CHAPTER 1
INTRODUCTION

1.1 Background Project

The public concern on environmental issues, especially on the rapid depletion of fossil fuels have imposed a huge impact on people around the world nowadays to find alternative sources of fuels that are environmental friendly. With respect towards this issue, renewable energy has been considered as the primary option of energy sustainability after fossil fuel. The most promising types of renewable energy are biomass.

Malaysia has substantial potential for biomass energy utilization given its equatorial climate with high sunlight intensity and high rainfall throughout the year. About more than 70 million tonnes of biomass are collected each year (Hassan, et al., 2002). Biomass is defined as an organic matter available on a renewable basis, including forest and mill residues, wood wastes, agricultural crops and wastes, animal wastes and municipal solid waste (MSW). Palm oil industry waste offers the largest potential for biomass energy utilization in Malaysia, as they are abundant, easily available and moreover there is a need to be disposed of cost-effectively. As shown in Figure 1.1, oil palm takes up 85.5% of the total nation’s agricultural wastes of biomass residues (Hassan, et al., 2002).

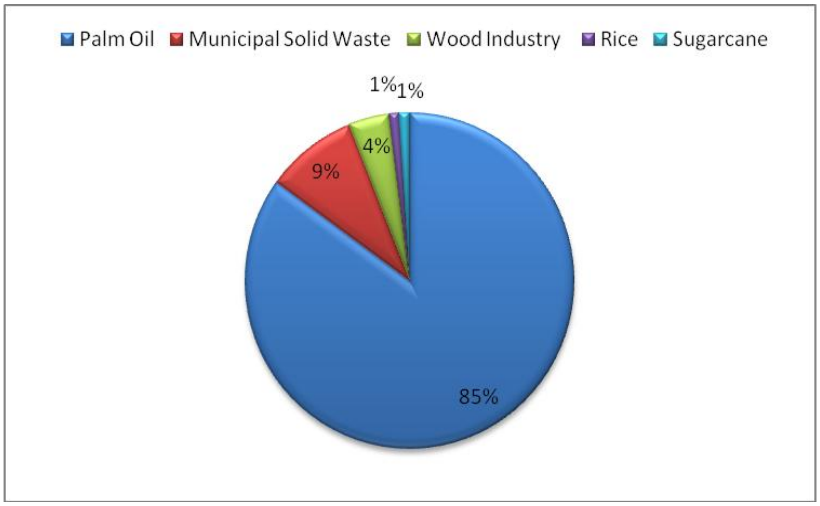


Figure 1.1: Distribution of agricultural wastes of biomass residues (Hassan, et al., 2002)

Gasification is the conversion of biomass (a renewable source of fixed carbon) into a fuel gas (also known as producer gas), which can be used in heat, power or combined heat and power applications. It is an efficient method of extracting energy as a useful source from different types of organic material, and also has its application as a clean waste disposal technique. It is a process of converting the carbonaceous material into carbon monoxide and hydrogen, by reacting the raw material at high temperature with a controlled amount oxygen or steam.

There have been many studies on the oil palm trees in order to exploit its parts for various applications or products, however very little attention has been paid on the oil palm fronds. Currently the oil palm fronds are used as a substitute for grasses in cases where forage or fodder is a limiting factor in providing feed for animals. Exploring and exploiting the potential of oil palm fronds as a biomass feed would be a new challenge in energy industry. Figure 1.2 shows that the oil-palm fronds (OPF) contain calorific value higher than those of other available biomass feeds such as wheat straw, cereal straw, corn stalk, switch grass and vine shoot, but lower compared to conventional fossil fuels such as coal.

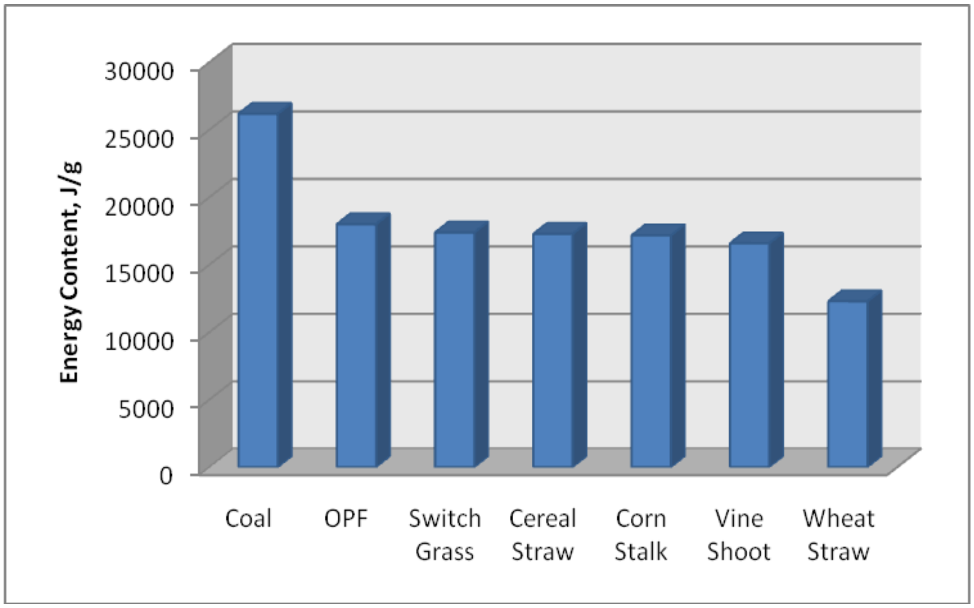


Figure 1.2: Calorific value of each biomass feeds (Balamohan, 2008)

1.2 Problem Statement

Pruned oil-palm fronds are normally left on the ground within the plantation area. As a result, the oil-palm fronds contain high moisture and it is not suitable to be fed into a gasifier. According to Balamohan (2008), the high water content (which is higher than 30%) will reduce the possibility of ignition in the process and reduces the quantity of product gas due to the need to evaporate the additional moisture before combustion or gasification. Due to this problem, some study regarding the drying of oil-palm fronds should be carried to ensure the effectiveness of ignition in the gasification process.

1.3 Objective

The objective of this study is to study the drying characteristics of oil palm fronds in terms of drying temperature, frond’s part and size, and storage condition, for use in downdraft gasifiers.

1.4 Scope of Study

In the present research, there were three segments of test conducted to investigate the drying characteristic of fronds. In the first segment, the fronds were dried using oven to determine which drying temperature and fronds size would produce the highest moisture rate loss. After being dried, the fronds were tested for their calorific value using the bomb calorimeter. Finally, the chemical composition of the fronds was determined using the CHNS machine. The purpose of this test was to determine the effect of drying temperature and storage condition on the chemical composition. Investigation on the calorific value and ultimate analysis of the dried oil palm fronds would determine the potential of the sample to become future biomass utilization in Malaysia.

CHAPTER 2
LITERATURE REVIEW

2.1 Gasification

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, or biomass, into carbon monoxide (CO) and hydrogen (H_2) by reacting the raw material at high temperatures with a controlled amount of oxygen or steam. The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. The clean syngas can be burnt to generate electricity or used as a feedstock for production of chemicals, fuels and fertilizers.

2.2 Characteristics of Oil-Palm Fronds

Figure 2.1 shows the components of an oil palm frond (OPF). An OPF is made up from two main components which are petiole and leaflet. Dry matter weight ratio of petiole to leaflets is 1.5 to 1.0. It contains about 18.5% hemicelluloses and moisture contents of fresh leaflets and petioles range from 54-56% and from 75-79% (Wan Zahari, 2003).

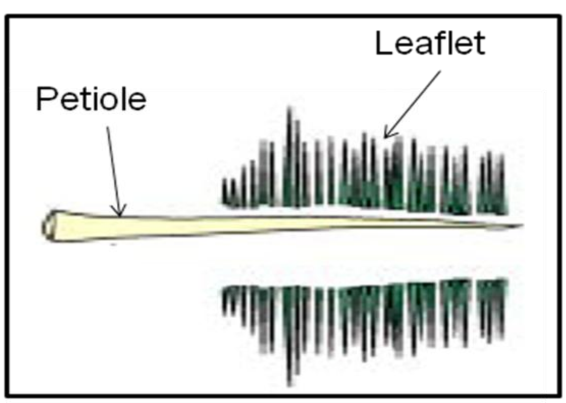


Figure 2.1: Components of oil-palm frond (Wan Zahari, 2003)

Proximate analysis was conducted to estimate the weight percentage of moisture in the oil palm fronds. A study by Balamohan (2008) shows that the average moisture content obtained is 4.0 %. The results proofed that the oil-palm fronds are capable of performing well in a gasifier producing syngas with high heating value, as the fuels with moisture content above about 30% makes ignition difficult and reduce the quantity of the product gas due to the need to evaporate the additional moisture before combustion/gasification can occur (Mckendry, 2001). The moisture content value obtained is lower than other available biomass fuels as shown in Figure 2.2.

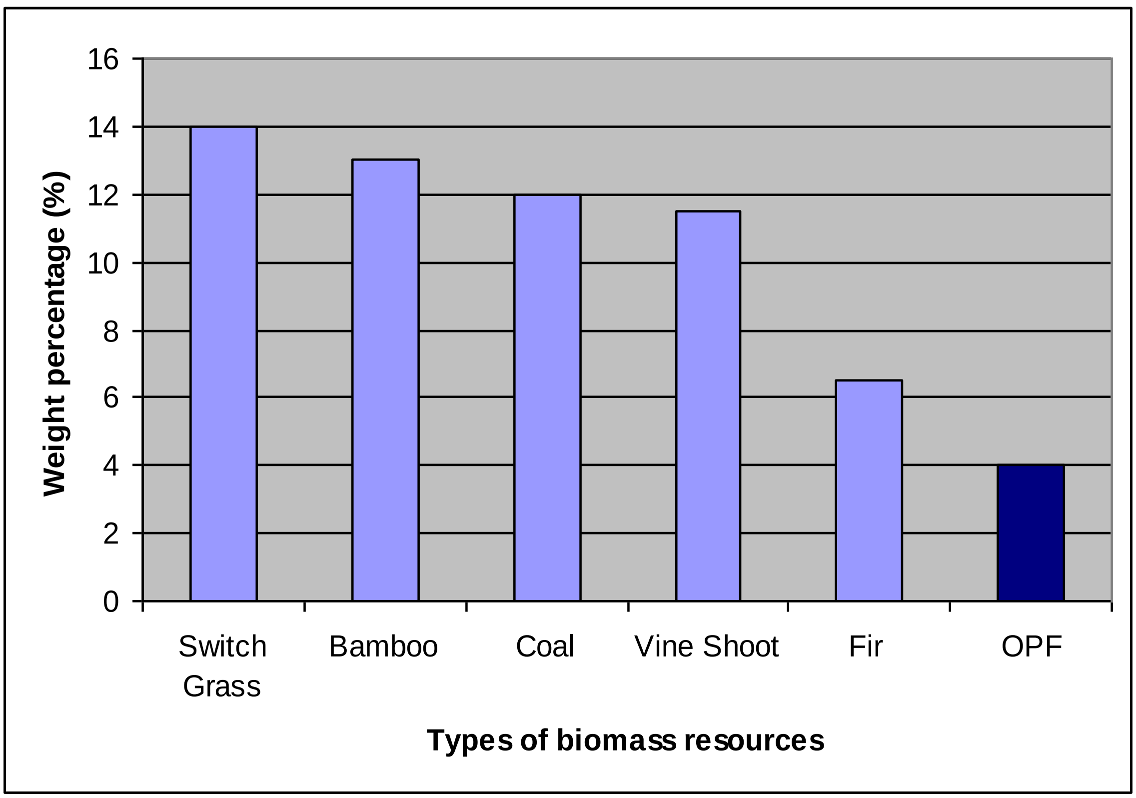


Figure 2.2: Moisture content of OPF and various biomass resources (Balamohan, 2008)

2.3 Dryer Principles

According to Liptak (1998), there are three requirements for drying which are source of heat, method of removing the water evaporated, and some form of agitation to expose new material for drying.

2.3.1 Stages of Drying

A study by Amos (1998) shows that there are two main stages of drying. For the first step, the material will be heated up to wet bulb temperature, to produce a driving force for water to leave the wet material. Apart from that, any surface moisture on the material will be evaporated where this process will occur quickly. Then, the material will be heated to drive water from the inside of biomass to the surface to ensure that it can be evaporated. This stage occurs during ‘falling rate period’. During this period, surface temperature of material remains close to the wet bulb temperature. Finally when the material is completely dry, it began to heat up the surrounding temperature.

There are two points in drying process when there is a significant of fire risk. It will occur after the surface moisture has evaporated but before an appreciable amount of water has been driven out from inside biomass. Another factor is when the material is over dried.

2.4 Dryer Descriptions

There are three main choices of biomass drying which are rotary dryers, flash dryers, and superheated steam dryers (Amos, 1998).

2.4.1 Rotary Dryers

This is the most common type for biomass. The most widely-used is the directly heated single pass rotary dryer as in Figure 2.3.

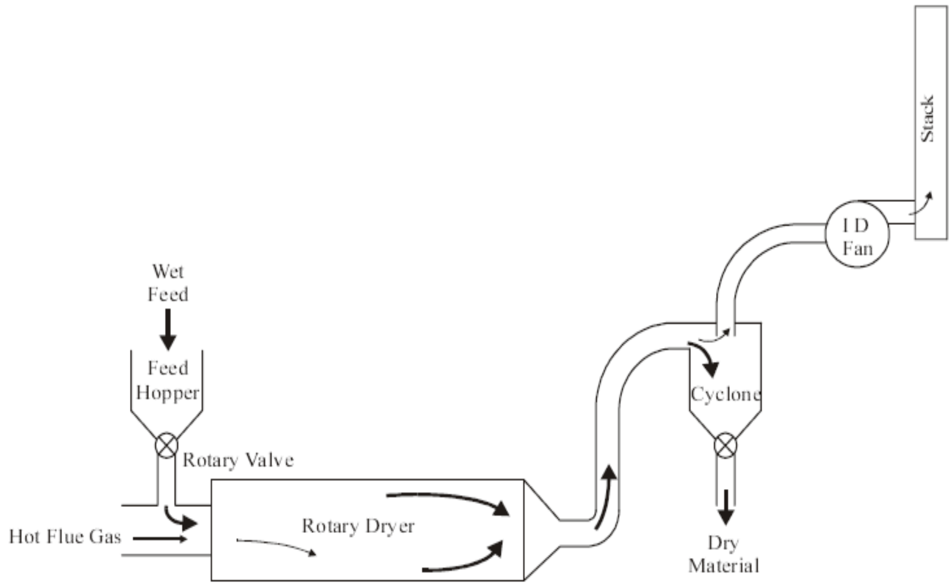


Figure 2.3: Single-pass rotary dryer (Amos, 1998)

The biomass and hot air normally flow co-currently to the dryer so the hottest gas come in contact with the wettest material, but for materials where the temperature is not a concern, the flue gas and solids flow opposite directions, so the driest solids are exposed to the hottest gas with lowest humidity. This configuration produces the lowest moisture leaving the dryer but would increase the fire risk.

2.4.2 Flash Dryers

In a flash dryer, the solids mixed with high-velocity hot air stream. The solids and air are separated using cyclone and continue through a scrubber to remove any entrained particle. A simple flash dryer is shown in the Figure 2.4.

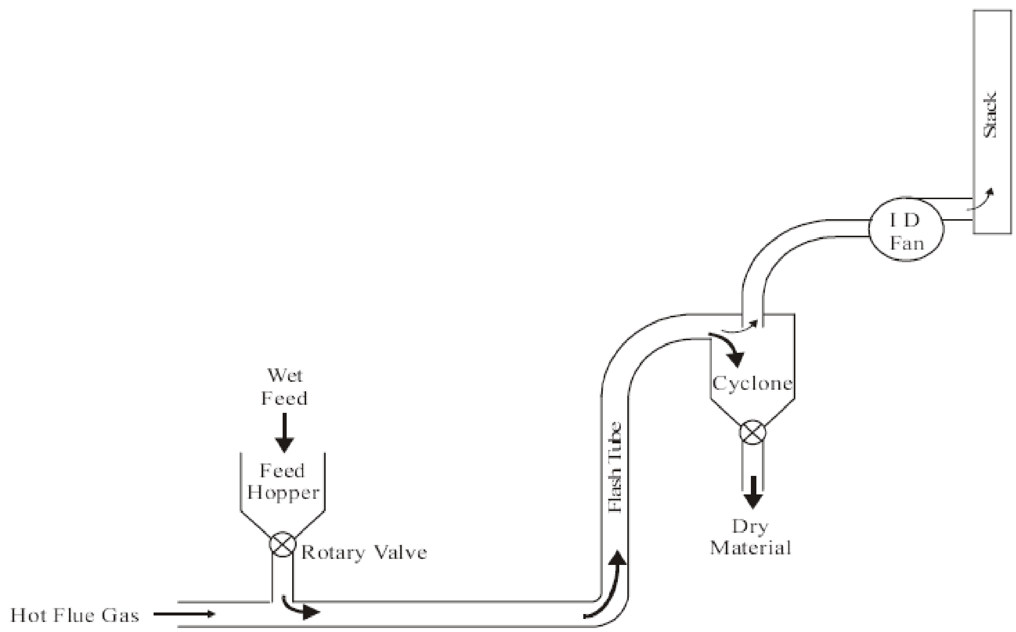


Figure 2.4: Typical flash dryer (Amos, 1998)

Flash dryer have been used successfully for drying biomass such as wood, sludge and bagasse. Gas temperatures are slightly lower than rotary dryers, but still operate at temperature above combustion point. The retention time is less than 30 seconds to minimizing the fire hazards.

2.4.3 Superheated Steam Dryers

The dryers are similar to flash dryer, except the fluid suspending the solids and providing heat is steam instead of air. The 90% of steam leaving the dryer is re-circulated while another 10% of steam is removed and either condensed or used directly in other parts of plants.

There are several Superheated Steam Dryers designs which in development or in limited operation. The first is the Imatran Voima Oy (IVO) Dryer where biomass material is mixed with a recirculating superheated steam stream. The superheated steam and biomass pass through flash tube and the solids are separated from the steam by cyclone. Most of the steam is recycled through a fan to provide a motive force to suspend the solid material and then the steam will passes through the heat exchanger to increase the temperature. The excess steam can be condensed to recapture the latent heat, compressed to a higher temperature or with high pressure operation; the steam can be injected into gas turbine to increase the power output. Figure 2.5 shows the basic Superheated Steam Dryers.

