The Development of Thermal Insulation from Oil Palm Waste Material

by

Mohd Aizzat Bin Omar

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(Mechanical Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(Ir. Dr. Mohd Shiraz Bin Aris)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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CERTIFICATION OF ORIGINALITY

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

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MOHD AIZZAT BIN OMAR

ABSTRACT

Thermal insulation can refer to those materials and combinations of materials used to reduce the rate of heat transfer, or the method and processes used to retard the flow of heat energy. Thermal insulation has been used on many applications such as pipe insulation, window insulation, building insulation, and clothing. The problem of managing the abundantly oil palm waste material has become critical for the manufacturers. Thus, by utilized the wastes as useful products can contribute to on how to manage the abundantly wastes materials. The purpose of this project is to perform research and study on the development of thermal insulation from oil palm waste material which is oil palm mesocarp fiber and by using this waste, the thermal insulation for the condenser pipe in steam turbine system in oil palm mill can be designed. The reason for choosing condenser pipe is because the operating temperature in the condenser pipe falls within the temperature used in the thermal conductivity experiment. The project mainly focuses on the data acquisition of the thermal conductivity of the oil palm mesocarp fiber in order to know the efficiency of the material as the thermal insulation. The tests have been performed to the oil palm mesocarp fibers characterized by their packing density by using the Thermal Conductivity of Building and Insulating Material Unit B480. From the result, the thermal conductivity of the oil palm mesocarp fiber is decrease as the packing density increase. At the packing density of 155.27 kg/m^3, the average thermal conductivity is 0.063 W/mK which is less than 0.1 W/mK. Usually the thermal insulating materials have the thermal conductivity of less than 0.1 W/mK. With this value of thermal conductivity, the designing of insulation for the condenser pipe can be done. In order to keep the temperature of the surface at 31 °C, while the hot water temperature inside the pipe is at 65 °C and the ambient temperature is 30 °C for the purpose of energy conservation, the required insulation thickness is 0.17 m. By applying insulation to the condenser pipe, the energy rate that can be saved for every 1 meter is equal to 155.39 W, and the fuel that can be saved for every 1 meter is equal to 37.29 kg /hr.

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NOMENCLATURE

D	diameter of pipe (m)
dT	temperature difference (°C)
HFM	milivolt output (mV)
h	surface coefficient (W/m^2K)
k_1-k_6	calibration constant
k	thermal conductivity (W/mK)
l_s	specimen thickness (m)
N	number of data
Nu_D	Nusselt number
P_r	Prandtl number
q'_{cond}	conduction heat flow per unit length (W/m)
q'_{conv}	convection heat flow per unit length(W/m)
q'_{rad}	radiation heat flow per unit length(W/m)
R	thermal resistance (W/K)
Ra_D	Rayleigh number
r_1	radius of pipe (m)
r_2	radius of pipe with insulation (m)
T_1	hot plate temperature
T_2	cold plate temperature
T_f	mean temperature of fluid properties (K)

T_m	mean temperature (°C)
$T_{s,1}$	surface temperature (K)
$T_{s,1}$	outer surface temperature (K)
T_{sur}	ambient temperature (K)
T_∞	ambient temperature (K)
t	thickness of insulation (m)
x_i	data
x	mean value

Greek Letters

α	thermal diffusivity (m^2/s)
β	volumetric thermal expansion coefficient (K^{-1})
ε	emissivity
Σ	standard deviation
λ	thermal conductivity (W/mK)
υ	kinematic viscosity (m^2/s)
σ	Stefan Boltzman constant (W/m^2K^4)
σ^2	variance
σ_x	standard error of the mean

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Background of Study

The term thermal insulation can refer either to materials used to reduce the rate of heat transfer, or the methods and processes used to reduce heat transfer [1]. Thermal insulation is used in many applications such as:

- Clothing - To maintain the temperature of human body
- Buildings - To maintain the acceptable temperatures in buildings
- Piping - To prevent heat loss or gained for pipes that carry heated or cooled fluids and many other applications

There are three types of insulation which are fibrous, cellular and granular insulation. Fibrous insulation composed of small diameter fibers which finely divide the air space. The fibers may be perpendicular or horizontal to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibers are used. The most widely used insulating materials of this type are glass fiber and mineral wool [2]. Cellular insulation composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), polyurethane, polyisocyanurate, polyolefin, and elastomeric [2]. Granular insulation composed of small nodules which contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a loose or pourable material, or combined with a binder and fibers to make a rigid insulation. Examples of these insulations are calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene [2]. Most of these materials have their own cost. In order to find new materials with cheaper cost, this study is done. The alternative material comes from the agricultural waste which is the oil palm mesocarp fiber. Oil palm mesocarp fiber can be categorized as fibrous insulation.

In 2006, the production of oil palm is about 14.96 million tons and the total solid waste generated more than 3.96 million tons [3]. This shows that the waste generated is very high. The solid wastes consist of empty fruit bunch, mesocarp fibers, and shell. Figure 1.0 and 2.0 shows the component of the oil palm waste materials. Oil palm empty fruit bunch fibers are suitable for the manufacture of mattress, car seat, insulation, composite panel product and particle board [4]. The oil palm mesocarp fiber has been used as the fuel in the boiler when it is mix with the shell usually in the percentage of 30% of shell and 70% of mesocarp fiber. However, this is not sufficient for the waste management thus; they can be transformed into useful products such as thermal insulation. The source is very cheap and the availability is very high. In order to know the suitability and the efficiency of the oil palm waste material as the thermal insulation, their thermal conductivity can be determined by conducting several experiments to them. The thermal conductivity of the oil palm mesocarp fiber will be tested by using the Thermal Conductivity of Building and Insulating Materials Unit B480 in laboratory at Block 20. The low thermal conductivity material is a good insulator because it reduces the capability of heat to transfer.

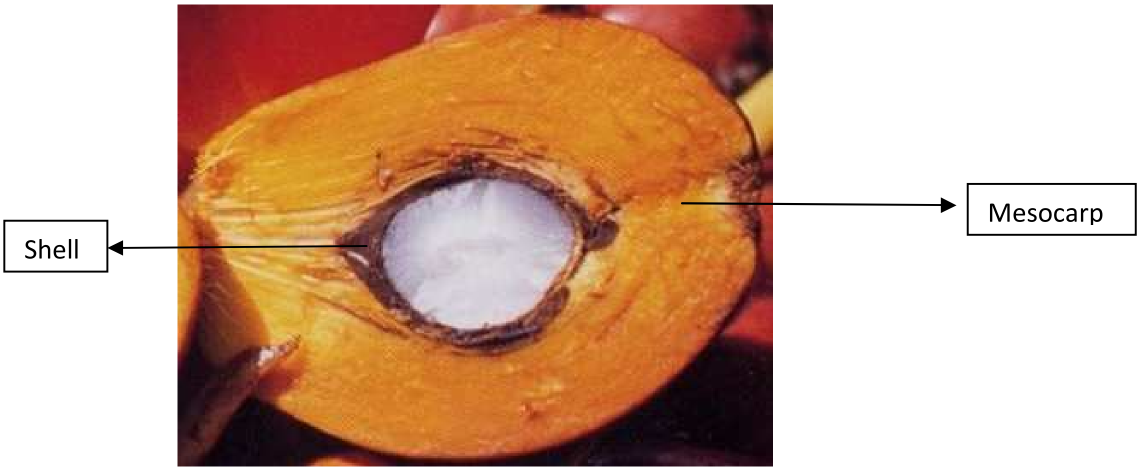

Figure 1.0: Oil palm fruit component [5]

Figure 2.0: Oil palm empty fruit bunch [6]

1.2 Problem Statement

Currently, the oil palm mesocarp fiber is used as the boiler feedstock but, not all of them will be used and some of them are also left to degrade. However, it takes a long time to break down and hence during the rainy season it provides an ideal condition for fungi to grow [7]. This will cause trouble to the oil palm manufacturers in managing the wastes. Thus, the idea is to utilize the oil palm mesocarp fiber as the alternative material for thermal insulation. Thermal insulation can be made of various materials with low thermal conductivity. Thermal conductivity is the quantity of heat transmitted through a unit thickness in a direction normal to a surface area, due to a unit temperature gradient under steady state conditions [8]. In order to find the alternative material with low thermal conductivity and cheaper in cost, a research need to be done. The material with all this criteria is needed in order to make sure the thermal insulation is efficient to be used for the commercial and industrial installations.

