Characterization of Solid Biomass Fuel Briquettes

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

SEPTEMBER 2012

Universiti Teknologi PETRONAS
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CERTIFICATION

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

_____
(MS CHIN YEE SING)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

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.

_____

(MD NASRUN FARIS BIN MOHD AZNAN)

ACKNOWLEDGMENT

The authors would like to acknowledge with appreciation the numerous valuable comments, suggestions, constructive criticisms, morale support and monetary support from all people, lecturers, family and friends:

Supervisor, Ms Chin Yee Sing
Mechanical Department UTP staffs and lab technicians
Civil Department UTP staffs and lab technicians
Chemical Department UTP staffs and lab technicians
Friends in nearest circle of life
Kilang Sawit FELCRA Nasaruddin and staffs

Their contribution to the completion of this work is very valuable.

ABSTRACT

The objective of this final year project is to characterize solid biomass fuel briquettes. The research involves conducting several analysis; proximate analysis, ultimate analysis, combustion test, calorific value determination, and burning temperature profile investigation. From these analyses and tests, the materials are characterized and discussed.

Energy demand keeps on increasing day by day. Demand of electricity is usually met by power generation plants that use fossil fuel to generate heat. Current consumption of non-renewable energy from fossil fuel is very high, thus alternative source of energy, renewable energy should be considered. Since Malaysia is one of the largest producers of oil palm in the world, the waste of the production should be huge too. Thus, oil palm mill residue is selected to be material of interest here. This renewable energy source is a good alternative to generate electricity by using it as fuel. Since most biomass materials are in loose form, random shapes, and not really efficient to be used as fuel directly from their raw states, briquetting them is one of the good moves in order for them to be used in controlled manner. Prior to briquetting, materials would be dried to a desired level of moisture content, unmixed or mixed with other materials for better properties, and compressed into regular shapes. This uniform shape would be beneficial in terms combustion characteristics as they would give controlled manner in terms of combustion rate, energy content and precise operation for plants usage.

TABLE OF CONTENTS

CERTIFICATION i

ACKNOWLEDGMENT iii

ABSTRACT iv

CHAPTER 1: INTRODUCTION 1
1.1. Background of Study 1
1.2. Problem Statement 2
1.3. Objective and Scope of Study 3
1.4. Relevancy and Feasibility 5

CHAPTER 2: LITERATURE REVIEW 6
2.1. Briquetting 6
2.2. Materials for Biomass Fuel Briquette 6
2.3. Parameters Affecting Quality of Biomass Fuel Briquette 7
2.3.1. Binder 7
2.3.2. Particle Size 7
2.3.3. Briquette Shape 8
2.3.4. Compressive Force 8
2.4. Analysis Method 8
2.4.1. Proximate Analysis 8
2.4.2. Ultimate Analysis 10
2.4.3. Calorific Value Determination 10
2.4.4. Temperature Profile Investigation 10

CHAPTER 3: METHODOLOGY 11
3.1. Research Methodology 11
3.2. Project Activities 12
3.2.1. Materials Gathering 12
3.2.2. Mould Fabrication 13
3.2.3. Drying 14
3.2.4. Grinding and Sieving 15
3.2.5. Weighing and Mixing 15
3.2.6. Briquetting 17
3.2.7. Materials Analysing 18
3.3. Gantt Chart and Key Milestones 20
3.4. Tools and Software 22

CHAPTER 4: RESULTS AND DISCUSSION 26
4.1. Proximate Analysis 26
4.2. Ultimate Analysis 34
4.3. Calorific Value Determination 35
4.3.1. Experimental vs Correlation HHV 36
4.4. Combustion Test 38
4.5. Temperature Profile Investigation 47

CHAPTER 5: CONCLUSION AND RECOMMENDATION 50
5.1. Conclusion 50
5.2. Recommendations 51

REFERENCES 52

APPENDICES 55
APPENDIX A: TGA DATA FOR ALL SAMPLES 56
APPENDIX B: ULTIMATE ANALYSIS DATA 60
APPENDIX C: BOMB CALORIMETER DATA 62
APPENDIX D: AIR FUEL RATIO FOR COMBUSTION TEST 64
APPENDIX E: COMBUSTION TEST DATA 66
APPENDIX F: TEMPERATURE PROFILE INVESTIGATION DATA 69

LIST OF FIGURES

Figure 2.1: Example of TGA graph 9
Figure 3.1: Flow chart of study 11
Figure 3.2: Oil palm shell 12
Figure 3.3: Oil palm fibre 12
Figure 3.4: Palm frond 13
Figure 3.5: Empty fruit bunch 13
Figure 3.6: Sugarcane 13
Figure 3.7: Sawdust 13
Figure 3.8: 15 mm doughnut shape mould 14
Figure 3.9: Mild steel material 36
Figure 3.10: Full disk shape mould 14
Figure 3.11: 8 mm doughnut shape mould 14
Figure 3.12: Materials during sieving 15
Figure 3.13: Group 1 (small particle) materials 15
Figure 3.14: Samples after weighted and put in plastic container 16
Figure 3.15: Briquettes mad after pressing 17
Figure 3.16: Full disk shape 17
Figure 3.17: 8 mm doughnut shape 17
Figure 3.18: 15 mm doughnut shape 17
Figure 4.1: HHV correlation from proximate analysis 27
Figure 4.2: PS+PF+SC burning profile 29
Figure 4.3: PS+PF+SD burning profile 30
Figure 4.4: PS+PF+EFB burning profile 31
Figure 4.5: PS+PF+PFr burning profile 32
Figure 4.6: PS+PF burning profile 33
Figure 4.7: Percentage of carbon content of different materials 34
Figure 4.8: Experiment HHV obtained from bomb calorimeter 35
Figure 4.9: HHV correlation vs HHV experiment 36
Figure 4.10: Rate of energy and total energy released by big particle and 100 kN compression briquettes 39

Figure 4.11: Rate of energy and total energy released by big particle and 200 kN compression briquettes.....40
Figure 4.12: Rate of energy and total energy released by small particle and 100 kN compression briquettes.....41
Figure 4.13: Rate of energy and total energy released by small particle and 200 kN compression briquettes.....42
Figure 4.14: Average rate of energy released from different compression force for big particle briquettes.....43
Figure 4.15: Average rate of energy released from different compression force for small particle briquettes 44
Figure 4.17: Thermography sequence photo of burning fuel briquettes; (a) initial burning, (b) full disk shape briquette burn at all surface, (c) full disk shape briquette half completed burnt, (d) full disk shape briquette burnt completely.....47

LIST OF TABLES

Table 3.1: Weight percent for materials to be briquetted.....16
Table 3.2: Gantt chart and key milestone for FYP 1.....20
Table 3.3: Gantt chart and key milestone for FYP 2.....21
Table 3.4: Analysis equipment and its purpose 22
Table 3.5: Software and their purpose 25
Table 4.1: Proximate analysis data.....26
Table 4.2: Ultimate analysis data.....34
Table 4.3: Data on total energy and average rate of energy released 38
Table 4.4: Positions of solid fuel briquettes.....47

LIST OF ABBREVIATIONS

AC	Ash content
CHNS	Carbon hydrogen nitrogen and sulfur
CNC	Computer numerical control
EFB	Empty fruit bunch
FC	Fixed carbon
HHV	High heating value
MC	Moisture content
PF	Palm fibre
PFr	Palm frond
PS	Palm shell
SC	Sugar cane
SD	Sawdust
TGA	Thermogravimetry analysis
VM	Volatile matter
WT	Weight

CHAPTER 1: INTRODUCTION

1.1. Background of Study

Malaysia is one of the world largest producers of oil palm [1][2]. As in March 2012, Malaysia has five million hectares (5024894 ha) of oil palm planted area [3]. This number of plantation area gives huge potential of biomass as the oil palm processing will give lots of waste products; empty fruit bunch (EFB), oil palm shell (PS), oil palm fibre (PF) and palm frond (PFr). These waste products could be utilized as biomass fuel to generate heat for boilers. These wastes could be briquetted for better combustion properties and logistics issues [3].

Fuel briquettes are compressed form of biomass materials into regular shapes. One of the most common shapes of briquettes is a disk shape. Biomass fuel briquettes are commonly made from oil palm mills residue, baggase, wood chips, sludge and many more.

For biomass materials to be made into briquettes there are many issues to be considered so that they are worth to be made and can be used safely. In terms of energy content, several analyses can be done to quantify the energy content of biomass materials, which are proximate analysis, ultimate analysis and using bomb calorimeter. To justify the quality of combustion and rate of combustion, combustor can be used along with infrared camera to capture images of materials being burned. From the images captured by infrared camera, analysis can be done to show the location of higher temperature and lower temperature.

1.2. Problem Statement

Energy usage keeps on increasing day by day. To generate the energy required in daily life, especially the electricity, fossil fuel is used. The fuel is used to generate heat that be used to produce steam and generate electricity in steam power plant. Apart from that, fuel is also burnt for other purpose and for that, current consumption of this non-renewable energy from fossil fuel is very high, thus alternative source of energy, renewable energy should be considered.

As Malaysia has abundant source of oil palm mill residues, these materials have high potential to be used as alternative energy, which is a renewable energy source. However, there are parameters that need to be studied so that these materials could be practically used in daily life. If these materials are to be briquetted, parameters that affect combustion characteristics need to be studied and they include energy content, rate of combustion and elemental composition.

1.3. Objective and Scope of Study

The aim of the research is to characterize solid biomass fuel briquettes. The detailed objectives of this study are as follows:

1. To study the effect of varying binders to the combustion characteristics
2. To study the effect of different particle sizes to the combustion characteristics
3. To analyse the impact of varying briquette shapes to combustion characteristics
4. To compare the differences of combustion characteristics when different compressive force is used

Since Malaysia is one of the largest producer of oil palm in the world, the waste or by product of the production should be huge also. Thus, oil palm mill waste residue is selected to be material of interest here. There are a few oil palm mill residues that are selected to be used in this research. They are palm shell (PS), palm fibre (PF), empty fruit bunch (EFB), and palm frond (PFr). Apart from that, other waste materials like sawdust (SD) and sugarcane (SC) are also considered to be used as binders in fuel briquettes.

The scope of study in this research is easily presented as follows:

- Manipulated variables:
    a) Binder
    b) Particle size
    c) Briquette shape
    d) Compressive force
- Through analysis of:
    a) Proximate analysis

b) Ultimate analysis
c) Calorific value determination
d) Combustion test
e) Temperature profile investigation

- Details of manipulated variables:
  a) Binder
     - Sawdust (SD)
     - Sugar cane (SC)
     - Empty fruit bunch (EFB)
     - Palm frond (PFr)

  b) Particle size
     - Group 1 (small particle)
       - Main material (palm shell and palm fibre) less than 600 μm
       - Binders less than 425 μm
     - Group 2 (big particle)
       - Main material (palm shell and palm fibre) greater than 600 μm
       - Binders greater than 425 μm

  c) Briquette shape
     - Full disk / solid shape
     - Doughnut / concentric hole of 8mm inner diameter
     - Doughnut / concentric hole of 15 mm inner diameter

  d) Compressive force
     - 100 kN
     - 200 kN

1.4. Relevancy and Feasibility

This project is relevant and feasible in Malaysia. The waste materials to be used in fuel briquette are available in huge amount and readily available throughout Malaysia. The availability of the materials help the research in finding the materials and the success of the research could be implemented in the industry in Malaysia directly.

CHAPTER 2: LITERATURE REVIEW

2.1. Briquetting

Biomass briquetting is the work of compacting loose raw materials of biomass into a regular shape by application of pressure [4]. It increases the density and durability of biomass thus make it more appealing in handling and storage [5].

2.2. Materials for Biomass Fuel Briquette

From previous researches, there have been many types of biomass materials used in biomass fuel briquette. Raw materials from rice husk, sawdust, waste paper, oil palm shell, oil palm fiber, oil palm fronds, sugar cane, and poultry sludge have been researched and from the research, many conclusions were drawn. From one of the research, a conclusion is made that combination of materials would yield better briquettes with better characteristics [7]. Research on dewatered poultry sludge has shown that the material has promising potential to be used as alternative solid fuel as the higher heating value (HHV) of the material was found to be higher than HHV of low-grade coal [6].

2.3. Parameters Affecting Quality of Biomass Fuel Briquette

There are a few factors that affect the quality of biomass fuel briquette:

- Binder
- Particle size
- Briquette shape
- Compressive force

2.3.1. Binder

Different types of binder do affect the quality of biomass fuel briquette such as carbon content and calorific value. This is shown in a research using oil palm shell and fibre as main ingredients with binders from paper and starch, in which using paper, has higher value of HHV compared to using starch [8][9]. Even in research done by Sotannde et al., they concluded that the type of binder and blending ratio used will affect the physical and combustion properties of the briquettes [10].

From one research on oil palm mill residues, a finding that shows a mixture of 60% palm kernel shell and 40% palm fibre with paper as binder is optimum ratio for viable solid fuel [8].

2.3.2. Particle Size

From previous research works, coarse particle size will give shorter duration of burning but less unburned carbon, compared to small particle size that allow longer duration of burning, but leave more unburned carbon at combustion termination [11].

2.3.3. Briquette Shape

Shapes of fuel briquette also affect quality of biomass fuel briquette, as conducted in a research using solid shape and concentric hole, in which the burn rate of briquette with concentric hole is higher compared to solid shape fuel briquette [6].

2.3.4. Compressive Force

In the same research also, different pressure of compression leads to different burn rate in which pressure at 5 MPa gives higher burn rate than 13 MPa [6].

2.4. Analysis Method

There are several analysis methods that are common in biomass study and they are discussed as following subsections.

2.4.1. Proximate Analysis

Proximate analysis is an attempt to quantify certain key physical characteristics of biomass that could affect combustion characteristics and they include moisture content, volatile matter, fixed carbon and ash content [4]. Moisture content shows amount of water in samples. High moisture content can cause difficulty in ignition. Volatile matter is components that turn into vapor when heated such as carbon, hydrogen and oxygen. Fixed carbon is a percentage of carbon that is available for char combustion. Ash content is the component that cannot be burnt and this could affect char combustion as it hinders oxygen diffusion to fuel surface.

For proximate analysis, thermogravimetry analyser (TGA) will be used. From proximate analysis, percentage of moisture content, volatile matter, fixed carbon and ash content can be obtained. These values can be used in correlation derived by

Parikh et al. to find high heating value (HHV) [12]. The correlation is given in equation 1 below.

$$HHV = 0.3536FC + 0.1559VM - 0.0078ASH \text{ (MJ/kg)} \qquad (1)$$

In the correlation, three data obtained from proximate analysis are used which are fixed carbon (FC), volatile matter (VM) and ash content (ASH). This correlation has an average absolute error of 3.74% with respect to measured values of HHV, as derived by Parikh et al. [12].

From the correlation also, comparison of value can be done with experimental value obtained in calorific value test using bomb calorimeter.