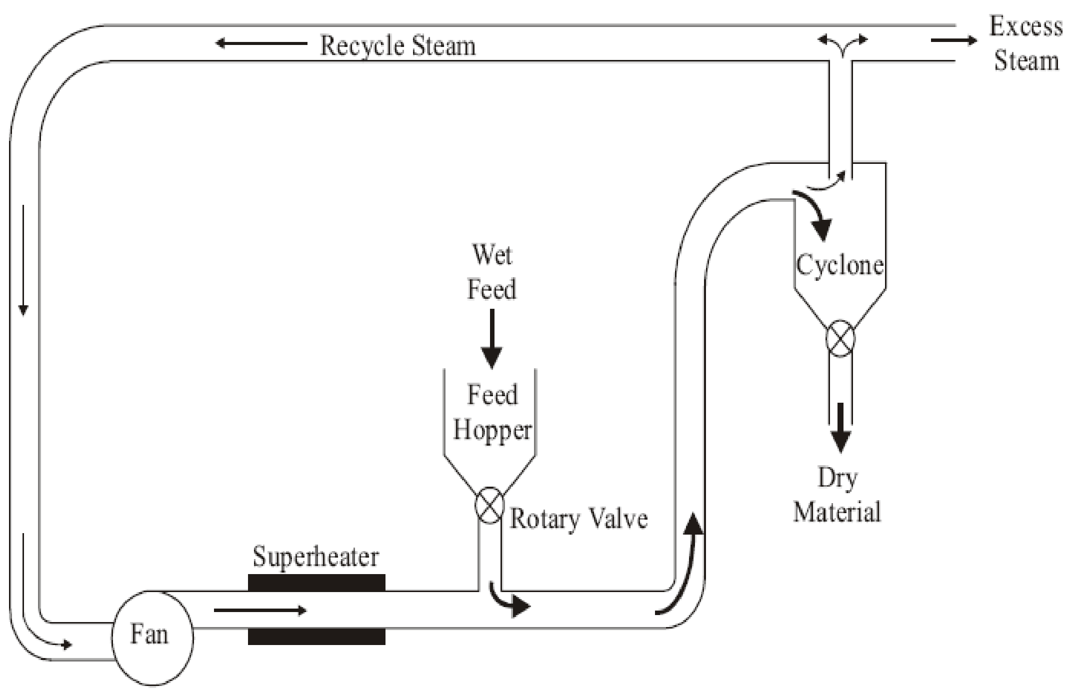


Figure 2.5: Basic superheated steam dryers (Amos, 1998)

A second IVO Superheated Steam Dryer design called a bed mixing dryer, as shown in Figure 2.6. Some of the hot bed material from combustion chamber is mixed with wet biomass in steam atmosphere. The sensible heat from hot bed material evaporates the water from fuel, while steam can be recycled, with excess steam being used for other process heating.

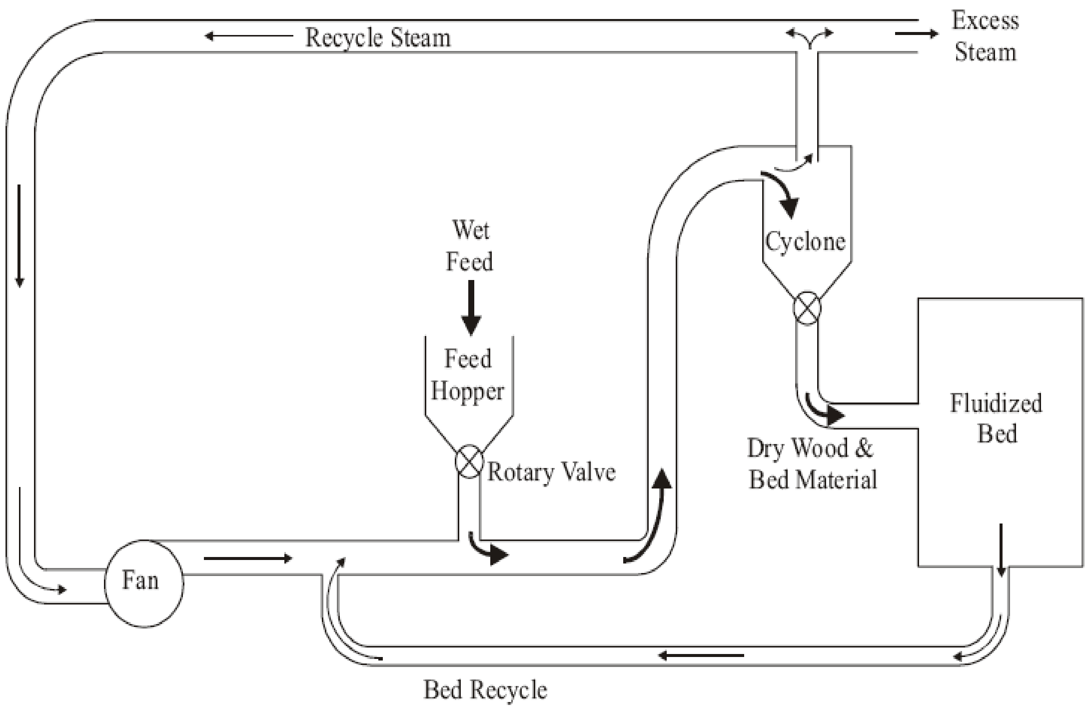


Figure 2.6: Bed mixing superheated steam dryer (Amos, 1998)

CHAPTER 3
METHODOLOGY

3.1 Project Flow

Shown in Figure 3.1 is the flowchart of procedure planned for final year project. Firstly, the samples need to be prepared by dividing them into different sizes. Each of samples which have been divided will be classified into three different storages. For the next stage, all samples will be dried using oven according to their respective drying temperatures of 80°C, 120°C, 160°C, and 200°C. All readings will be recorded and some discussion and comparison will be made here.

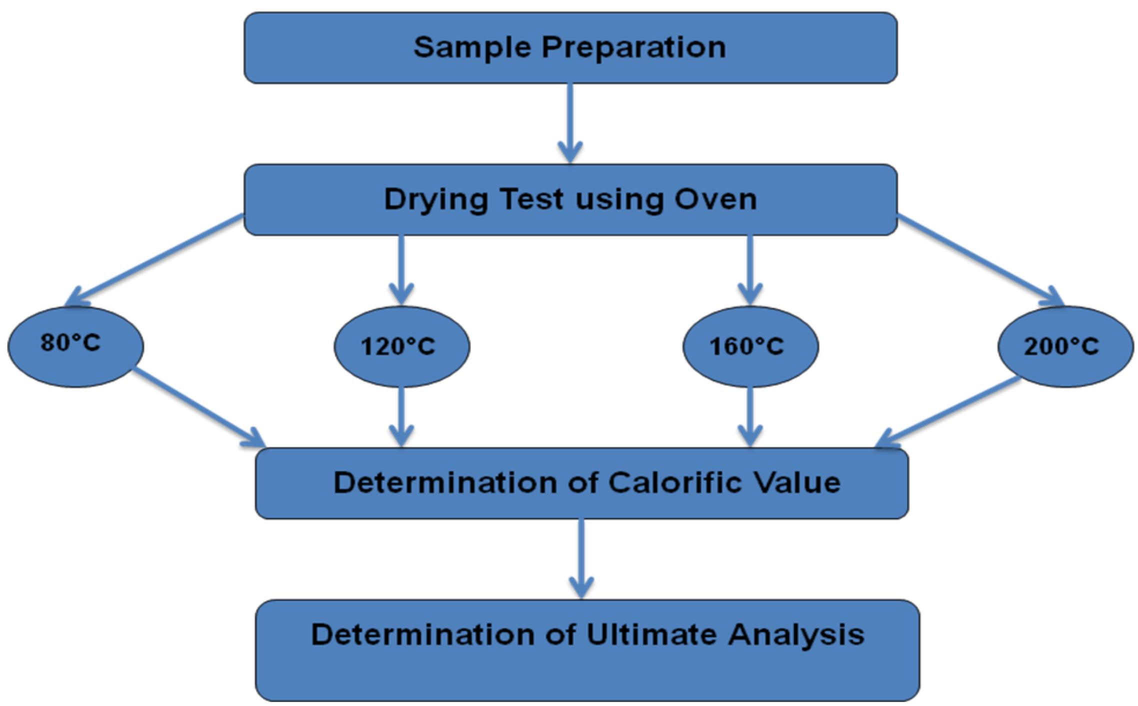


Figure 3.1: Project flow planning for both semesters

After being dried, all samples will be determined their calorific value to obtain the amount of energy that can be extracted, and ultimate analysis to obtain the amount of carbon, hydrogen, nitrogen and sulphur percentages. The Gantt chart is shown in Tables 3.1 and 3.2.

Table 3.1: Gantt chart for Semester 1

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Data Gathering on Topic														
3	Submission of Preliminary Report														
4	Sample OPF Preparation														
5	Preliminary Drying Test														
6	Results Gathering														
7	Submission of Progress Report														
8	Seminar														
9	Selection of Drying Method														
10	Results Gathering														
11	Submission of Interim Report														
12	Oral Presentation														

Table 3.2: Gantt chart for Semester 2

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Method and Procedure Planning														
2	Leaflets Drying Test														
3	Results Gathering & Discussion														
4	Submission of Progress Report 1														
5	Petioles Drying Test														
6	Results Gathering & Discussion														
7	Submission of Progress Report 2														
8	Calorific value & CHNS Test														
9	Results Gathering & Discussion														
10	Seminar														
11	Poster Exhibition														
12	Submission of Dissertation (softbound)														
13	Oral Presentation														
14	Submission of Dissertation (hardbound)														

3.2 Drying Test

The drying test is being conducted to determine which drying temperature and size of the fronds will produce highest moisture rate loss. The drying test is performed on both petiole and leaflet parts.

3.2.1 Oven as Drying Device

The drying device used in this experiment is Universal Oven Model UNB 400 which produced by Memmert. The actual view of the oven is shown in Figure 3.2.

Figure 3.2: Universal oven Model UNB 400

The oven has natural convection application and continuous adjustment of pre-heated fresh air admixture. In order to control the temperature, the oven is installed with microprocessor PID-temperature controller assisted by integrated auto diagnostic system with fault indicator. This temperature controller is able to produce an overtemperature protection function. In case of total breakdown of sensor or failure of switching element, the heating is switched off at approximately 10 °C above set value. The dimension’s detail, temperature range and voltage/power rating of Model UNB 400 are shown in Tables 3.3 and 3.4:

Table 3.3: Dimension's detail of Model UNB 400 (Exterior casing and Interior)

Exterior casing	**Interior**
• Wide x height x depth = 550mm x 680mm x 480mm • Fully insulated stainless steel door with double locking and 4-point adjustment • Rear zinc-plated steel	• Wide x height x depth = 400mm x 400mm x 330 mm • Easy-to-clean interior, made of stainless steel, reinforced by deep drawn ribbing with integrated and protected large-area heating on four sides • 2 stainless steel grids

Table 3.4: Temperature range and voltage/power rating of Model UNB 400

Temperature range	from +30 °C up to +220 °C
Voltage	230 V (+/- 10%), 50/60 Hz
Power rating	1,400 W (during heating)

3.2.2 Petioles as Sample

The oil palm frond sample was freshly pruned at the oil-palm plantation in Kampung Bali, Tronoh. All leaflets are shredded away using cleaver to obtain only a petiole as a main sample to be investigated. The petiole being shaped into three different physical conditions which as shown in Figure 3.3. Sample A (block) has length of 3cm with least surface area being exposed, while the sample B (chip) has length of 5 cm with higher surface area being exposed compared to sample A. For sample C (granule), the sample is obtained by cutting them using granulator to produce the sample's length smaller than 1cm.

(a) Block

(b) Chip

(c) Granule

Figure 3.3: Petioles after differentiate in three physical conditions which are (a) block, (b) chip and (c) granule

Each petioles condition being divided into three types of storage which are air-sealed, air-ventilated and without storage. For petioles without storage, the drying test will be handled immediately after the petioles have been pruned. While for storage settings, the samples will be stored for two months period in their respective types of storage before conducting the drying test.

The purpose of the drying test is to investigate the effect of petioles size with various drying temperature. During the drying test, about 10 grams of each petioles condition (block, chip and granule) are taken as a drying sample. The samples are dried at their respective drying temperatures which are 80°C, 120°C, 160°C and 200°C. For each 15 minutes, each sample's weights are recorded to determine how much percentages of moisture loss from the sample. The drying test is stopped when there is not much difference in sample's weight with the previous one. The experiment map for petioles is shown in Table 3.5. To calculate the percentage of moisture loss from each sample, the following formula (3.1) is being used:

$$X\ \% = ((\text{Initial weight} - \text{current weight}) / \text{Initial weight}) \times 100 \qquad (3.1)$$

Table 3.5: Drying petiole's test map for determination of moisture loss

Type of storages	**Drying temperature**	**Overall percentages moisture loss, %**		
		Block	Chip	Granule
Without storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X
Air-ventilated storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X
Air-sealed storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X

3.2.3 Leaflets as Sample

The oil palm frond sample was freshly pruned at the oil-palm plantation in Kampung Bali, Tronoh. All leaflets are collected from the fronds as a main sample to be investigated. The leaflets being shaped into three different physical conditions which as shown in Figure 3.4. Sample D (chip) is obtained by cutting the leaflets into a length ranging from 1cm to 4cm using scissors, while sample E (granule) is obtained by cutting them using granulator to produce the sample's length smaller than 1cm For the sample F (powder), the granule which has been obtained previously, will be strain using a sieve which allow the fine particle to pass. Below are the pictures of each sample.

(a) Chip

(b) Granule

(c) Powder

Figure 3.4: Leaflets after differentiate in three physical conditions which are (a) chip, (b) granule, and (c) powder

Each leaflets condition being divided into three types of storage which are air-sealed, air-ventilated and without storage. For leaflets without storage, the drying test will be handled immediately after the leaflets have been pruned. While for storage settings, the samples will be stored about two months period in their respective types of storage before conducting the drying test.

The purpose of the drying test is to investigate the effect of leaflets size with various drying temperature. During the drying test, about 10 grams of each leaflets condition (chip, granule and powder) are taken as a drying sample. The samples are dried at their respective drying temperatures which are 80°C, 120°C, 160°C and 200°C.

For each 15 minutes, each sample's weights are recorded to determine how much percentages of moisture loss from the sample. The drying test is stopped when there is not much difference in sample's weight with the previous one. The experiment map for leaflets is shown in Table 3.6. To calculate the percentage of moisture loss from each sample, Equation (3.1) is being used.

Table 3.6: Drying leaflet's test map for determination of moisture loss

Type of storages	**Drying temperature**	**Overall percentages moisture loss, %**		
		Chip	Granule	Powder
Without storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X
Air-ventilated storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X
Air-sealed storage	80°C	X	X	X
	120°C	X	X	X
	160°C	X	X	X
	200°C	X	X	X

3.3 Calorific Value Test

To determine the amount of energy stored in the oil palm frond, a Calorific Value Test would be done using a LECO AC-350 Bomb Calorimeter which is shown in Figure 3.5. Gross Calorific value of a fuel specimen is the heat produced by a complete combustion of a unit quantity of sample, at a constant volume, in an oxygen bomb calorimeter under standard condition. The parameter for the calorific test was done according to ASTM D 5865-07, Standard test Method for Gross Calorific Value of Coal and Coke. The test would be a judging parameter on the suitability or potential of the fronds as a biomass feed. A measure of 0.2 mg quantity from the sample will be taken and a set of two runs would be conducted for each sample to determine the average energy value contained in the oil palm fronds in units of J/g. The experiment map for petioles and leaflets are shown in Table 3.7.

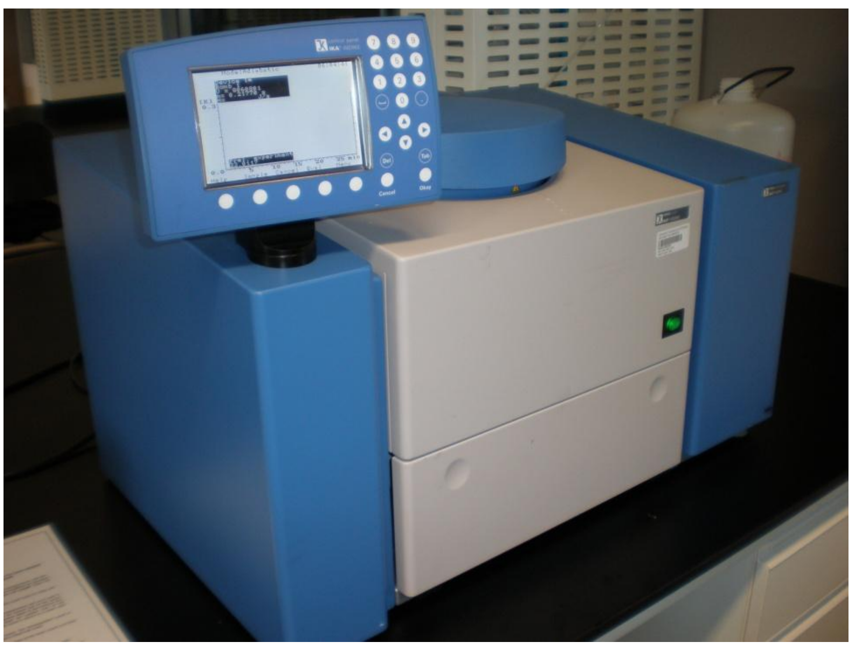


Figure 3.5: LECO AC-350 Bomb Calorimeter

Table 3.7: Average calorific content for petioles and leaflets

Type of storages	Drying temperature	Average calorific content, J/g					
		Petioles			Leaflets		
		Block	Chip	Granule	Chip	Granule	Powder
Figure		3.3 (a)	3.3 (b)	3.3 (c)	3.4 (a)	3.5 (b)	3.5 (c)
Without storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X
Air-ventilated storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X
Air-sealed storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X

3.4 Ultimate Analysis

The ultimate analysis or CHNS testing was performed using the Leco CHNS-932 machine which shown in Figure 3.6. The testing purpose is to analyze the chemical compositions of the oil palm fronds by preparing a fine dry powder of sample. The CHNS machine works based on the principle that high temperature combustion is used as the means of removing the elements from the material. This analysis will report the (carbon, hydrogen, nitrogen, and sulphur) content in the frond samples. The parameter for ultimate analysis was set according to ASTM D 3176-89. The weight that would be used for the test would be 1 mg in form of fine powder. A set of 5 runs would be conducted to obtain an average value for the composition of each carbon, hydrogen, nitrogen and sulphur in the palm fronds. High carbon content would highlight the possibility of the oil palm fronds to become a fuel source for the gasification process.