1.3 Objectives

The objective of this study and research is to find the suitability and the efficiency of the agricultural waste material which is the oil palm mesocarp fiber as the new material for the thermal insulation. This can be done by acquiring the thermal conductivity of the oil palm mesocarp fiber by using the Thermal Conductivity of Building and Insulating Materials Unit B480.

The second objective is to help the manufacturers to solve their problem regarding on the abundantly oil palm waste material which rapidly filling the space of the oil palm mill area.

The last objective is to design the thermal insulation from the oil palm mesocarp fiber in order to reduce loss of heat energy in the oil palm mill and achieve savings from the conservation of the energy.

1.4 Scope Of The Study

For this Final Year Project, the scope of the study will be revolves around the acquisition of the thermal conductivity of the oil palm mesocarp fiber from various oil palm mills and the designing of thermal insulation from oil palm mesocarp fiber for the industrial application. The samples from two oil palm mills will be tested for many times in order to find the range of the thermal conductivity. The thermal conductivity will be tested against the packing density. Then, by using the thermal conductivity of the oil palm mesocarp fiber, the thermal insulation for the industrial application will be designed.

CHAPTER 2

LITERATURE REVIEW

2 LITERATURE REVIEW

Insulation is defined as those materials or combinations of materials which retard the flow of heat energy by performing one or more of the following functions:

1. Conserve energy by reducing heat loss or gain
2. Control surface temperatures for personnel protection and comfort
3. Facilitate temperature control of a process
4. Prevent vapor flow and water condensation on cold surfaces
5. Increase operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in commercial and industrial installations
6. Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres

The temperature range within which the term "thermal insulation" applies is from –73.3ºC (–100ºF) to 815.6ºC (1500ºF). [9].

Thus, by introducing new alternative material with cheaper cost for insulation will create energy conservation with low cost for all piping insulation. One of the alternative materials is from the agriculture wastes such as from the oil palm mesocarp fiber.

For every 100 kg of crude palm oil produced during the oil palm milling process, 52 kg fiber, 22 kg shell and 85 kg empty fruit bunch are generated [3].

This shows that the amount of wastes generated is very high. Thus, these wastes can be recycled into useful product in order to manage their disposal. In this study, the oil palm mesocarp fiber will be recycled into a thermal insulating material. However the thermal conductivity of the material need to be test and determined to know the efficiency and the suitability of them as the thermal insulating material. The oil palm mesocarp fiber can be categorized as fibrous insulation.

Other than oil palm mesocarp fiber, empty fruit bunches (EFB) could be a source for conversion into useful fibers. From the Business Line Internet Edition of Financial Daily from the Hindu group of publications, the fibers from EFB have potential to be converted into an economical, value-added product such as thermal insulating materials. From the research team of the Oil Palm Research Centre under the Indian Council for Agricultural Research (ICAR), the tensile strength and bulk density of the fiber were found to be 979.8 g and 27.67 kg/m^3. This shows that it is a good fiber to be converted into useful products. The researchers modified a coconut decorticating machine for the purpose of large-scale extraction of the fiber form EFB obtained from small as well as large size oil palm bunches. Initially, they tried the combing machine that is used in the extraction of fiber from the Palmyra leaf but it is not so successful. Best result from the coconut decorticating machine were obtained when the EFB were soaked in water for two days.

Besides, the oil palm leaves also can be converted into thermal insulating materials. A thermal insulation board of average thermal conductivity of 0.127 W/mK has been made by mixing oil palm leaves with granular wood glue in the ratio (glue:leaf) 1:4 by weight [10].

In order to design thermal insulation from fibrous material, we need to know the modes of heat transfer in fibrous materials.

Convection, solid fiber conduction, air conduction, and radiation can all be heat-transfer modes that are present in fibrous insulations. These modes of heat transfer can combine in a complex manner to give a total conductivity as shown in Figure 3.0. The exact shape of the curve in Fig. 3.0 is dependent upon the mean temperature, the type of fibrous insulation, the fiber orientation, the specimen size, and other factors.

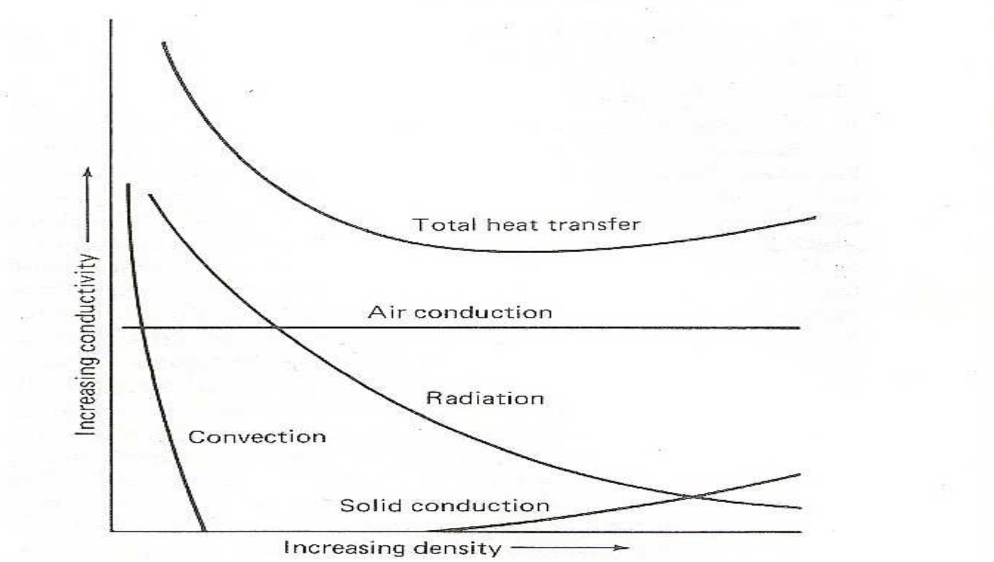

Figure 3.0: Modes of heat transfer in fibrous insulations [11]

Solid-Fiber Conduction

Solid-fiber conduction occurs when, because of a temperature gradient, heat energy is transmitted down one fiber and passes to another fiber at their point of contact. At very low densities this factor is small; but as the density increases, the fibers are packed closer together and the solid fiber conduction increases. In fact, as Fig 3.0 shows, this is the mode responsible for an increase in the total thermal conductivity beyond its minimum value as density increases [11].

Convection

Convection, the transmission of heat by mass movement of air (or gas) particles, depends on many factors, including the size of the cavity occupied by the particles, the cavity orientation, and the temperature gradient. Convection can be significant in the absence of insulation, but drops off when insulation impedes the gas currents. Commercially available fibrous insulation is designed at high enough density to make convection within the insulation is significant. If fibrous insulation is installed such that it essentially fills a cavity, convection within the cavity will not be significant. If however, the insulation is installed with one or two boundaries exposed to air, the potential for natural or forced convection exists [11].

