is determined by using bomb calorimeter. The objectives of burning characteristics test are to test the briquette's ignitability and time taken to burn to ashes. Durability, stability and crack analyses are also performed experimentally to evaluate the transport, handling and storage characteristics of the briquettes. Experimentally, it is found that POME sludge and oil palm fronds mixture as an alternative biomass fuel is feasible.

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LIST OF ABBREVIATIONS

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CPO	Crude palm oil
DOE	Department of Environment, Malaysia
EFB	Empty fruit bunches
FFB	Fresh fruit bunches
POME	Palm oil mill effluent

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

Oil palm is one the most rapidly expanding crops and plays a major role in the economic development of many countries. Malaysia has the most ideal climate conditions for growing oil palm. The growth of the palm oil industry in Malaysia has been phenomenal over the last 4 decades. Nowadays Malaysia is the world's second largest producer and exporter of palm oil country as shown in the statistics from Figure 1.1. In Malaysia, the oil palm industry has contributed a lot to the country's economic development. In fact, crude palm oil (CPO) production has increased from only 1.3 million tonnes in 1975 to approximately 18.60 million tonnes in 2010 [1, 2]. Meanwhile, the total oil palm planted area in the country increased to 4.85 million hectares in 2010 with 418 crude palm oil mills, 18 oleochemical plants, 59 refineries and 57 downstream industries. [1, 3].

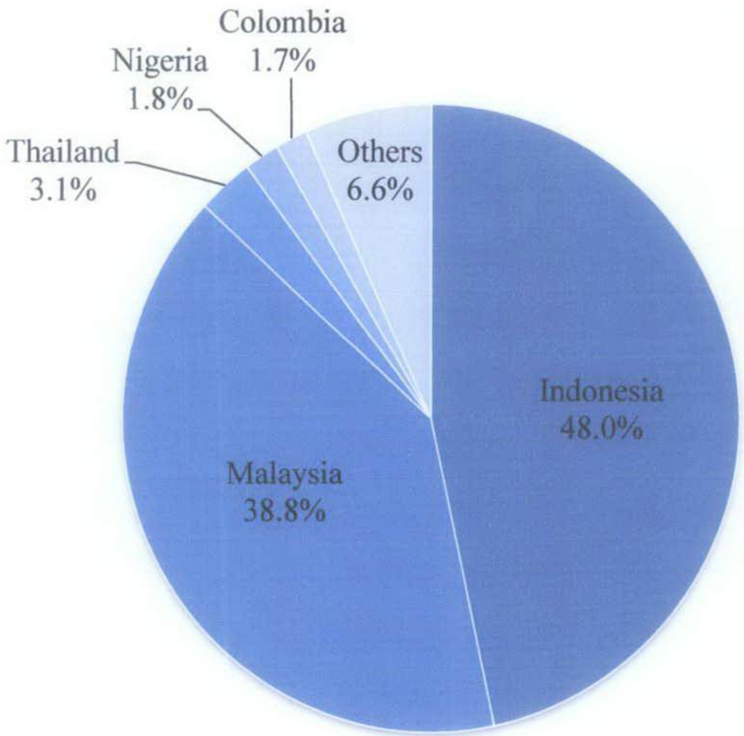


Figure 1.1: World palm oil production by country in 2010 [2]

Nevertheless, palm oil industry is one of the most pollution generating agro industry in Malaysia. This important economic activity generates a large amount of wastes and liquid effluent from milling processes. The two main wastes resulting from palm oil production in a mill are solid and liquid wastes. The solid wastes typically consist of fronds, palm kernel shells, mesocarp fruit fibers and empty fruit bunches. The liquid waste generated by the extraction of palm oil comes mainly from oil room after separator or decanter. This liquid waste combined with the wastes from sterilizer condensate and cooling water known as palm oil mill effluent (POME).

Hence, the increase in number of mills will generate more environmental problem. It is estimated that for each tonne of CPO that is produced, 5–7.5 tonnes of water are required, and more than 50% of this water ends up as POME [4]. It has been reported that for every tonne of the CPO produced, about 3.5 m^3 of POME is generated [4], which indicates that more than 55 million m^3 of POME is generated from the palm oil industry in 2010.

With the significantly large plantations areas in Malaysia, a large amount of fronds are pruned regularly during the harvesting of fresh fruit bunches (FFB). In 2003, it was estimated that 36 million tonnes of pruned fronds were produced [5], with an average rate of 24 pieces per year from every oil palm tree. From another point of view, for every tonne of palm oil produced from FFB, a farmer harvests around 6 tonnes of oil palm fronds [5].

Despite the fact that the palm oil industry is one of the causes of the environmental pollution, not enough effort has been done to reduce the negative effects [1]. However, an increasingly stringent environmental regulation from the government and increased public awareness of pollution problems caused the palm oil industries facing tremendous challenges. On the other hand, the biomass produced from the oil palm waste has a great potential as a renewable energy source and the use of biomass briquettes can earn carbon credits for reducing emissions in the atmosphere.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

As one of the world largest producer of palm oil, huge quantities of wastes are produced in this industry. The process of oil extraction results in production of palm oil mill effluent (POME). POME also contains substantial quantities of solids which are left after anaerobic treatment. These solids are commonly known as POME sludge. Therefore due to large quantity of POME production each year, the amount of sludge increases, respectively. This sludge results in bad odors and is considered as a source of water and ground pollution. Therefore, there is room to utilize the sludge as an alternative biomass fuel.

Besides, Malaysia has an abundant supply of oil palm fronds due to the large plantation areas in the country. The fronds are pruned regularly but have little use and left on the ground for natural decomposition which is a slow and uneconomical process. Open burning or simply abandon the waste away is a great lost of energy source since these biomasses have quite significant energy content.

Considering their large and consistent supply, oil palm fronds and POME sludge mixture as an alternative biomass fuel could be a promising source of energy.

1.2.2 Significant of the Project

Today the most economical biomass fuels for generating electricity come from the organic by-products of food, fiber, forest and animal manure [6]. The abundant availability of oil palm by-products biomass for use as energy generation would definitely path the way for the future development in Malaysia.

This is significantly important as it helps solving the problems concerning pollution by the by-products. At the same time, this increases the profitability by supplying of surplus energy to local electricity net and generates local employment by conversion of biomass residues into value added products. This technology could also be utilized by other countries around the world for better management of a sustainable and environmental friendlier electricity generation industry.

1.3 OBJECTIVES AND SCOPE OF STUDY

Objectives of this project are as follows:

i. To study on the feasibility of palm oil mill effluent (POME) sludge and oil palm fronds mixture as an alternative biomass fuel.
ii. To develop experimental testing of the biomass fuel in briquette form.
iii. To investigate performance of each sample with different weight percentage.

The scope of study is mainly on preparing biomass briquette and conducting experiments on each sample in order to investigate their performance. A general review of POME and frond characteristics is first carried out. This was followed by a refined review of the literature in order to gain thorough understanding for the commencement of the laboratory and experimental aspects of the project.

In line with the second and third objectives, the POME sludge and frond were collected from palm oil mill. The materials were then processed into compact briquettes, following a simple briquetting process. Several tests were performed on the briquettes as a whole. The tests could be divided into two categories - chemical properties tests and mechanical properties tests, in which the first set of tests, are to evaluate the intrinsic properties of the materials whereas the second set of tests are to evaluate the transport, handling and storage characteristics of the briquettes.

All the procedures, material and equipments which utilized in the experiment would be evaluated, compared and analyzed to obtain the most accurate results. Results of the analysis were tabulated and discussed further.

1.4 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

In order to fit within the time frame, all the researches and analyses were carried out according to the initial planning and allocated time duration. All the activities carried out followed strictly the planning in Gantt chart in Methodology section.

CHAPTER 2
LITERATURE REVIEW

2.1 PALM OIL MILL PROCESSING

Crude palm oil (CPO) is extracted from the mesocarp of fresh fruit bunch (FFB). The FFB harvested from the oil palm plantation have to be processed immediately to prevent poor quality CPO due to increased free fatty acid content. Several units of operations are involved in order to extract palm oil from FFB. The main stages of palm oil processing are shown in Figure 2.1 and the major steps are discussed as follows:

i. Sterilization - The first stage in extraction of crude palm oil is sterilization. This is carried out in autoclave by steam application at the temperature of 140°C and a pressure of 3 bar, for 75–90 min. Sterilization prevents fatty acid formations and assists in fruits stripping, as well as preparing the fruit fiber for the next processing steps. One of the major sources of waste water is formed by the steam condensate coming out of the sterilizer [1, 6, 7].

ii. Stripping - After sterilization the FFB is fed to a rotary drum-stripper where the fruits are separated from the spikelet. The waste from this step is empty fruit bunches [6].

iii. Digestion - The fruits are then mashed in the digester under steam heated condition with temperature around 90°C. This process releases palm oil in the fruit through breaking the mesocarp oil bearing cells. The fruit is pounded by the rotary beater arms at high temperature, which reduces the oil viscosity. No residue from this step [1, 4, 7].

iv. Extracting the palm oil - Twin screw presses are generally used to press out the oil from the digested mashed fruits under high pressure. The CPO is directed to the clarification tank and the temperature is maintained at about 90°C to enhance oil separation. The clarified oil is then purified by using the centrifuge and vacuum drier before storage. The oily fiber and nuts from the press cake are separated by passing through the depericarper. [4, 6].