Low sulphur content would portray the potential of the palm fronds as an environmental friendly renewable energy source as sulphur would and react with water, oxygen and oxidants to form acidic compound as found in acid rains.

Figure 3.6: Leco CHNS-932 machine

The CHNS experiment map for petioles and leaflets are shown in Table 3.8:

Table 3.8: CHNS test map for petioles and leaflets

		Chemical composition, %					
		Petioles			Leaflets		
Type of storage	**Drying temp.**	a) Block	b)Chip	c)Granule	d)Chip	e)Granule	f)Powder
Without storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X
Air-ventilated storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X
Air-sealed storage	80°C	X	X	X	X	X	X
	120°C	X	X	X	X	X	X
	160°C	X	X	X	X	X	X
	200°C	X	X	X	X	X	X

CHAPTER 4

RESULTS AND DISCUSSIONS FOR DRYING TEST

The drying tests are conducted to determine which drying temperature and fronds size will produce the highest moisture rate loss. The samples are petioles and leaflets and they are categorized into three types, which are: 1.air-sealed storage, 2.air-ventilated storage and 3.without storage. All samples are dried in the oven and readings are taken for every 15 minutes.

4.1 Sample: Petioles, without Storage

The drying test is conducted on the petioles immediately after they have been freshly pruned from the plantation. No storage is needed for this sample.

4.1.1 Typical Drying Test

Figure 4.1 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

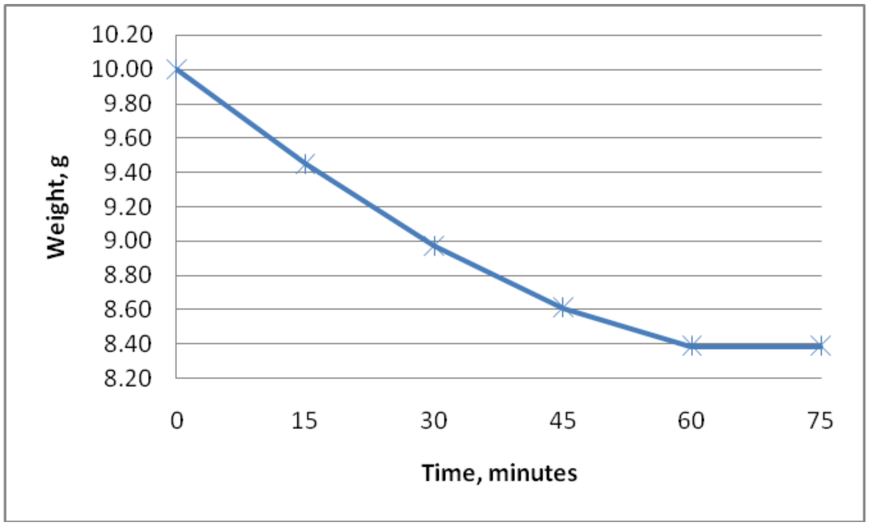


Figure 4.1: Typical drying test result for petiole with size of chip, and dried at 80°C

4.1.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample A (block), B (chip) and C (granule) are shown in Figure 4.2, 4.3 and 4.4.

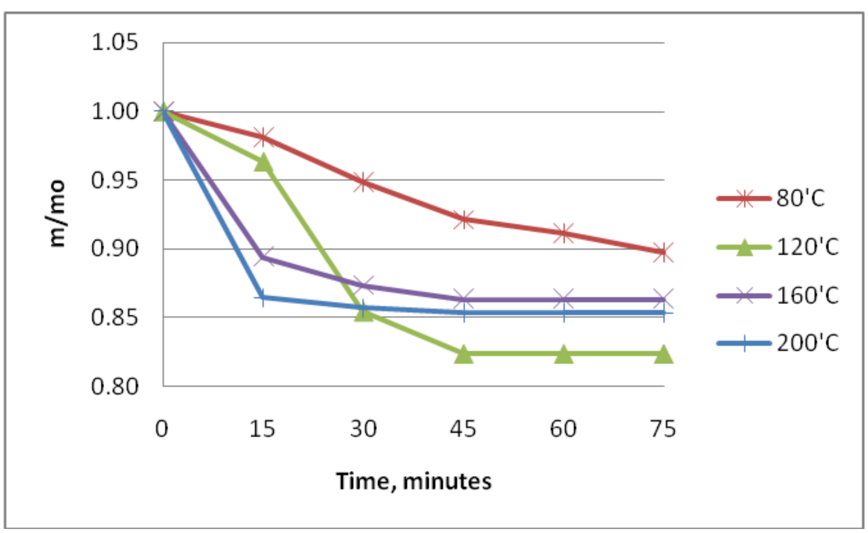


Figure 4.2: Comparison on different drying temperature on size of sample A

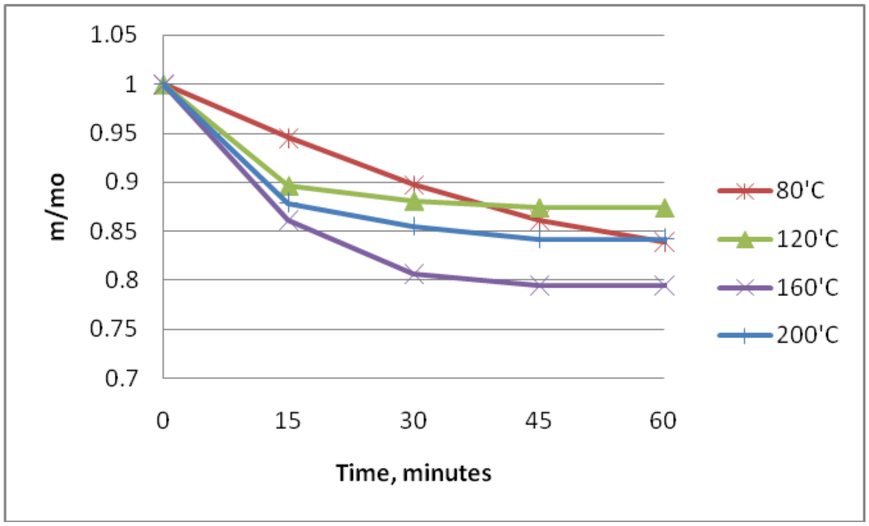


Figure 4.3: Comparison on different drying temperature on size of sample B

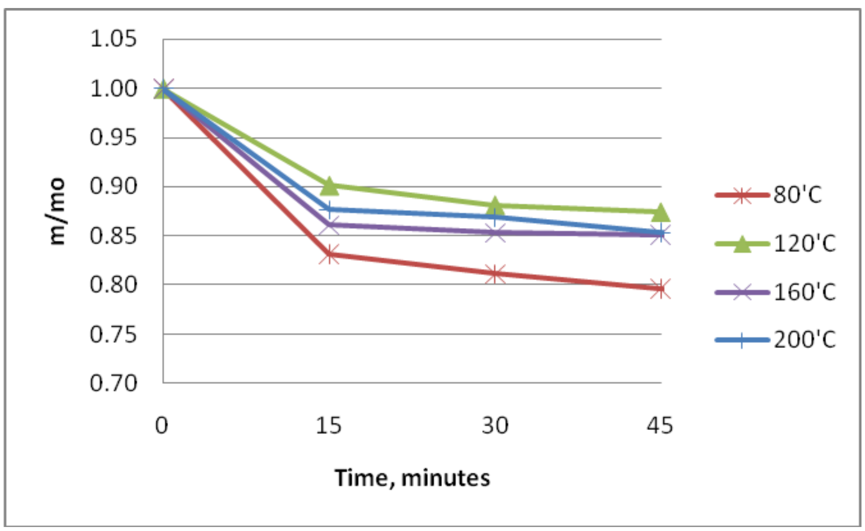


Figure 4.4: Comparison on different drying temperature on size of sample C

According to the results for each sample size, the drying temperatures of 160°C and 200°C are able to produce the highest moisture removal from the petioles in the shorter period of time. But for sample B and C, the drying temperature of 120°C has slight differences of drying rate between 160°C and 200°C at the early stage of the drying test. For sample C, the drying temperature of 80°C removes the highest amount of moisture within 15 minutes.

4.1.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature 80°C, 120°, 160°C and 200°C are shown in Figures 4.5 to 4.8.

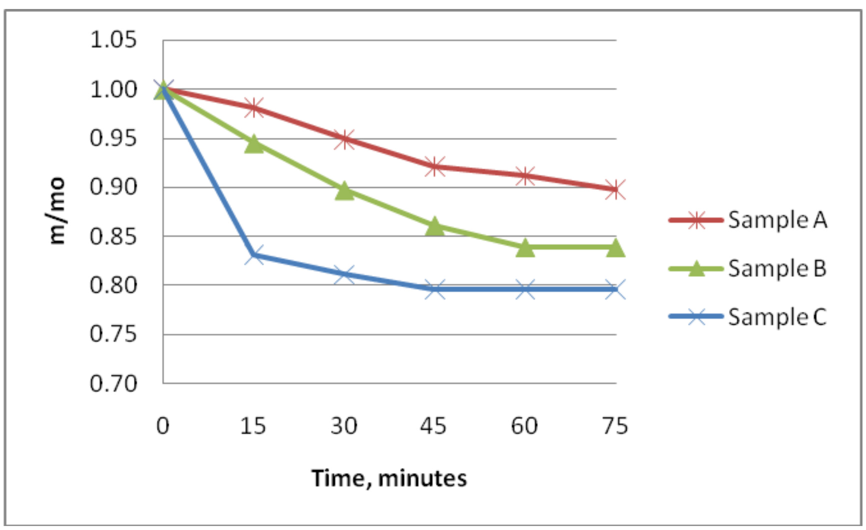


Figure 4.5: Comparison on different size of sample for drying temperature of 80°C

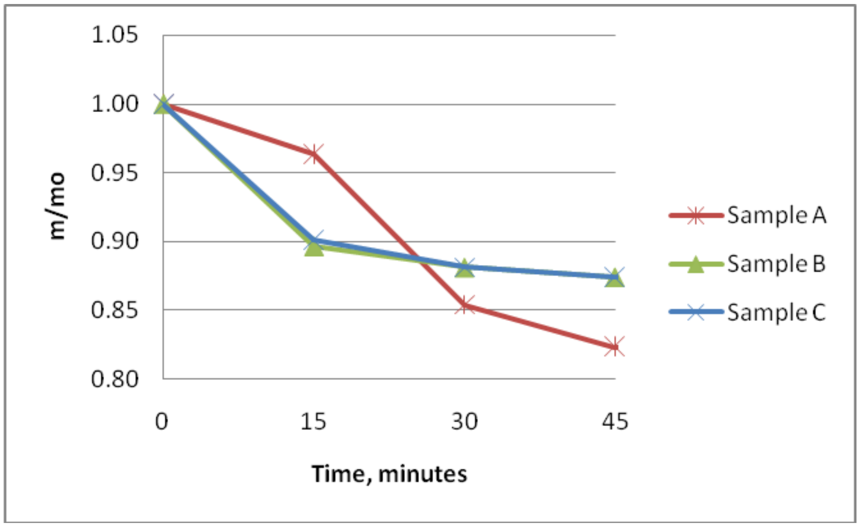


Figure 4.6: Comparison on different size of sample for drying temperature of 120°C

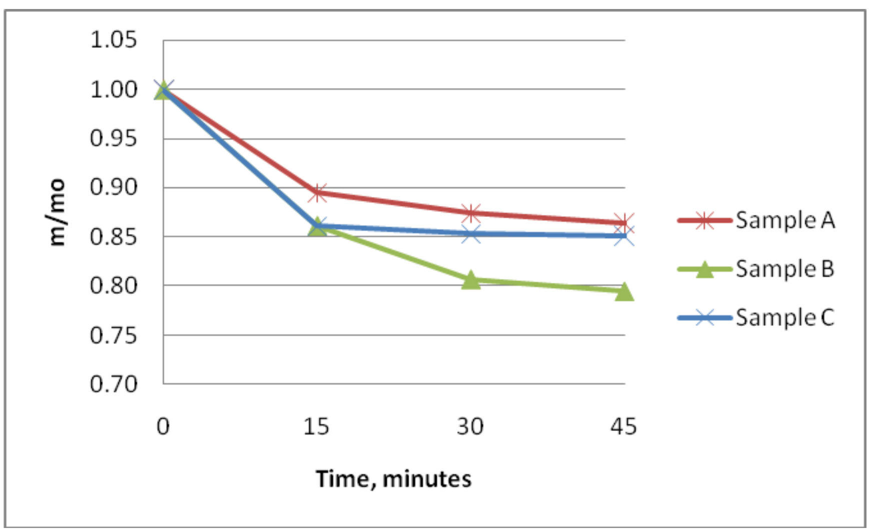


Figure 4.7: Comparison on different size of sample for drying temperature of 160°C

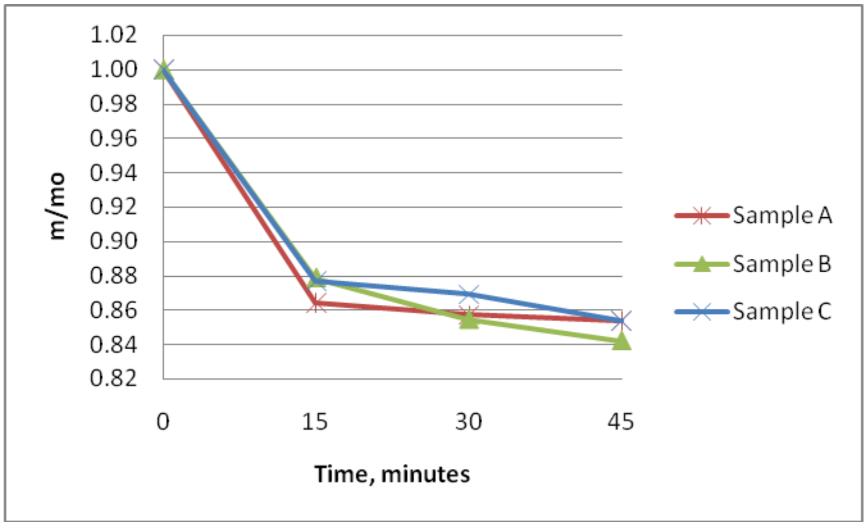


Figure 4.8: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, both sample B and C are able to produce highest moisture removal from the petioles within the shorter period of time. But for drying temperature of 200°C, sample A has the potential to produce the highest moisture removal same as sample B and C.

4.2 Sample: Petioles, with Air-Ventilated Storage

The drying test is conducted on the petioles after two months being stored in air-ventilated storage.

4.2.1 Typical Drying Test

Figure 4.9 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

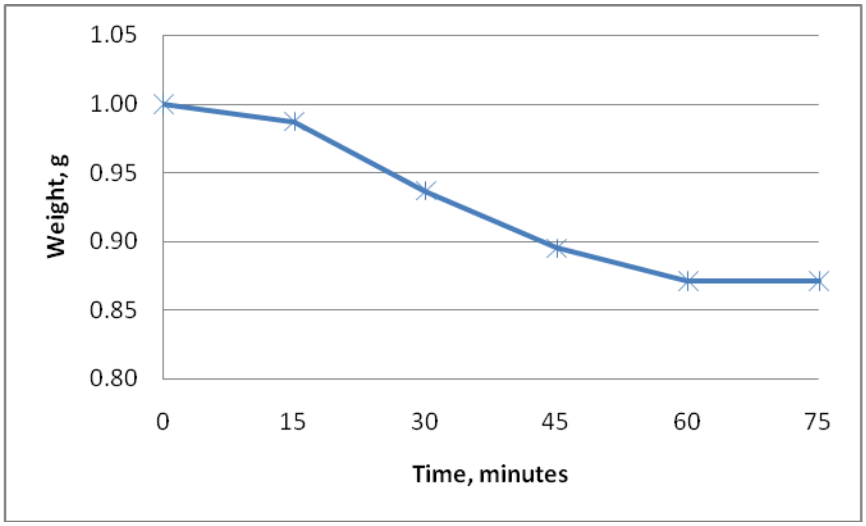


Figure 4.9: Typical drying test result for petiole with size of chip, and dried at 80°C

4.2.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample A (block), B (chip) and C (granule) are shown in Figures 4.10 to 4.12.