Radiation

Radiation heat transmission is a very large factor when there is no insulation present, but it is reduced rapidly as the insulation density increases. Radiation is reduced by scattering from or absorption on and reemission by the fibers. At densities beyond the minimum total conductivity point, radiant heat transfer is negligible. Other factors that influence radiation are the temperature level and the surface emissivity according to the following equation:

$$q_{rad} = \frac{constant(T_h^4 - T_c^4)}{\frac{1}{\varepsilon_c} + \frac{1}{\varepsilon_h} - 1 + N}$$ [11]

Where T_h = hot-surface absolute temperature
T_c = cold-surface absolute temperature
ε_c = emissivity of cold surface
ε_h = emissivity of hot surface
N = opacity factor

Since radiation is controlled by the difference of the absolute temperatures to the fourth power, it becomes increasingly important as the temperature increases. For this reason it is common for high-temperature insulations to be higher in density than insulation used for moderate temperature applications [11].

Still-Air Conductivity

Fibrous insulation even at relatively high densities is, by volume, mostly air. Thus still-air conductivity is an important contributor to the total conductivity. Its influence is nearly constant over a wide range of densities [11].

Thus, the optimum packing density of oil palm mesocarp fiber that provides the most insulation must be determined for the thermal insulation application.

In order to design the thermal insulation for pipe, a few assumptions need to be done.

The heat transfer assumptions are:

1. Inside surface temperature of the insulation is the same as the temperature of the process fluid [12]. Figure 4.0 shows the condition of the pipe;

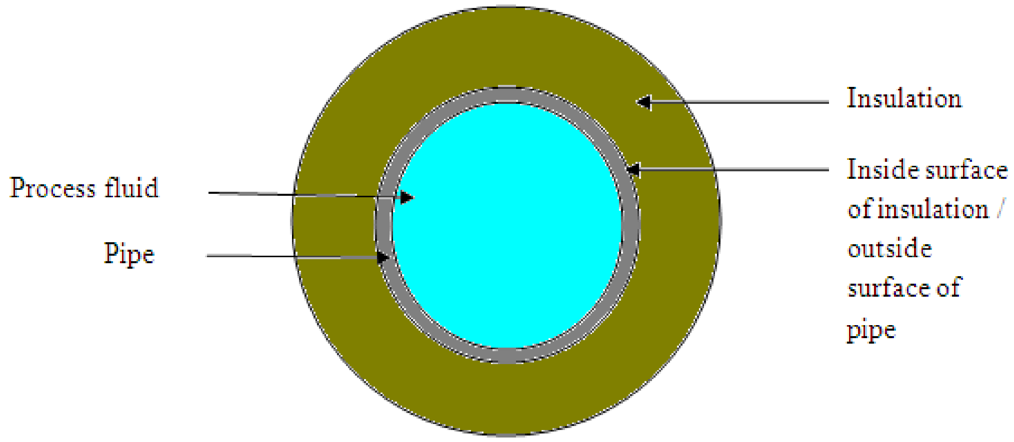

Figure 4.0: Pipe cross section

2. Thermal conductivity of the insulation is constant at a value corresponded to the mean temperature of the operating condition [12]

3. Convection coefficient at the outside surface is constant [12]

4. Radiation loss from surface is included as a constant part of the overall surface resistance [12].

Thus in order to design the thickness of the thermal insulation, all these assumptions should be taken into account.

Since the thermal insulation from the oil palm mesocarp fiber will be applied to the application in the oil palm mill itself, the insulating will be done to the condenser pipe of the boiler and steam turbine system. While doing the experiment using the Thermal Conductivity of Building and Insulating Material Unit B480, the hot plate temperature is set for 60 °C. The cold plate temperature is usually around 34 °C thus; the mean temperature is 47 °C. The reason for choosing condenser pipe is because the operating temperature in the condenser pipe (see Appendix A) falls within the temperature used in the thermal conductivity experiment. The value of the thermal conductivity of the insulation is constant at value corresponded to the mean temperature of the operating condition [12]. Figure 5.0 below shows where the insulation will be applied. The part where the insulation is applied is highlighted in the red line.

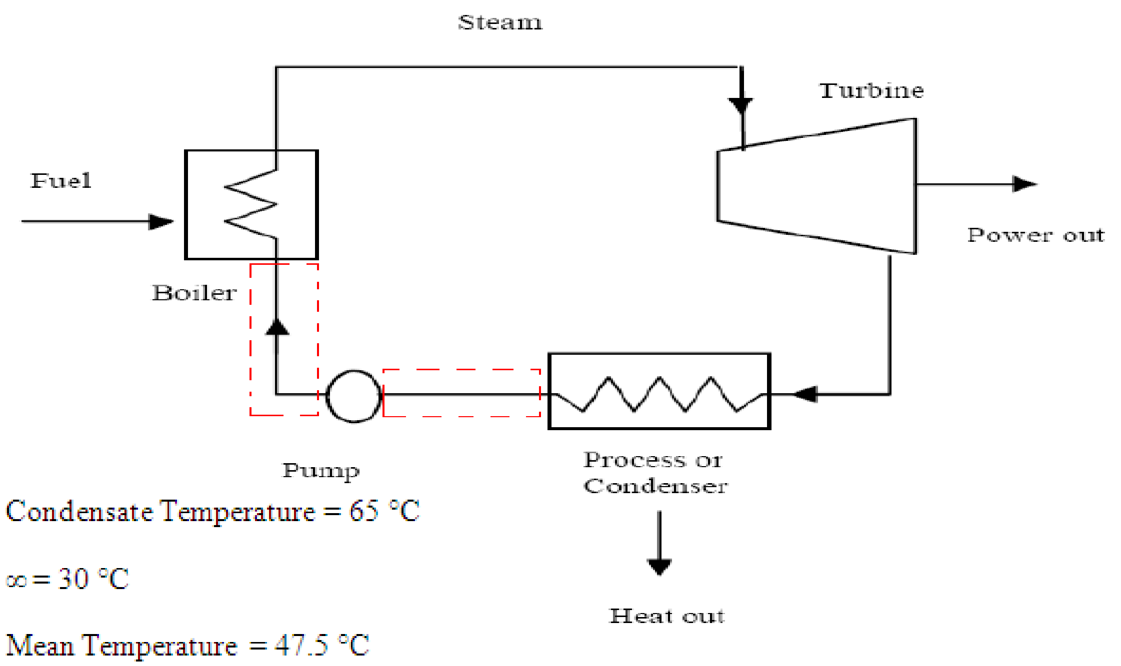

Figure 5.0: Boiler/Steam turbine parts [13]

CHAPTER 3

METHODOLOGY

3 METHODOLOGY

3.1 Tests for Thermal Conductivity

The main purpose of this study is to get the thermal conductivity of the oil palm mesocarp fiber. For the first step, I need to collect the sample of the oil palm mesocarp fibers from various oil palm mills. Then the oil palm mesocarp fiber will be dry under the sunshine. Next, the sample from each mill will be divided into 5 groups with different weight in order to get different packing density for the testing. The weights are 100g, 120g, 125g, 140g, and 160g. For each packing density, 10 tests will be done with the set temperature. The temperature is 60°C. This is to ensure the accuracy of the value of the thermal conductivity resulted from the tests. By doing this, we can determine the range of the thermal conductivity of the oil palm mesocarp fiber. These fibers will be tested for the thermal conductivity by using the Thermal Conductivity of Building and Insulating Materials Unit B480 (See figure 6.0). Then, the graph of Thermal Conductivity vs. Packing Density will be plotted.

The method of thermal conductivity measurement used is the heat flowmeter method. The specimen under test is placed between a hot plate and the heat flowmeter which is attached to a cold plate. The apparatus is surrounded by insulation. The hot and cold plates are maintained at suitable constant temperatures, measured by surface thermocouples. A calibration constant for the individual apparatus is derived from testing a sample of known constant thermal conductivity. By measuring the heat flowmeter output and the mean temperature of the test sample, the thermal conductivity is calculated using this calibration constant. This method is faster than other methods and as the heat flow through the specimen is measured directly, no guarding or estimation of the heat loss is necessary.

Figure 6.0: Thermal Conductivity of Building and Insulating Material Unit B480

For the procedure of how the thermal conductivity of oil palm mesocarp fiber experiment is done, see Appendix B.