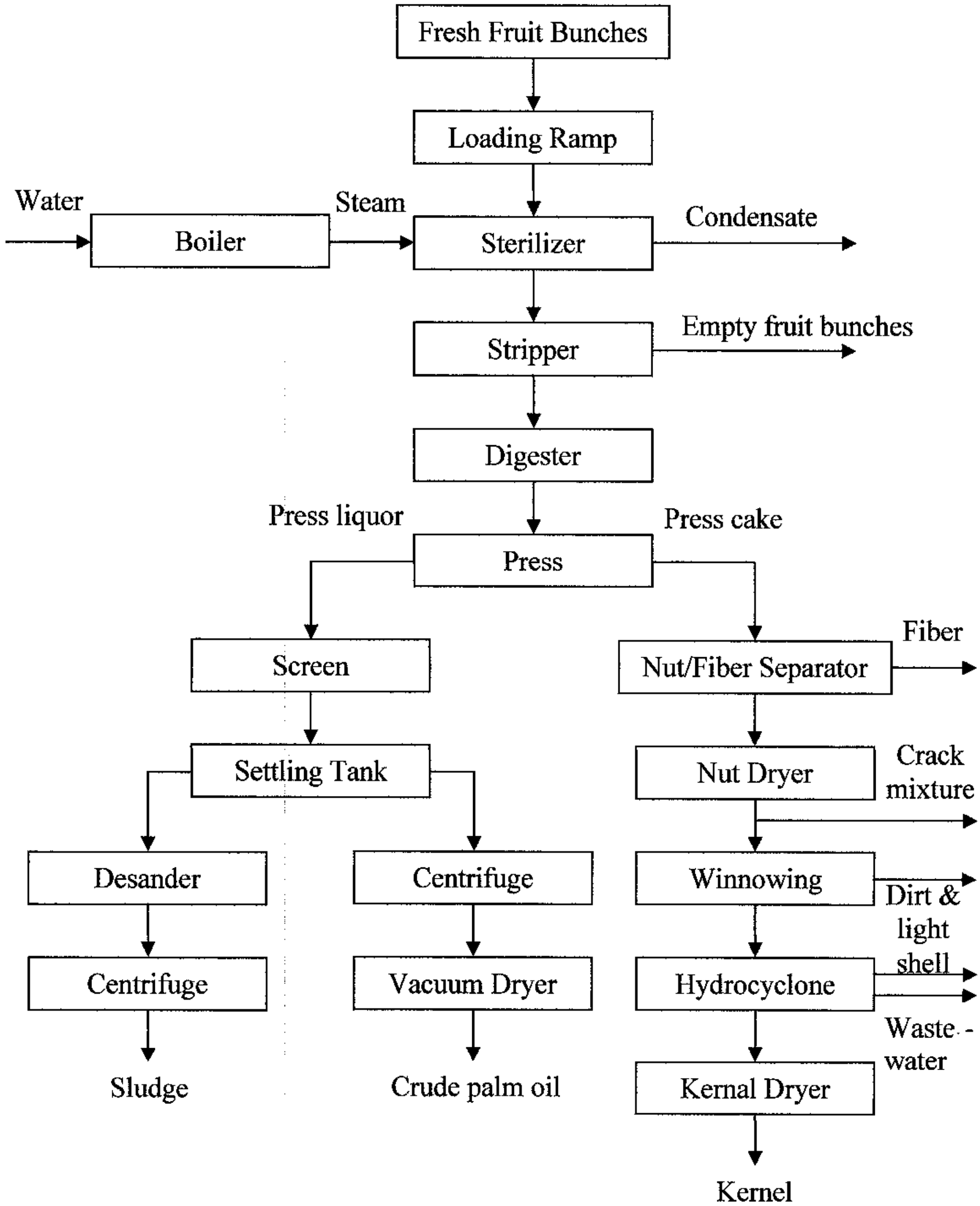


Figure 2.1: Schematic flow of palm oil extraction process [4]

2.2 CHARACTERISTICS OF PALM OIL MILL EFFLUENT (POME)

According to Sethupathi [8], POME is mainly generated from sterilization of fresh fruit bunches, clarification of the extracted crude palm oil and hydrocyclone separation in which large amounts of steam and hot water are used. It has been estimated that 5–7.5 tonnes of water is required for producing 1 tonne of crude palm oil and more than 50% of the water ends up as POME.

Wastewater composition depends mainly on raw matter quality, the season and the palm oil mill operations being conducted at any given time. POME, when fresh is in the form of thick brownish in colour colloidal slurry of water, oil and fruit residues. Typically, POME is generated from mill operation at a temperature of between 80°C and 90°C and it is slightly acidic with a pH of 4–5 [4]. POME is a non-toxic waste, as no chemical is added during the oil extraction process, but will pose environmental issues due to large oxygen depleting capability in aquatic system due to organic and nutrient contents. Characteristics of untreated POME from literature are tabulated in Table 2.1.

Table 2.1: Characteristics of untreated POME [4]

Parameters	Value*
pH	4.7
Temperature (°C)	80–90
BOD; 3-days at 30 °C	25,000
COD	50,000
Total solids	40,500
Total suspended solids	18,000
Total volatile solids	34,000
Ammonia-nitrate	35
Total nitrogen	750

*All units in mg/L except for pH and temperature

POME consists of suspended solids and dissolves solids which are left after POME anaerobic treatment. Therefore due to large quantity of POME production each year, the amount of the sludge increases, respectively. It has high amount of moisture content, with pH of 8.4 and enriched with organic matter. It has been shown in Table 2.2, the sludge contains 60 mg/L and 33 mg/L of organic matter and total organic carbon, respectively.

Table 2.2: Physiochemical analysis of raw POME sludge [4]

Parameters	Value*
Moisture content (%)	85.0
pH	8.4
Organic matter	60.0
Total organic carbon (mg/L)	33.0
Total nitrogen (mg/L)	3.6
Phosphorus (mg/l)	0.9
Potassium (mg/L)	2.1

*All units in mg/L except for pH and moisture content

2.3 CHARACTERISTICS OF OIL PALM FROND

The average density of oil palm frond is about 700 kg/m^3. The weight of each frond is between 15 and 20 kg depending on the age and condition of the palm tree. The frond comprises of two main components which are petiole and leaflets. The dry matter weight ratio of petiole to leaflets (including the rachis) is 1.5.

Typically, the main biomass composition is carbon which comprises 30–60% of the dry matter. After that, typically 30–40% is oxygen. Hydrogen is the third main constituent making up between about 5–6%. Typically nitrogen and sulfur (and chlorine) normally make up less than 1% of dry biomass [9]. As shown in Table 2.3 that oil palm fronds have reasonably high carbon content which is 42.65% and the contents of nitrogen and sulfur are low. The H:C and O:C ratios are 0.13 and 1.17, respectively.

In terms of energy available in the fuel, one significant collection of natural fuels shows a linear correlation of the heat of combustion at 400°C with the carbon content of the analysis [10]. This revealed that oil palm fronds could be a good candidate for fuel briquette as high carbon content would be desired since it is an important element in the combustion. A low content of sulfur would be desired as well since its emission could react with water and oxygen to form acidic compound such as acid rain. A comparison of the average carbon content with other types of biomass feed reveals that oil palm fronds have reasonably high carbon content, which would be considered as competitive with other biomass sources.

Table 2.3: Chemical composition of oil palm frond [5]

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
Average	42.65	5.48	2.18	0.11
Std. Dev	0.44	0.25	0.05	0.01

According to the research work undertaken by Sulaiman et al [5], the average calorific value of oil palm fronds was 18,040 kJ/kg and the standard deviation of less than 0.5%. Shown in Figure 2.2 are the variations of calorific values for different biomass sources and coal for comparison with oil palm fronds. In comparison with other biomass sources, the calorific value of oil palm fronds is competitive although the value is lower than coal's energy content.