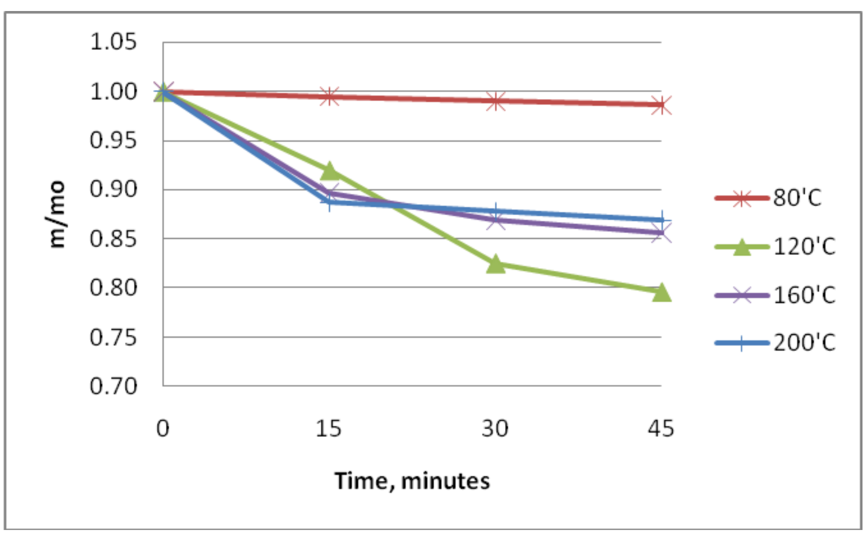


Figure 4.10: Comparison on different drying temperature on size of sample A

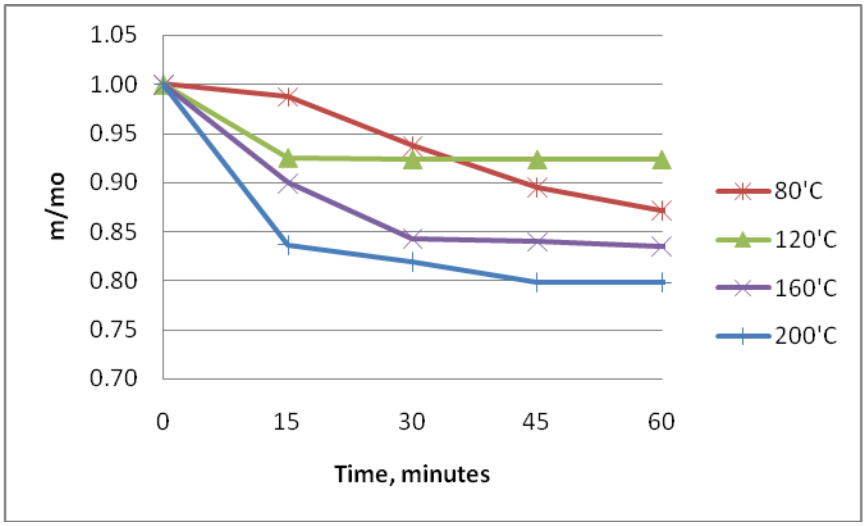


Figure 4.11: Comparison on different drying temperature on size of sample B

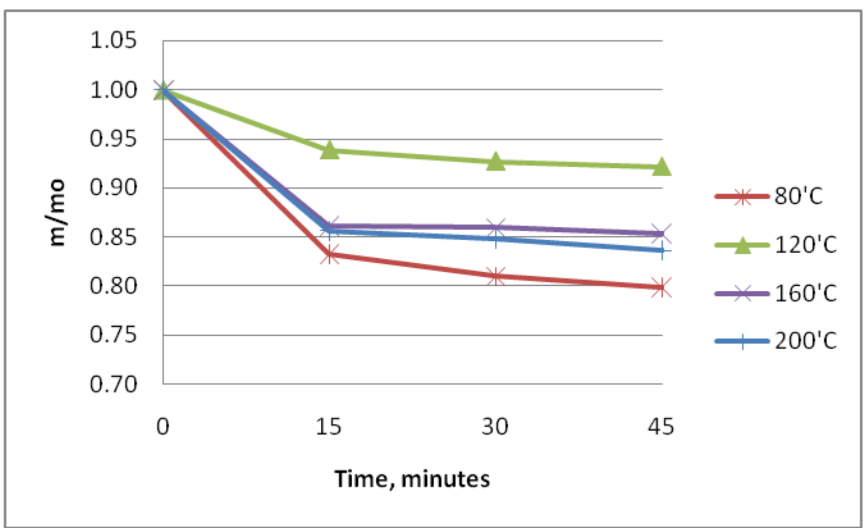


Figure 4.12: Comparison on different drying temperature on size of sample C

According to the results for each sample size, the drying temperature of 200°C able to produce highest moisture removal from the petioles in within the shorter period of time. But in sample A and C, the drying temperature of 160°C has the potential to produce the highest moisture removal within 15 minutes same as drying temperature 200°C.

4.2.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature of 80°C, 120°C, 160°C, and 200°C are shown in Figures 4.13 to 4.16.

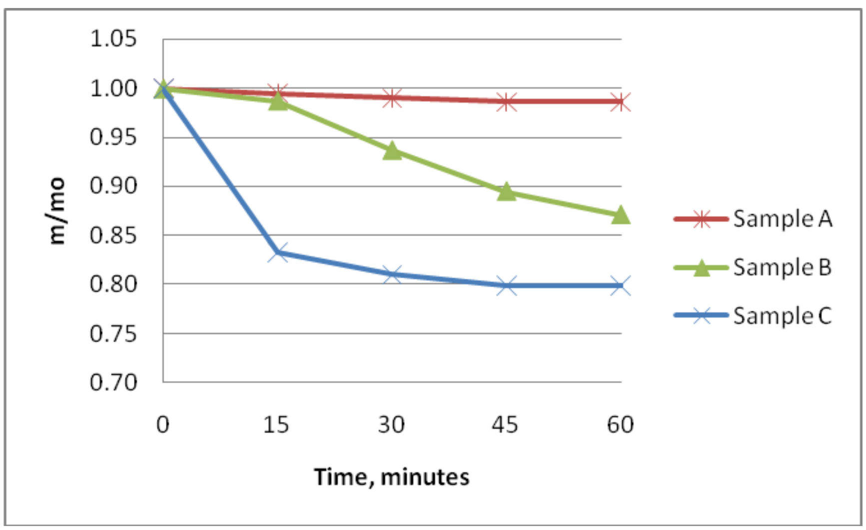


Figure 4.13: Comparison on different size of sample for drying temperature of 80°C

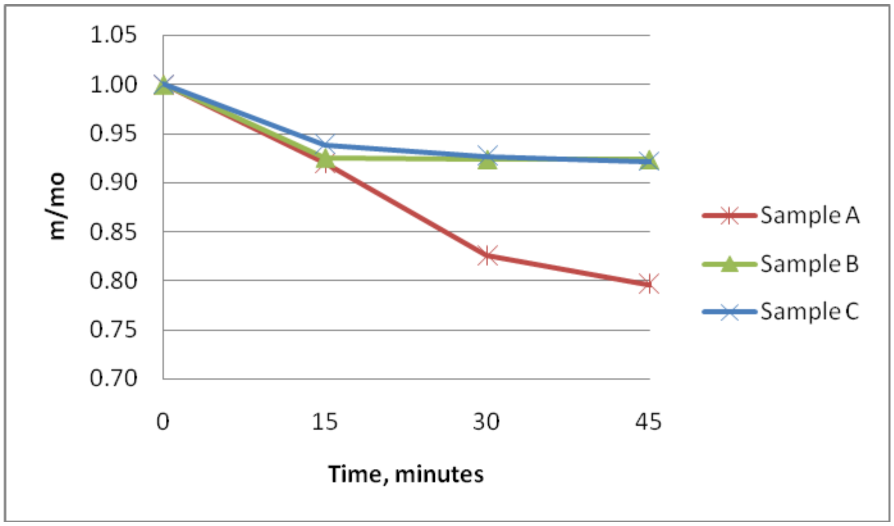


Figure 4.14: Comparison on different size of sample for drying temperature of 120°C

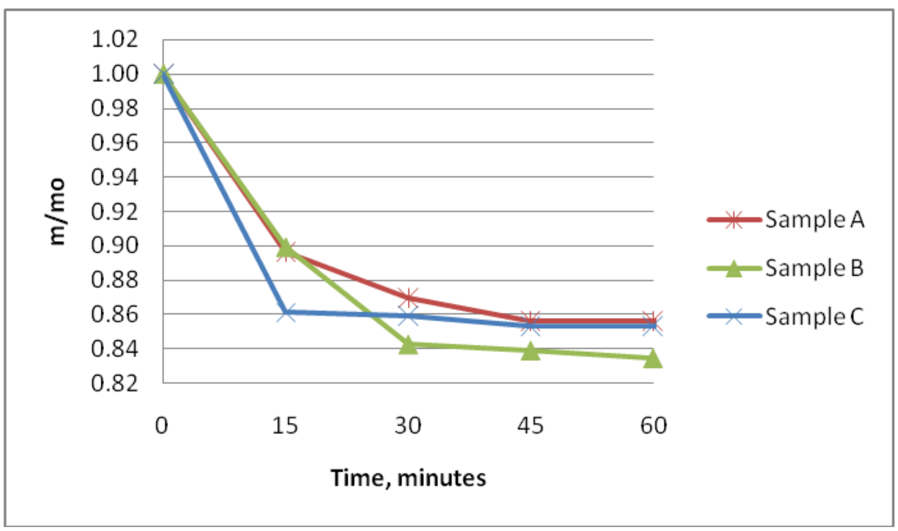


Figure 4.15: Comparison on different size of sample for drying temperature of 160°C

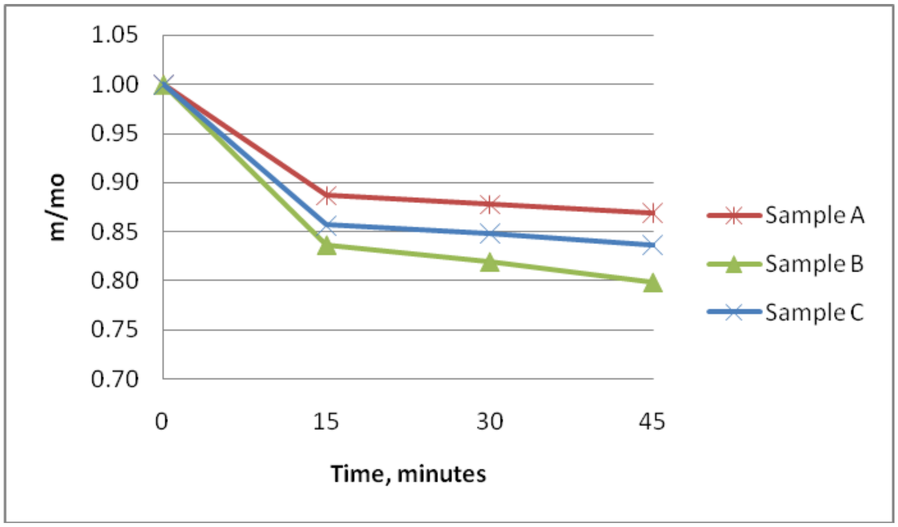


Figure 4.16: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, the sample A, B and C are able to produce highest moisture removal from the petioles within the shorter period of time.

4.3 Sample: Petioles, with Air-Sealed Storage

The drying test is conducted on the petioles after two months being stored in air-sealed storage.

4.3.1 Typical Drying Test

Figure 4.17 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

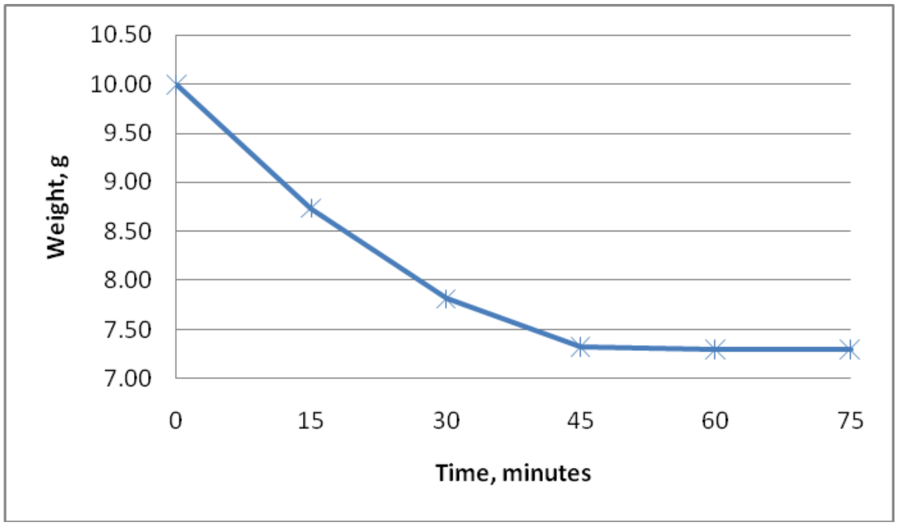


Figure 4.17: Typical drying test result for petiole with size of chip, and dried at 80°C

4.3.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample A (block), B (chip) and C (granule) are shown in Figures 4.18 to 4.20.

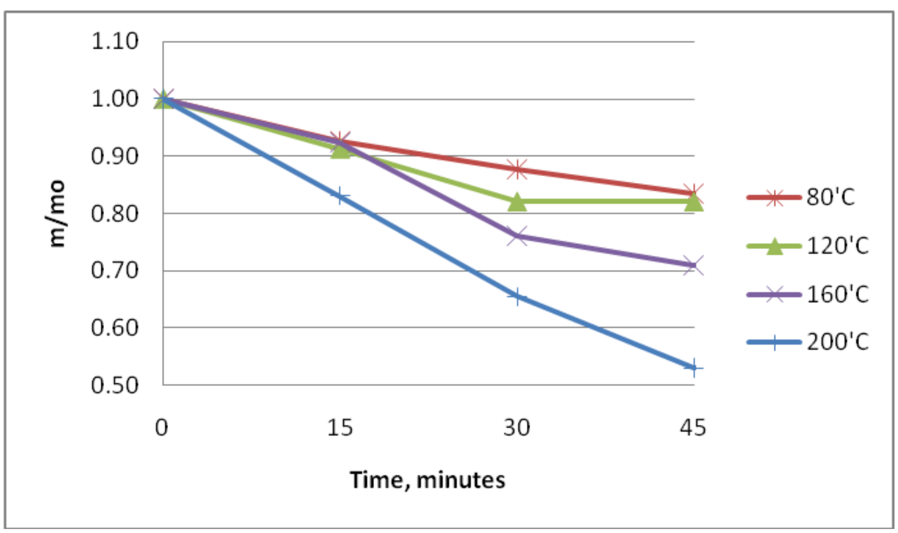


Figure 4.18: Comparison on different drying temperature on size of sample A

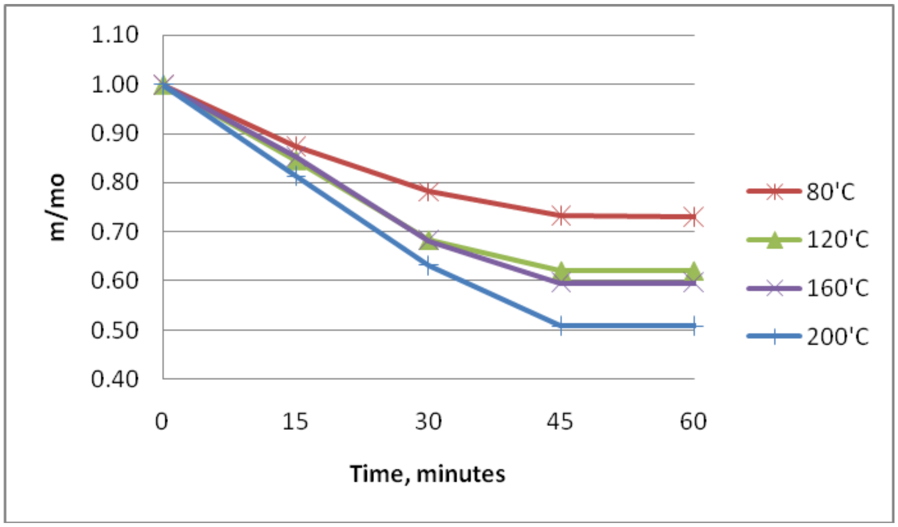


Figure 4.19: Comparison on different drying temperatures on size of sample B

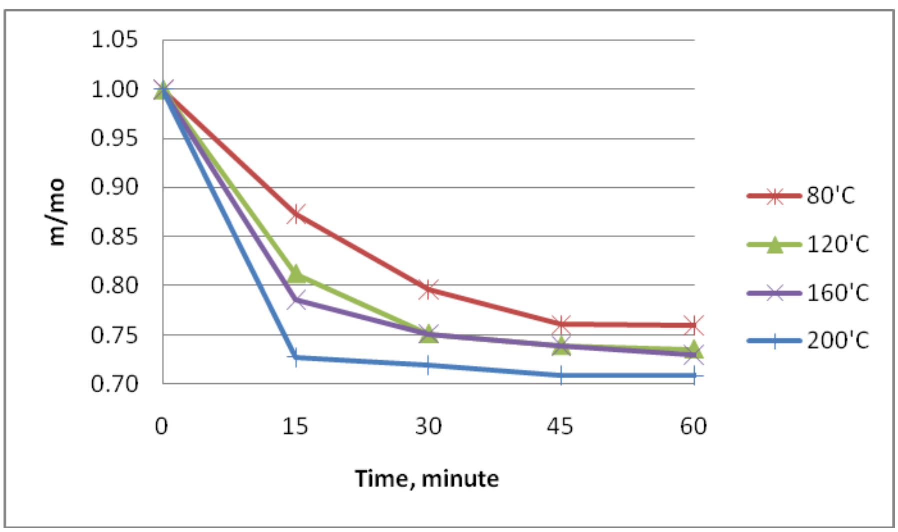


Figure 4.20: Comparison on different drying temperatures on size of sample C

According to the results for each sample size, the drying temperature of 200°C able to produce highest moisture removal from the petioles compared to other temperature within the shorter period of time. In sample A, there is a huge difference of drying rate between the drying temperature of 200°C and 160°C.

4.3.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature of 80°C, 120°C, 160°C, and 200°C are shown in Figures 4.21 to 4.24.