Besides, in order to check for the accuracy of the Thermal Conductivity of Building and Insulating Material Unit B480, the test has been conducted by using the sample with known thermal conductivity. The materials that have been test were expanded polystyrene. All the test procedure will be apply to these materials.

From the data, the error analysis will be done. The standard deviation, variance and standard error of the mean is calculated. The method of calculation is attached in Appendix C.

3.2 Designing Thermal Insulation for Condenser Pipe in Steam Turbine System in Oil Palm Mill

3.2.1 Points to Consider

In order to design the thermal insulation from the oil palm mesocarp fiber, a few points need to be considered.

Table 1.0: Points to consider

Purpose	Energy conservation; minimizing heat loss
Availability	Abundantly
Cost	Very cheap or free (waste)
HSE	Non-toxic
Moisture absorption	- Products from oil palm are hygroscopic which could lose and gain moisture when there is a change in relative humidity [14] - Hygroscpy is the ability of a substance to attract water molecules from the surrounding environment through either absorption or adsorption [15] - Thermal insulators work by trapping bubbles or pockets of gas inside a foam structure. When these cells of gas are filled with moisture, there are significant losses in insulating efficiency[16] - However by Silane Treatment can increase the hydrophobicity [17]. - By silynylation, the hydrophobic coupling agent forms a protective

	monolayer on the proton-bearing surfaces and thus removes the sites for moisture absorption[17]

3.2.2 Sketch & Data

Figure 7.0 below shows the sketching of the condenser pipe.

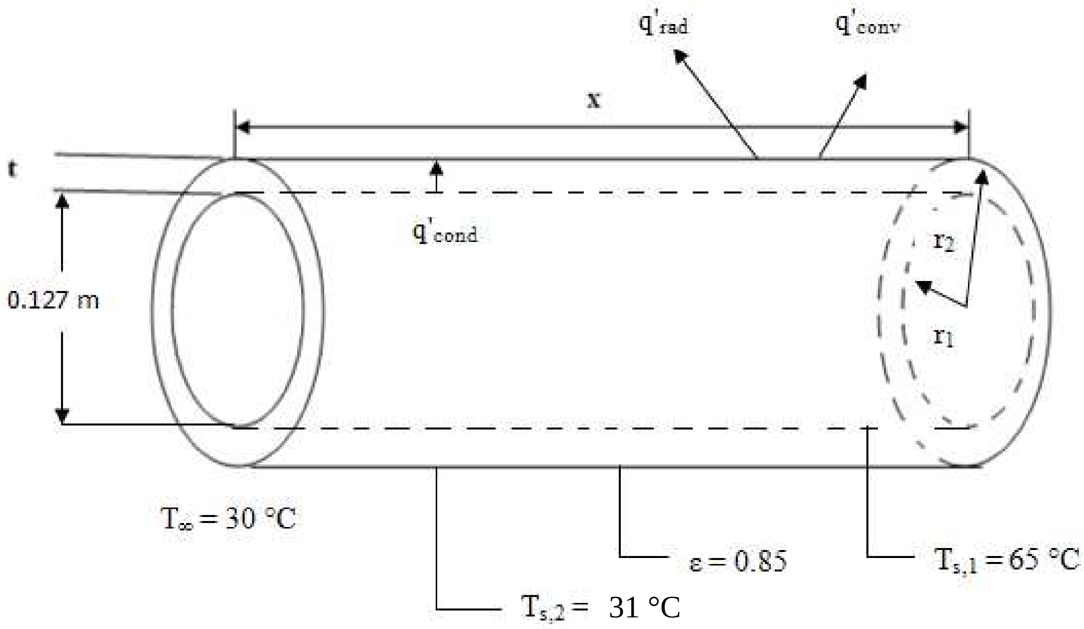

Figure 7.0: Sketching of the condenser pipe with insulation

<u>Data</u>

$T_{s,1}$ = 65 °C (Usually the condensate temperature is below 100°C. See Appendix A)

$T_{s,2}$ = 31 °C

T_{∞} = 30 °C

E = 0.85

T_{mean} = 47.5 °C

3.2.3 Assumptions

There are few assumptions that have been done in order to simplify the designing of the thermal insulation for the condenser pipe.

1. Heat conduction from inner pipe surface to outer pipe surface

   Using Lumped System Analysis

   - Heat conduction within an object is much faster than heat conduction across the boundary of the object
   - Reduce one aspect of the transient conduction (within the object) to an equivalent steady state system
   - Assume temperature of object is completely uniform
   - Since temperature of the steam inside the pipe is 65 °C, the inner surface temperature of the pipe must be similar to that, thus by using lumped system analysis, the outer temperature surface of the pipe is assume to be 65 °C

2. Thermal conductivity of the insulation is constant at a value corresponded to the mean temperature of operating condition [12]

3. Thermal conductivity, k, of oil palm mesocarp fiber is assume to be constant
   - From the experiment to determine the thermal conductivity of the oil palm mesocarp fiber, the lowest thermal conductivity is from the highest packing density tested. At 155.27 kg/m^3, the k = 0.063 W/mK.
   - Thus in the calculation, the value of k used is 0.063 W/mK.

4. Convection coefficient at the outside surface is constant [12]

5. Pipe surface is small compared to surroundings [18]

6. Surrounding air is quiescent [18]

3.2.4 Calculation

At steady state, the heat flow through the insulation to the outside surface equals the heat flow from the surface to the ambient air [19]. In equation form:

$$q'_{cond} = q'_{conv} + q'_{rad}$$ [18]

Where

q'_{cond} = conduction heat flow per unit length (W/m)

q'_{conv} = convection heat flow per unit length(W/m)

q'_{rad} = radiation heat flow per unit length(W/m)

The above equation also can be written as:

$$\frac{2\pi k(T_{s,1} - T_{s,2})}{\ln(r_2 / r_1)} = h(2\pi r_2)(T_{s,2} - T_\infty) + \varepsilon 2\pi r_2 \sigma (T_{s,2}^4 - T_{sur}^4)$$ [18]

Where

k = thermal conductivity (W/mK)

$T_{s,1}$ = surface temperature (K)

$T_{s,1}$ = outer surface temperature (K)

r_2 = outer diameter (m)

r_1 = inner diameter (m)

h = surface coefficient (W/m^2K)

T_∞ = ambient temperature (K)

ε = emissivity

σ = Stefan Boltzman constant (W/m^2K^4)

T_{sur} = ambient temperature (K)

By using this equation, we can calculate the thickness of the thermal insulation that is needed in order to keep the surface at certain temperature for energy conservation.

3.3 Milestone

For Milestone of this Final Year Project, see Appendix D.

3.4 Work Flow

The project work flow is shown in the Figure 8.0 below:

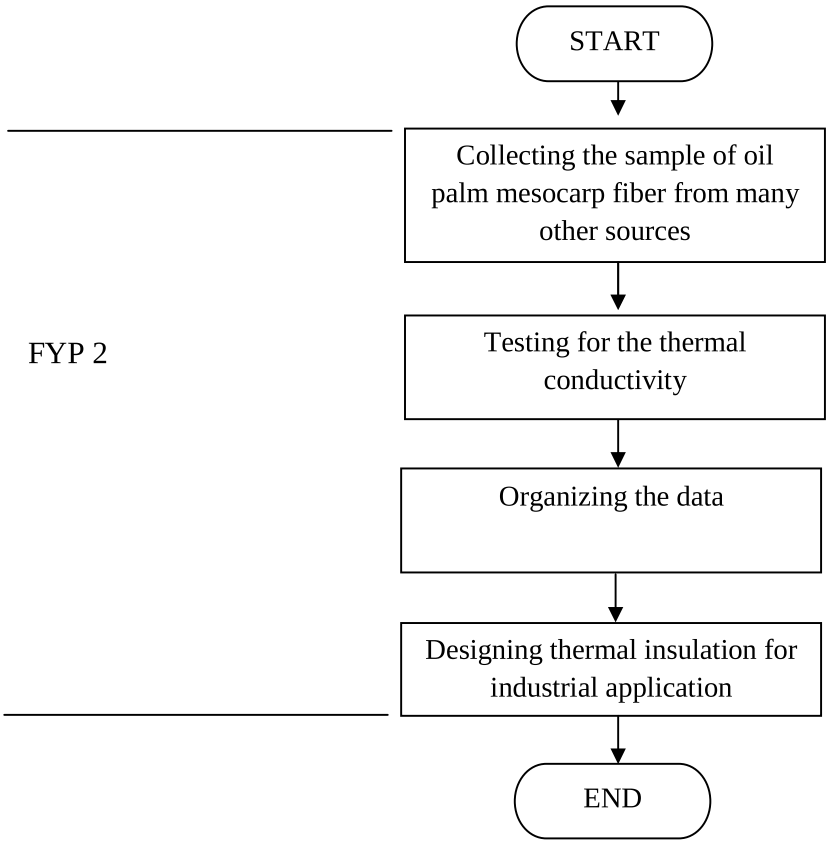

Figure 8.0: Project Work Flow

CHAPTER 4

RESULTS AND DISCUSSION

4 RESULTS

4.1 Results for Thermal Conductivity of Oil Palm Mesocarp Fiber

4.1.1 Thermal Conductivity

From the test that have been conducted, the result of the thermal conductivity of the expanded polystyrene testing at 60°C by using Thermal Conductivity of Building and Insulating Material Unit B480 has been determined. Below are the results and the errors between thermal conductivity of expanded polystyrene of the tests:

<u>Polystyrene</u>

Thermal Conductivity of expanded polystyrene at 60°C = 0.044 W/mK

Table 2.0: Results and errors of expanded polystyrene

Sample	Thermal Conductivity (W/mK)			
	1	2	3	Average
Polystyrene	0.51	0.52	0.51	0.52
Error (%)	16.75%	18.55%	16.75%	17.35%

Below are the results of the thermal conductivity of the oil palm mesocarp fiber from both of the oil palm mills:

Table 3.0: Result of the thermal conductivity of the oil palm mesocarp fiber from FPISB Kilang Sawit Neram (oil palm mill Neram)

	Thermal Conductivity (W/mK)										
Density	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
100.18 kg/m^3	0.093	0.093	0.092	0.090	0.091	0.091	0.091	0.092	0.091	0.091	0.092
103.51 kg/m^3	0.083	0.082	0.084	0.085	0.086	0.085	0.086	0.086	0.087	0.091	0.085
107.83 kg/m^3	0.080	0.080	0.079	0.074	0.080	0.080	0.080	0.079	0.080	0.079	0.079
129.39 kg/m^3	0.074	0.073	0.074	0.074	0.077	0.079	0.080	0.079	0.079	0.079	0.077
138.02 kg/m^3	0.063	0.068	0.069	0.071	0.072	0.071	0.072	0.070	0.071	0.071	0.070

Then, the result of Average Thermal Conductivity of Oil Palm Mesocarp Fiber vs. Packing Density is plotted.

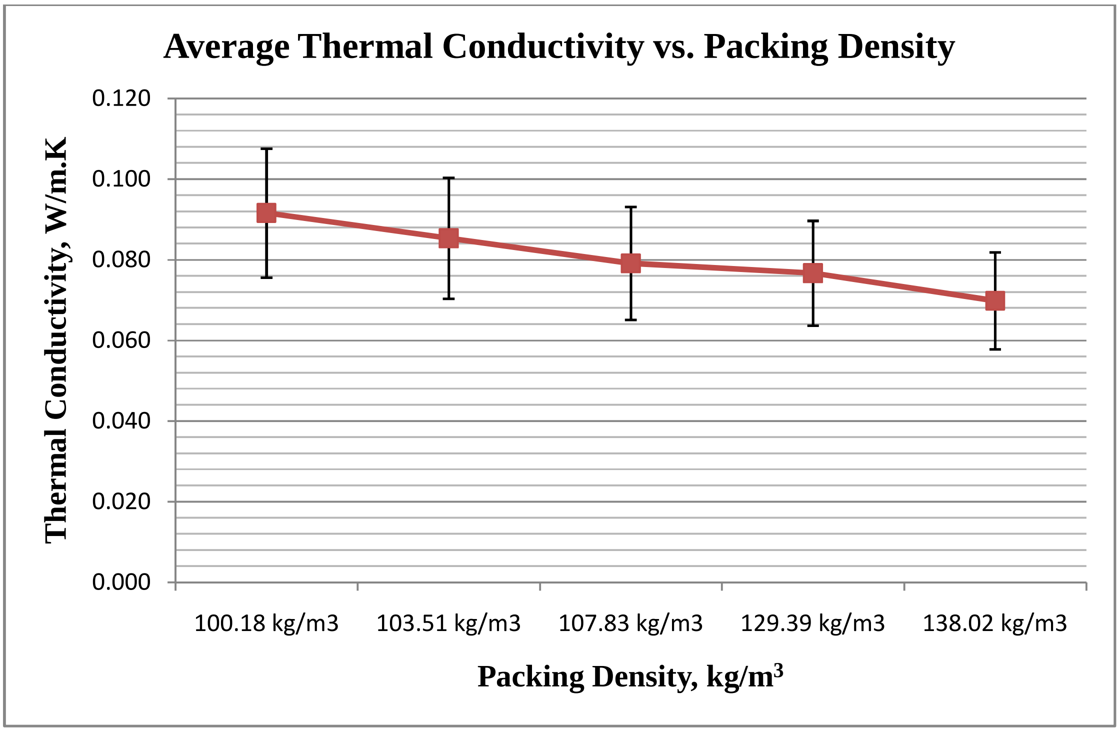

Figure 9.0: Average Thermal Conductivity of Oil Palm Mesocarp Fiber vs. Packing Density (Oil Palm Mill Neram)

Table 4.0: Result of the thermal conductivity of the oil palm mesocarp fiber from FPISB Kilang Sawit Kerteh (oil palm mill Kerteh)

Density	Thermal Conductivity (W/mK)										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
118.30 kg/m^3	0.096	0.092	0.093	0.086	0.093	0.092	0.092	0.087	0.087	0.086	0.090
120.77 kg/m^3	0.092	0.089	0.091	0.088	0.088	0.088	0.089	0.088	0.089	0.089	0.089
129.39 kg/m^3	0.071	0.071	0.071	0.056	0.062	0.064	0.065	0.066	0.065	0.066	0.066
154.04 kg/m^3	0.072	0.073	0.072	0.071	0.071	0.073	0.073	0.073	0.073	0.073	0.072
155.27 kg/m^3	0.052	0.058	0.060	0.058	0.066	0.068	0.068	0.069	0.063	0.064	0.063

Then, the result of Average Thermal Conductivity of Oil Palm Mesocarp Fiber vs. Packing Density is plotted.