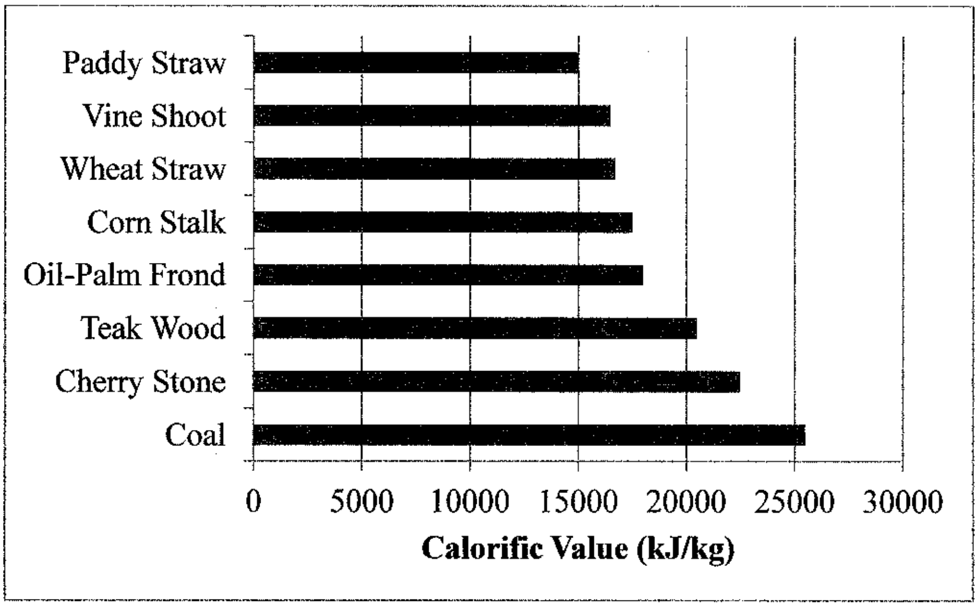


Figure 2.2: Calorific value of various biomass feeds [5]

CHAPTER 3
METHODOLOGY

The project is divided into two main phases which are briquette preparation and briquette performance testing. The procedures for all the preparation and investigations were obtained from various standard tests as well as manual of equipments. The underlying flow of work will be illustrated in Figure 3.1 and the following respective sub-chapter.

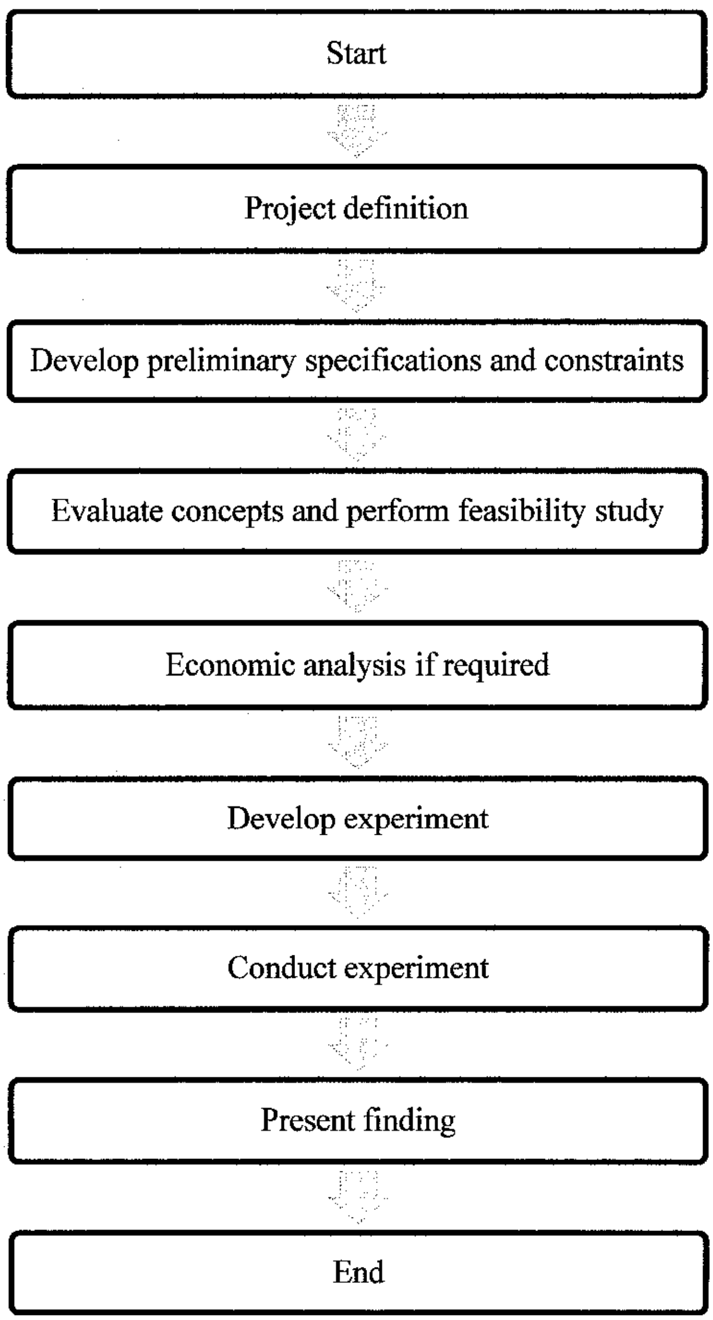


Figure 3.1: Project flow chart

3.1 METHOD OF WORK

After gathering palm oil mill effluent sludge and fronds, the materials are processed into compact briquettes, following a simple process. Several tests are performed on the fuel briquettes. The tests could be divided into two categories - chemical properties tests and mechanical properties tests, in which the first set of tests are to evaluate the intrinsic properties of the materials whereas the second set of tests are to evaluate the transport, handling and storage characteristics of the briquettes.

3.2 BRIQUETTE PREPARATION

3.2.1 Pretreatment Process

The first step of preparing is to reduce the moisture contents of oil palm residues (POME sludge and fronds). In order to do this, the samples were dried in a temperature controlled environment, by placing them in an oven at 105°C until consistency in the sample's mass is obtained in order to reach 0% moisture content [9]. Majority of the experiments undertaken in this study were conducted with oven dried samples except with the samples used to study the effect of moisture content to calorific value. The samples used to study the effect of moisture content to calorific value were let dry under ambient condition for 24 hours. The samples were then oven dried. The change in mass can be used to determine the sample's percentage moisture content. Moisture content is presented on a wet basis, which is the moisture content as a percentage of the total as received mass.

$$\text{Moisture content} = \frac{\text{mass of water}}{\text{mass of water} + \text{mass of solid}} \times 100\%$$

3.2.2 Grinding

After completing the pretreatment process, the fronds were grinded into powder by using mortar grinder. The grinded sample was then collected and removed from the mortar grinder.

3.2.3 Briquetting

In this study, POME sludge and frond biomass mixture was produced. The materials ratios used were (POME sludge to frond ratio): 10.90, 30:70, 50:50, 70:30 and 90:10.

After completing all the previous processes, the last part is to compact the mixture by using automatic pellet press. A pressure of 25 MPa was used to form briquettes. The samples was loaded into a cylindrical mould with an external diameter of 60 mm and a central hole diameter of 40 mm. The height of the briquette can be varied by changing the charge mass in the mould. In the research, the briquette produced in this study weighed 10 g and approximately 7 mm in height. Before undergoing any kind of testing, briquettes were rested under ambient conditions for a week to stabilize inner tensions that would affect the microstructures and the porosity of briquette. Briquettes produced in this project are shown in Figure 3.2.

Figure 3.2: Briquettes produced in this project

3.3 BRIQUETTE PERFORMANCE TESTING

The chemical properties tests performed were calorific value determination, ultimate analysis, burning characteristics test which are the analyses performed on a common solid fuel whereas the mechanical properties tests conducted were dimensional stability analysis, crack analysis and durability test.

3.3.1 Calorific Value Determination

The briquette that produced was re-grinded by mortar grinder again to become powder. 0.5 g of sample was required to use in this analysis. The sample was put into bomb unit and igniter was attached together to allow heat transfers to the sample. The bomb was then put into bomb calorimeter. The calorific value of the sample was recorded from the screen on the bomb calorimeter after a few minutes. To monitor repeatability between samples, a set of three measurements were conducted for each of the calorific value tests.

3.3.2 Ultimate Analysis

For ultimate analysis, the carbon, hydrogen, nitrogen and sulfur content of the materials could be evaluated. Powdery sample was put into a small capsule. The capsule and sample were then weighted together with the microbalance. The sample was then put into CHNS analyzer. Three measurements were taken for each of the ultimate analysis test.

3.3.3 Burning Characteristics Test

The objectives of the burning characteristics test are to test the briquette's ignitability and time taken to burn to ashes. Bunsen burner, stand and wire gauze were prepared in this test. The briquette was put on the wire gauze and the Bunsen burner was ignited after that. Once a moment, the briquette was removed and placed on a piece of tissue paper to determine whether the briquette has ignited or not. The briquette was deemed to be ignited if the briquette was able to burn through the tissue paper. The interval time was recorded after the briquette was ignited. After the ignition has occurred, the briquette was then allowed to burn into ashes. Time taken to burn the briquette to ashes was recorded.

3.3.4 Crack Analysis

The crack analysis was done to study the impact resistance of a fuel briquette. The analysis was performed by dropping the briquette from a height of 1 m. The number of cracks and length of crack are noted [11].

3.3.5 Dimensional Stability Analysis

Stability test is to determine how well a briquette could sustain its dimensions during storage. It serves as an index of the extent of resistance of briquettes to change in their initial physical dimensions and shape [12]. In order to determine the stability, measurements of diameter was taken immediately on removal from die press and measured weekly by using a Vernier caliper at different positions. The average was then calculated.