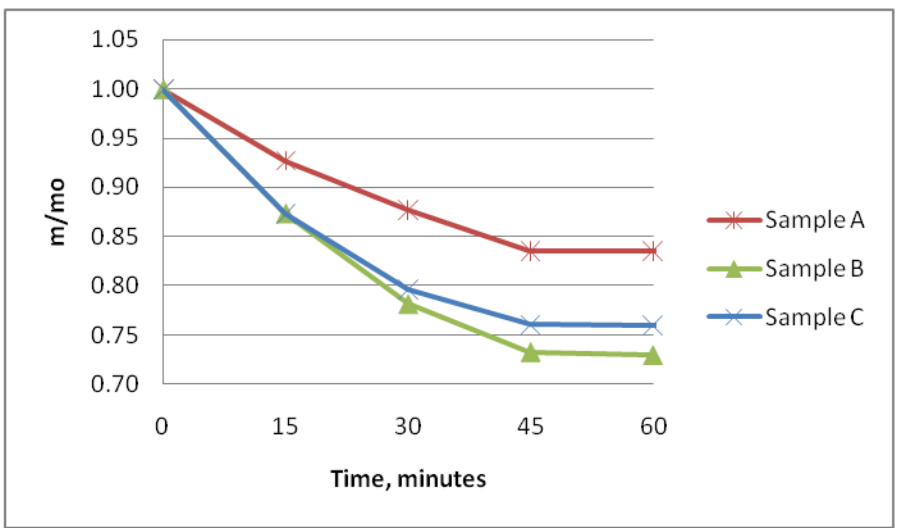


Figure 4.21: Comparison on different size of sample for drying temperature of 80°C

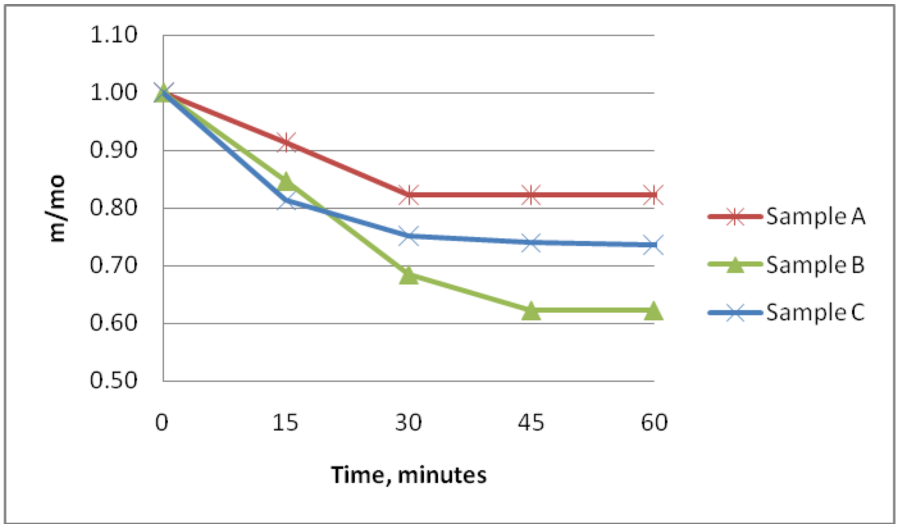


Figure 4.22: Comparison on different size of sample for drying temperature of 120°C

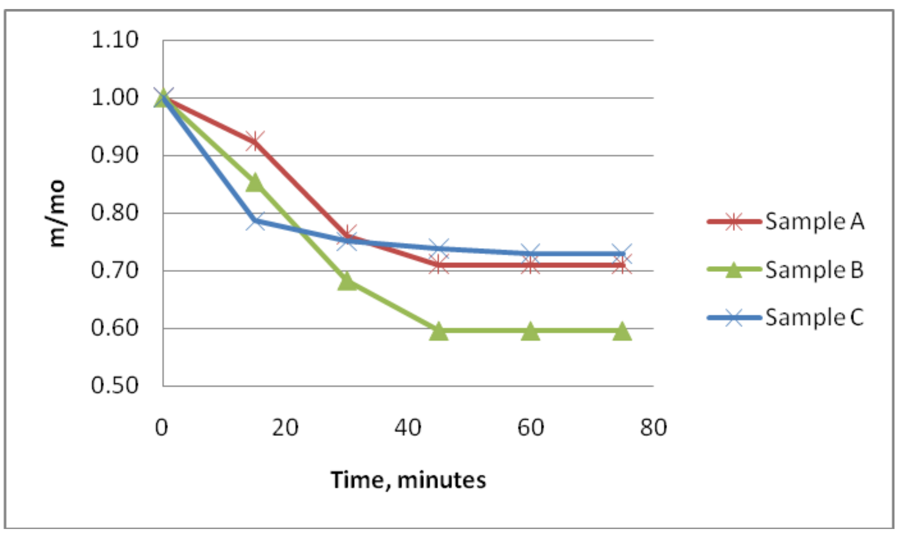


Figure 4.23: Comparison on different size of sample for drying temperature of 160°C

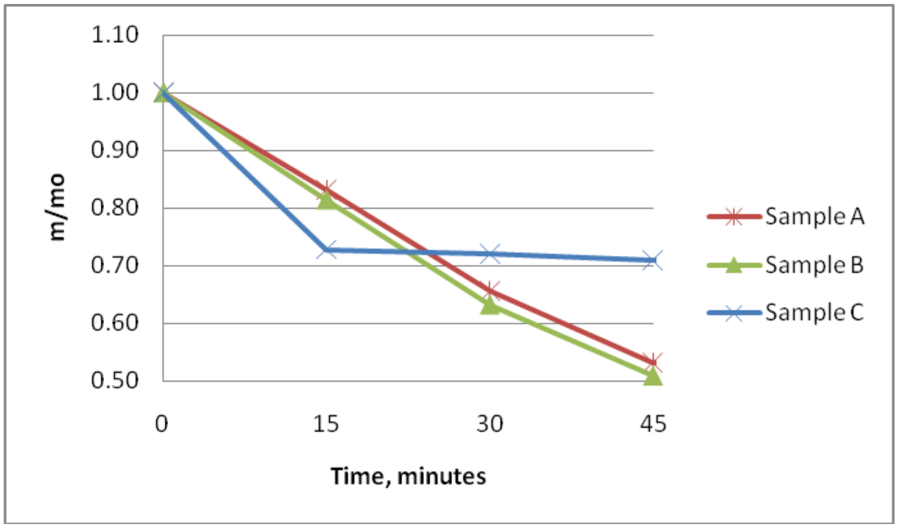


Figure 4.24: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, the sample C is able to produce highest moisture removal from the petioles within the shorter period of time. Only for drying temperature of 80°C and 120°C, sample B is having the same potential of moisture removal as sample C.

4.4 Sample: Leaflets, without Storage

The drying test is conducted on the leaflets immediately after they have been freshly pruned from the plantation.

4.4.1 Typical Drying Test

Figure 4.25 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

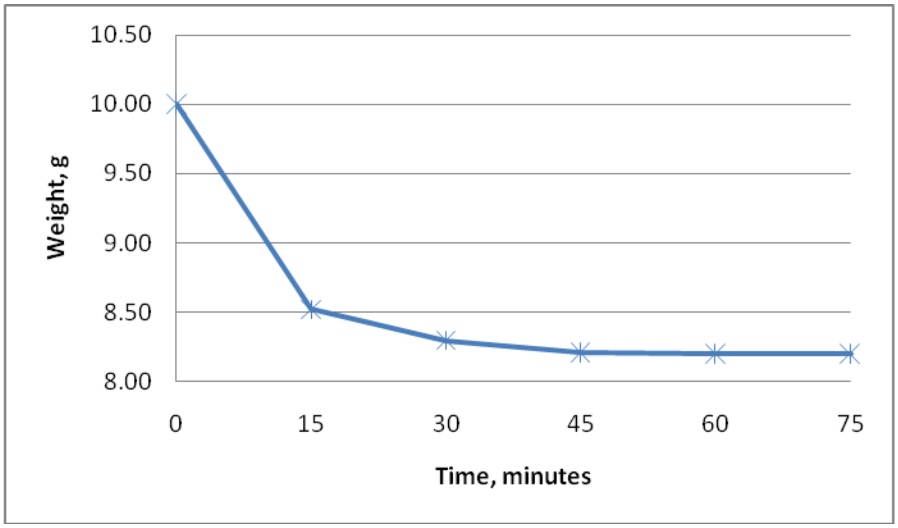


Figure 4.25: Typical drying test result for leaflet with size of chip, and dried at 80°C

4.4.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample D (chip), E (granule) and F (powder) are shown in Figures 4.26 to 4.28.

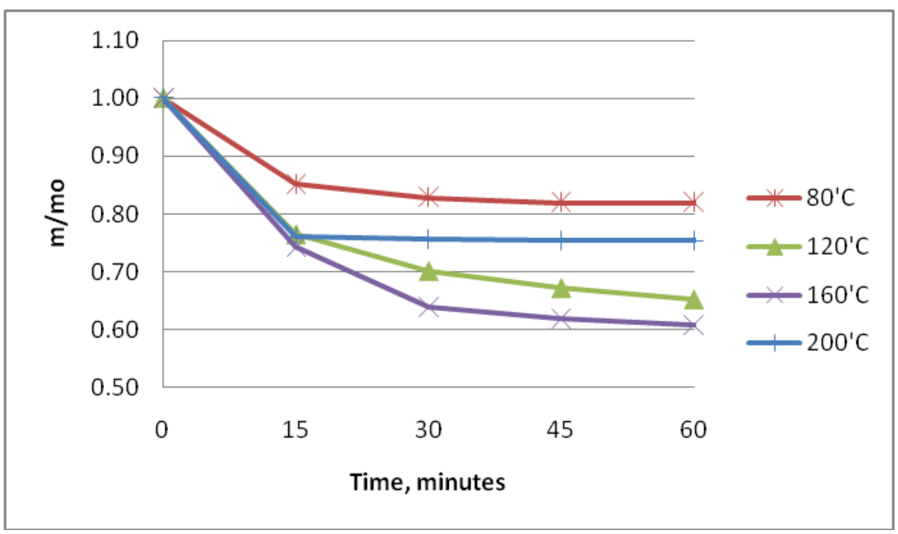


Figure 4.26: Comparison on different drying temperatures on size of sample D

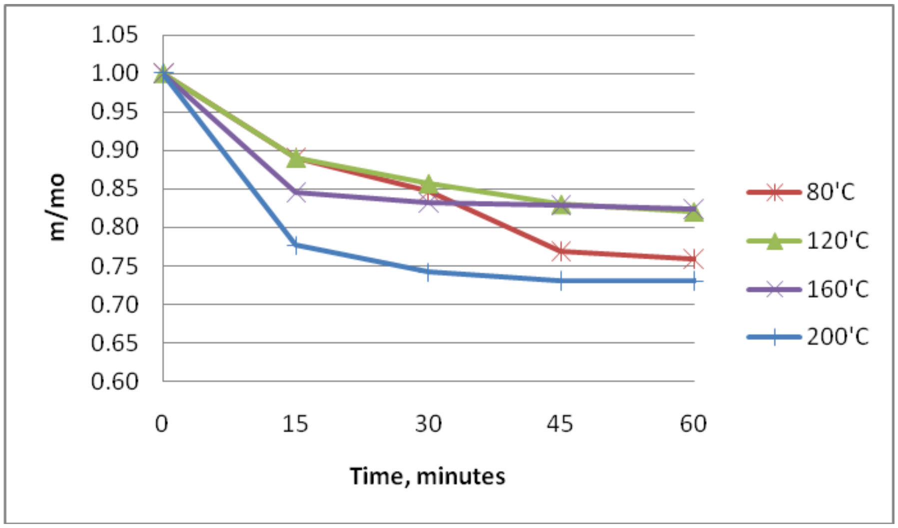


Figure 4.27: Comparison on different drying temperatures on size of sample E

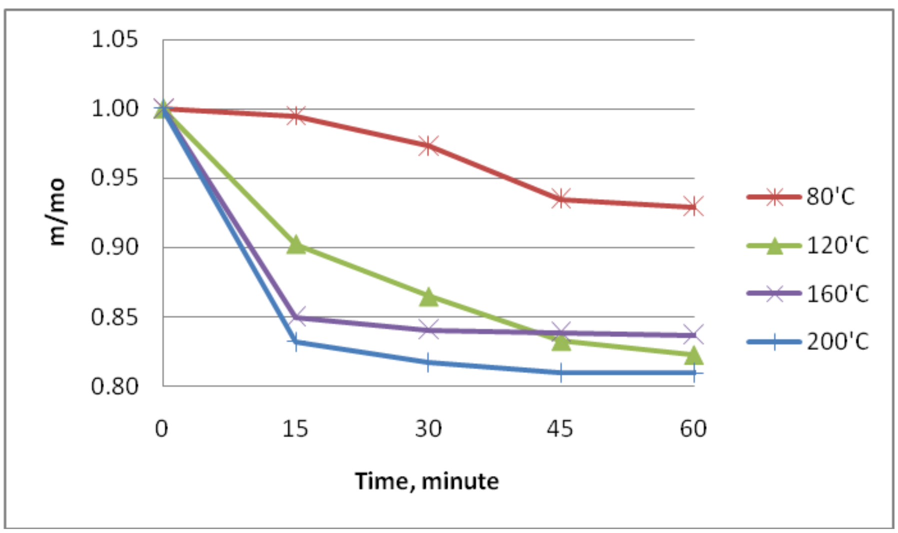
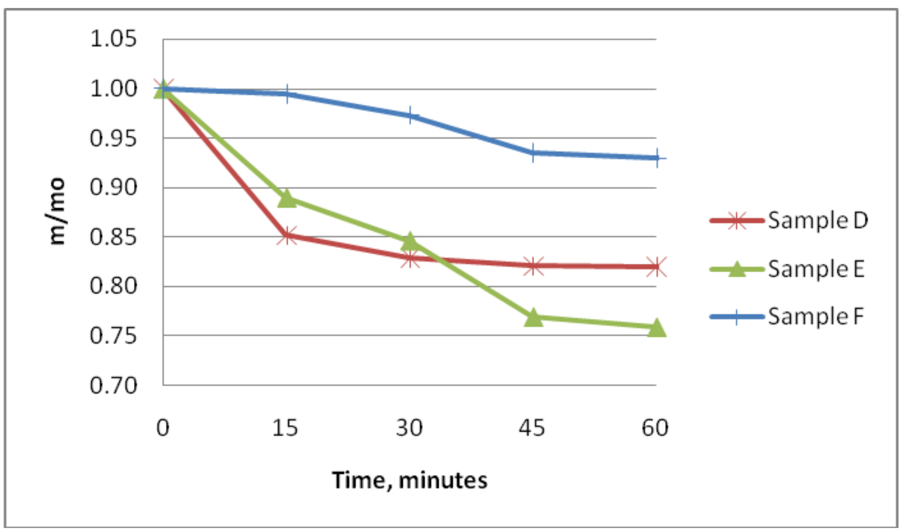


Figure 4.28: Comparison on different drying temperature on size of sample F

According to the results for each sample size, the drying temperatures of 160°C and 200°C able to produce highest moisture removal from the leaflets in shorter period of time. But for sample D, the drying temperature of 120°C has the same potential of moisture removal as temperature 160°C and 200°C.

4.4.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature of 80°C, 120°C, 160°C, and 200°C are shown in Figures 4.29 to 4.32.



. Figure 4.29: Comparison on different size of sample for drying temperature of 80°C

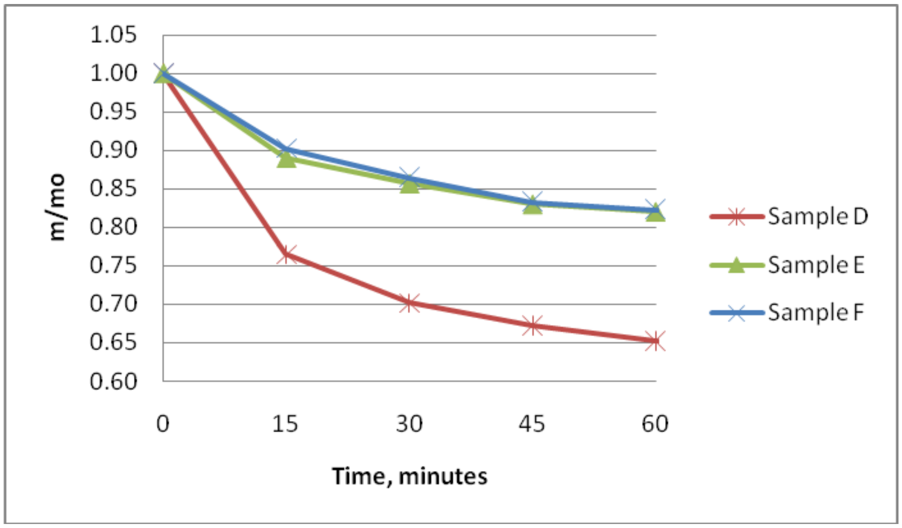


Figure 4.30: Comparison on different size of sample for drying temperature of 120°C

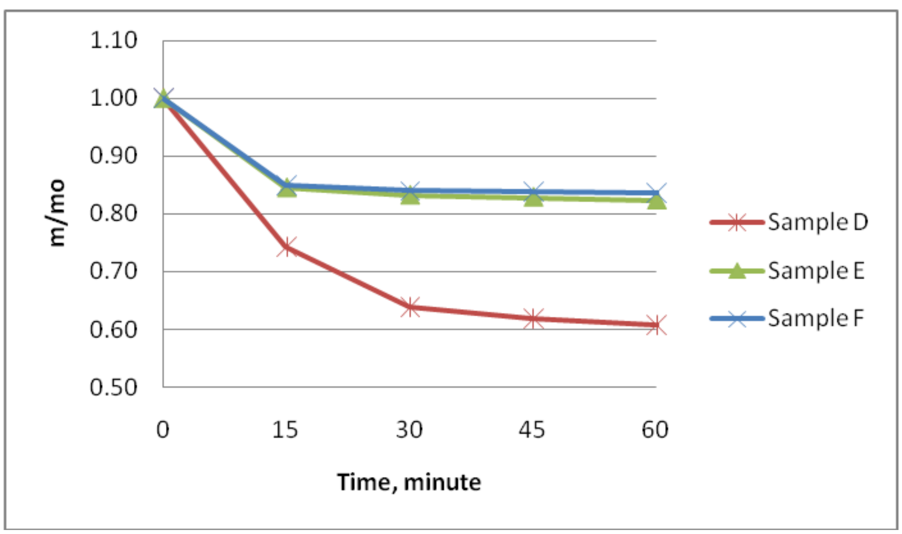


Figure 4.31: Comparison on different size of sample for drying temperature of 160°C

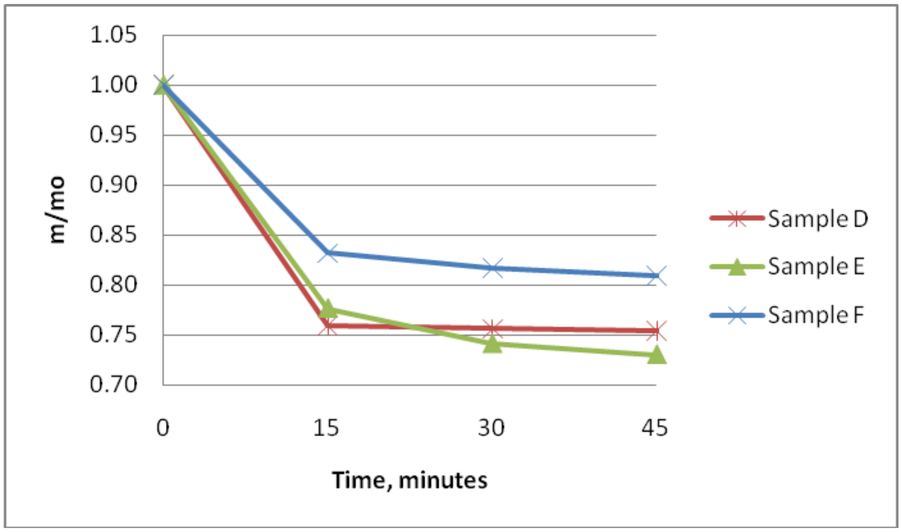


Figure 4.32: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, the sample D is able to produce highest moisture removal from the leaflets within shorter period of time. But for drying temperature of 200°C, sample E has the potential to remove the highest amount of moisture same as sample D.