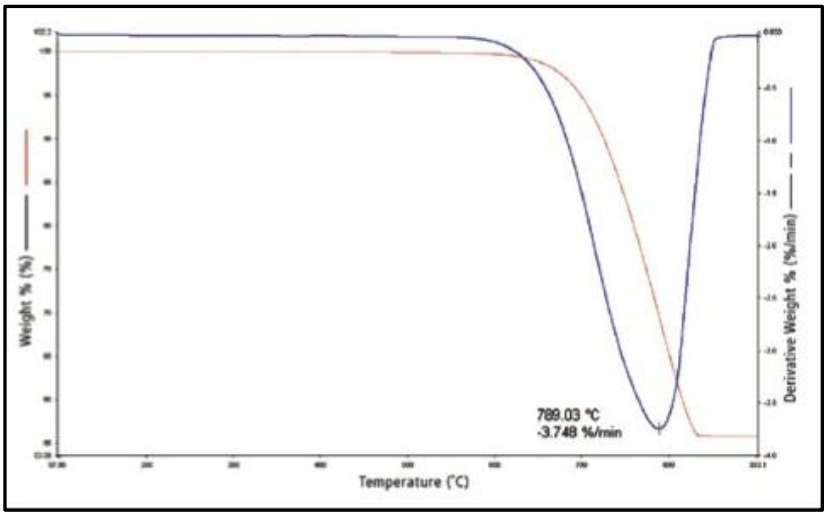


Figure 2.1: Example of TGA graph [15].

2.4.2. Ultimate Analysis

Ultimate analysis is used to identify chemical elements in sample; carbon, hydrogen, nitrogen and sulfur. Using special equipment such as LECO CHNS-932, these elements are identified automatically and take least amount of time.

2.4.3. Calorific Value Determination

Calorific value is the energy content of a fuel and it is related to amount of oxygen that is required for complete combustion [5]. It can be done using bomb calorimeter.

2.4.4. Temperature Profile Investigation

Previous research was done on qualitative study of burning rates of different briquettes designs using infrared thermography. In the work, photos were taken using the infrared camera equipment, and the photos showed solid fuels with temperature profile. Based on the temperature profile, it can be seen the location of higher temperature and lower temperature qualitatively on the photos.

CHAPTER 3: METHODOLOGY

3.1. Research Methodology

To conduct this project, simple methodology is drawn out. The project is initiated by knowing the problem statement first. After that, information is gathered further to know the background of the project or anything related to the problem statement. By understanding the information about the problem statement leads to material gathering and materials preparation. After all materials are prepared, experimenting can be done. From results obtained, data are then analysed and compared with previous works done by other researchers. After that, a conclusion is obtained in which meeting the objective of this research or not. The process flow chart of this research is simplified as in figure follows:

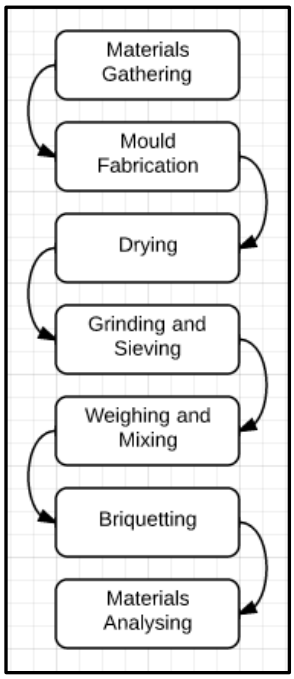


Figure 3.1: Flow chart of study

3.2. Project Activities

In doing this research, there are many activities to be done. After understanding problem statement, literature review was done first to get more information on the project. In conducting this project, it was found that many analyses should be done to assess the materials to be used as fuel briquette. They included proximate analysis, ultimate analysis, calorific value determination, combustion test and temperature profile investigation. Prior to testing, material preparation was also discussed in detail.

3.2.1. Materials Gathering

Raw materials to be used in this research are palm shell, palm fibre, palm frond and empty fruit bunch (EFB), in which these were obtained from Kilang Sawit Felcra Nasaruddin in Bota, Perak. Other materials collected were sawdust from a sawmill in Ipoh, Perak and sugarcane from stalls selling drinks. Figure 3.2, Figure 3.3, Figure 3.5 show picture of oil palm shell, oil palm fibre and EFB obtained from Kilang Sawit Felcra Nasaruddin, Figure 3.4 shows palm frond obtained nearby Kilang Sawit Felcra Nasaruddin, Figure 3.6 and Figure 3.7 show picture of sugarcane obtained from stall that sells sugarcane drinks in Taman Maju, Perak while sawdust was obtained in a sawmill in Ipoh, Perak.

Figure 3.2: Oil palm shell

Figure 3.3: Oil palm fibre

Figure 3.4: Palm frond

Figure 3.5: Empty fruit bunch

Figure 3.6: Sugarcane

Figure 3.7: Sawdust

3.2.2. Mould Fabrication

To do briquetting, mould for full disk shape and doughnut shape of 8 mm inner diameter were already available, and obtained from previous work in Universiti Teknologi PETRONAS, shown in Figure 3.10 and Figure 3.11. Only doughnut shape of 15 mm inner diameter mould needed to be fabricated. The mould used was from mild steel. To fabricate this mould, a block of mild steel cylinder was cut into two and by using Computer Numerical Control (CNC) turning center, the mould was machined into desired shapes with high precision. Figure 3.8 was photo captured during the mould preparation. Figure 3.9 shows the mould manufactured.

Figure 3.8: Mold preparation

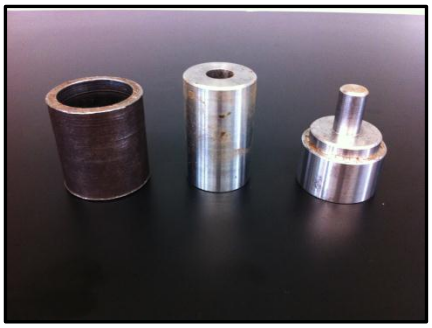


Figure 3.9: 15 mm doughnut shape mould

Figure 3.10: Full disk shape mould

Figure 3.11: 8 mm doughnut shape mould

3.2.3. Drying

To prepare the materials, palm shell, palm fibre, palm frond, EFB, sugar cane and sawdust were dried in oven at 105 °C until a constant mass was obtained, and they were also subjected to sun drying before oven was used. Sun drying was done by exposing the materials under direct sunlight so that they could be dried. However, care was to be taken as they could be wet if they were not protected or moved away when rain falls.

3.2.4. Grinding and Sieving

After drying the materials, they were ground into fine particles using granulator, mortar grinder and analytical mill grinder. After that, they were sieved into two groups which were group 1 and group 2. Group 1 (small particle) comprised of palm shell and palm fibre with less than 600 µm and binders less than 425 µm. Group 2 (big particle) comprised of palm shell and palm fibre with greater than 600 µm and greater than 425 µm for the binders. Figure 3.12 shows materials sieved using sieving equipment and Figure 3.13 shows group 1 (small particle) materials.

Figure 3.12: Materials during sieving

Figure 3.13: Group 1 (small particle) materials

3.2.5. Weighing and Mixing

Fuel briquettes to be made were from different combination of materials and percentage. Main ingredients were palm shell and palm fibre, with binders from EFB, palm frond, sugar cane and sawdust. Main ingredients were in combination of 60 % palm shell and 40 % palm fibre. Each briquette was made from a total mass of 10 grams, with 90 % of main ingredients and 10 % binder. Samples are weighed as shown in Table 3.1 as follows:

Table 3.1: Weight percent for materials to be briquetted

	Weight %				
Materials	PS+PF+SC	PS+PF+SD	PS+PF+ EFB	PS+PF+ PFr	PS+PF
Palm Shell	54	54	54	54	60
Palm Fibre	36	36	36	36	40
Sugar cane	10	0	0	0	0
Sawdust	0	10	0	0	0
EFB	0	0	10	0	0
Palm Frond	0	0	0	10	0

The samples were weighed using mass balance to ensure precise mass fraction or composition. Figure 3.14 shows a photo after each type of samples were weighted and put into a plastic container.

Figure 3.14: Samples after weighted and put in plastic container

3.2.6. Briquetting

From here, briquetting could be done using Auto Pellet Machine. Briquetting process used different level of force, which were 100 kN (10200 kg) and 200 kN (20400 kg). Figure 3.15 shows briquettes made after pressing.

Figure 3.15: Briquettes made after pressing

Each type of combination of fuel briquette was shaped into 3 different shapes; full disk shape as in Figure 3.16, doughnut shape of 8 mm inner diameter as in Figure 3.17, and 15 mm inner diameter as in Figure 3.18. All shapes had outside diameter of 40 mm.

Figure 3.16: Full disk shape

Figure 3.17: 8 mm doughnut shape

Figure 3.18: 15 mm doughnut shape

3.2.7. Materials Analysing

3.2.7.1. Proximate Analysis

To study the combustion characteristics of the materials, several analysis were done. Proximate analysis was done by using thermo gravimetric analyser (TGA). From this analysis, data of moisture content, volatile matter, fixed carbon and ash contents of the materials were obtained. These data could be used to estimate HHV value based on correlation by Parikh et al. The actual data obtained from TGA was data of weight change against time and temperature. From these, further analysis could be done and proximate analysis is one of them. In Universiti Teknologi PETRONAS, the TGA machine used was from Perkin Elmer, Pyris 1 TGA. Each powdered samples of about five (5) mg or less were required to conduct this analysis.

3.2.7.2. Ultimate Analysis

Ultimate analysis was done to obtain data on carbon, hydrogen, nitrogen and sulfur content. Equipment used in this study was from LECO CHNS-932 where the standard chemical for CHNS for carbon was 51.78%, hydrogen 5.07%, nitrogen 20.13% and sulfur 11.52%. This known reference material was called sulfamethazime.

3.2.7.3. Calorific Value Determination

To determine calorific value, a device called bomb calorimeter was used. From this experiment, higher heating values (HHV) for different materials were obtained. These experimental values obtained would be used to compare those values obtained theoretically using a correlation by Parikh et al.

To conduct this test, a small amount of powdered samples were put into a pan and weighed using mass balance. This pan was then assembled in the component to be inserted inside the bomb calorimeter. Prior to start the bomb calorimeter, input of mass of sample was required as to give result of HHV.

3.2.7.4. Combustion Test

Combustion test was done using small combustor. From this experiment, rate of combustion and total of useful energy were obtained. Different shapes of briquette, particle size and compression force showed different rate of combustion.

In conducting the experiment, personal protective equipment (PPE) such as glove and shoes are necessary as this test involves combustion and high temperature.

3.2.7.5. Temperature Profile Investigation

To get temperature profile, an infrared camera was used to capture the image of burning fuel briquettes during the combustion. From the image captured, qualitative analysis was done to see the location of combustion and the rate of combustion of the fuel briquettes.

3.3. Gantt Chart and Key Milestones

Table 3.2: Gantt chart and key milestone for FYP 1

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection & allocation														
Preliminary Research Work / Literatures Review														
Submission of Extended Proposal														
Proposal Defence														
Material Gathering														
Material Preparation														
Submission of Interim Report														

Table 3.3: Gantt chart and key milestone for FYP 2

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Material Preparation															
Proximate Analysis															
Ultimate Analysis															
Calorific Value Determination															
Combustion Test															
Temperature profile investigation															
Prepare the Progress Report															
Submission of Progress Report															
Submission of FYP poster															
Submission of Draft Report															
Submission of Dissertation (softbound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation (hardbound)															

3.4. Tools and Software

Many tools and equipment are required to conduct this research. They are listed in Table 3.4.

Table 3.4: Analysis equipment and its purpose

No.	Equipment / Tools	Purpose
1	TGA machine 	To conduct thermo gravimetric analysis or TGA analysis. Data obtained are used to plot graph of weight and derivative weight against time and temperature. From this, MC, VM, FC, and AC can be obtained. (Location: UTP, 17-02-02)
2	CHNS analyser 	To conduct ultimate analysis. Data obtained are the elemental composition of carbon, hydrogen, nitrogen and sulfur. (Location: UTP, 4-00-07)
3	Auto Pellet Machine 	To compress materials into briquette. (Location: UTP, 17-00-04)

4	CNC turning centre 	To fabricate mould. (Location: UTP, 16-00-04)
5	Combustor 	To burn briquetted samples. (Location: UTP, BLOCK H)
6	Infrared camera 	To capture images of burning samples inside small combustor. (With: Ir. Dr. Mohd Shiraz Aris)
7	Oven 	To remove and reduce moisture content from materials. (Location: UTP, 17-02-06)

8	Granulator 	To grind raw materials into smaller pieces, but not in powder form. (Location: UTP, 17-00-04)
9	Sieve 	To sieve powdered form materials into desired groups of particle sizes. Used sieve sizes are 1.18 mm, 600 µm, 425 µm, 300 µm, and 212 µm. (Location: UTP, 13-00-06)
10	Mass balance 	To weigh powdered form materials precisely to make accurate combination of materials for analysis and briquetting. (Location: UTP, 17-02-08)
11	Mortar grinder 	To grind small pieces of raw materials into fine and powdered. (Location: UTP, 17-02-08)

12	Bomb calorimeter 	To find calorific value or actual high heating value (HHV) of samples. (Location: UTP, 4-02-04)
13	Analytical mill grinder 	To grind materials and sieve or filter automatically to desired particle size. (Location: UTP, 13-00-06)

There are softwares that have been used in this study. They are listed in Table 3.5 as follows:

Table 3.5: Software and their purpose

NO	Software	Purpose
1	Microsoft Word 2010	For documentation of project
2	Microsoft Excel 2010	For result tabulation and graph plotting
3	Prism 6 Trial	For graph plotting

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Proximate Analysis

Table 4.1: Proximate analysis data (dry basis)

Components (wt %)	PS+PF+ SC	PS+PF+ EFB	PS+PF+ SD	PS+PF+ PFr	PS+PF
Volatile Matter	72.04	70.17	71.38	69.10	68.34
Fixed Carbon	23.28	23.97	23.39	25.04	23.42
Ash Content	4.68	5.86	5.23	5.86	8.24

Table 4.1 shown above is a dry basis weight percent. From data obtained in proximate analysis, combination of palm shell and palm fibre with palm frond as binder gave the highest amount of fixed carbon content (25.04 %) compared with other combinations. Second highest fixed carbon here is the sample with EFB as binder, having value of 23.97 %, followed by sample reference which has only palm shell and palm fibre without any binder, having value of 23.42 % , then sample with sawdust as binder, having value of 23.39 %, then and lastly by sample with sugarcane as binder which has value of 23.28 % of fixed carbon.

In view of ash content, sample with sugar cane showed the lowest which is 4.68 % and sawdust as binder showed 5.23 %, followed by samples with palm frond and EFB as binders, both having value of 5.86 %. The reference value shown by sample of palm shell and palm fibre only is 8.24 %. Thus, samples with sugarcane as binder gave the least amount of ash content, even lower than the reference value. This low content of ash is very important in boiler operation as high amount of ash will affect the boiler efficiency as ash stick to boiler tube surface. However, the values of ash content shown from samples with binders from EFB, palm frond and sawdust are not

too high compared to 4.68 %. These three samples are also acceptable in terms of ash content.