3.3.6 Durability Analysis

Durability test is performed to investigate how durable a briquette could be when subjected to a few drops. It is intended to simulate the ability to withstand the rigors of handling such that they keep their mass, shape, and integrity. The mass of a briquette was first measured and then dropped from 1.85 m high onto a flat steel plate four times [13]. The final weight of briquette remained in the plate was recorded. The durability (%) is taken as the ratio of final mass retained by the briquette after four drops to the initial mass [13]. It could be calculated by using this formula:

$$\text{Durability} = \frac{\text{mass of material remained in plate after 4 drops}}{\text{initial mass of material}} \times 100\%$$

3.4 EXPERIMENT FLOW CHART

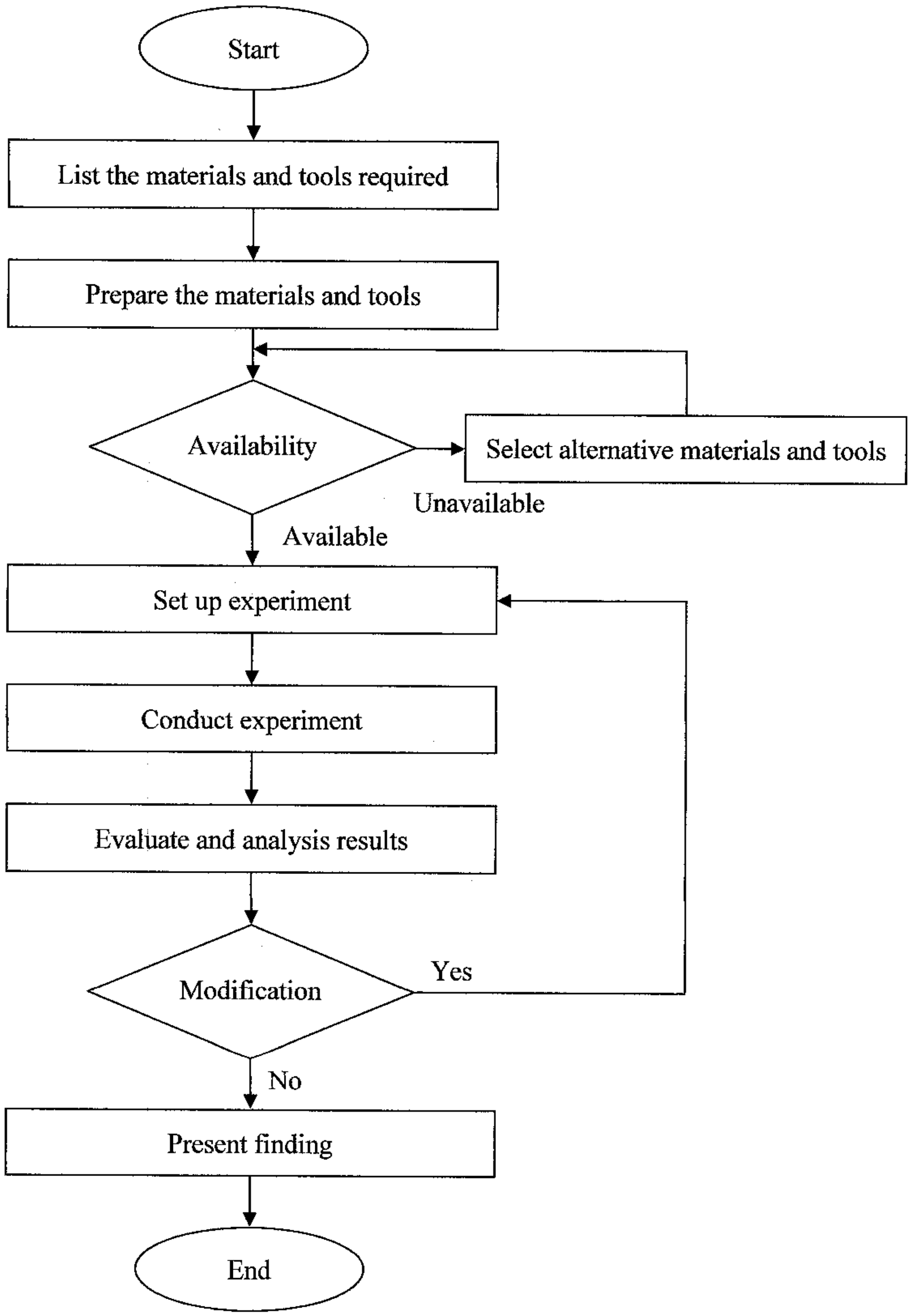


Figure 3.3: Steps in conducting experiment

3.5 TOOLS AND MATERIALS

3.5.1 Tools Required

The tools required to carry out this research are listed as below:

i. Oven - to remove the moisture content of samples.
ii. Electronic weight scale - to determine the mass of samples.
iii. Mortar grinder - to triturate raw material into powder.
iv. Automatic pellet press - to compare sample into briquette form.
v. CHNS analyzer - to determine the elemental composition of samples.
vi. Bomb calorimeter - to measure the calorific value of samples.
vii. Vernier caliper - to measure the diameter of briquette.
viii. Bunsen burner - to burn briquette.
ix. Stop watch - to measure ignition time and time take to burn to ashes.

3.5.2 Materials Required

i. Palm oil mill effluent sludge.
ii. Oil palm fronds.

3.6 GANTT CHART

Table 3.1: Project completion Gantt chart of Final Year Project I

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Submission of Extended Proposal Defence														
4	Project Work														
5	Proposal Defence														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Table 3.2: Project completion Gantt chart of Final Year Project II

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work (Continue)															
2	Submission of Progress Report															
3	Project Work (Continue)															
4	Poster Exhibition															
5	Submission of Draft Report															
6	Submission of Project Dissertation (Soft Bound)															
7	Oral Presentation															
8	Submission of Technical Paper															
9	Submission of Project Dissertation (Hard Bound)															

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents the results obtained from comprehensive experimental investigations which cover: proximate and ultimate analysis, burning characteristics test, dimensional stability analysis, durability analysis and crack analysis.

4.1 PROXIMATE ANALYSIS

4.1.1 Moisture Content

The raw materials obtained were oven dried at 105°C until constant mass is obtained in order to reach 0% moisture content. A time of 7 hours is required for POME sludge to achieve constant mass. As for frond, 5 hours is required to reach constant mass. The moisture contents of the raw samples are recorded in Table 4.1. The moisture content of POME sludge and oil palm fronds obtained are 21.39% and 11.91%, respectively.

Table 4.1: Moisture content of raw residues

Sample	Initial Mass (g)	Final Mass (g)	Moisture Content (%)
POME Sludge	50	39.308	21.39
Frond	15	13.213	11.91

To study the effect of moisture content to calorific value, other samples were let dry under ambient condition for 24 hours. After that, the samples were then oven dried 7 hours for POME sludge and 5 hours for oil palm fronds. The change in mass can be used to determine the sample's percentage moisture content. Table 4.2 presents the moisture content of the samples dried under ambient condition.

Table 4.2: Moisture content of the sample dried under ambient condition

Sample	Initial Mass (g)	Final Mass (g)	Moisture Content (%)
POME Sludge	50	44.851	10.30
Frond	15	14.441	3.73

The moisture content of the POME sludge and oil palm fronds dried under ambient condition are 10.30% and 3.73%, respectively.

Moisture content comparison between POME sludge and fronds was made and shown in Figure 4.1.

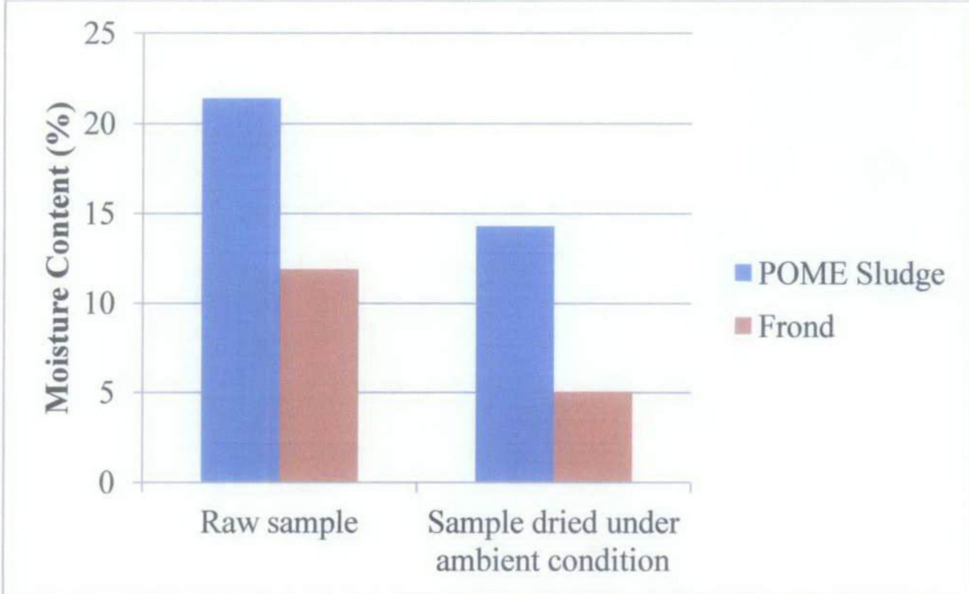


Figure 4.1: Moisture content comparison between POME sludge and fronds

4.1.2 Calorific Value Determination

In order to determine the calorific value of sample, bomb calorimeter was used. Measurements of the calorific value were repeated three times under the same conditions. The calorific value test result for 0% moisture content sample is as shown in Table 4.3 and the average value is presented in Figure 4.2.