4.5 Sample: Leaflets, with Air-Ventilated Storage

The drying test is conducted on the leaflets after two months being stored in air-ventilated storage.

4.5.1 Typical Drying Test

Figure 4.33 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

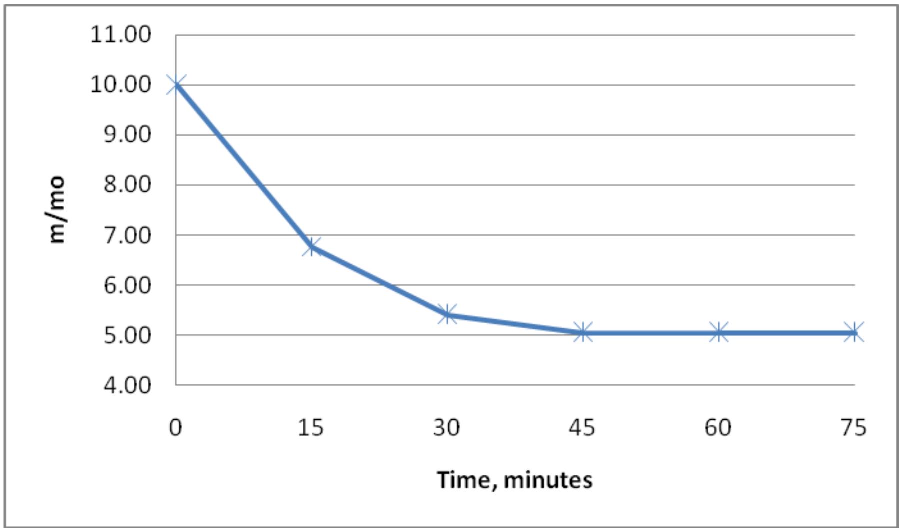


Figure 4.33: Typical drying test result for leaflet with size of chip, and dried at 80°C

4.5.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample D (chip), E (granule) and F (powder) are shown in Figures 4.34 to 4.36.

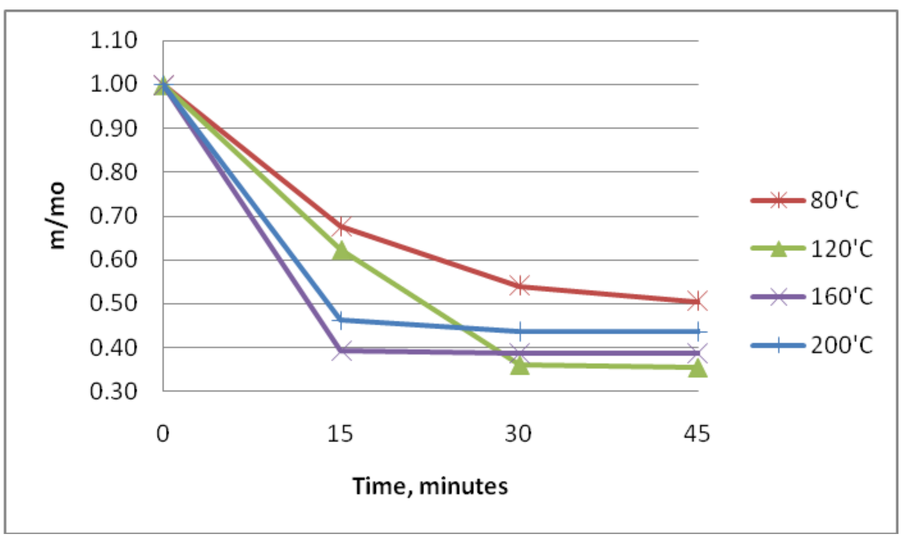


Figure 4.34: Comparison on different drying temperature on size of sample D

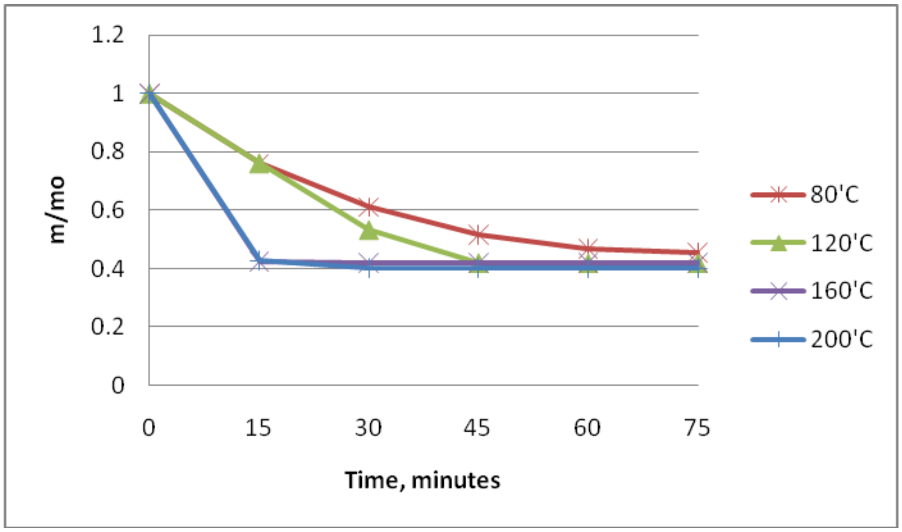


Figure 4.35: Comparison on different drying temperature on size of sample E

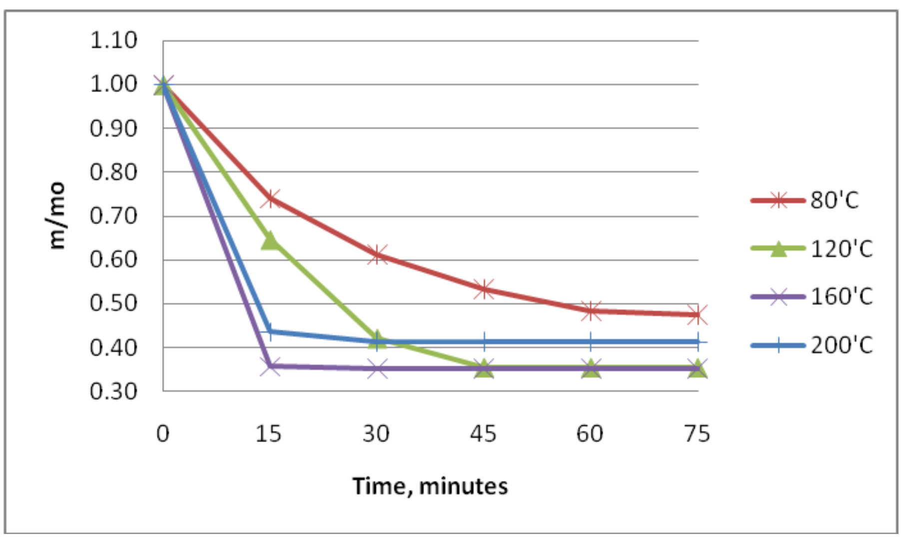


Figure 4.36: Comparison on different drying temperature on size of sample F

According to the results for each sample size, both drying temperature of 160°C and 200°C are able to produce the highest moisture removal within the shorter period of time.

4.5.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature of 80°C, 120°C, 160°C, and 200°C are shown in Figures 4.37 to 4.40.

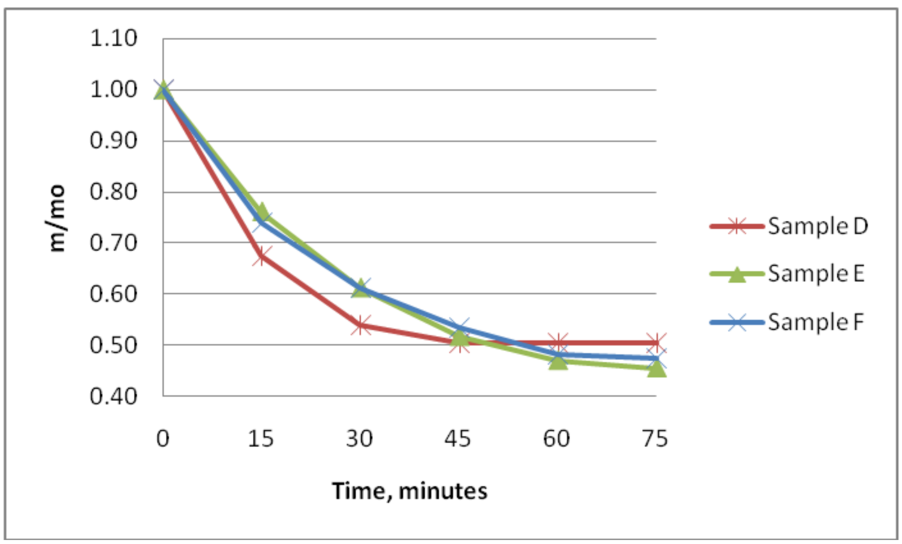


Figure 4.37: Comparison on different size of sample for drying temperature of 80°C

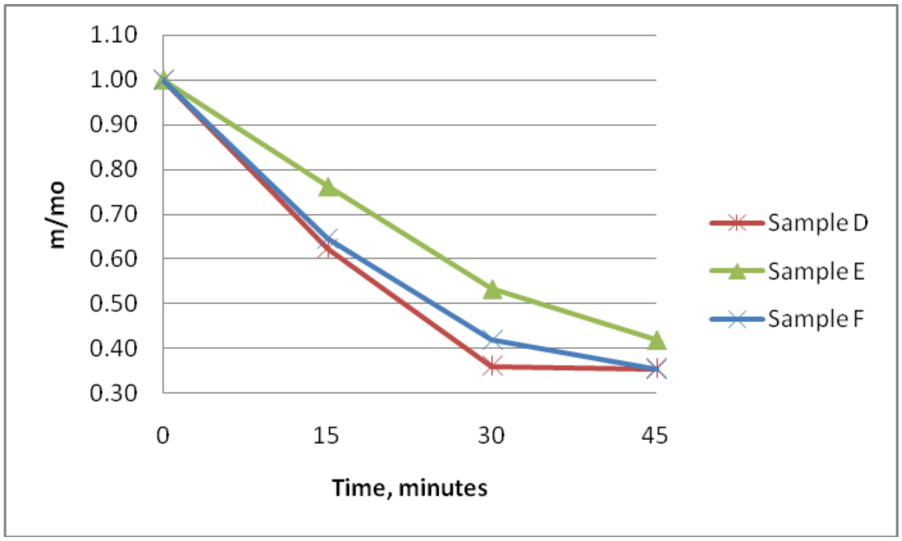


Figure 4.38: Comparison on different size of sample for drying temperature of 120°C

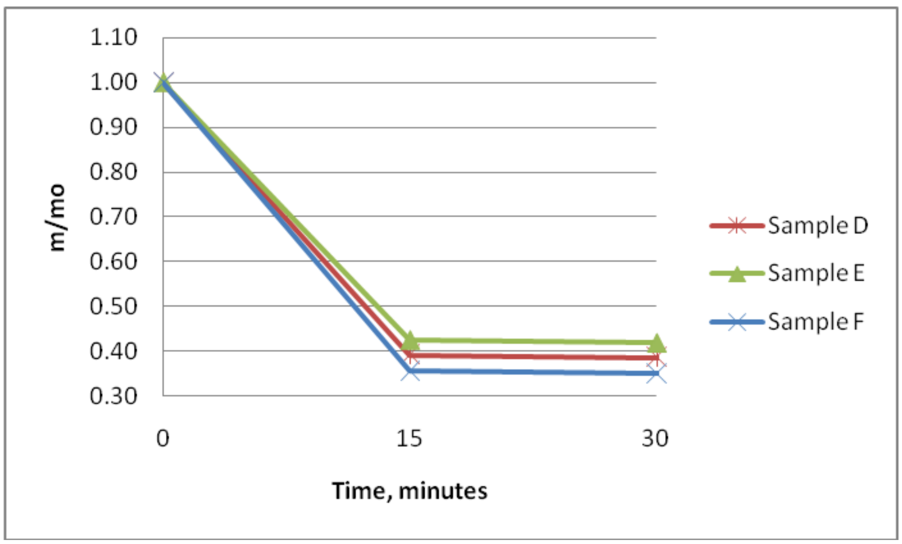


Figure 4.39: Comparison on different size of sample for drying temperature of 160°C

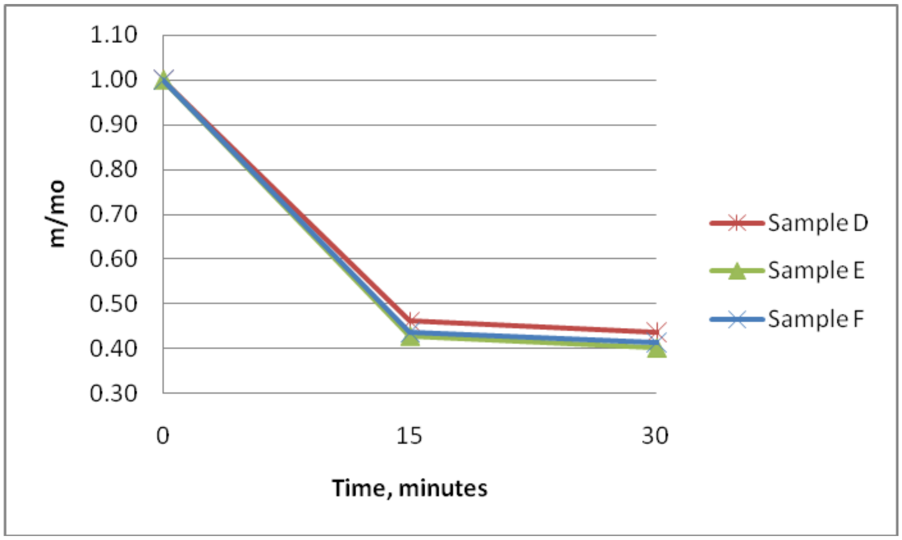


Figure 4.40: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, the sample D is able to produce the highest moisture removal within shorter period of time. But for drying temperature of 120°C, both sample D and F are able to remove much amount of moisture. While at drying temperature of 160°C and 200°C, all samples have the potential to produce the highest moisture removal within shorter period of time.

4.6 Sample: Leaflets, with Air-Sealed Storage

The drying test is conducted on the leaflets after two months being stored in air-sealed storage.

4.6.1 Typical Drying Test

Figure 4.41 shows the typical test result for this sample. The sample is in a size of chip and dried at temperature of 80°C.

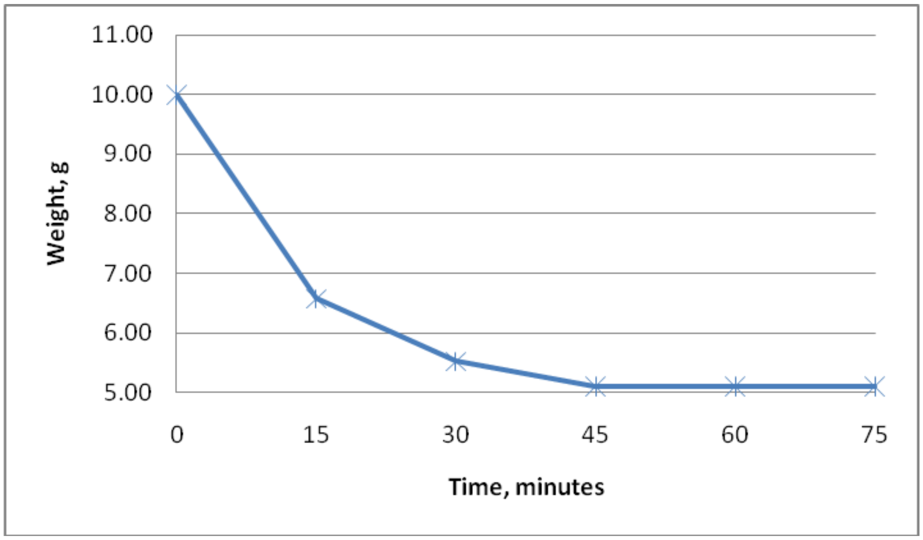


Figure 4.41: Typical drying test result for leaflet with size of chip, and dried at 80°C

4.6.2 Effect of Drying Temperature

The comparisons on different drying temperature for each size of sample D (chip), E (granule) and F (powder) are shown in Figures 4.42 to 4.44.