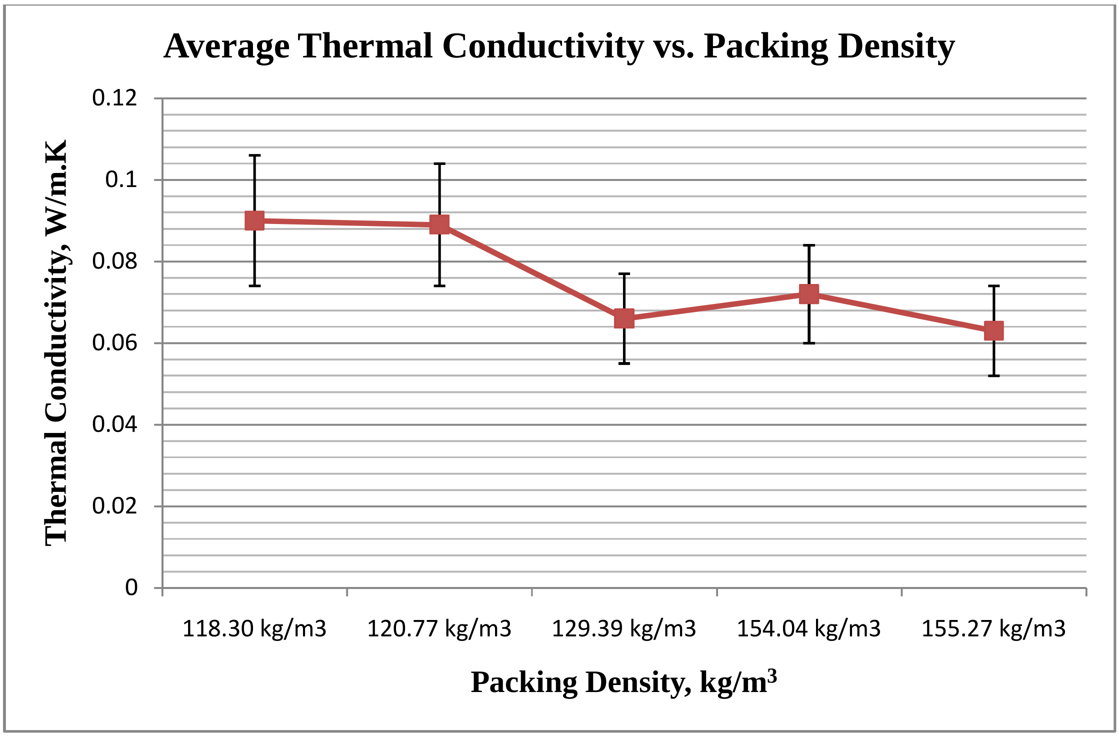

Figure 10.0: Average Thermal Conductivity of Oil Palm Mesocarp Fiber vs. Packing Density (Oil Palm Mill Kerteh)

4.1.2 Error calculation

In order to analyze the data, we need to calculate standard deviation and standard error of the thermal conductivity for each packing density for samples from both oil palm mills.

Example of standard error calculation for oil palm mesocarp fiber with packing density of 100.18 kg/m^3 from oil palm mill Neram:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x)^2}{N-1}}$$

Where

σ = standard deviation

x_i = data

x = mean value

N = number of data

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}((0.093-0.092)^2 + (0.093-0.092)^2 + (0.092-0.092)^2 + (0.090-0.092)^2 + (0.091-0.092)^2 + (0.091-0.092)^2 + (0.091-0.092)^2 + (0.092-0.092)^2 + (0.091-0.092)^2 + (0.091-0.092)^2)}{10}}$$

σ = 0.00097

Example of variance calculation for oil palm mesocarp fiber with packing density of 100.18 kg/m^3 from oil palm mill Neram:

σ^2 = variance = 0.00097^2

σ^2 = 0.0000009444

Example of standard error of the mean calculation for oil palm mesocarp fiber with packing density of 100.18 kg/m^3 from oil palm mill Neram:

$$\sigma_x = \frac{\sigma}{\sqrt{N}}$$

Where

σ_x = standard error of the mean

$$\sigma_x = \frac{0.00097}{\sqrt{10}}$$

σ_x = 0.00031

By using the method above, the standard deviation, variance and standard error of the mean of the thermal conductivity of the oil palm mesocarp fiber from both oil palm mills are calculated and tabulate in the table below

Table 5.0: Standard deviation, variance and standard error of the mean of thermal conductivity of oil palm mesocarp fiber from oil palm mill Neram

Density	**Standard deviation**	**Variance**	**Standard error of the mean**
100.18 kg/m^3	0.00097	0.0000009444	0.00031
103.51 kg/m^3	0.00246	0.0000060556	0.00078
107.83 kg/m^3	0.00185	0.0000034333	0.00059
129.39 kg/m^3	0.00274	0.0000075111	0.00087
138.02 kg/m^3	0.00270	0.0000072889	0.00085

Table 6.0: Standard deviation, variance and standard error of the mean of thermal conductivity of oil palm mesocarp fiber from oil palm mill Kerteh

Density	**Standard deviation**	**Variance**	**Standard error of the mean**
118.30 kg/m^3	0.00357	0.0000127111	0.00113
120.77 kg/m^3	0.00137	0.0000018778	0.00043
129.39 kg/m^3	0.00467	0.0000217889	0.00148
154.04 kg/m^3	0.00084	0.0000007111	0.00027
155.27 kg/m^3	0.00552	0.0000304889	0.00175

The Graph of Normal Distribution for Thermal Conductivity of Oil Palm Mesocarp Fiber is plotted in Appendix E.

4.1.3 Uncertainty Analyses

The uncertainty analysis is calculated by using the calibration error. From the result of the thermal conductivity of the expanded polystyrene tested by using Thermal Conductivity of Building and Insulating Material Unit B480, the percentage of error compared to the value from the research is 17.35%. Thus this value is the calibration error. However, the accurate uncertainty analysis should be done by method in Appendix F but due to unavailable of some information, the analysis is simplified by using calibration error. Below are the results of the uncertainty analysis by using calibration error.

Table 7.0: Uncertainty analysis of sample from Oil Palm Mill Neram

Density	**Average**	**Uncertainty**
100.18 kg/m^3	0.092	±0.016
103.51 kg/m^3	0.085	±0.015
107.83 kg/m^3	0.079	±0.014
129.39 kg/m^3	0.077	±0.013
138.02 kg/m^3	0.070	±0.012

Table 8.0: Uncertainty analysis of sample from Oil Palm Mill Kerteh

Density	**Average**	**Uncertainty**
118.30 kg/m^3	0.090	±0.016
120.77 kg/m^3	0.089	±0.015
129.39 kg/m^3	0.066	±0.011
154.04 kg/m^3	0.072	±0.012
155.27 kg/m^3	0.063	±0.011

The uncertainties are plotted using the error bar in the Figure 9.0 and 10.0.