From correlation given by Parikh et al., value of HHV can be estimated from data obtained in proximate analysis. The value is shown in Figure 4.1 as follows:

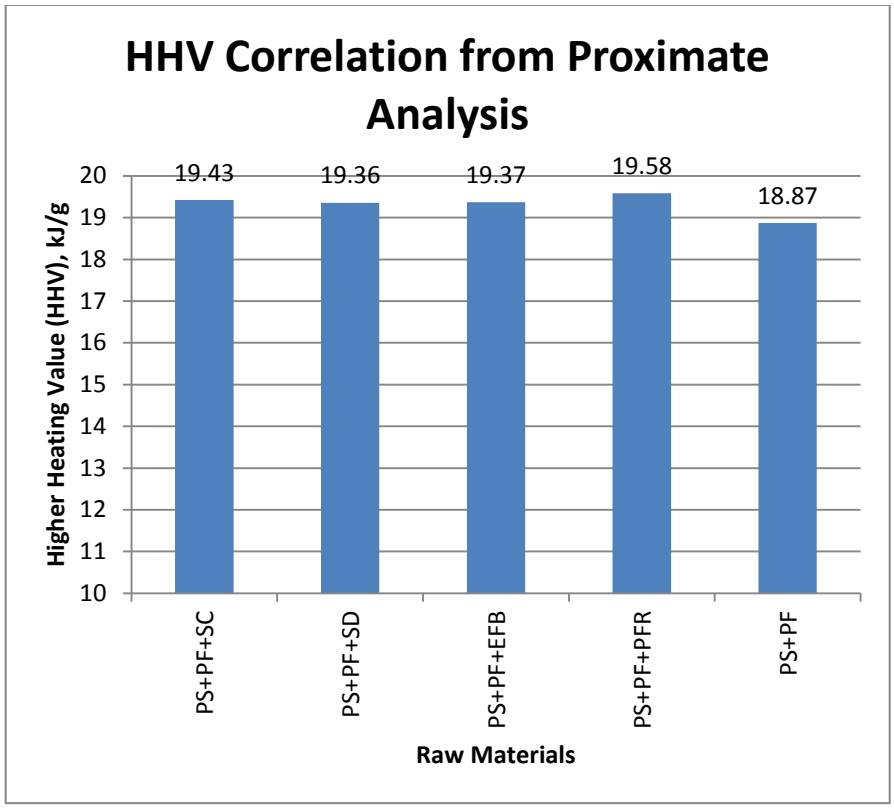


Figure 4.1: HHV correlation from proximate analysis

From this Figure 4.1, it can be seen that sample with palm frond as binder has highest value for HHV, which is 19.58 kJ/g and other samples with binders of sugar cane, EFB and sawdust, have lower values which are 19.43 kJ/g, 19.37 kJ/g and 19.36 kJ/g respectively. Reference HHV value of sample having no binder is 18.87 kJ/g.

From TGA data also, burning profile could be drawn, which could represent the burning rate of actual briquettes. For all burning profiles of these samples, there were three regions that could be observed, which were moisture release, rapid burning and slow burning region. Between these three regions, there would be two temperatures that separate the three regions.

In the first region, the moisture release could be recognized with the first fluctuating graph or line. Within this region, volatile matters were released and partial ignition occurred. As for these, the rate of change in mass was slightly high.

In the second region, the rapid burning could be recognized easily as there would be peak or peaks that were the highest during the burning. This region started after the first region or moisture release and rapidly losing mass toward the maximum mass loss rate and after that, quickly slowed down. This rapid mass loss rate was due to the combination of the release and then ignition of volatile matter. As reported in previous work, the oily components of palm shell and palm fibre within the sample could lead to the increase of burning rate [8].

The third region, the slow burning could be recognized after the maximum mass loss rate and relatively showed stable or moving towards zero mass loss rate. In this region, there would be coverage of ash over the surface of samples and this made oxygen harder to diffuse in through the ash layer. This resulted in the remaining combustible sections difficult to be burned.

Thus, there are 5 figures (Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6) obtained from proximate analysis to show the burning profile for each type of samples burnt. These figures will show the three regions discussed earlier which are moisture release, rapid burning and slow burning.

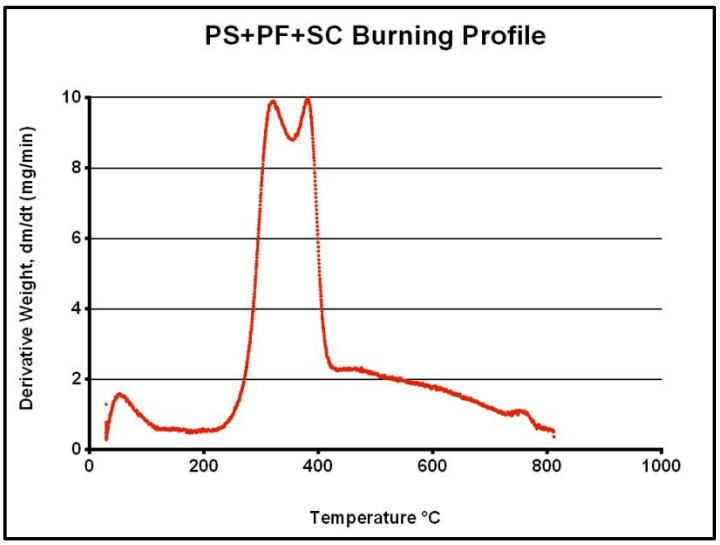


Figure 4.2: PS+PF+SC burning profile

As in Figure 4.2, this sample of palm shell, palm fibre and sugarcane as binder, had three regions separated at around 120 °C and 434 °C. Maximum mass loss rate was found to be at 10 mg/min at 382 °C and then quickly slowed down to about 2.27 mg/min at 434 °C. As in proximate analysis, this sample has 72.04 % of volatile matter in dry basis, which was high enough to explain the rapid burning region (release and then ignition of volatile matter).

This sample was analysed in proximate analysis using Procedure A, mentioned in Appendix A.

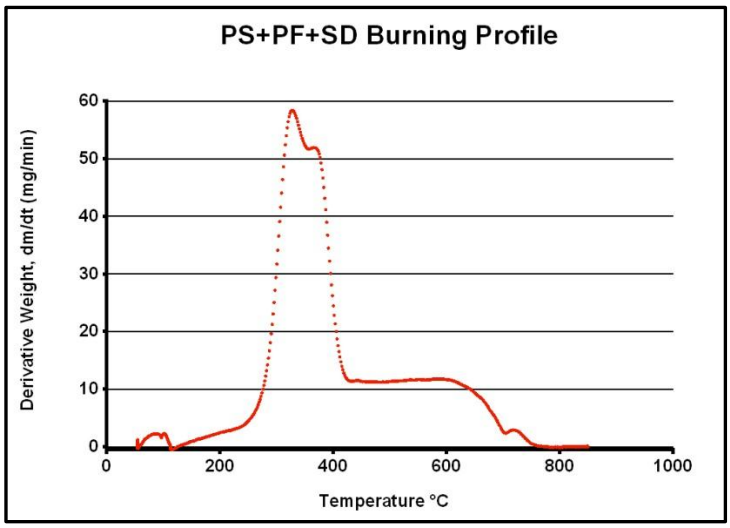


Figure 4.3: PS+PF+SD burning profile

As in Figure 4.3, this sample of palm shell, palm fibre and sawdust as binder, had three regions separated at around 127 °C and 432 °C. Maximum mass loss rate was found to be at 58 mg/min around 330 °C and then quickly slowed down to about 10.7 mg/min at 432 °C. Towards the end, at around temperature 849 °C, the mass loss rate was found to be only 0.07 mg/min. As in proximate analysis, this sample has 71.38 % of volatile matter in dry basis, which was high enough to explain the rapid burning region (release and then ignition of volatile matter).

This sample was analysed in proximate analysis using Procedure B, mentioned in Appendix A.

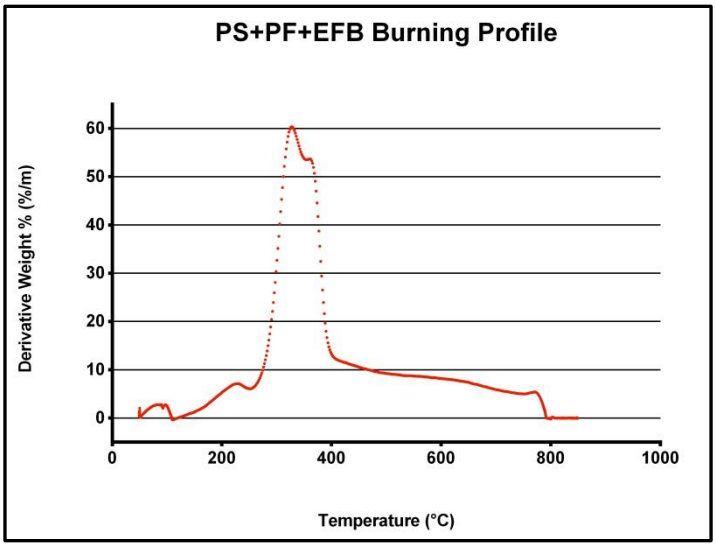


Figure 4.4: PS+PF+EFB burning profile

As in Figure 4.4, this sample of palm shell, palm fibre and EFB as binder, had three regions separated at around 110 °C and 415 °C. Maximum mass loss rate was found to be at 60.35 mg/min around 327 °C and then quickly slowed down to about 11.85 mg/min at 415 °C. Towards the end, at around temperature 847 °C, the mass loss rate was found to be only 0.02 mg/min. As in proximate analysis, this sample has 70.17 % of volatile matter in dry basis, which was high enough to explain the rapid burning region (release and then ignition of volatile matter).

This sample was analysed in proximate analysis using Procedure B, mentioned in Appendix A.

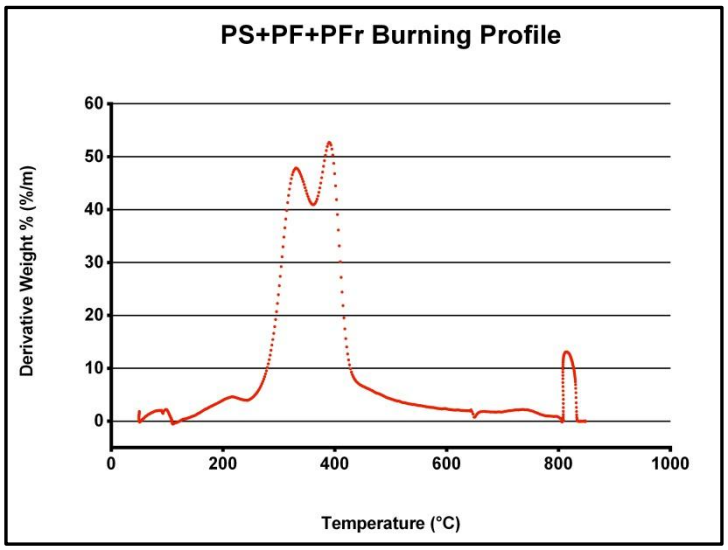


Figure 4.5: PS+PF+PFr burning profile

As in Figure 4.5, this sample of palm shell, palm fibre and palm frond as binder, had three regions separated at around 115 °C and 446 °C. Maximum mass loss rate was found to be at 52.7 mg/min around 390 °C and then quickly slowed down to about 6.81 mg/min at 446°C. Towards the end, at around temperature 847 °C, the mass loss rate was found to be only 0.03 mg/min. As in proximate analysis, this sample has 69.10% of volatile matter in dry basis, which was high enough to explain the rapid burning region (release and then ignition of volatile matter).

This sample was analysed in proximate analysis using Procedure B, mentioned in Appendix A.

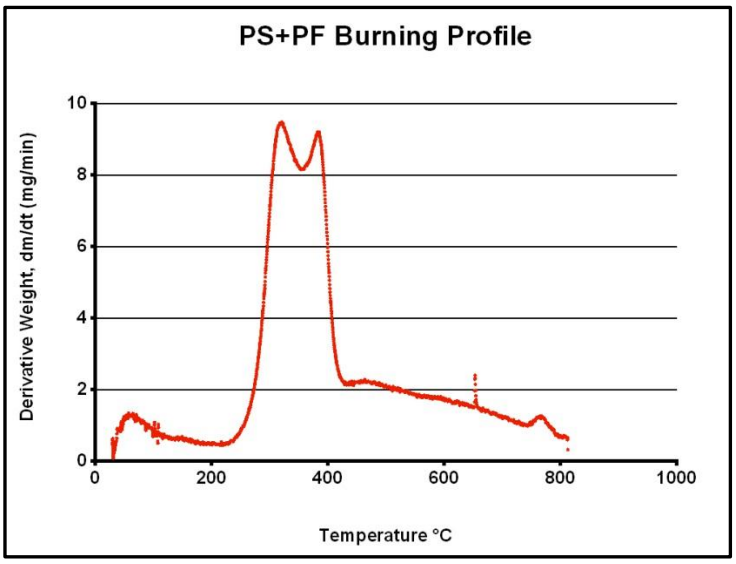


Figure 4.6: PS+PF burning profile

As in Figure 4.6, this reference sample of palm shell and palm fibre, had three regions separated at around 110 °C and 435 °C. Maximum mass loss rate was found to be at 9.45 mg/min around 323 °C and then quickly slowed down to about 2.04 mg/min at 435°C. Towards the end, at around temperature 817 °C, the mass loss rate was found to be only 0.565 mg/min. As in proximate analysis, this sample has 68.34 % of volatile matter in dry basis, which was high enough to explain the rapid burning region (release and then ignition of volatile matter).

This sample was analysed in proximate analysis using Procedure A, mentioned in Appendix A.

4.2. Ultimate Analysis

Table 4.2: Ultimate analysis data

Components (wt %)	PS+PF + SC	PS+PF + EFB	PS+PF +SD	PS+PF+ PFr	PS+PF
Carbon	46.47	46.33	46.27	46.27	45.99
Hydrogen	6.43	4.72	5.40	5.27	5.52
Nitrogen	0.80	0.79	0.78	0.80	0.80
Sulfur	0.32	0.23	0.26	0.24	0.27

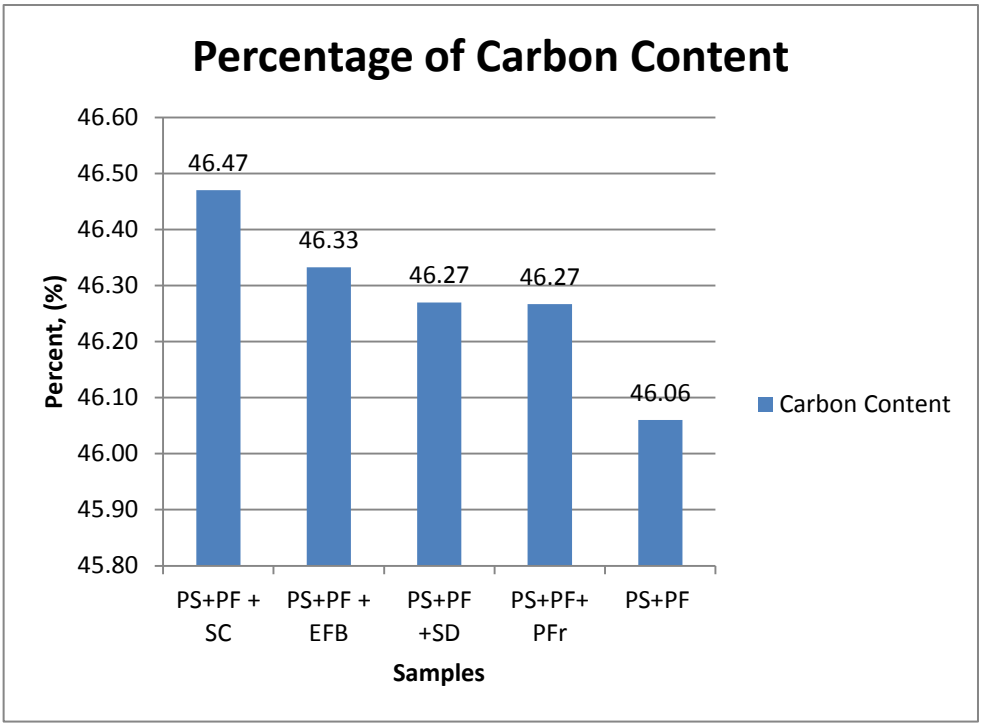


Figure 4.7: Percentage of carbon content of different samples

From data shown in Table 4.2 and Figure 4.7, it can be seen that the carbon content for all samples are relatively the same, around 46 %. According to this data, sample with sugarcane as binder has the highest carbon content, which is 46.47%, followed by sample with EFB, sawdust and palm frond as binders, with carbon content of 46.33%, 46.27% and 46.27% respectively. The reference sample which has no binder is found to have 46.06 % of carbon content.