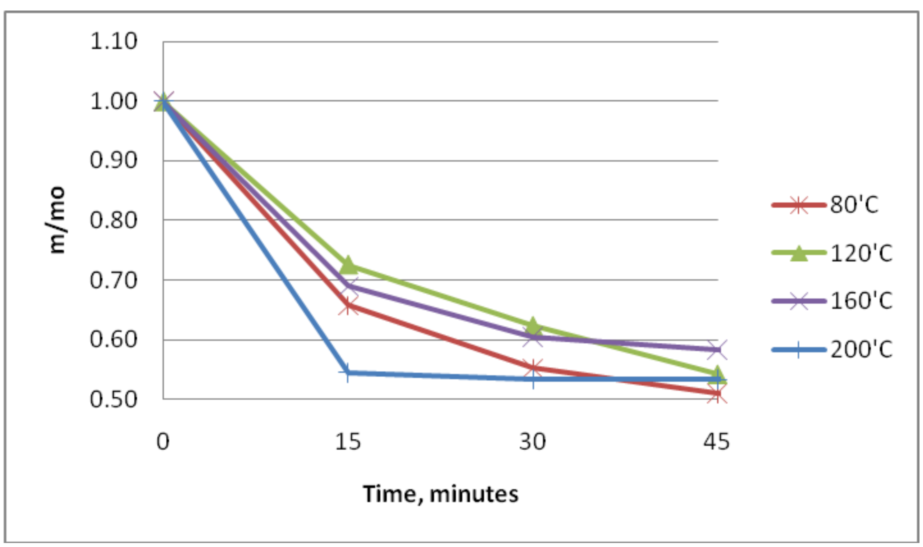


Figure 4.42: Comparison on different drying temperatures on size of sample D

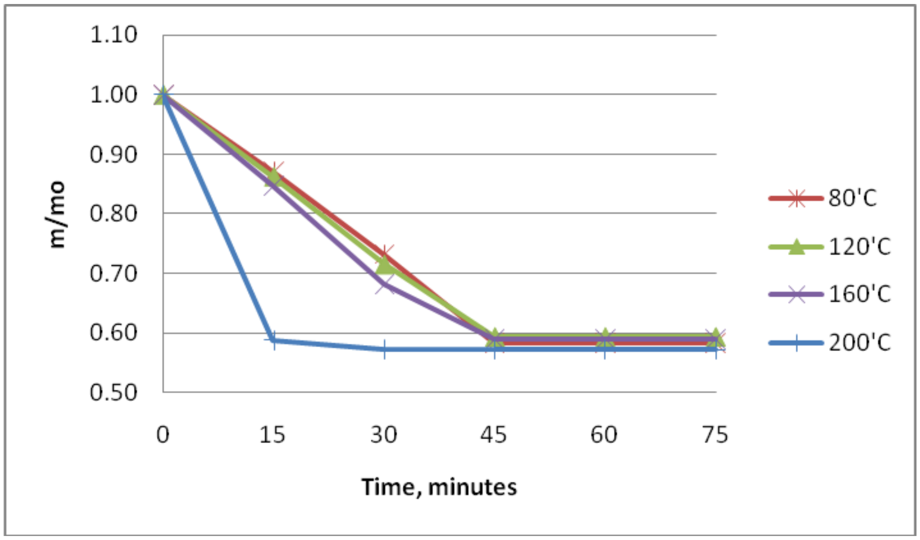


Figure 4.43: Comparison on different drying temperatures on size of sample E

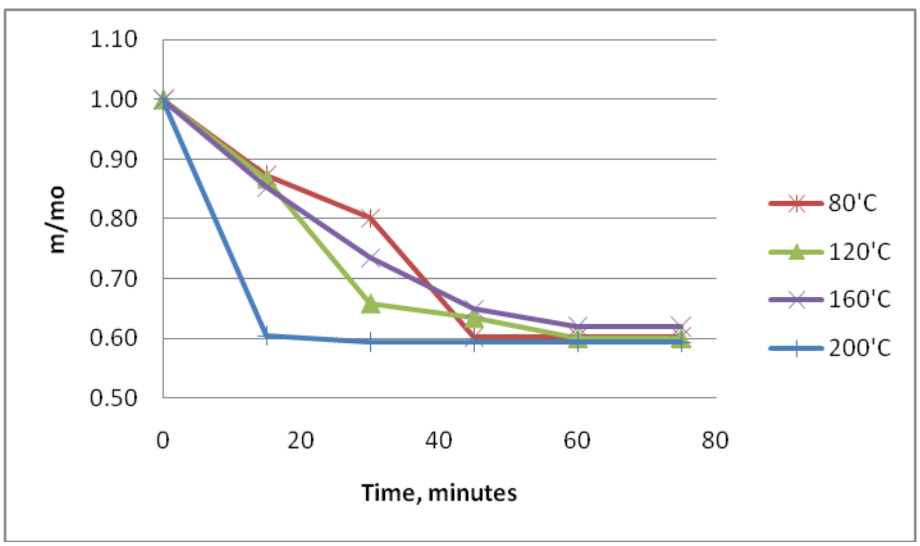


Figure 4.44: Comparison on different drying temperature on size of sample F

According to the results for each sample size, the drying temperature of 200°C is able to produce highest moisture removal from the leaflets within the shorter period of time.

4.6.3 Effect of Size of Sample

The comparisons on different size of sample for each drying temperature are shown in Figures 4.45 to 4.48.

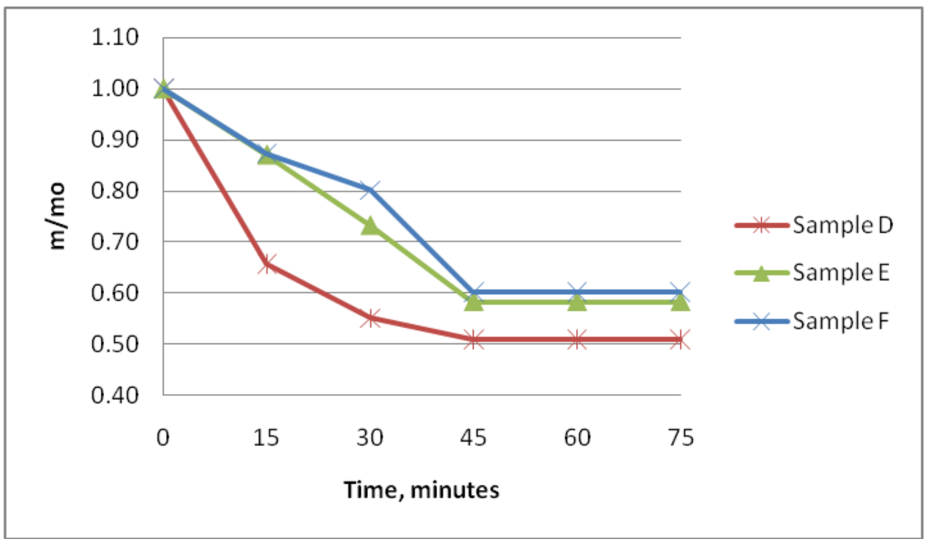


Figure 4.45: Comparison on different size of sample for drying temperature of 80°C

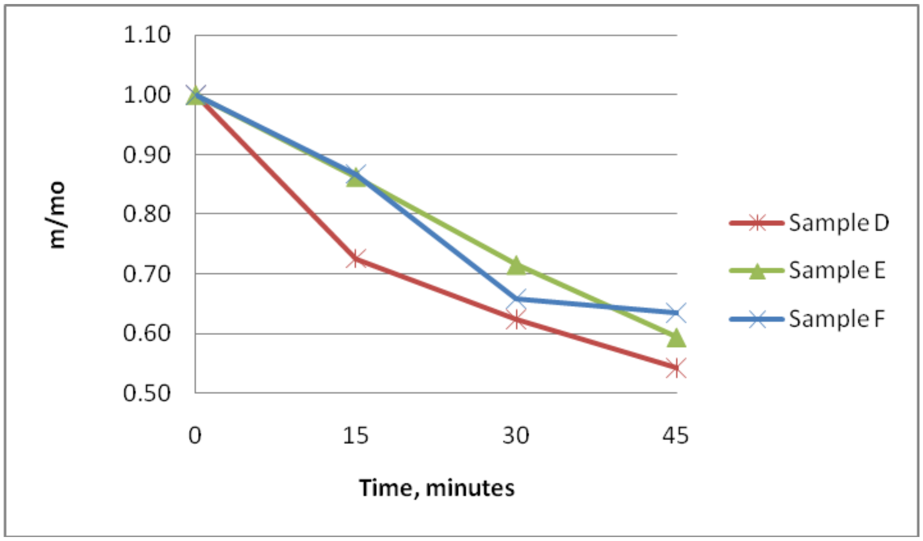


Figure 4.46: Comparison on different size of sample for drying temperature of 120°C

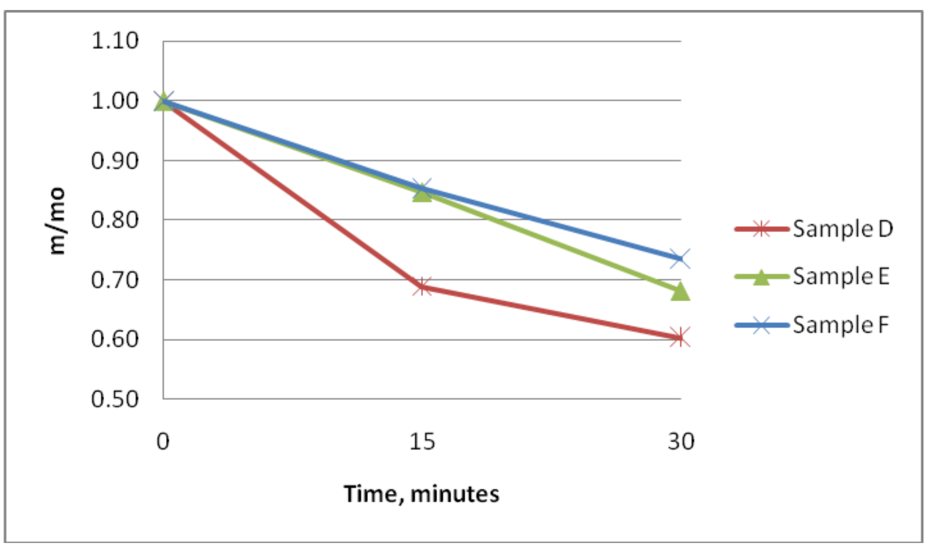


Figure 4.47: Comparison on different size of sample for drying temperature of 160°C

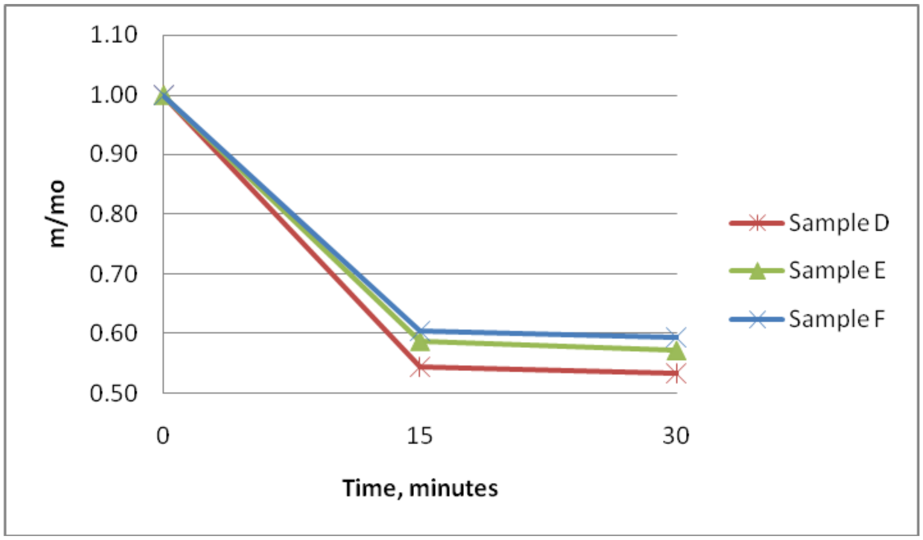


Figure 4.48: Comparison on different size of sample for drying temperature of 200°C

According to the results for each drying temperature, the sample D is able to produce highest moisture removal from the leaflets within the shorter period of time. But for drying temperature of 200°C, all samples are able to produce the highest moisture removal.

4.7 Overall Percentages Moisture Loss

Figure 4.49 and 4.50 shows the overall percentages of moisture loss from the petioles and leaflets. The overall percentages of moisture loss are determined when there is no reduction of sample's weight as the drying test being conducted.

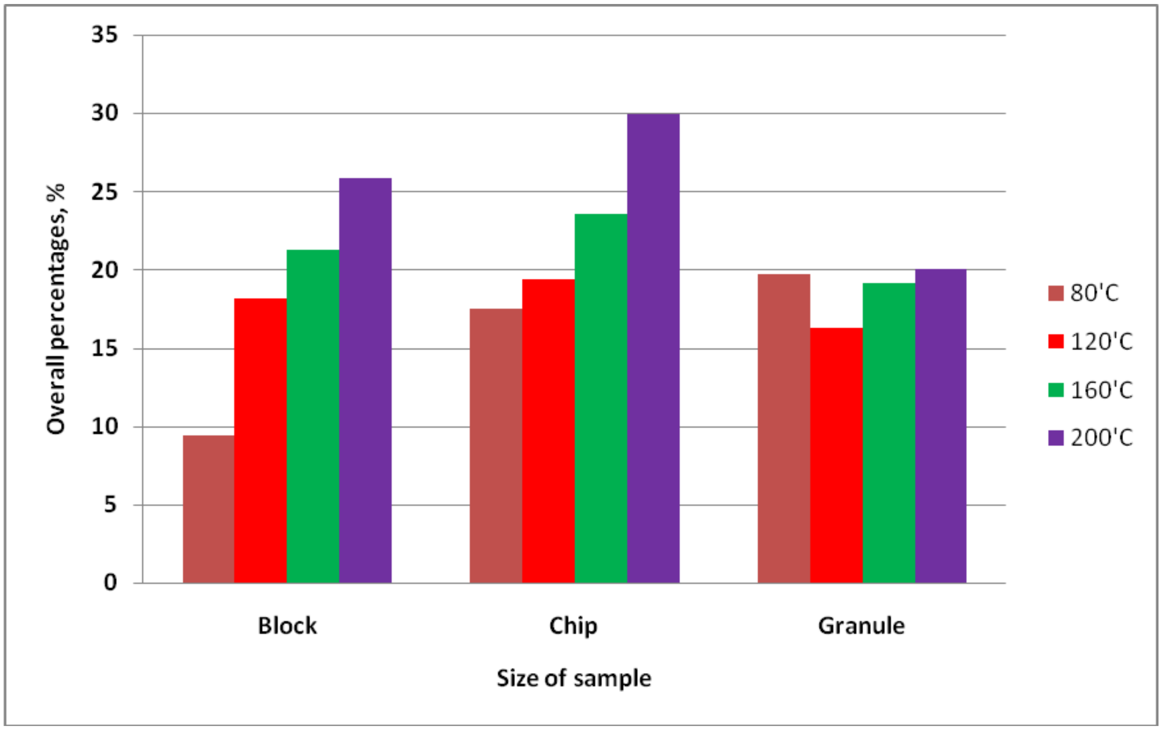


Figure 4.49: Overall percentages of moisture loss from petioles

According to the result in Figure 4.49, the drying temperature of 200°C has the ability to remove the highest amount of moisture from the sample. For block sample, the highest percentages of moisture which able to be removed is 25.87% by using the drying temperature of 200°C. Then followed by 21.27% (160°C), 18.12% (120°C), and 9.34% (80°C). For chip sample, the highest percentages of moisture which able to be removed is 29.91% by using the drying temperature of 200°C. Then followed by 23.53% (160°C), 19.36% (120°C), and 17.52% (80°C). For granule sample, the highest percentages of moisture which able to be removed is 20.16% by using the drying temperature of 200°C. Then followed by 19.16% (160°C), 16.31% (120°C), and 19.68% (80°C).

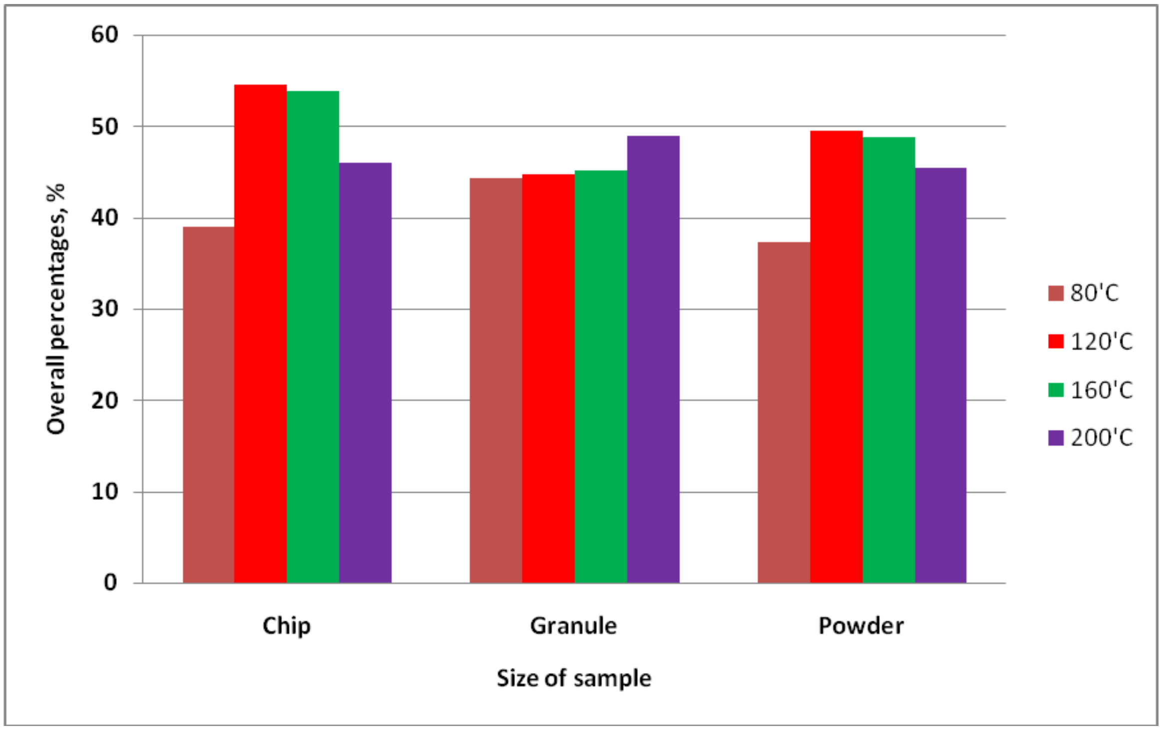


Figure 4.50: Overall percentages of moisture loss from leaflets

For chip sample, the highest percentages of moisture which able to be removed is 54.59% by using the drying temperature of 120°C. While the others are 39.02% (80°C), 53.90% (160°C), and 45.94% (200°C). For granule sample, the highest percentages of moisture which able to be removed is 48.90% by using the drying temperature of 200°C. While the others are 44.34% (80°C), 44.70% (120°C), and 45.08% (80°C). For powder sample, the highest percentages of moisture which able to be removed is 49.53% by using the drying temperature of 120°C. While the others are 37.30% (80°C), 48.75% (160°C), and 45.47% (200°C).

4.8 Time Needed for Overall Moisture Loss

The drying time will be recorded until there is no change in sample's weight to determine how much period is needed to ensure the completeness of sample's drying.