Table 4.3: Calorific value test result for 0% moisture content sample

POME Sludge Content (%)	Calorific Value (kJ/kg)			
	1	2	3	Average
10	18,710	18,547	19,031	18,763
30	22,026	21,858	21,120	21,668
50	23,574	23,405	24,100	23,693
70	26,053	26,550	25,600	26,068
90	30,408	31,065	31,076	30,850

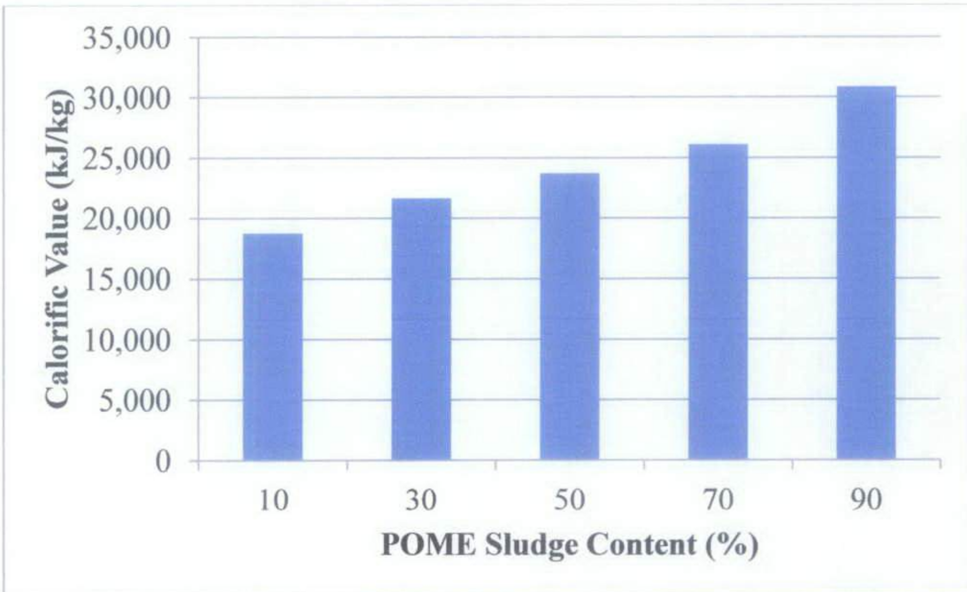


Figure 4.2: Average calorific value for 0% moisture content sample

From the test, it was found that the five ratios of POME sludge and oil palm fronds mixture with 0% moisture content show calorific value ranging from 18,763–30,850 kJ/kg. It was noted that the calorific value of the briquette increases with increasing POME sludge content, with the 90:10 POME sludge to frond showing the highest value.

Another set of calorific value test was conducted on the samples that were let dry under ambient condition for 24 hours in order to study the effect of moisture content. The moisture content of the POME sludge and frond after drying under ambient condition are 10.30% and 3.73%, respectively. The calorific value test result for this sample is shown in Table 4.4 and the average value is presented in Figure 4.3.

Table 4.4: Calorific value test result for the sample dried under ambient condition

POME Sludge Content (%)	Calorific Value (kJ/kg)			
	1	2	3	Average
10	17687	18004	18605	18099
30	19507	20134	19921	19854
50	20973	21491	21012	21159
70	22067	23054	23721	22947
90	26088	25834	26475	26132

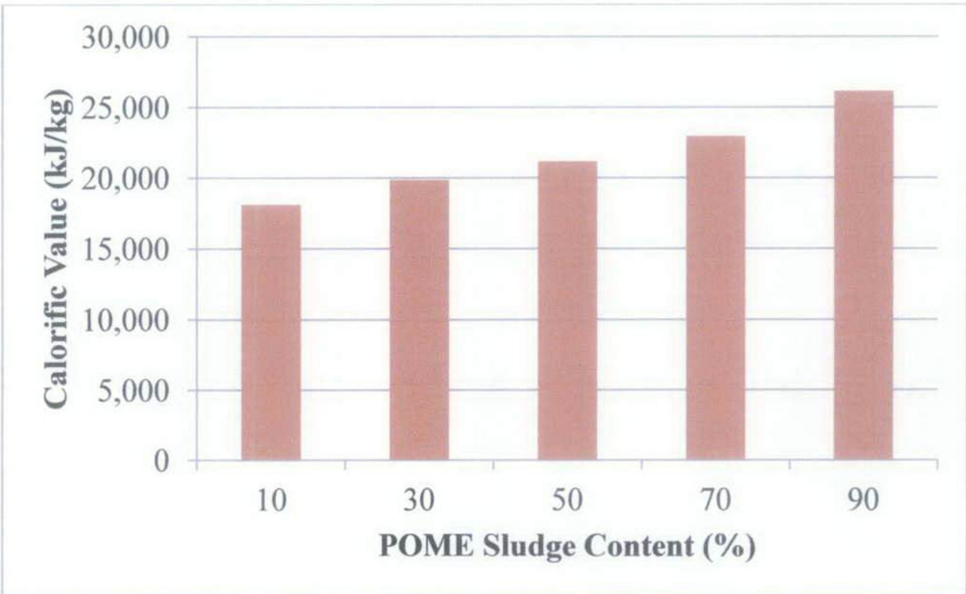


Figure 4.3: Average calorific value for the sample dried under ambient condition

For the five ratios of POME sludge and frond mixture that were dried under ambient condition, the energy content ranged from 18,099–26,132 kJ/kg, It was also noted that the calorific value of the briquette increases with increasing POME sludge content, with the 90:10 POME sludge to frond briquette showing the highest calorific value.

The relationship between the POME sludge content with the average calorific value of the briquette for both experiments is shown in Figure 4.4. By making comparison between the samples dried ambient condition with 0% moisture content samples, the difference in calorific value is noticed. Samples with 0% moisture content have higher calorific value than samples dried under ambient condition for all five ratios. Therefore, it can be concluded that the calorific value is limited by biomass moisture content. This is due to the reason that moisture in the biomass will absorb heat by vaporisation and heating of the resulting vapor during combustion in which significantly reducing the heating value of the mixture.

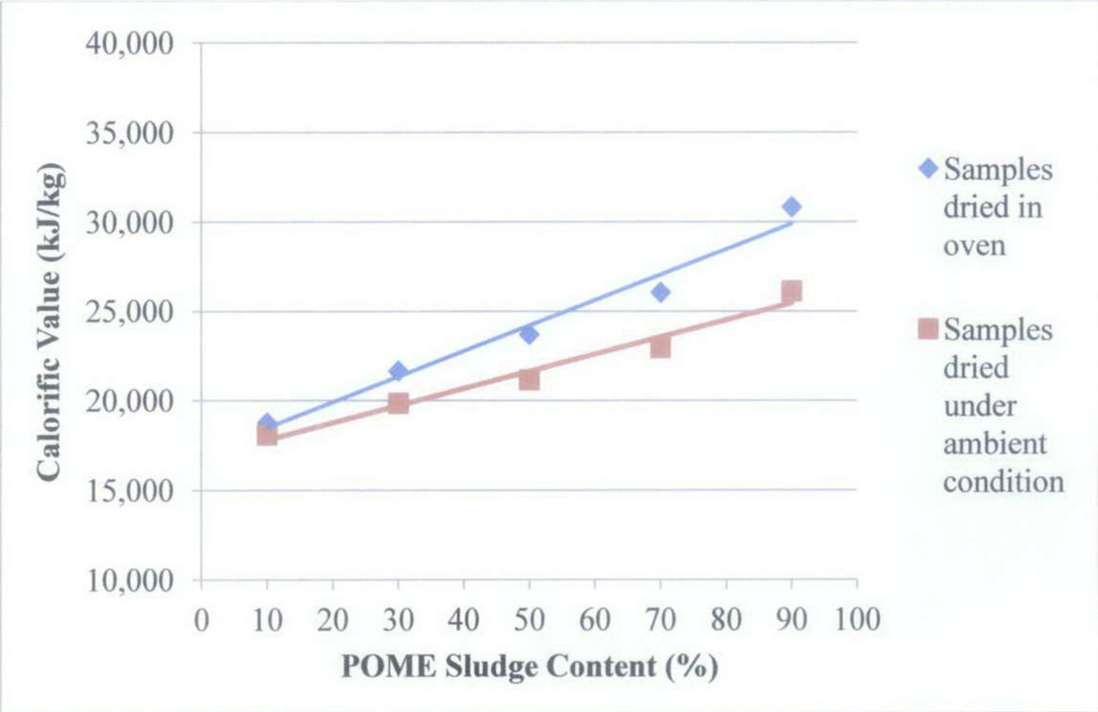


Figure 4.4: Graph of calorific value against POME sludge content

4.2 ULTIMATE ANALYSIS

Table 4.5, 4.6, 4.7, 4.8 and 4.9 show the measure composition of carbon, hydrogen, nitrogen and sulfur of 10:90, 30:70, 50:50, 70:30 and 90:10 POME sludge to frond briquette, respectively. Each composition of carbon, hydrogen, nitrogen and sulfur of the samples are shown in Figure 4.5, 4.6, 4.7 and 4.8, respectively.