From this ultimate analysis, sample with sugar cane has the highest potential for char burning, followed by the decreasing amount of carbon content; EFB, sawdust and palm frond.

4.3. Calorific Value Determination

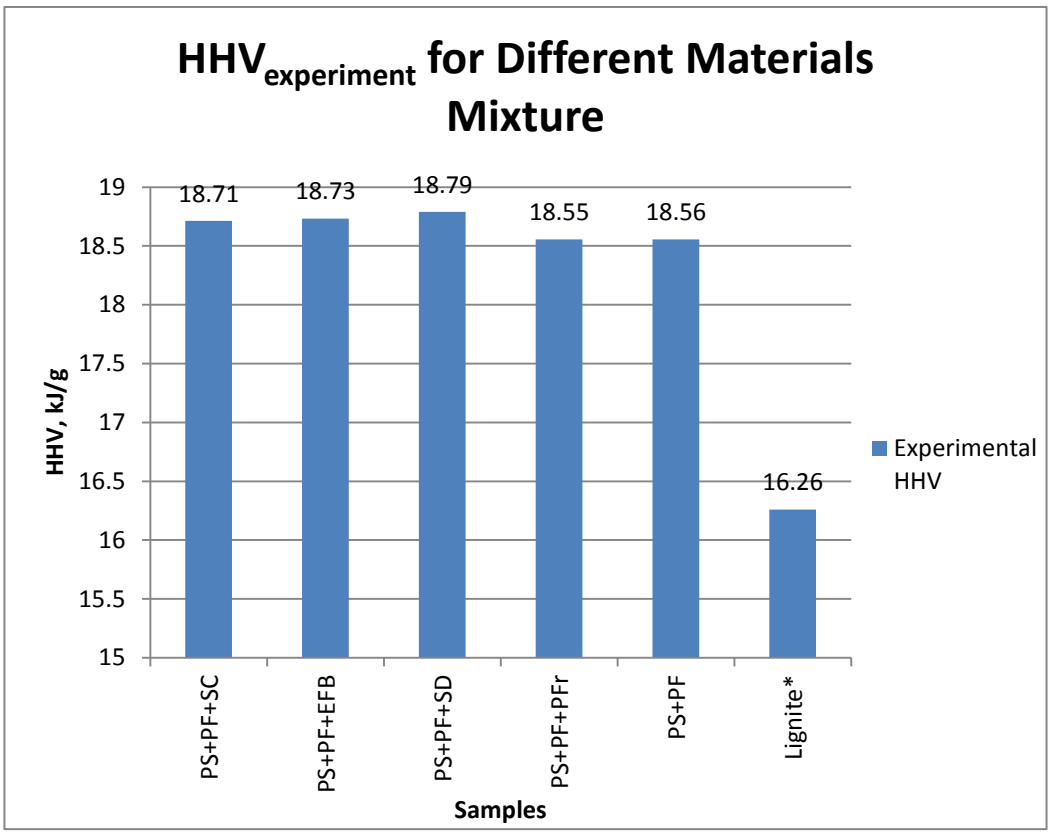


Figure 4.8: Experimental HHV obtained from bomb calorimeter

Calorific value has been obtained from bomb calorimeter. All values obtained were taken from three repetitions. From these three repetitions, average values obtained were expected to be more reliable and accurate. Based on Figure 4.8, the highest value of HHV is shown by sample of palm shell and palm fibre with sawdust as binder, in which the value is 18.79 kJ/g, followed by sample with binder of EFB, sugarcane and palm frond, in which the values are 18.73 kJ/g, 18.71 kJ/g and 18.55

kJ/g respectively. Reference value from sample of palm shell and palm fibre was obtained to be 18.56 kJ/g. All these values are much higher than the calorific value for lignite, a low rank coal which has value of 16.26 kJ/g [13].

4.3.1. Experimental vs Correlation HHV

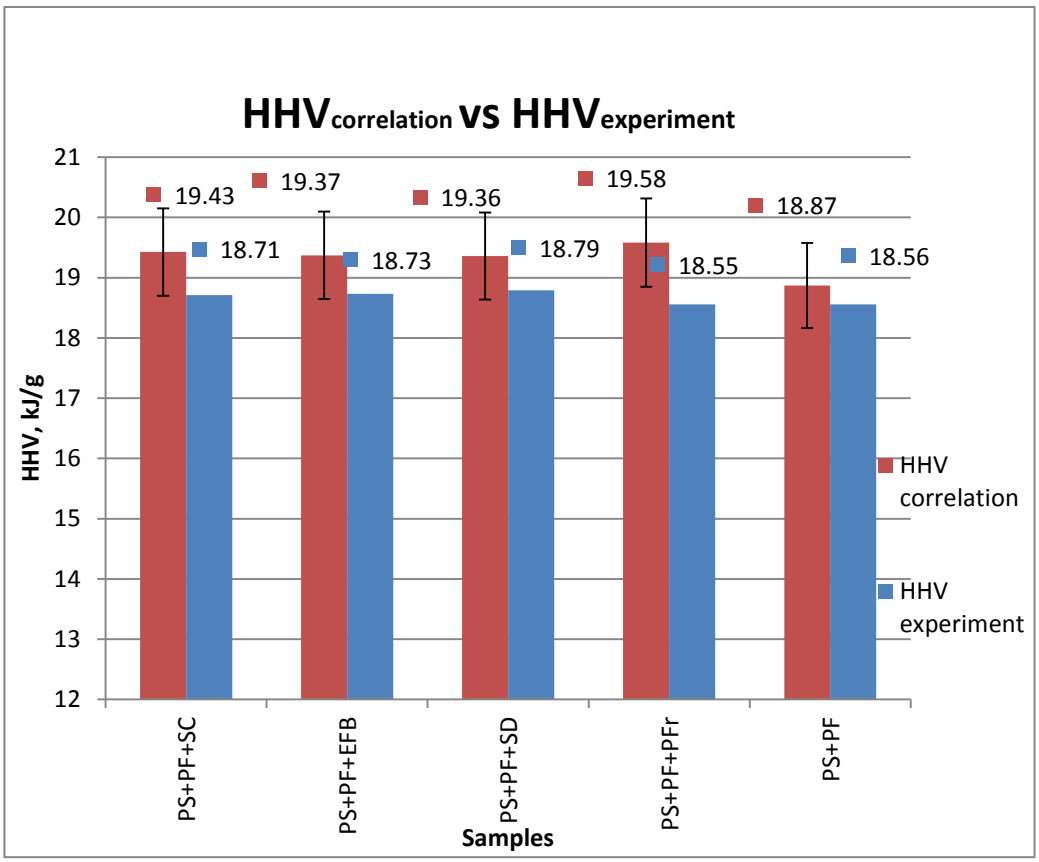


Figure 4.9: HHV correlation vs HHV experimental

Based on Figure 4.9, a bar chart has been constructed to compare values of HHV obtained in bomb calorimeter and correlation values from TGA data. From this bar chart, samples with sugar cane, EFB, sawdust as binders have data that matched between HHV correlation and HHV experiment. Sample with sugarcane as binder has 19.43 kJ/g of HHV correlation and 18.71 kJ/g of HHV experiment, while sample of EFB as binder has 19.37 kJ/g of HHV correlation and18.73 kJ/g of HHV

experiment and sample with sawdust as binder has 19.36 kJ/g of HHV correlation and 18.79 kJ/g of HHV experiment. These three samples have HHV experiment values which are within the 3.74% absolute error. Reference sample, the palm shell and palm fibre only, has data within the 3.74% error also, in which the HHV correlation is 18.87 kJ/g and HHV experiment is 18.56 kJ/g. Other data of palm shell and palm fibre with binder of palm frond was not within the 3.74 % absolute error.

4.4. Combustion Test

Prior to combustion test, there was a chemical equation involved. Using 40 % excess air, the chemical equation is shown as follow in equation 2.

$$C_{3.86}H_{5.27} + 7.25(O_2 + 3.76N_2) \rightarrow 3.86CO_2 + 2.64H_2O + 2.07O_2 + 27.25N_2 \quad (2)$$

From equation 2, air-fuel ratio can be calculated and equals to 19.39 kg air per kg fuel. Further details can be referred in Appendix D in section Appendices.

Combustion test was done and Table 4.3 shows the data obtained on total energy recorded and the average rate of energy released. Based on the data obtained, it can be seen that the average rate of energy released increases as the surface area of reaction increases (from full disk shape, to 8 mm inner diameter and 15 mm inner diameter doughnut shape briquettes).

Table 4.3: Data on total energy and average rate of energy released

Briquettes				
Particle size	**Compression force (kN)**	**Shape of Briquette**	**Total Energy (kJ)**	**Average Rate of Energy Released (kW)**
Big	100	Full	890.37	0.39
Big	100	8mm	960.81	0.40
Big	100	15mm	919.79	0.46
Big	200	Full	774.59	0.22
Big	200	8mm	613.18	0.25
Big	200	15mm	1052.38	0.59
Small	100	Full	1058.81	0.39
Small	100	8mm	965.74	0.62
Small	100	15mm	1008.39	0.56
Small	200	Full	382.60	0.09
Small	200	8mm	731.73	0.33
Small	200	15mm	915.27	0.39

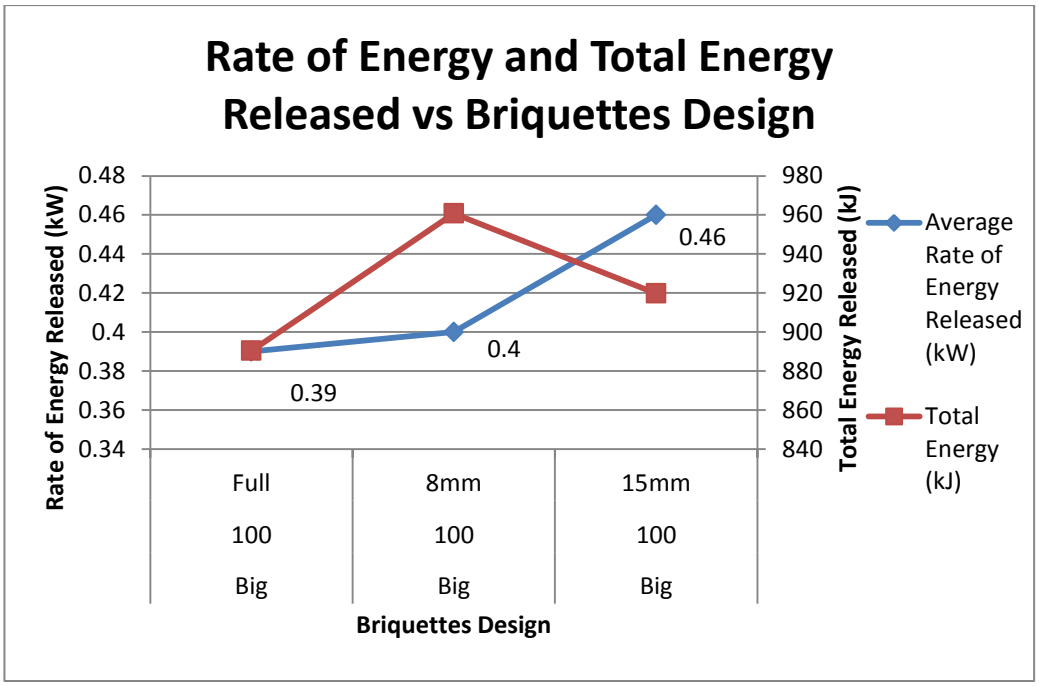


Figure 4.10: Rate of energy and total energy released by big particle and 100 kN compression briquettes

From Figure 4.10, it can be seen that as shape of briquettes is changed from full disk to 8 mm and 15 mm inner diameter doughnut shape, the rate of energy released increases. From full disk shape having 0.39 kW, to 0.4 kW from 8 mm inner diameter doughnut shape and 0.46 kW inner diameter doughnut shape. This result agreed with the theory that by increasing the surface area of reaction (from full disk to 15 mm inner diameter doughnut shape) the rate of energy released [11].

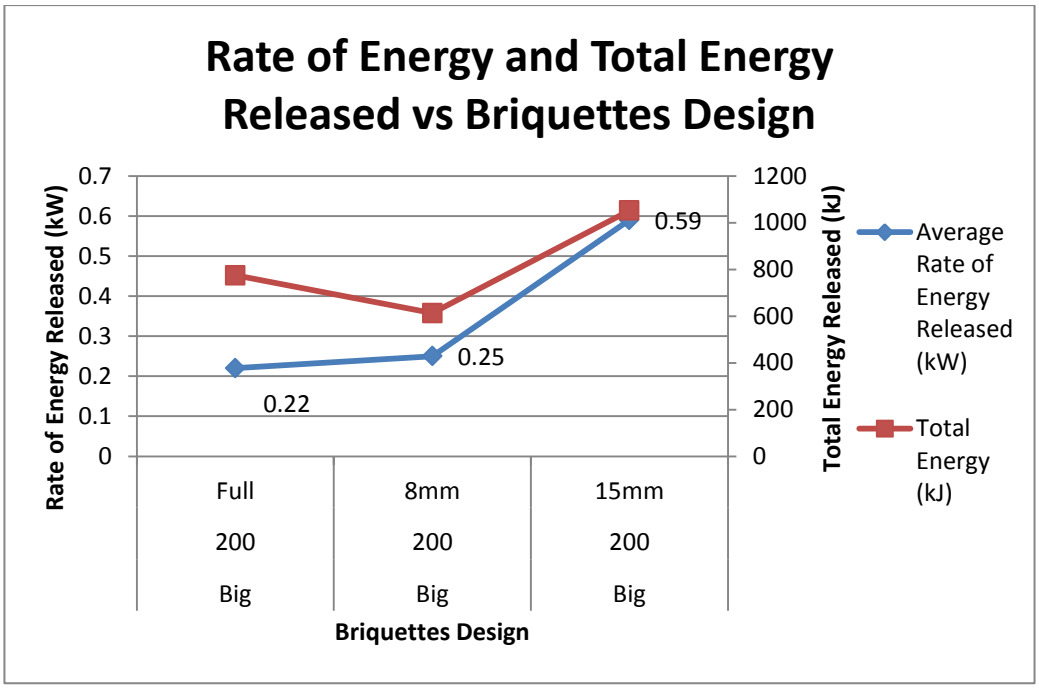


Figure 4.11: Rate of energy and total energy released by big particle and 200 kN compression briquettes

From Figure 4.11, it can be seen that as shape of briquettes is changed from full disk to 8 mm and 15 mm inner diameter doughnut shape, the rate of energy released increases. From full disk shape having 0.22 kW, to 0.25 kW from 8 mm inner diameter doughnut shape and 0.59 kW inner diameter doughnut shape. This result agreed with the theory that by increasing the surface area of reaction (from full disk to 15 mm inner diameter doughnut shape) the rate of energy released.