4.8.1 For Petioles

Table 4.1: Time needed for overall moisture loss from petioles

Type of storages	Drying temperature	Time needed for overall moisture loss, minutes		
		Block	Chip	Granule
Without storage	80°C	75	60	45
	120°C	45	45	45
	160°C	45	45	45
	200°C	45	45	45
Air-ventilated storage	80°C	45	60	45
	120°C	45	30	45
	160°C	45	60	45
	200°C	45	45	45
Air-sealed storage	80°C	45	60	60
	120°C	30	45	60
	160°C	45	45	60
	200°C	45	45	45

According to Table 4.1, majority of the sample need up to 45 minutes to complete the removal of moisture from the sample. The longest drying period is 75 minutes for the sample with block size, dried at temperature of 80°C, and never been stored.

4.8.2 For Leaflets

Table 4.2: Time needed for overall moisture loss from leaflets

Type of storages	Drying temperature	Time needed for overall moisture loss, minutes		
		Chip	Granule	Powder
Without storage	80°C	60	60	60
	120°C	60	60	60
	160°C	60	60	60
	200°C	45	45	45
Air-ventilated storage	80°C	45	75	75
	120°C	45	45	45
	160°C	30	30	30
	200°C	30	30	30
Air-sealed storage	80°C	45	75	75
	120°C	45	45	45
	160°C	30	30	30
	200°C	30	30	30

According to Table 4.2, majority of the sample which never been stored, need up to 60 minutes to complete the removal of moisture from the sample. Only the samples which dried at 200°C need up to 45 minutes to complete the drying. For samples which stored in air-ventilated and air-sealed storage, the samples which dried at 80°C and 120°C need up to 45 minutes to complete the removal of moisture but only 30 minutes for samples which dried at higher temperature 160°C and 200°C. The longest drying period is 75 minutes for the samples with granule and powder sizes, dried at temperature of 80°C, and stored in both air-ventilated and air-sealed storage.

CHAPTER 5
RESULTS AND DISCUSSION FOR CALORIFIC VALUE TEST AND ULTIMATE ANALYSIS

5.1 Calorific Value Test

The calorific value test is conducted on the petioles and leaflets immediately after they have been dried using oven. The purpose of calorific value test is to determine how much energy content left in the sample after undergoing a drying test. The calorific value will be recorded from each size to obtain an average calorific value under that drying temperature.

5.1.1 For Petioles

Figure 5.1 shows the comparison of petiole's average calorific value between their storage conditions, based on their respective drying temperature. According to the result, the petiole's calorific value which stored in air-ventilated storage shows the highest result compared to other petioles which never been stored and stored in air-sealed storage.

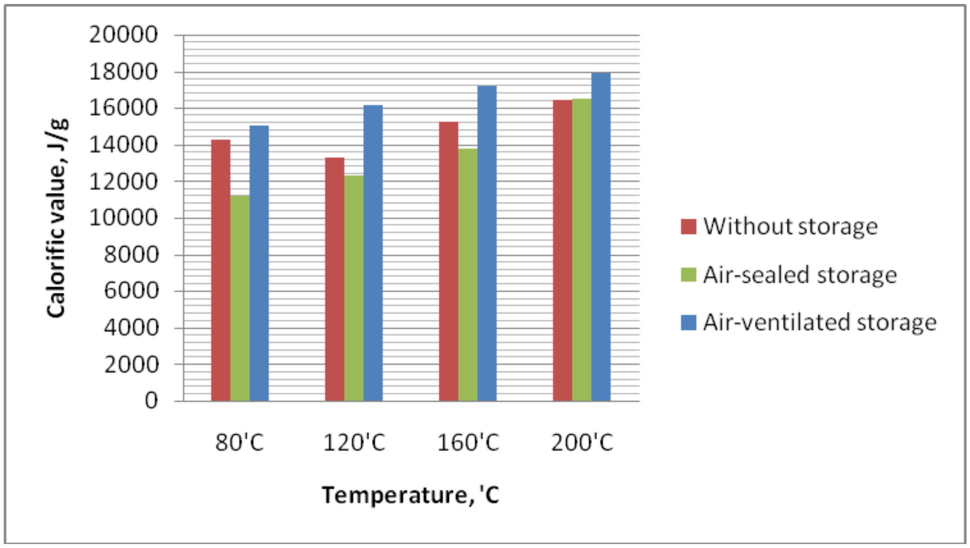


Figure 5.1: Comparison of petiole's average calorific value between three storage conditions, according to the respective drying temperature

5.1.2 For Leaflets

Figure 5.2 shows the comparison of leaflet's average calorific value between their storage conditions, based on their respective drying temperature. According to the result, it seems that calorific value obtained for leaflets is higher compared to petioles. The leaflet's calorific value which stored in air-ventilated storage shows the highest result compared to other leaflets which never been stored and stored in air-sealed storage.

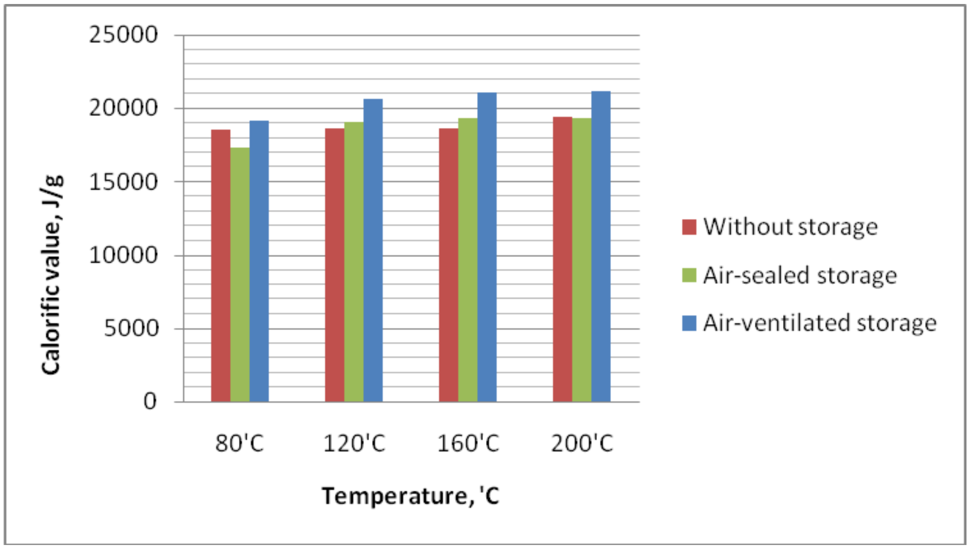


Figure 5.2: Comparison of leaflet's average calorific value between three storage conditions, according to the respective drying temperature

5.2 Ultimate analysis

The ultimate analysis or CHNS testing was performed using the Leco CHNS-932 machine. The chemical composition (carbon, hydrogen, nitrogen and sulphur) percentages will be recorded from each size, drying temperature and storage condition to obtain an average CHNS percentage for the overall sample. Figures 5.3 and 5.4 shows the comparison of CHNS percentages between petioles and leaflets.

5.2.1 For Petioles

Figure 5.3 shows the composition of each element in petioles according to their respective drying temperature.

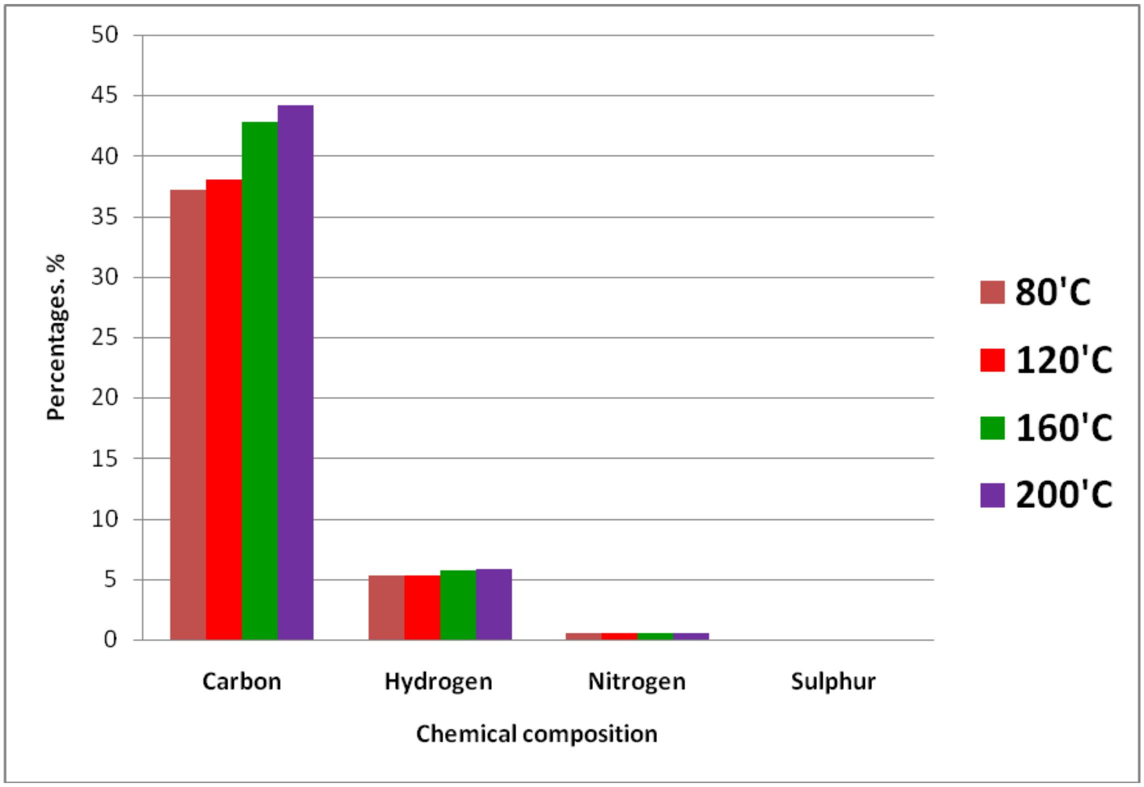


Figure 5.3: Composition of carbon, hydrogen, nitrogen and suplhur for petioles after being dried according to their respective drying temperature

As show in Figure 5.3, there is a high percentage of carbon content and a very low percentage of sulphur content in petioles. The high carbon content would highlight the possibility of petioles to become a fuel source for the gasification process while the low sulphur content would portray the potential of petioles as an environmental friendly renewable energy source as sulphur would and react with water, oxygen and oxidants to form acidic compound as found in acid rains. For carbon content, the percentages are 44.05% for drying temperature of 200°C, 43.15% for drying temperature of 160°C, 41.39% for drying temperature of 120°C, and 40.07% for drying temperature of 80°C.

5.2.2 For Leaflets

Figure 5.4 shows the composition of each element in leaflets according to their respective drying temperature.

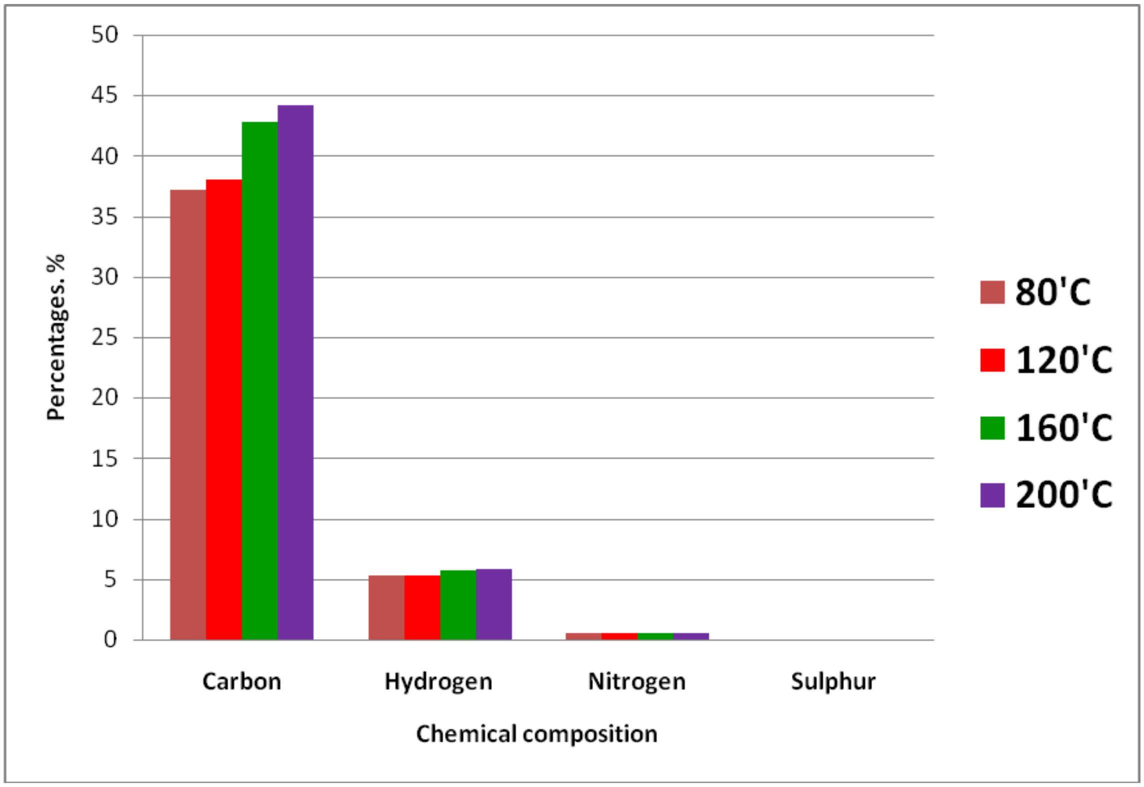


Figure 5.4: Composition of carbon, hydrogen, nitrogen and suplhur for leaflets after being dried according to their respective drying temperature

As shown in Figure 5.4, there is a high percentage of carbon content and a very low percentage of sulphur content in leaflets. The high carbon content would highlight the possibility of leaflets to become a fuel source for the gasification process while the low sulphur content would portray the potential of leaflets as an environmental friendly renewable energy source as sulphur would and react with water, oxygen and oxidants to form acidic compound as found in acid rains. For carbon content, the percentages are 44.13% for drying temperature of 200°C, 42.84% for drying temperature of 160°C, 38.06% for drying temperature of 120°C, and 37.15% for drying temperature of 80°C.

5.2.3 Comparison according to storage conditions

Table 5.1 shows the composition of each element according to their storage condition. As shown in Table 5.1, there is a high percentage of carbon in petioles which is stored in air-ventilated storage, and in leaflets which are no storage condition required. For petioles, the chemical components in air-ventilated storage condition are 42.49% for carbon, 5.76% for hydrogen, 0.62% for nitrogen, and 0.05% for sulphur. While for leaflets, the chemical components at without storage condition are 43.68% for carbon, 6.21% for hydrogen, 3.59% for nitrogen, and 0.10% for sulphur. By comparing between these two values, the chemical content for each element in leaflets is higher than petioles showing that the leaflets has more potential to become source of biomass.

Table 5.1: The effect of storage condition on chemical components in oil palm fronds after being dried

Sample	Storage condition	Carbon	Hydrogen	Nitrogen	Sulphur
Petioles	Without storage	37.44%	5.58%	0.59%	0.04%
	Air-vent storage	42.49%	5.76%	0.62%	0.05%
	Air-sealed Storage	41.71%	5.36%	0.42%	0.02%
Leaflets	Without storage	43.68%	6.21%	3.59%	0.10%
	Air-vent storage	43.46%	5.47%	3.32%	0.10%
	Air-sealed Storage	39.36%	5.21%	3.41%	0.08%

CHAPTER 6
CONCLUSIONS

Oil palms fronds gasification has huge untapped markets with high potential to be a main energy resource in the future. Drying of oil-palm fronds before biomass gasification is an important consideration to ensure the feasibility of oil-palm fronds to be a main source of biomass industries in Malaysia. However, Research and Development (R&D) are still lacking in producing studies on the feasibility of oil-palm fronds as a biomass fuel. Some initiative, efforts and funds should be focused into this matter. Based on the proposed objective and methodology regarding the studies, the project is accomplished within the time given.

To ensure the effectiveness of system in drying the oil palm fronds, there should be further study regarding the minimum requirement of drying biomass condition in order to save cost of energy. A very high drying temperature might not be an economical method since it consumes a large amount of power supply. Other than that, there should be repeatability tests for every test conducted to ensure the reliability of the results. Further research and development should be carried out on OPF utilization since OPF has great prospects for future biomass.

REFERENCES

Abu Hassan, O., Ishida, M., Mohd. Syukri, I., and Mohd Tajuddin, Z., (1995) Oil Palm Fronds as Roughage Feed Source For Ruminants in Malaysia, Livestock Research Division, MARDI

Amos, W.A., (1998) Report on Biomass Drying Technology, National Renewable Energy Laboratory, U.S Department of Energy

Balamohan, S., (2008) Studies on Suitability of Oil-Palm Fronds (OPF) for Biomass Gas Production, Final Year Project Dissertation, Department of Mechanical Engineering, Universiti Teknologi PETRONAS

Childress, J., (2005) Coal Gasification & IGCC / Polygen Performance and Prospects in the U.S, Indiana Industrial Energy Consumers, Alternative Energy Sources Workshop

Hassan, A., Yacob, S., (2002) Utilization of Biomass in Malaysia, Faculty of Biotechnology, Universiti Putra Malaysia

Liptak, B., (1998) Optimizing Dryer Performance Through Better Control, Chemical Engineering; Vol. 105, No. 2, pp. 110-114

Mckendry, P., (2001) Energy Production from Biomass (part3): Gasification technologies

Mohamad, H., Halim, H.A., and Ahmad, T.M., (1986) Availability and potential of oil palm trunks and fronds up to year 2000, Palm Oil Research Institute of Malaysia (PORIM), Occasional paper no. 20, pp 17

Nakamura, M., (2006) Research Team for Biomass Recycling System, Department of Rural Technologies, National Institute for Rural Engineering, 2-1-6 Kannondai, Tsukuba-shi, Ibaraki 305-8609

Wan Zahari, M., Sato, J., Furuichi, S., Azizan, A.R., and Yunus, M., (2003) Commercial Processing of Oil Palm Fronds Feed in Malaysia, Strategic Livestock Research Centre, MARDI and Japan International Cooperation Agency (JICA)