Table 4.5: Ultimate analysis of 10:90 POME sludge to frond briquette in weight percentage

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
1	44.71	6.093	0.775	0.316
2	46.27	6.184	0.857	0.336
3	45.62	6.123	0.806	0.357
Average	45.53	6.133	0.813	0.336

Table 4.6: Ultimate analysis of 30:70 POME sludge to frond briquette in weight percentage

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
1	51.70	6.810	0.991	0.335
2	48.97	6.429	0.777	0.393
3	51.02	6.556	0.932	0.310
Average	50.56	6.598	0.900	0.346

Table 4.7: Ultimate analysis of 50:50 POME sludge to frond briquette in weight percentage

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
1	50.43	6.242	0.898	0.296
2	55.24	6.678	1.028	0.356
3	55.12	6.919	1.032	0.354
Average	53.60	6.613	0.986	0.335

Table 4.8: Ultimate analysis of 70:30 POME sludge to frond briquette in weight percentage

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
1	57.47	7.368	0.967	0.362
2	59.12	7.748	0.989	0.398
3	59.59	7.629	1.020	0.336
Average	58.73	7.582	0.992	0.365

Table 4.9: Ultimate analysis of 90:10 POME sludge to frond briquette in weight percentage

	Composition (%)			
Element	Carbon	Hydrogen	Nitrogen	Sulfur
1	71.64	9.936	1.135	0.456
2	61.69	7.843	1.029	0.305
3	55.42	6.499	0.888	0.298
Average	62.92	8.093	1.017	0.353

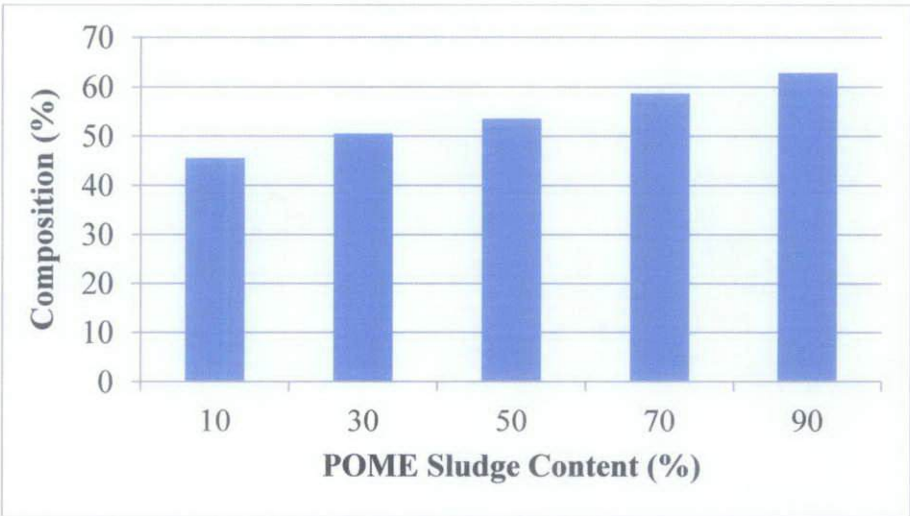


Figure 4.5: Carbon content of POME sludge and oil palm fronds mixture

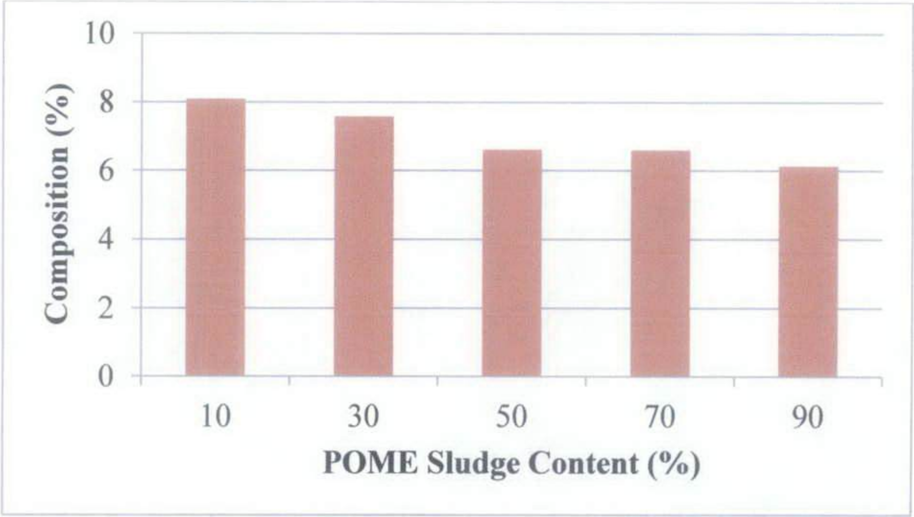


Figure 4.6: Hydrogen content of POME sludge and oil palm fronds mixture

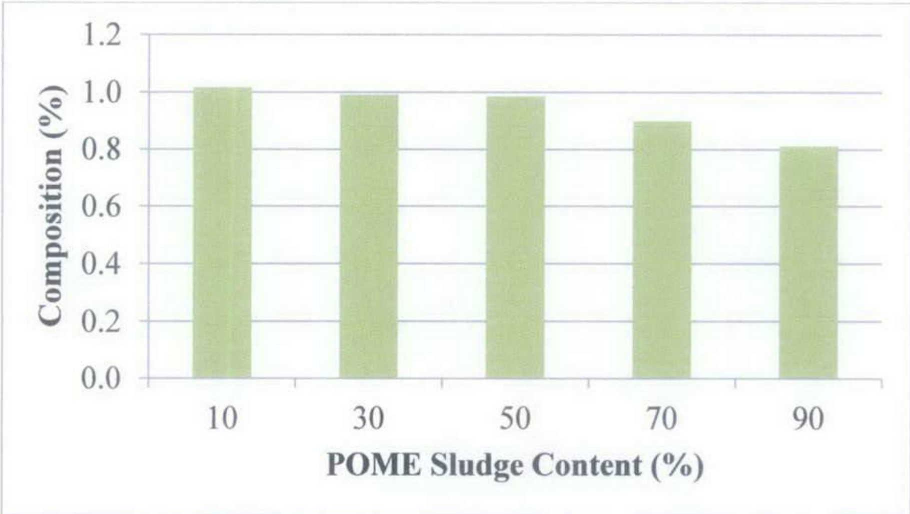


Figure 4.7: Nitrogen content of POME sludge and oil palm fronds mixture

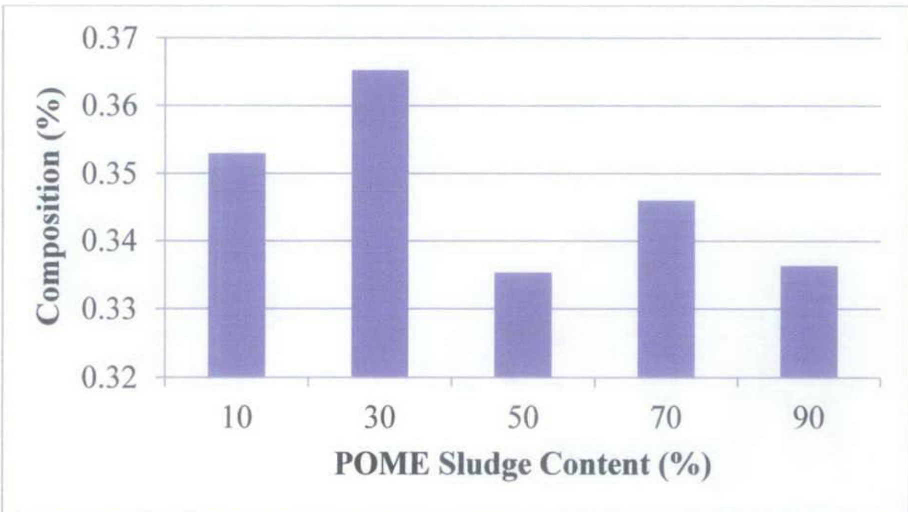


Figure 4.8: Sulfur content of POME sludge and oil palm fronds mixture

Ultimate analysis result reveals that these mixtures have reasonably high carbon and hydrogen content. A high carbon and hydrogen content means a high calorific value. This is due the reason that when biomass is combusted, energy is released by breaking of high-energy bonds between carbon and hydrogen.