4.2 Result for Designing Thermal Insulation for Condenser Pipe in Steam Turbine System in Oil Palm Mill

4.2.1 Schematic

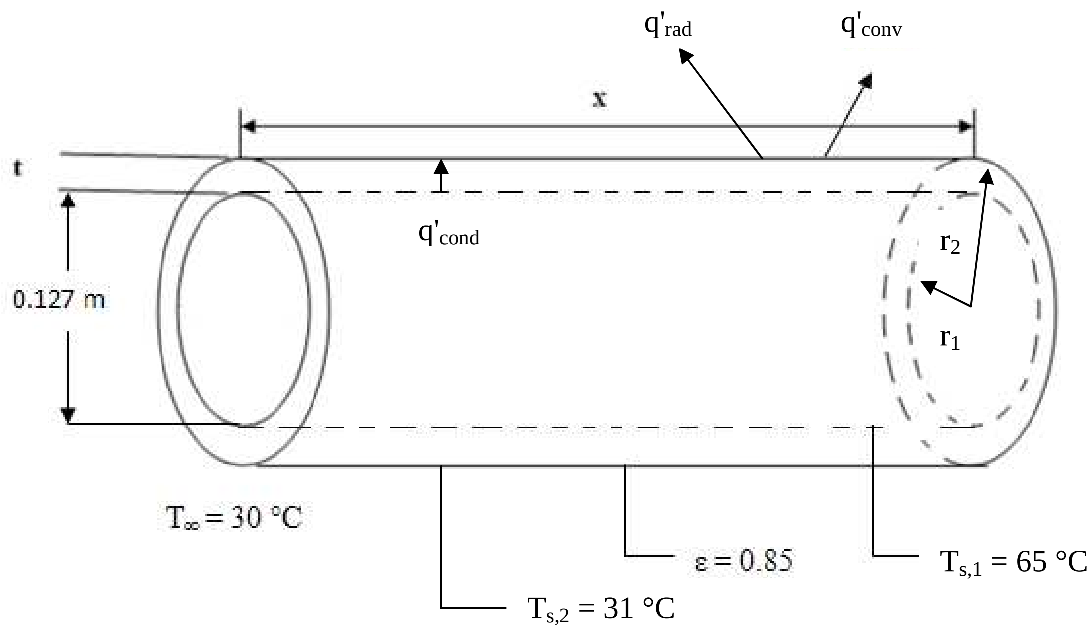

Figure 7.0: Sketching of the condenser pipe with insulation

* $T_{s,1}$ can be refer to Appendix A

4.2.2 Assumptions

1. Pipe surface is small compared to surroundings [18]
2. Surrounding air is quiescent [18]

4.2.3 Properties

$$T_f = (T_{s2} + T_\infty) / 2$$

$$T_f = (304\,K + 303\,K) / 2 = 303.5\,K$$

From Table of Thermophysical Properties of Gases at Atmospheric Pressure [18],

When air at T_f = 303.5 K

k = 0.0266 W/mK

υ = 16.2 x 10^{-6} m^2/s

α = 23.02 x 10^{-6} m^2/s

P_r = 0.707

β = 3.295 x 10^{-3} K^{-1}

4.2.4 Analysis

The convection coefficient may be obtained from equation below:

$$Nu_D = \left\{ 0.60 + \frac{0.387 Ra_D^{1/6}}{[1+(0.559/\Pr)^{9/16}]^{8/27}} \right\}^2 \quad [18]$$

Where

$$Ra_D = \frac{g\beta(T_s - T_\infty)D^3}{\upsilon\alpha} \quad [18]$$

$$Ra_D = \frac{9.8m/s^2 x 3.295x10^{-3} K^{-1}(31-30)°C(0.127m)^3}{16.2x10^{-6} m^2/sx23.02x10^{-6}\ m^2/s}$$

$$Ra_D = 0.177x10^6$$

Hence

$$Nu_D = \left\{ 0.60 + \frac{0.387(0.177x10^6)^{1/6}}{[1+(0.559/0.707)^{9/16}]^{8/27}} \right\}^2$$

$$Nu_D = 9.04$$

And

$$h = \frac{k}{D} Nu_D \quad [18]$$

$$h = \frac{0.0266W/mK}{0.127m}(9.04)$$

$$h = 1.89W/m^2K$$

At steady state, the heat flow through the insulation to the outside surface equals the heat flow from the surface to the ambient air. In equation form:

$$q'_{cond} = q'_{conv} + q'_{rad}$$ [18]

$$\frac{2\pi k(T_{s,1} - T_{s,2})}{\ln(r_2 / r_1)} = h(2\pi r_2)(T_{s,2} - T_\infty) + \varepsilon 2\pi r_2 \sigma (T_{s,2}^4 - T_{sur}^4)$$ [18]

$$= \frac{2(\pi)(0.063W/mK)(338-304)K}{\ln(r_2/0.0635m)} = (1.89W/m^2K)(2)(\pi)(r_2)(31-30)°C +$$
$$(0.85)(2)(\pi)(r_2)(5.67x10^{-8}W/m^2K^4)(304^4 - 303^4)K^4$$

$$= \frac{13.459W/m}{\ln(r_2/0.0635m)} = 11.875W/m^2(r_2) + 33.863W/m^2(r_2)$$

$$= \frac{0.2943m}{\ln(r_2/0.0635m)} = r_2$$

In order to find the r_2, we can use try and error method by construct a table and plot a graph. The point where they intersect is the right value of r_2.The initial guessing for r_2 = 0.15 and the table is construct for the increment of 0.01

Table 9.0: Try and error table

Trial	**r_2**	**0.2943/ln(r_2/0/0635)**
1	0.15	0.34
2	0.16	0.32
3	0.17	0.30
4	0.18	0.28
5	0.19	0.27
6	0.20	0.26
7	0.21	0.25
8	0.22	0.24
9	0.23	0.23
10	0.24	0.22

Then the graph is plotted corresponding to the value in the table:

Figure 11.0: Graph of try and error value

From the graph, the point where the two lines intersect is at r_2 = 0.23 m

Thus, thickness of the insulation,

$t = r_2 - r_1$

t = 0.23 m – 0.0635 = 0.1665 m

t ~ 0.17 m

4.3 Discussions

4.3.1 Discussion for Thermal Conductivity of Oil Palm Mesocarp Fiber

From the Figure 9.0 and 10.0, we can see the relationship between the average thermal conductivity of the oil palm mesocarp fiber and packing density. As the packing density of the oil palm mesocarp fiber increase, the thermal conductivity will decrease. This is due to the decreased in radiative and/or convective heat transfer. As the packing density increase, the amount of the fiber for a unit volume is increased thus the voids between the fibers will decreased. There will be less atmospheric air that trapped in the fibers. Thus, the convection and radiation mode of heat transfer will decrease. This explained why the thermal conductivity of the oil palm mesocarp fiber decreased when the packing density increased. However if the packing density increased further, the thermal conductivity may be increased. This is due to the solid conduction heat transfer that takes place. This can be explained in Figure 3.0. Thus the proper and optimum packing density of oil palm mesocarp fiber must be determined to make the convection within the insulation insignificant in order to get the lowest thermal conductivity possible. Low thermal conductivity material will act as better thermal insulation.

However in the Figure 10.0, we can see that there is a point where the thermal conductivity is increased. At packing density of 154.04 kg/m^3, the thermal conductivity suddenly increased. This is may be due to the error during the reading is taken or the error in the procedure of testing the sample. This error can be repair by taking more reading for the sample and ensure all the procedure is correct.

From the results, we can see that there is a little bit difference of the thermal conductivity for the nearly same packing density from both of oil palm mills. For example, for packing density of 129.39 kg/m^3 the thermal conductivity is a little bit higher for samples from oil palm mill Neram compared to Kerteh. This may be due to the different in size of the individual fiber itself. The individual fiber size for samples of oil palm mill Kerteh is smaller than the samples of oil palm mill Neram. This owes to the fact that a quantity of gas, usually air, is embodied in the material’s mass. Dry and firm air, when not moving and in small quantities, has the lowest thermal conductivity factor (approximately λ = 0.024 W/mK) over a wide range of temperatures. The atmospheric air is trapped between the fibers. In general, short fibers are more difficult to align and pack densely than the longer one. Thus, for a given fiber content the short fiber length makes a lot of voids leading, therefore, to low thermal conductivity of specimen due to insignificant of solid conduction. This explains why the thermal conductivity of samples from oil palm mill Kerteh is slightly smaller than the samples of oil palm mill Neram.

However, when the test is conducted to the materials that have known thermal conductivity which is expanded polystyrene, there are significant errors between the tested thermal conductivity and thermal conductivity from the research. The average error percentage is around 17.35%. The error may be due to the accuracy of the equipment or the error in procedure during the experiment is done. This is the systematic error. In order to make sure that this is a valid error result, more tests should be conducted on this material. This is to ensure the pattern of the errors of the result. Besides, more materials with known thermal conductivity also should be test. Thus if the error is constant for each test, this error can be applied to the thermal conductivity of the oil palm mesocarp fiber in order to get more accurate value of thermal conductivity.

From the data gathered, we can see that at packing density of 155.27 kg/m^3, the thermal conductivity is 0.063 W/mK. This reflects that the material is quite a good thermal insulating material. Usually the thermal conductivity materials have the thermal conductivity of less than 0.1 W/mK. Besides, the fact that this material is cheap can be a strong point for them to be utilized as an insulating material. This can help the manufacturer to save cost on insulation and also can solve their problem on the abundantly oil palm waste materials.