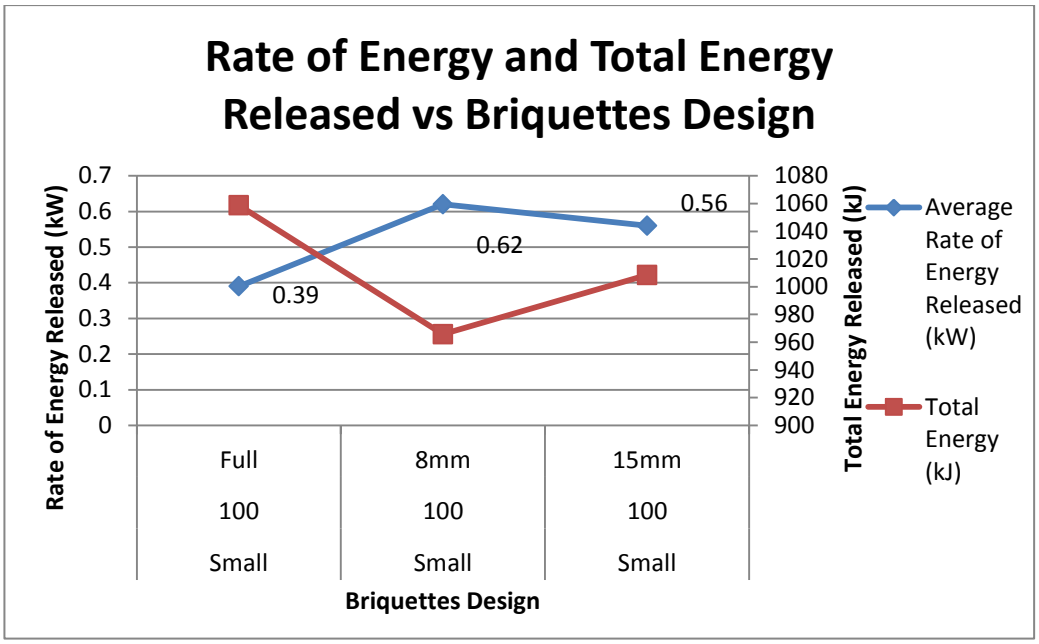


Figure 4.12: Rate of energy and total energy released by small particle and 100 kN compression briquettes

From Figure 4.12, it can be seen that as shape of briquettes is changed from full disk to 15 mm inner diameter doughnut shape, the rate of energy released increases. From full disk shape having 0.39 kW, to 0.62 kW from 8 mm inner diameter doughnut shape and 0.56 kW inner diameter doughnut shape. This result agreed with the theory that by increasing the surface area of reaction (from full disk to 15 mm inner diameter doughnut shape) the rate of energy released. However, it seems that the value of rate of energy released in 15 mm inner diameter briquette is lower than the 8 mm inner diameter briquette. It could be error in the experiment done that led this way. Nonetheless, both are higher than full disk shape briquette and this is expected as the surface area of reaction increases.

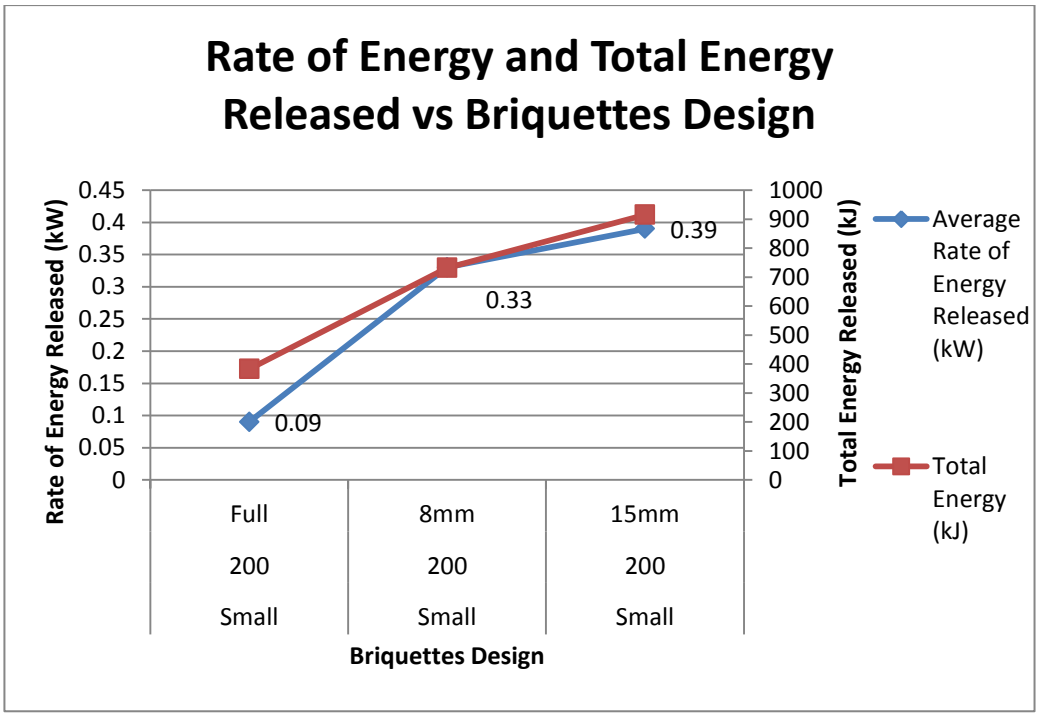


Figure 4.13: Rate of energy and total energy released by small particle and 200 kN compression briquettes

From Figure 4.13, it can be seen that as shape of briquettes is changed from full disk to 8 mm and 15 mm inner diameter doughnut shape, the rate of energy released increases. From full disk shape having 0.09 kW, to 0.33 kW from 8 mm inner diameter doughnut shape and 039 kW inner diameter doughnut shape. This result agreed with the theory that by increasing the surface area of reaction (from full disk to 15 mm inner diameter doughnut shape) the rate of energy released.

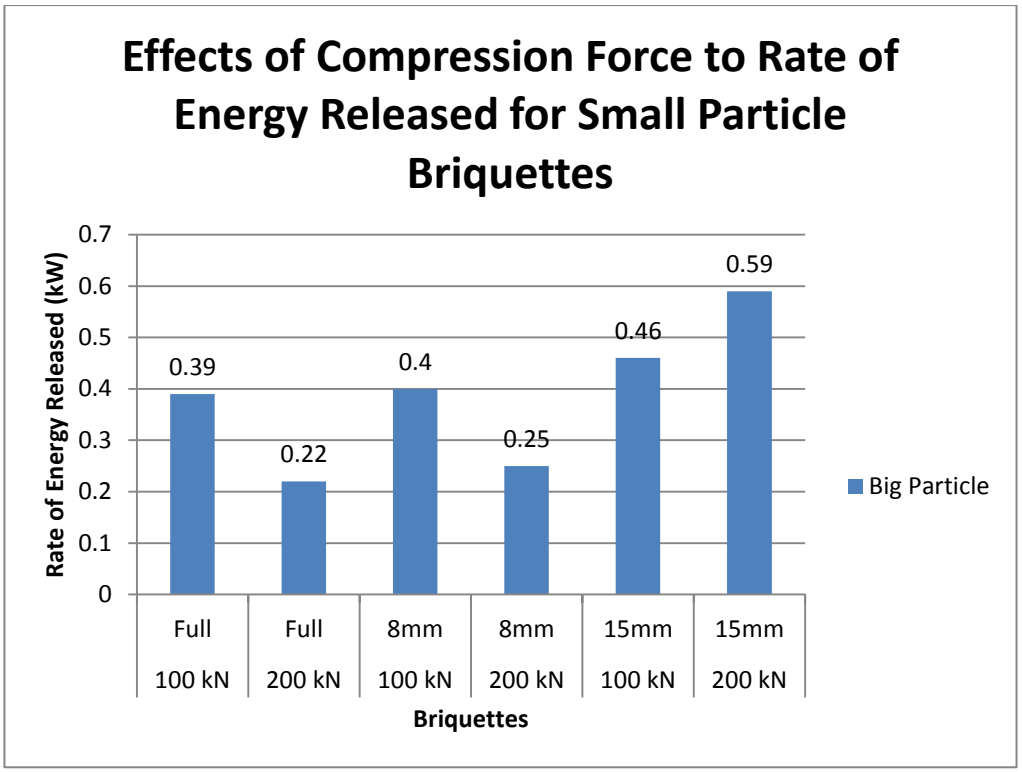


Figure 4.14: Average rate of energy released from different compression force for big particle briquettes

From Figure 4.14, there is a pattern shown from the data which shows that the increase in compression force will decrease the average rate of energy released. This is based on big particles briquettes. For a full disk shape briquette, a compression force of 100 kN has value of 0.39 kW while a compression force of 200 kN has 0.22 kW, and the same for 8 mm inner diameter doughnut shape for 100 kN having value of 0.4 kW and for 200 kN compression force having value of 0.25 kN. However, data obtained in 15 mm inner diameter doughnut shape briquettes were not as expected. 100 kN compression force shows value of 0.46 kW while 200 kN compression force has value 0.59 kW. There could be error during the experiment that led to this different pattern compared with the previous shapes of briquettes (full disk shape and 8 mm inner diameter shape briquettes).

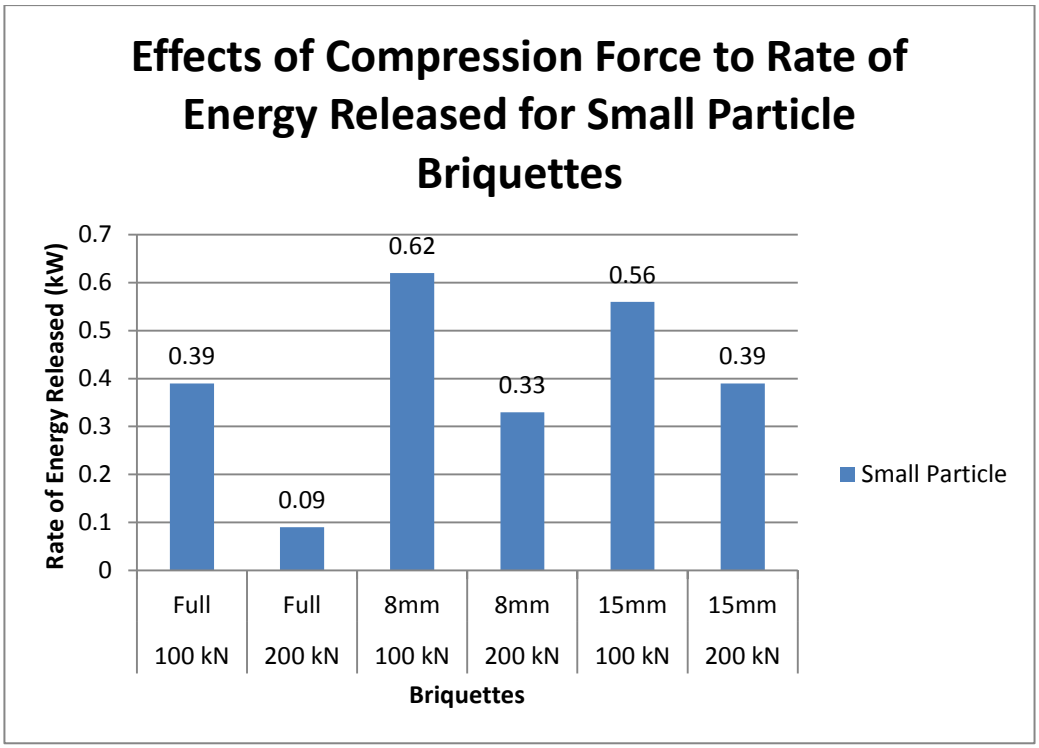


Figure 4.15: Average rate of energy released from different compression force for small particle briquettes

From Figure 4.15, there is a pattern shown from the data which shows that the increase in compression force will decrease the average rate of energy released. This is based on small particles briquettes. For a full disk shape briquette, a compression force of 100 kN has value of 0.39 kW while a compression force of 200 kN has 0.09 kW, and the same for 8 mm inner diameter doughnut shape for 100 kN having value of 0.62 kW and for 200 kN compression force having value of 0.33 kN. For the 15 mm inner diameter doughnut shape briquettes also, the average rate of energy released decreases as compression force increases, in which for 100 kN compression force, the value is 0.56 kW while for 200 kN compression force the value is 0.39 kW.

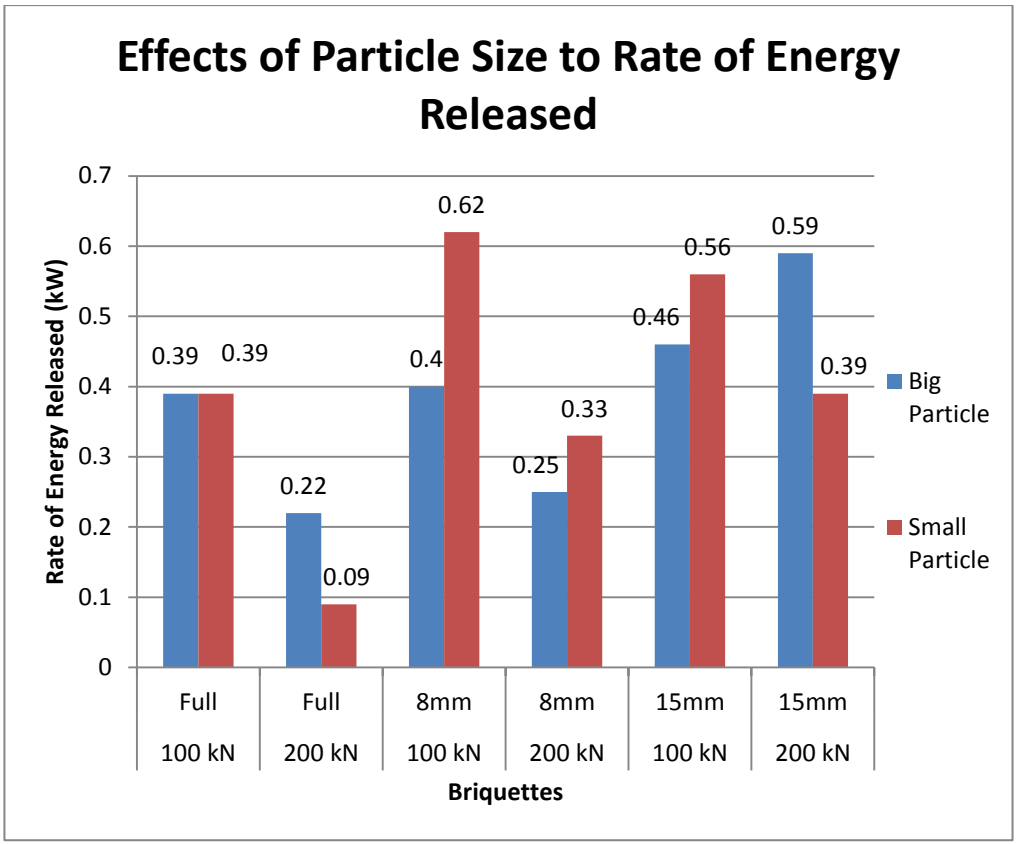


Figure 4.16: Effects of particle size to average rate of energy released

Figure 4.16 shows the effects of particle size to average rate of energy released. For full disk shape briquettes compressed at 100 kN, both big particle and small particle briquettes show same value at 0.39 kW. Full disk shape briquettes compressed at 200 kN, show that big particle briquettes has higher average rate of energy released (0.22 kW) compared to small particle briquettes (0.09 kW). For 8 mm inner diameter doughnut shape briquette compressed at 100 kN, big particle briquettes has value of 0.4 kW and small particle briquettes has value of 0.62 kW. For 8 mm inner diameter doughnut shape briquettes compressed at 200 kN, big particle briquettes has value of 0.25 kW and small particle briquettes has 0.33 kW. For 15 mm inner diameter doughnut shape briquettes compressed at 100 kN, big particle briquettes has value of 0.46 kW and small particle briquettes has 0.56 kW. For 15 mm inner diameter

doughnut shape briquettes compressed at 200 kN, big particle briquettes has value of 0.59 kW and small particle briquettes has 0.39 kW.