The ultimate analysis result also shows that the contents of nitrogen and sulfur, which are low. Fuel-bound nitrogen is responsible for most nitrogen oxide (NO_x) emissions produced from biomass combustion. Low nitrogen content in this mixture should lead to lower NO_x emissions which would bring negative effects to the environment. Sulfur oxides (SO_x) are formed during combustion and contribute significantly to particulate matter pollution and acid rain. Since this mixture has almost negligible sulfur content with average below 0.4%, its combustion does not contribute significantly to sulfur emissions.

4.3 BURNING CHARACTERISTICS TEST

The time measured from the burning characteristics test was tabulated in Table 4.10. Figure 4.9 and 4.10 show the graph of ignition time against POME sludge content and the graph of time taken to burn to ashes against POME sludge content, respectively.

Table 4.10: Burning characteristics test result

POME Sludge Content (%)	Ignition Time (s)	Time Taken to Burn to Ashes (s)
10	59	630
30	84	674
50	153	812
70	199	833
90	266	848

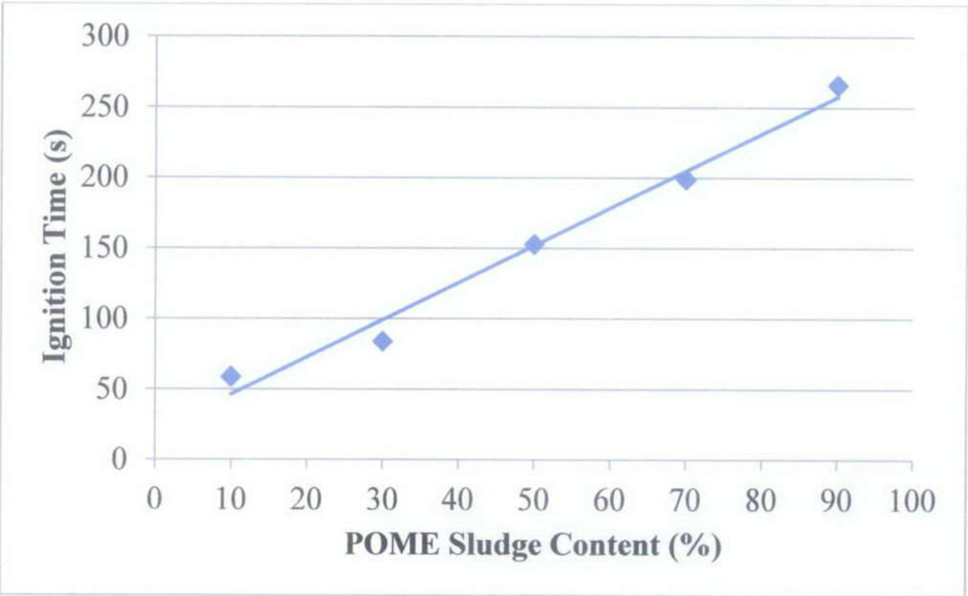


Figure 4.9: Graph of ignition time against POME sludge content

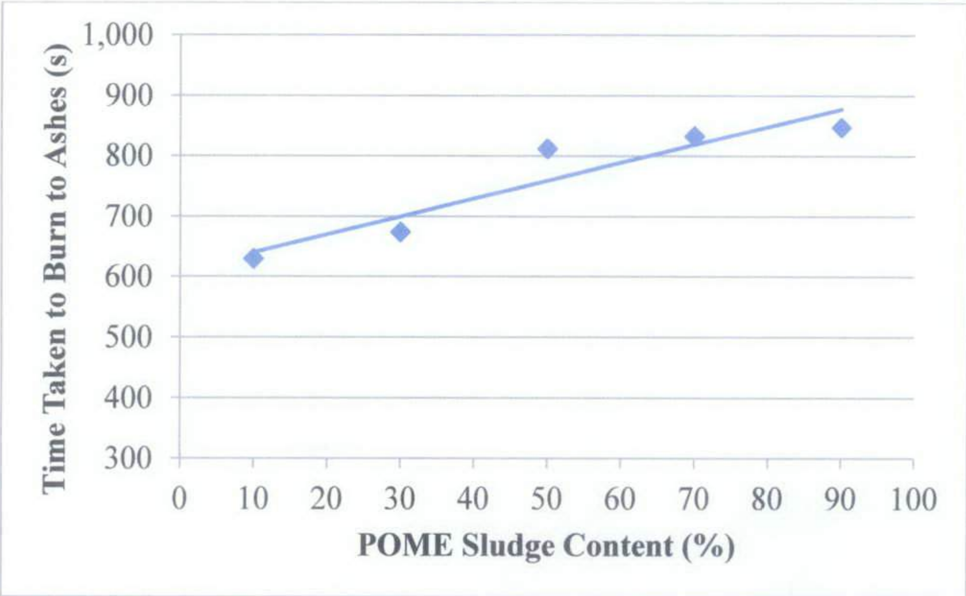


Figure 4.10: Graph of time taken to burn to ashes against POME sludge content

From Figure 4.9, the 90:10 POME sludge to frond briquette has the highest ignition time while the 10:90 POME sludge to frond briquette has the lowest ignition time. It is observed that ignition time increases with increasing POME sludge content. From Figure 4.10, the 90:10 POME sludge to frond briquette has the longest time taken to burn into ashes among all the samples. Same as observation before, time taken to burn to ashes increases with increasing POME sludge content.

This observation might be due to lower porosity and higher density of the briquettes. POME sludge is an oily material and would result in a mixture with low porosity after undergoing compression. Thus, the ignition time and time taken to burn to ashes of the briquettes which contain small percentage of POME becomes shorter. Short ignition time is required in order to ease biomass fuel to start combustion. However, the time taken to burn the briquette into ashes for a good quality biomass briquette should be as long as possible. This is very important as it shows the briquettes can supply heat in longer period.

4.4 DIMENSIONAL STABILITY ANALYSIS

Stability serves as an index of the extent of resistance of briquettes to changes in their initial physical dimensions. Table 4.11, 4.12, 4.13, 4.14 and 4.15 respectively show the dimensional stability analysis results of 10:90, 30:70, 50:50, 70:30 and 90:10 POME sludge to frond briquette. The average measured diameter for all the five ratios of POME sludge and frond mixture is plotted in Figure 4.11.

Table 4.11: Dimensional stability analysis of 10:90 POME sludge to frond briquette

Duration (Week)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Average (mm)	Expansion (%)
0	41.50	41.00	41.10	41.20	0.00
1	41.50	41.75	42.00	41.75	1.33
2	41.50	42.00	42.15	41.88	1.66
3	42.00	42.00	41.50	41.83	1.54

Table 4.12: Dimensional stability analysis of 30:70 POME sludge to frond briquette

Duration (Week)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Average (mm)	Expansion (%)
0	40.85	40.85	40.70	40.80	0.00
1	41.00	41.00	41.05	41.02	0.53
2	41.00	41.20	40.90	41.03	0.57
3	41.10	41.00	41.00	41.03	0.57

Table 4.13: Dimensional stability analysis of 50:50 POME sludge to frond briquette

Duration (Week)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Average (mm)	Expansion (%)
0	40.30	40.20	40.35	40.28	0.00
1	40.50	40.60	40.35	40.48	0.50
2	40.20	40.50	40.70	40.47	0.46
3	40.50	40.60	40.25	40.45	0.41

Table 4.14: Dimensional stability analysis of 70:30 POME sludge to frond briquette

Duration (Week)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Average (mm)	Expansion (%)
0	40.35	40.55	40.50	40.47	0.00
1	40.60	40.60	40.65	40.62	0.37
2	40.60	40.60	40.70	40.63	0.41
3	40.65	40.60	40.65	40.63	0.41

Table 4.15: Dimensional stability analysis of 90:10 POME sludge to frond briquette

Duration (Week)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Average (mm)	Expansion (%)
0	40.45	40.50	40.35	40.43	0.00
1	40.60	40.70	40.55	40.62	0.45
2	40.75	40.65	40.40	40.60	0.41
3	40.65	40.70	40.55	40.63	0.49

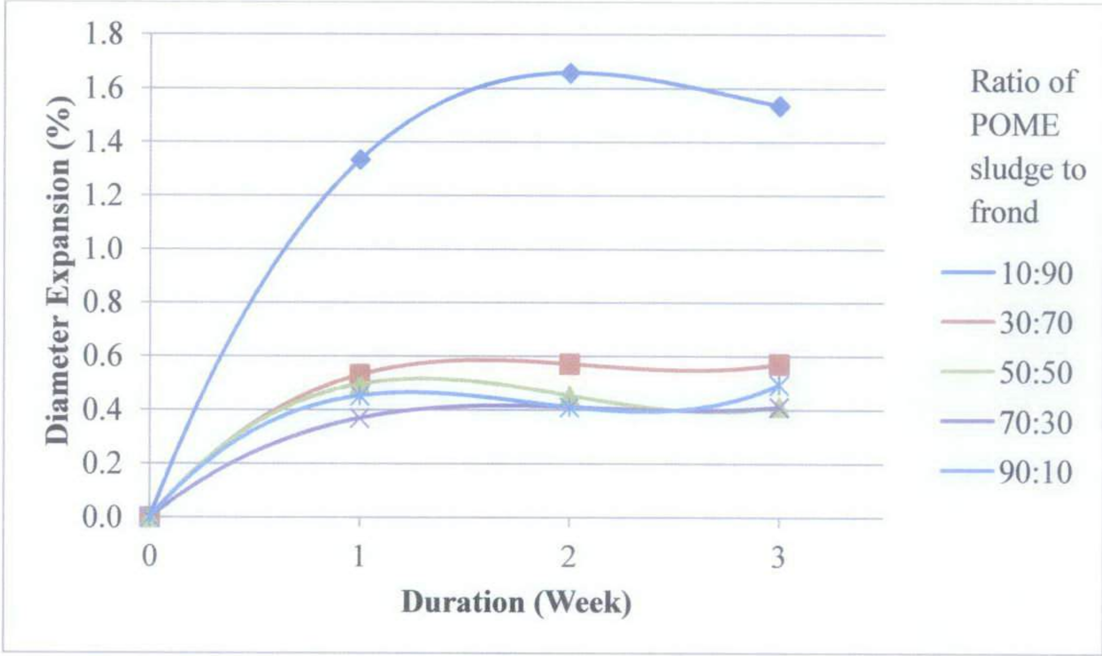


Figure 4.11: Graph of diameter expansion against duration

The results revealed that the 10:90 POME sludge to frond briquette is the least stable, followed by the 30:70 POME sludge to frond briquette. Generally 50:50, 70:30, 90:10 POME sludge to frond briquettes are stable and expanded less than 0.5% in the first three weeks. This is contributed by the high POME sludge content that acts as binder which in turn held the briquette firmly together.

4.5 DURABILITY ANALYSIS

For durability test, the percentage of material still intact after four drops from 1.85 m was noted. The durability test result is shown in Table 4.16.

Table 4.16: Durability test result

POME Sludge Content (%)	Initial Mass (g)	Final Mass (g)	Durability (%)
10	10.009	7.348	73.41
30	10.109	9.008	89.11
50	9.976	9.474	94.97
70	9.928	9.809	98.80
90	9.541	9.523	99.81

The result shows that the durability of briquettes ranged between 73–100%. 10:90 POME sludge to frond briquette is the least durable briquette, with durability of only 73.41%. The most durable briquette is the one that consists of 90:10 POME sludge to fronds, with durability of 99.81%. Generally, briquettes made of POME sludge percentage more than 30% are densified biomasses with good quality and very durable.

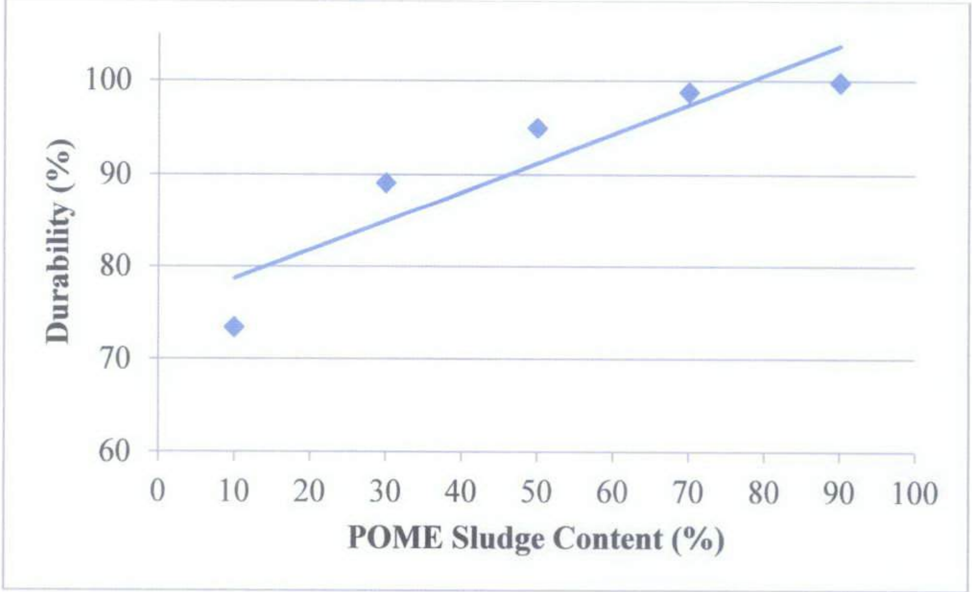


Figure 4.12: Graph of durability against POME sludge content

The relationship between POME sludge content with durability of briquette is shown in Figure 4.12. It was noted that the durability of the briquette increase with increasing POME sludge content. Briquette with high POME sludge content can withstand the rigors of handling such that they keep their mass, shape and integrity. This could probably due to the reason that POME sludge is oily material that act as binder and tended to hold the briquette strongly and therefore, these briquettes were relatively durable.

4.6 CRACK ANALYSIS

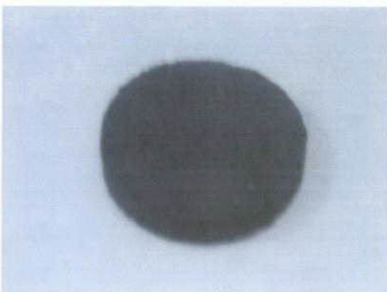
The third mechanical property test is crack analysis, where a briquette was dropped from 1 m high and any crack in the radial direction was noted. Result from the crack analysis is illustrated in Figure 4.13 (a)–(e). Crack analysis results show that 10:90 POME sludge to frond briquette had partially broken into small pieces. Meanwhile, 30:70 POME sludge to frond briquette shows a very minor crack only. Whereas 50:50, 70:30, 90:10 POME sludge to frond briquettes are strong and free of crack.

(a)

(b)

(c)

(d)



(e)

Figure 4.13: Crack analysis on (a) 10:90 (b) 30:70 (c) 50:50 (d) 70:30 and (e) 90:10 POME sludge to frond briquettes

From the crack analysis result obtained, the briquettes made of lower percentage of POME have tendency to exhibit more cracks. This could due to the reason that oily material like POME sludge tend to hold briquette tightly together.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In short the purpose of the project is to experimentally study palm oil mill effluent (POME) sludge and oil palm fronds mixture for energy potential. This proposed study aims to examine the possibility of POME sludge and oil palm fronds mixture as an alternative biomass fuel. A general review of POME and fronds characteristics is first carried out. This was followed by a refined review of the literature in order to gain thorough understanding for the commencement of the laboratory and experimental aspects of the project. A series of experimentally works have been started after that to develop experimental testing of the biomass fuel in briquette form and to investigate the performance of each sample with different weight percentage.

From the experimental testing, it was found that 90:10 POME sludge to fronds briquette shows a good combination of properties. This briquette produces the highest calorific value among all the briquettes. However, the calorific value is limited by biomass moisture content as the results show that briquettes with 0% moisture content have higher calorific value than samples dried under ambient condition for all the five ratios.

Ultimate analysis result reveals that these mixtures have high carbon and hydrogen content but the contents of nitrogen and sulfur are low. This mixture is a good candidate for fuel briquette as high carbon content would be desired since it is an important element in the combustion. A low content of sulfur and nitrogen would be desired as well since it minimizes negative effects to the environment.

The burning test result shows that the 90:10 POME sludge to frond briquette has longest time taken to burn into ashes but the longest ignition time. A good quality of biomass briquette should have short ignition time and long time taken to burn into ashes. Long ignition time is a disadvantage of a biomass briquette because more time is required for the briquette to start burning.

As for durability test, the most durable briquette was the one that consisted of 90:10 POME sludge to frond, with durability of 99.81%, whereas 50:50, 70:30, 90:10 POME sludge to frond briquettes are strong and free of crack based on the results from crack analysis. From dimensional stability analysis, 50:50, 70:30, 90:10 POME sludge to frond briquettes are stable and expanded less than 0.5% in the first three weeks.

Experimentally, it was found that POME sludge and oil palm fronds mixture as an alternative biomass fuel is feasible and the objectives of this research are achieved successfully.

5.2 RECOMMENDATION

There are few optional analyses that can be done in order to further investigate the characteristic and performance of the briquettes. One of the analyses is immerse test in which the water resistance of the briquettes is quantified by taking the time that a briquette required to fully disintegrate in water. This property is important because it would enable user to decide the storage method or location of the briquettes. For biomass fuel briquettes that do not have good water resistance, they should be stored under cover and not at places with high humidity.

Lastly, several die pressures could be applied to the briquette. This is because fuel briquettes produced under different pressure have been reported to have different handling characteristics [14]. Briquette density is one of the most important properties which bear on the combustion characteristics, handling characteristics including the ignition behavior of briquettes and this property depends on the briquetting pressure [14].

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