Two sets of briquettes which are full disk shape briquettes compressed at 200 kN and 15 mm inner diameter doughnut shape briquettes compressed at 200 kN show data that agree with the previous study stating that big particle briquettes will burn at higher burning rate compared to smaller particle size. Other data do not match well with this. This could be due to experiment conducted only once for each type of briquette design, thus error could present and lead to these kind of data.

In small particle briquettes, porosity of the briquettes will be low. Low porosity will affect combustion rate as the mass transfer will be affected. Low porosity means low mass transfer during drying, devolatisation and also char burning process, thus slow rate of combustion. In contrary, big particle briquettes allow higher porosity, thus better mass transfer and directly increase rate of burning.

4.5. Temperature Profile Investigation

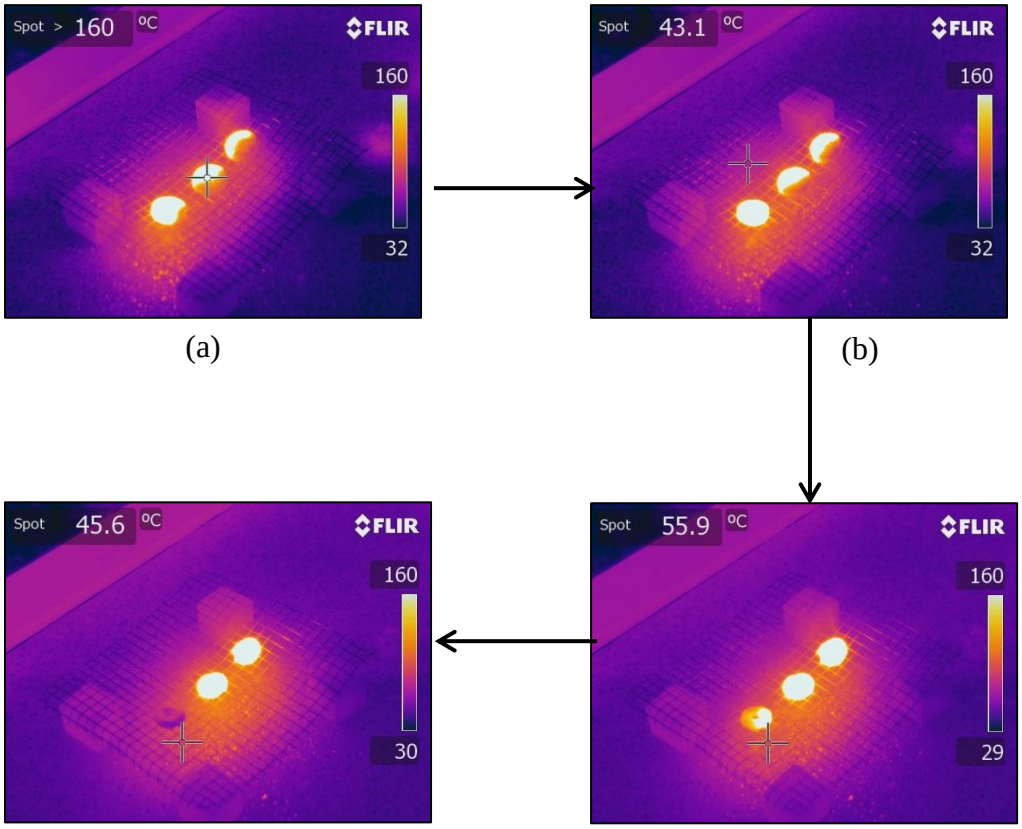


Figure 4.17: Thermography sequence photo of burning fuel briquettes; (a) initial burning, (b) full disk shape briquette burn at all surface, (c) full disk shape briquette half completed burnt, (d) full disk shape briquette burnt completely

Table 4.4: Positions of solid fuel briquettes

Briquette	15 mm inner diameter doughnut shape	8 mm inner diameter doughnut shape	Full disk shape
Position	Left	Middle	Right

From Figure 4.17 and Table 4.4, temperature profile investigation was done successfully by using infrared camera. These thermography photos captured

successfully show that shape of briquette affect the rate of burning of solid fuel briquettes. In Figure 4.17 (a), initial burning, 15 mm inner diameter doughnut shape briquette almost burnt on all surface area while the 8 mm inner diameter doughnut shape briquette burnt almost half of the surface and full disk shape briquette burnt less than half of the surface. This photo also showed the temperature recorded by infrared camera on the surface of burning to be greater than 160 ° C.

After a while, as shown in Figure 4.17 (b), 15 mm inner diameter doughnut shape briquette burnt on all surface area while the 8 mm inner diameter doughnut shape briquette burnt almost the entire surface and full disk shape briquette burnt about half of the surface. From this photo also, the temperature recorded by infrared camera on the surrounding of the burning briquettes was 43.1 ° C.

In Figure 4.17 (c), 15 mm inner diameter doughnut shape briquette has completed burning about half of the briquette while the 8 mm inner diameter doughnut shape briquette burnt the entire surface and full disk shape briquette burnt the entire surface also. From this photo also, the temperature recorded by infrared camera on the surrounding of the burning briquettes was 55.9 ° C. Comparing with Figure 4.17 (b), this surrounding temperature increased and this proved that heat was released from the combustion of briquettes.

In Figure 4.17 (d), 15 mm inner diameter doughnut shape briquette has completed burning and turned to ash, while the 8 mm inner diameter doughnut shape briquette and full disk shape briquette were still continue to burning. From this photo also, the temperature recorded by infrared camera on the surrounding of the burning briquettes was 45.6 ° C. Comparing with Figure 4.17 (b) and (c), the temperature surrounding the briquettes or specifically nearest to 15 mm inner diameter doughnut shape briquette dropped. This proved that in this stage, the 15 mm inner diameter doughnut shape briquette has completely burnt and turned to ash, thus no more heat was released to the nearest surrounding.

This sequence of photos show that the 15 mm inner diameter doughnut shape briquette which has the highest surface area of reaction burnt at the fastest rate compared with all three shapes of briquettes.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In conclusion, different binders would definitely give different energy content value for solid biomass briquettes. Based on calorific value obtained, all samples contained higher energy content compared to lignite, a low rank coal, in which the energy content for all samples were above 18 kJ/g, while lignite was 16.26 kJ/g.

From binders of non-palm oil related residue such as sugar cane and sawdust, they could give potential in terms of high energy content to be used in solid biomass briquettes. However, these materials were at disadvantage as they could not be collected at oil palm mill and thus require further action to acquire them (searching and transporting them).

Considering materials from oil palm mill residue or oil palm related materials, aside from EFB being the binder or component of solid biomass briquettes, palm frond could also be used. Palm frond was not given high attention as EFB in solid biomass briquettes, when it has potential to give high energy content also. Thus, this put palm frond as a potential to be used in solid biomass briquettes. This justified the project if the solid biomass briquettes were to be made from only oil palm mill residue and oil palm related materials.

Different briquettes design will give different rate of burning. From combustion test and temperature profile investigation, shapes of briquette would affect the rate of burning in which higher surface area of reaction will give higher rate of burning. Compression force will affect rate of burning in which the higher the compression

force, the less rate of burning of fuel briquettes. Lastly, particle size of briquette affect the rate of burning in which the bigger the particle size, the higher the rate of burning of fuel briquette.

5.2. Recommendations

In this research, many constraints are made. There are still many more factors that can be considered to produce better fuel briquette. Other types of binder could be analyzed and studied their effects on combustion characteristics.

Procedure in preparing the materials still has rooms for improvement. This is crucial to ensure the consistency of materials analysis and results to be obtained. After briquettes were prepared, they should be stored in air-tight container as to control the amount of moisture that might be absorbed after preparation.

In combustion test, each type of briquette design was done only once, thus many errors could present and future work should be to conduct the experiment with more repetitions to reduce error in data obtained.

In temperature profile investigation, infrared photos should be taken more carefully and at time interval to allow for more accurate analysis.

REFERENCES

[1] Malaysian Palm Oil Board (MPOB). (2012, July) Malaysian Palm Oil Board Web site. [Online]. http://bepi.mpob.gov.my/images/area/2012/Area_summary.pdf

[2] World Growth, "Palm oil- the sustainable oil," World Growth, Report by World Growth 2009. [Online]. http://www.worldgrowth.org/assets/files/Palm_Oil.pdf

[3] P.N. Manga, C.R. Ruttoh C.K.W. Ndiema, "Influence of die pressure on relaxation characteristics of briquetted biomass," Energy Conversion and Management, vol. 43, no. 16, pp. 2157-2161, Nov 2002.

[4] Chaney, J. O., "Combustion characteristics of biomass briquettes," University of Nottingham, PhD Thesis, 2010.

[5] H.H. Al-Kayiem, C. Rangkuti, M.S. Aris, S. Hassan, Y.S. Chin, "Experimental investigations of fuel briquettes produced from agricultural and industrial waste," Universiti Teknologi PETRONAS, Tronoh,.

[6] M.S. Aris, Y.C. Chin, A.B.A. Ibrahim, "Development of fuel briquettes from dewatered poultry sludge," in *International Conference on Future Electrical Power and Energy Systems*, 2012, pp. 469-476.

[7] Z. Husain, Z. Zainac and Z. Abdullah, "Briquetting of palm fibre and shell from the processing of palm nuts to palm oil," *Biomass Bioenergy*, vol. 22, pp. 505-509, 6, 2002

[8] M.S. Aris & Y.S. Chin, "A study of biomass fuel briquettes from oil mill residues," *Asian J. Scientific Research,*, Nov. 02, 2012.

[9] Y. S., Chin, and M.S., Aris, "*An Experimental Investigation on the Handling and Storage Properties of Biomass Fuel Briquettes Made from Oil Palm Mill Residues" in* ESTCON-ICPER2012., 2012.

[10] O.A. Sotandde, A.O. Oluyege, G.B. Abah, "Physical and combustion properties of charcoal briquettes from neem wood residues" in International Agrophysics, vol. 24, pp 189-194, 2010.

[11] H. Saptoadi, "The best biobriquette dimension and its particle size," *Asian J. Energy Environment"* vol. 9, no. 3 and 4, pp. 161-175, 2008.

[12] S.A. Channiwala, G.K. Ghosal J. Parikh, "A correlation for calculating HHV from proximate analysis of solid fuels," *Fuel*, vol. 84, no. 5, pp. 487-494, March 2005.

[13] Theodore B., Ali M. S. Eugene A. A., *Marks' Standard Handbook for Mechanical Engineers*, 11th ed.: Mcgraw-Hill, 2006.

[14] M.L. Brown, W.S. Bulpitt, J.L. Walsh Jr T.F. McGowan, Ed., *Biomass and alternate fuel systems - An engineering and economic guide*. New Jersey, United States of America: John Wiley & Sons, 2009.

[15] Perkin Elmer, (2010). *Thermogravimetric analysis (TGA): A beginner's guide.* [Online]. Available: http://www.perkinelmer.com/CMSResources/Images/44-74556GDE_TGABeginnersGuide.pdf

APPENDICES

APPENDIX A: TGA DATA FOR ALL SAMPLES 56

APPENDIX B: ULTIMATE ANALYSIS DATA 60

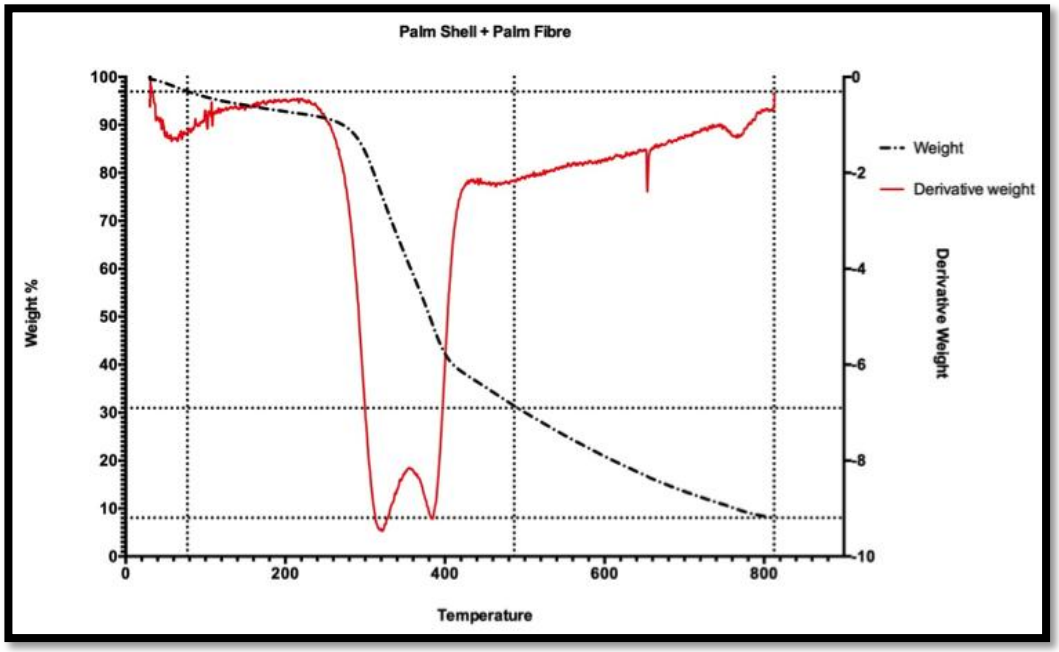
APPENDIX C: BOMB CALORIMETER DATA 62

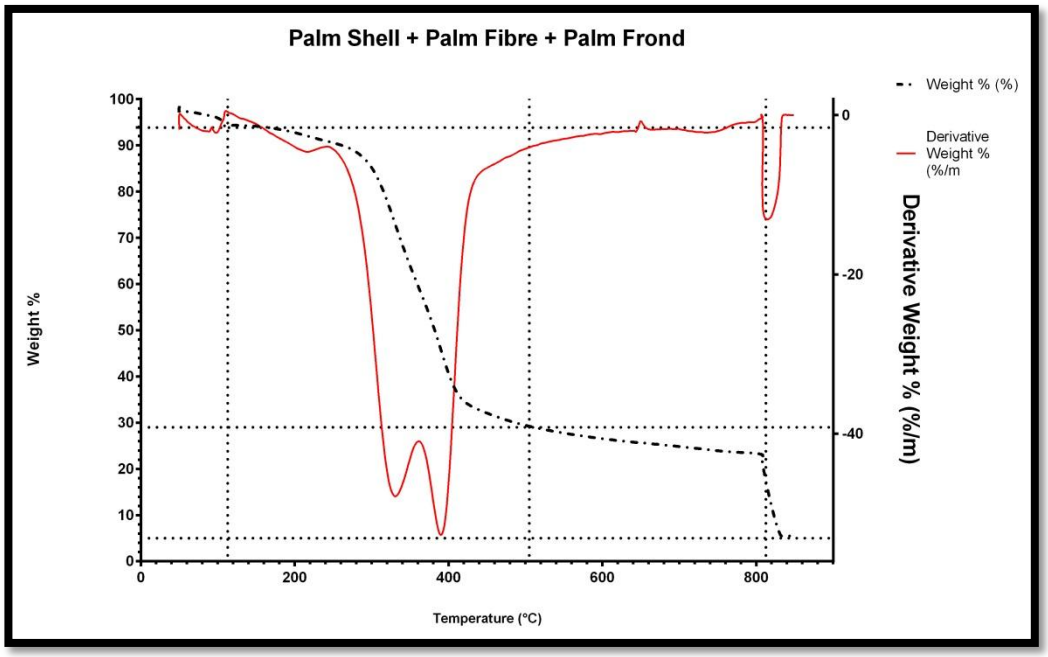
APPENDIX D: AIR FUEL RATIO FOR COMBUSTION TEST 64

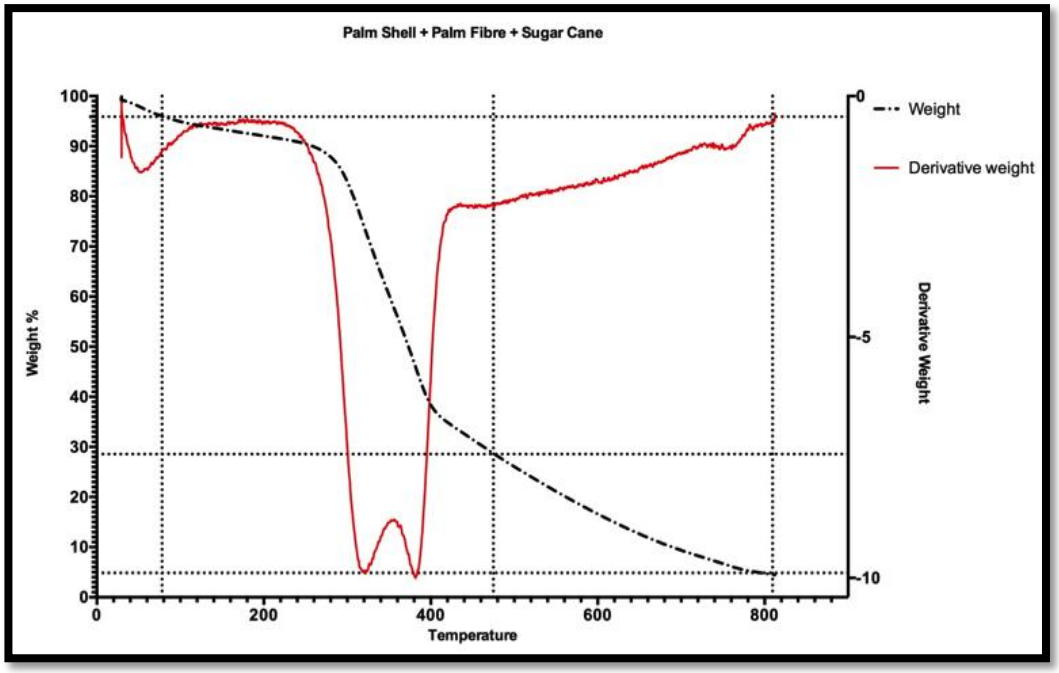
APPENDIX E: COMBUSTION TEST DATA 66

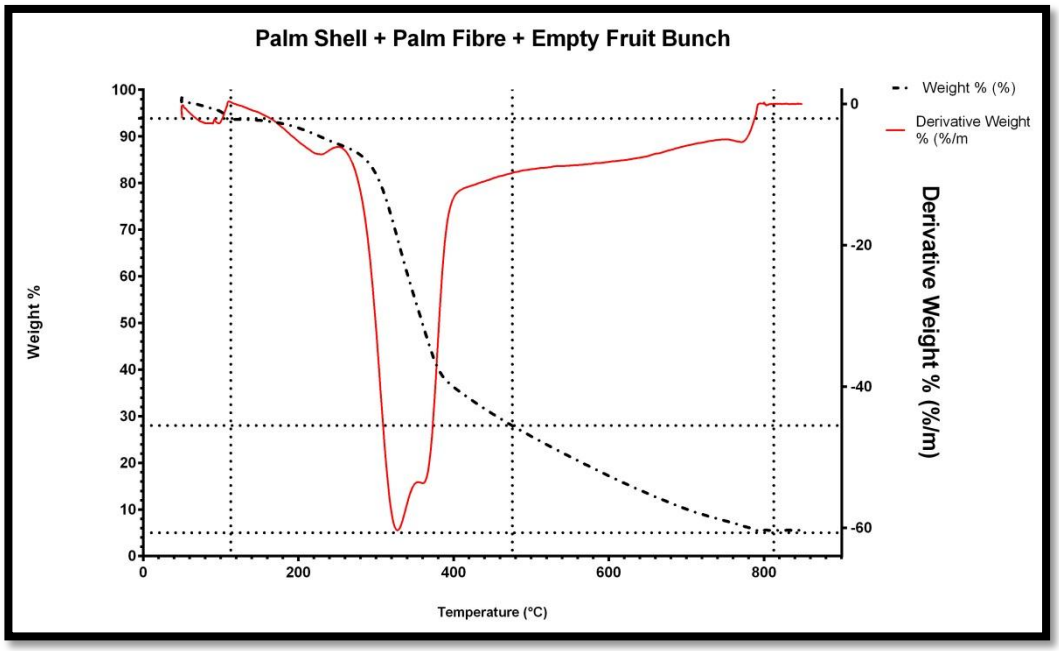
APPENDIX F: TEMPERATURE PROFILE INVESTIGATION DATA 69

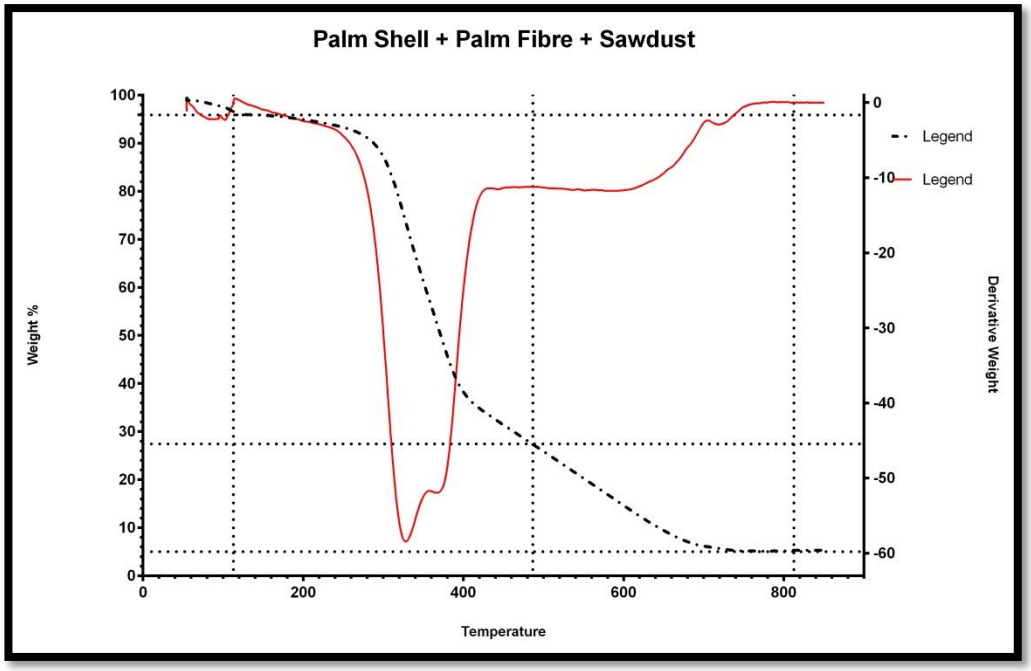
APPENDIX A: TGA DATA FOR ALL SAMPLES






Palm Shell + Palm Fibre + Sugar Cane
Weight
Derivative weight
Weight %
Derivative Weight
Temperature
0
200
400
600
800
100
90
80
70
60
50
40
30
20
10
0
-5
-10


Palm Shell + Palm Fibre + Empty Fruit Bunch
Weight % (%)
Derivative Weight % (%/m
Weight %
Derivative Weight % (%/m)
Temperature (°C)
0
200
400
600
800
100
90
80
70
60
50
40
30
20
10
0
-20
-40
-60



Material	PS + PF+ SC	PS + PF+ SD	PS + PF+ EFB	PS + PF+ PFr	PS + PF
Moisture Content	5	4.137	6.135	6.135	3.05
Volatile Matter	68.44	68.423	65.865	64.865	66.26
Fixed Carbon	22.112	22.423	22.502	23.504	22.703
Ash Content	4.448	5.017	5.498	5.496	7.987

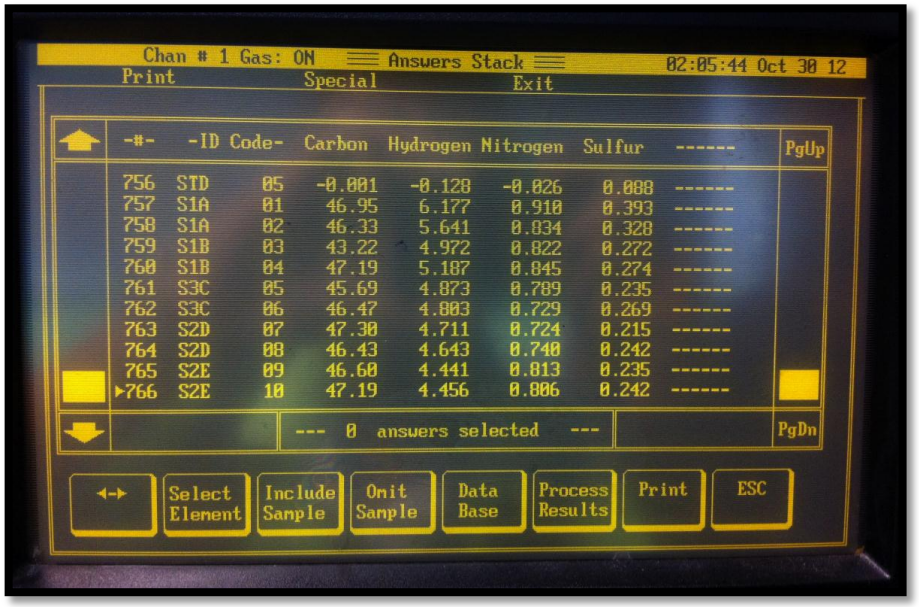
Procedure A

1. Weigh sample using mass balance about 5 mg and put in crucible.
2. Carefully place the crucible in the holder for hangdown pan.
3. Start the program. Procedure of program:
    a. Hold for 1 minute at 29 °C
    b. Heat from 29 °C to 800 °C at 20 20 °C/min
4. End program.
5. Clean crucible and repeat step 1 until 5 for next set of experiment.

Procedure B

1. Weigh sample using mass balance about 5 mg and put in crucible.
2. Carefully place the crucible in the holder for hang down pan.
3. Start the program. Procedure of program:
    a. Sample is heated from initial temperature of 50°C C to 110°C, at heating rate of 60 °C /min with nitrogen gas flow rate of 30 ml/min.
    b. Sample is held isothermally for 5 minutes.
    c. Sample is heated until 800 °C at heating rate of 100 °C min with same nitrogen flow rate
    d. Sample is held for another 3 minutes.
    e. Sample is heated from 800 °C to 850 °C at a rate of 20 °C /min.
    f. The gas used was changed to oxygen.
    g. Sample temperature was held constant for 10 minutes at 850 °C
4. End program.
5. Clean crucible and repeat step 1 until 5 for next set of experiment.

APPENDIX B: ULTIMATE ANALYSIS DATA



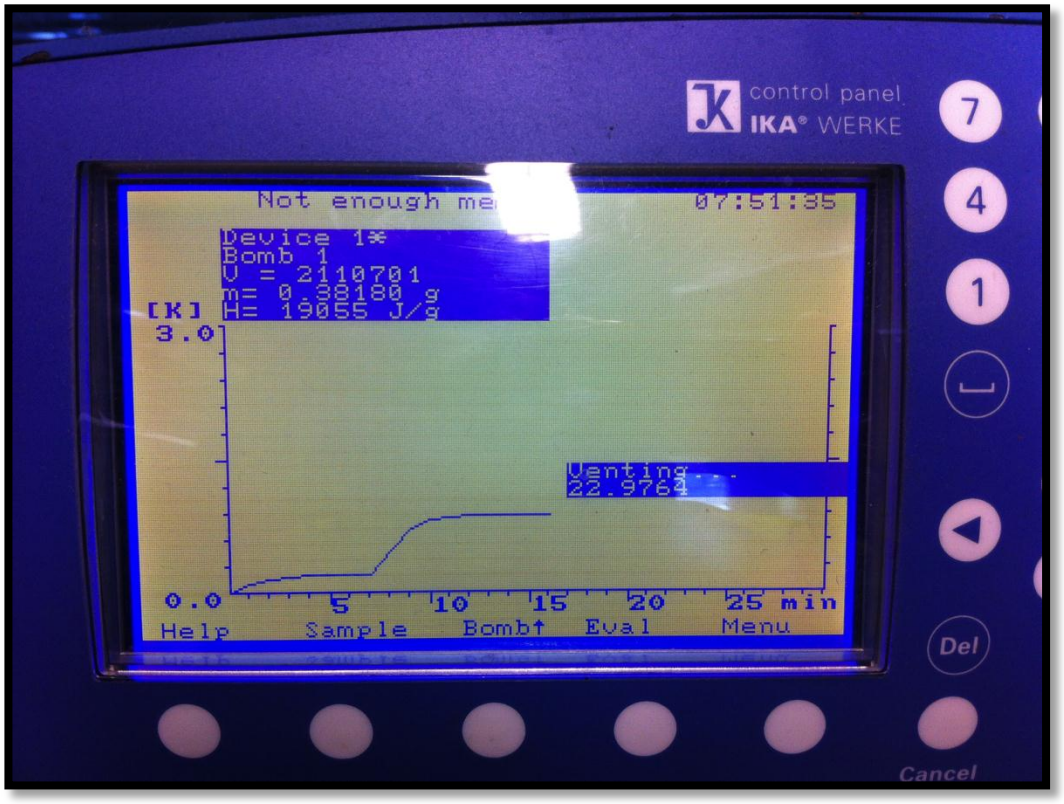
MATERIAL	LABEL	C (%)	H (%)	N (%)	S (%)	Average Carbon
PS+PF+SC	S1A	46.95	6.177	0.91	0.393	46.47
PS+PF+SC	S2A	46.33	5.641	0.834	0.328	
PS+PF+SC	s1a	46.67	7.361	0.728	0.263	
PS+PF+SC	s1a	45.93	6.544	0.736	0.293	
PS+PF	S1B	43.22	4.972	0.822	0.272	46.06
PS+PF	S2B	47.19	5.187	0.845	0.274	
PS+PF	s1b	45.58	6.144	0.916	0.27	
PS+PF	s1b	45.41	5.757	0.62	0.247	
PS+PF+SD	S1C	45.69	4.873	0.789	0.235	46.27
PS+PF+SD	S2C	46.47	4.803	0.729	0.269	
PS+PF+SD	s1c	46.65	5.67	0.742	0.235	
PS+PF+SD	s1c	53.17	6.269	0.866	0.291	
PS+PF+PFr	S1D	47.3	4.711	0.724	0.215	46.27
PS+PF+PFr	S2D	46.43	4.643	0.74	0.242	
PS+PF+PFr	s1d	45.07	5.217	0.821	0.229	
PS+PF+PFr	s1d	58.27	6.524	0.899	0.286	
PS+PF+EFB	S1E	46.6	4.441	0.813	0.235	46.33
PS+PF+EFB	S2E	47.19	4.456	0.806	0.242	
PS+PF+EFB	s1e	46.01	5.053	0.747	0.223	
PS+PF+EFB	s1e	45.53	4.941	0.812	0.234	

* Raw data on ultimate analysis were shown in table and cell with no color shows data omitted in calculation for average value for carbon percentage.

Procedure

1. Prepare instrument as outlined in the operator's instruction manual (perform maintenance and leak checks, etc.).
2. Analyse blanks until instrument is stable (nitrogen results will reach a plateau), then analyse three to five crimped 502-206 Silver Capsules. Enter 2.0 mg as the weight. Set blank using results from these capsules.
3. Analyse three to five standards using the following procedure.
    a. Weigh ~ 2 mg of standard material into a 502-206 Silver Capsule, crimp capsule, and analyse.
    b. Calibrate using these values (refer to operator's instruction manual for details).
4. Mix sample well, weigh ~ 2 mg sample into a 502-206 Silver Capsule, crimp capsule, and analyse.
5. Analyse a standard at the end of the set to verify calibration.

APPENDIX C: BOMB CALORIMETER DATA



No	PS+PF+SC		PS+PF+SD		PS+PF+EFB		PS+PF+PFr		PS+PF	
	Mass, g	HHV, kJ/g	Mass, g	HHV, kJ/g	Mass, g	HHV, kJ/g	Mass, g	HHV, kJ/g	Mass, g	HHV, kJ/g
1	0.3818	19.055	0.4246	18.908	0.4183	18.852	0.3779	18.666	0.4069	18.128
2	0.51	18.666	0.3985	18.765	0.3615	18.671	0.3656	18.382	0.3585	18.806
3	0.3066	18.418	0.4146	18.698	0.3615	18.671	0.4408	18.614	0.413	18.733
Average		18.713		18.790		18.731		18.554		18.556

Procedure

1. Turn on oxygen gas regulator. Adjust the outlet pressure 30 PSI.
2. Turn on controller unit and cooling system, wait 20 minutes for WAITING STABLE.
3. Prepare sample (weighing below 1.0 gram)
4. Place sample into crucible, secure a cotton thread with a loop in it on the middle of the ignition wire. Place into the decomposition vessel.
5. Open the SAMPLE dialog window to enter parameter.
6. Suspending the decomposition vessel into the filling head of the measurement cell cover.
7. Activate START. The measurement cell cover closes the decomposition vessel, and is then filled with oxygen. Next the inner vessel is filled with water. As soon as the system begins with the experiment, the display shows a graph of the change over time in temperature of the inner vessel.
8. When the measurement is complete, remove the decomposition vessel, clean, dry and prepare for the next experiment.

APPENDIX D: AIR FUEL RATIO FOR COMBUSTION TEST

From CHNS analysis, composition of C, H, N and S in % were obtained. For this combustion test, type of sample selected was PS+PF+PFr. Number of moles can be calculated as follows:

Element	Weight %	a.m.u.	Moles
C	46.27	12	3.86
H	5.27	1	5.27

Thus, in chemical equation, using 40% of excess air, it can be written as follow:

$$C_{3.86}H_{5.27} + 1.4a(O_2 + 3.76N_2) \rightarrow xCO_2 + yH_2O + 0.4aO_2 + (1.4 \times 3.76)aN_2$$

Solving the unknowns:

Element	Balancing left hand side and right hand side of equation
C	$x = 3.86$
H	$2y = 5.27; y = 2.635$
O	$2(1.4a) = 2x + y + 2(0.4a); a = \frac{10.355}{2} = 5.1775$
N	$2(1.4a \times 3.76) = 2(1.4 \times 3.76)a\,; a = 5.1775$

Thus, the chemical equation of the combustion with 40 % excess air is as follow:

$$C_{3.86}H_{5.27} + 7.2485(O_2 + 3.76N_2) \rightarrow 3.86CO_2 + 2.635H_2O + 2.071O_2 + 27.254N_2$$

To calculate air-fuel ratio:

1 kmol O_2 + 3.76 kmol N_2 = 4.76 kmol air

Air-fuel ratio = $\frac{m_{air}}{m_{fuel}}$, with molar mass of air = 28.97 kg/mol

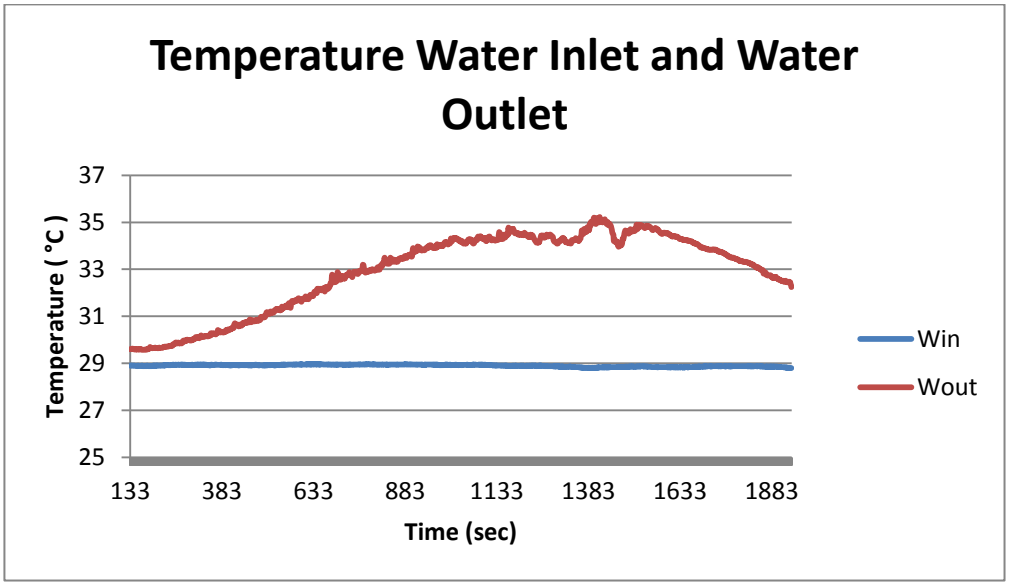
$$= \frac{(7.2485 \times 4.76 kmol)\left(\frac{29kg}{kmol}\right)}{(3.86 kmol)\left(\frac{12kg}{kmol}\right) + (5.27 kmol)\left(\frac{1kg}{kmol}\right)}$$

$$= 19.395 \ \frac{kg\ air}{kg\ fuel}$$

For 0.1 kg of fuel, only 1.9395 kg of air is required. Thus, for complete combustion and at 40% excess air, this is the amount of air required by the fuel. If more air is supplied, still complete combustion occurs.

APPENDIX E: COMBUSTION TEST DATA

From combustion test, fuel briquettes were burnt in small combustor and water was heated by the combustion. The difference in water temperature showed the energy released and rate of burning of fuel briquettes. Table and figure shown below are examples of data obtained in the experiment for briquettes of PS+PF+PFr, small particle, 100 kN compression force and of 15 mm inner diameter doughnut shape..



Time (s)	Win (°C)	Wout (°C)	Delta T (°C)	Energy (kJ)
133	28.91	29.6	0.69	0.09585158
134	28.9	29.6	0.7	0.097240733
135	28.89	29.61	0.72	0.10001904
1935	28.8	32.35	3.55	0.493149433
1936	28.8	32.33	3.53	0.490371127
1937	28.79	32.24	3.45	0.4792579

From data of water temperature change, energy released from combustion can be calculated.

$$Q_{briquette} = Q_{water}$$

$$Q_{water} = \dot{m}_{water} c_{p,water} \Delta T t$$

Where; $Q_{briquette}$ and Q_{water} are the energy from combustion components in kJ, $\dot{m}_{water}$ is the water mass flow rate in kg/s, $c_{p,water}$ is specific heat of water in kJ/kg.K, ΔT is the difference in temperature of the water inlet and outlet, and t is time taken. Total energy released from fuel briquettes is calculated by multiplying the water mass flow with specific heat of water, change of water inlet and outlet temperature and time.

Total energy released = $\sum_{n=a}^{n=b} \dot{m}_{water} c_{p,water} \Delta T_n (t_{n+1} - t_n)$, where a is the time for briquettes to start burning and b is the time for briquettes to complete burning. Example:

Total Energy Released = (0.03323kg/s)(4.18kJ/kg.K)(0.69 K)(134-133)s + (0.03323kg/s)(4.18kJ/kg.K)(0.7 K)(135-134)s + (0.03323kg/s)(4.18kJ/kg.K)(0.72 K)(135-134)s … + (0.03323kg/s)(4.18kJ/kg.K)(3.45 K)(1938-1937)s = 1008.39 kJ

Based on data obtained, average rate of energy released is calculated by taking the total energy released divided by total time taken for briquettes to complete burning. Average rate of burning is calculated as follow:

$$\text{Average rate of burning} = \frac{Q_{water}}{t_{total}}$$

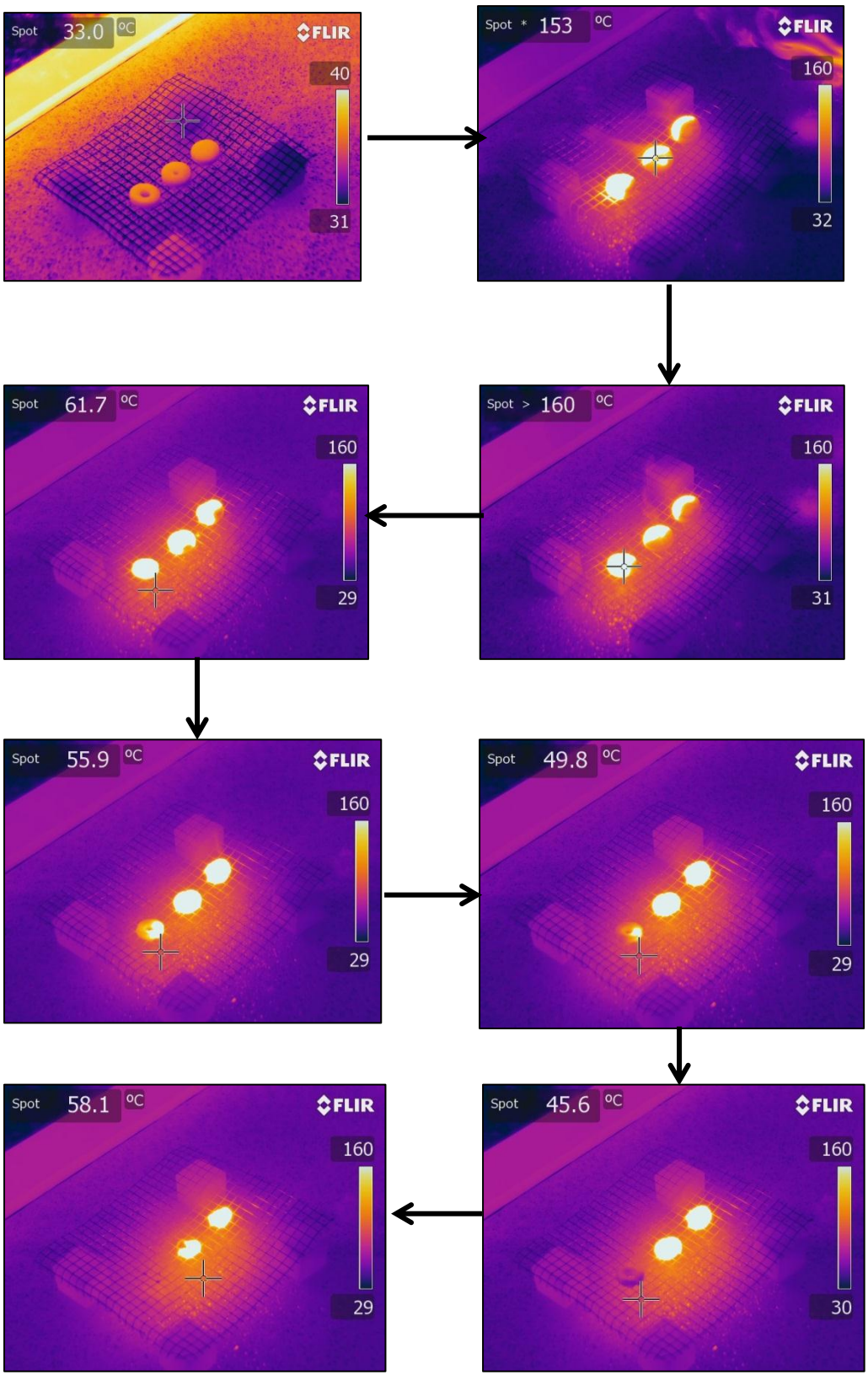
$$= 1008.39\text{kJ}/(1937-133)\text{s}$$

$$= 0.558972508 \text{ kW}$$

Procedure

1. Set up small combustor, fix connection for air compressor, fix connection for water connection and fix thermocouple connection to computer.
2. Set volumetric flow rate of water to 2 litre per minute by using valve of tap water, set air volumetric flow rate to 4 litre per second using valve.
3. Put 10 pieces of briquettes inside the small combustor in same orientation and position. Arrange 3 fire starters in between to help in initial combustion.
4. Start recording temperature of thermocouple using computer.
5. Quickly ignite fire starters and let them burn.
6. Close reactor door.
7. Observe graph on computers until combustion of briquettes end.
8. Save data obtained on computer.
9. Repeat for next set of briquettes starting from step 3 to step 8.

APPENDIX F: TEMPERATURE PROFILE INVESTIGATION DATA



Procedure

1. Set up grate on top of small bricks.
2. Put briquettes on top of grate.
3. Burn the briquettes simultaneously to start combustion using fire starter.
4. Take photos of burning briquettes using infrared camera.