Under the error calculation, for a set of data of thermal conductivity for each packing density, the standard deviation, variance and standard error of the mean is calculated. From the standard deviation, we can get an idea of how tightly the group a set of data is by seeing if the variation is small or large. For the data gathered by using the sample from Oil Palm Mill Neram, we can see that the standard deviation for each packing density is varied. The lowest is for packing density of 100.18 kg/m^3 which its standard deviation is 0.00097. This shows that the data is very tightly to each other and reflect the accuracy and correctness of thermal conductivity for that packing density. The highest standard deviation is for packing density of 129.39 kg/m^3. This may be due to some human error during reading is taken and the accuracy of the device that is used for the test. For the data gathered by using the sample from Oil Palm Mill Kerteh, we can see the same pattern in the variation of the standard deviation. The standard deviation is quite low. The lowest is for packing density of 154.04 kg/m^3 with standard deviation of 0.00084. The data is very precise to each other. The highest standard deviation is for packing density of 155.27 kg/m^3 with value of 0.00552. This shows that the data not too tight to each other. However the standard deviation can be considered as low. Thus, these reflect that the data gathered for both samples is quite tight and is a reliable data.

The uncertainty analysis is done in order to show the range of value that the thermal conductivity will varies for each time the test is conducted. This range of value will acts as reference for the next tests. Each value that lies outside the range can be assumed as invalid and the test must be repeated.

4.3.2 Comparison of oil palm mesocarp fiber and rock wool

Rock wool is a common insulating material used in condenser pipes [20]. Below are the comparison between the insulation characteristics of rock wool and oil palm mesocarp fiber insulation:

Table 10.0: Insulation characteristics of oil palm mesocarp fiber and rock wool

Properties	Oil Palm Mesocarp Fiber	Rock Wool
Thermal Conductivity	Lowest tested = 0.063 W/mK	0.040 – 0.045 W/mK
Moisture Absorption	-Hygroscopic -Silane treatment can increase hydrophobicity	Does not absorb any water or moisture
Fire Resistance	Not fire resistant	-Fire resistant -Not a combustible material
Aging effect	-May aging with time	-Chemically inert fiber -Maintain its characteristic with time
Weight	Light weight	Light weight

From Table 10.0, we can see the comparison between the oil palm mesocarp fiber and rock wool. The rock wool has more advantage compared to the oil palm mesocarp fiber. However, the oil palm mesocarp fiber is a free material since it is waste materials. So, the problem regarding aging effect and moisture absorption can be solved. It is because, since it will be used in the oil palm mill itself, the source is abundant thus when problem occurred to the material, it can be replace instantly. Thus, oil palm mesocarp fiber can be an alternative thermal insulating material for the condenser pipe in the oil palm mill.

4.3.3 Discussion for Designing Thermal Insulation for Condenser Pipe in Steam Turbine System in Oil Palm Mill

Condenser pipe is one of the components in a boiler and steam turbine system. Condenser pipe carries condensate from the condenser back into the boiler as feedwater to generate steam. Usually the condensate temperature is below the 100 °C (see Appendix A). In boiler, the condensate will be heat until it evaporates into steam in order to be used for the steam turbine. Energy is required in order to heat the condensate. By insulating the condenser pipe, the heat loss can be reduced. Thus, we can save the energy required to heat the condensate into steam. From the result above, in order to keep the temperature of the surface at 31 °C, while the hot water temperature inside the pipe is at 65 °C and the ambient temperature is 30 °C for the purpose of energy conservation, the insulation thickness of 0.17 m is needed. At steady state, the heat flow through the insulation to the outside surface equals the heat flow from the surface to the ambient air [19]. In order to design for the thermal insulation thickness, the rate of heat transfer from the outside surface to the ambient air needs to be calculated. This rate of heat transfer then is used in the conduction heat transfer formula in order to determine the thickness of the thermal insulation needed. By insulating the condenser pipe, the fuel needed for that certain amount of heating can be saved. In the long period run, this type of savings will become significant to the oil palm mill manufacturers.

4.3.4 Energy saved

In other to calculate the amount of energy saved when insulation is applied to the condenser pipe, the amount of heat loss when no insulation is applied must be calculated.

4.3.4.1 Calculation for natural convection coefficient without insulation

Schematic

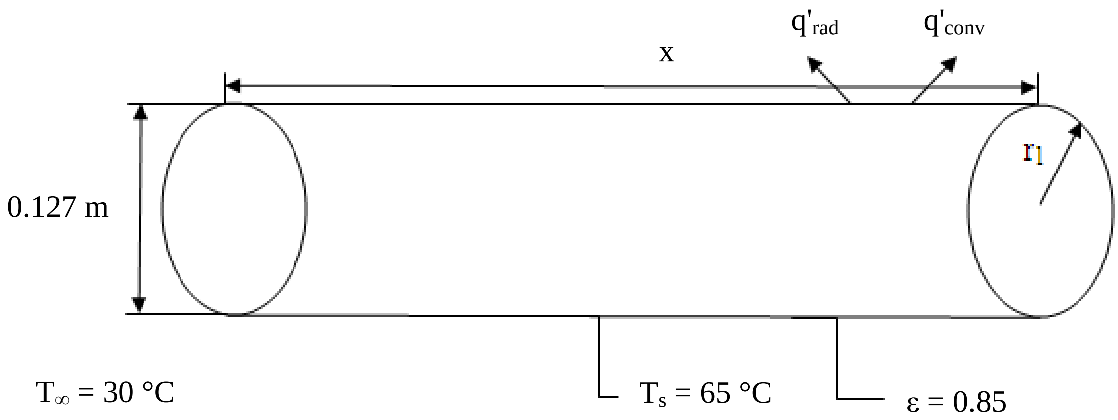

Figure 12.0: Sketching of condenser pipe without insulation

Properties

$T_f = (T_s + T_\infty) / 2$

$T_f = (338\,K + 303\,K) / 2 = 320.5\,K$

From Table of Thermophysical Properties of Gases at Atmospheric Pressure [18],

When air at T_f = 320.5 K

k = 0.0278 W/mK

$\upsilon = 18.0 \times 10^{-6}\ m^2/s$

α = 25.53 x 10^{-6} m^2/s

P_r = 0.704

β = 3.120 x 10^{-3} K^{-1}

<u>Analysis</u>

The convection coefficient may be obtained from equation below:

$$Nu_D = \left\{0.60 + \frac{0.387 Ra_D^{\ 1/6}}{[1+(0.559/\Pr)^{9/16}]^{8/27}}\right\}^2 \quad [18]$$

Where

$$Ra_D = \frac{g\beta(T_s - T_\infty)D^3}{\upsilon\alpha} \quad [18]$$

$$Ra_D = \frac{9.8 m/s^2 x 3.120 x 10^{-3} K^{-1}(65-30)°C(0.127m)^3}{18.0x10^{-6} m^2/sx25.53x10^{-6}\ \ m^2/s}$$

$$Ra_D = 4.770x10^6$$

Hence

$$Nu_D = \left\{0.60 + \frac{0.387(4.770x10^6)^{1/6}}{[1+(0.559/0.704)^{9/16}]^{8/27}}\right\}^2$$

$$Nu_D = 22.71$$

And

$$h = \frac{k}{D} Nu_D \quad [18]$$

$$h = \frac{0.0278 W/mK}{0.127m}(22.71)$$

$$h = 4.97 W/m^2K$$

4.3.4.2 Heat Loss without Insulation

$q' = q'_{conv} + q'_{rad}$ [18]

$q' = h\pi D(T_s - T_\infty) + \varepsilon\pi D\sigma(T_{s,2}^4 - T_{sur}^4)$

$$q' = (4.97W/m^2K)(\pi)(0.127m)(65-30)°C +$$
$$(0.85)(\pi)(0.127m)(5.67x10^{-8}W/m^2K^4)(338^4 - 303^4)K^4$$

$q' = 158.29W/m$

4.3.4.3 Heat Loss with Insulation

$q' = q'_{conv} + q'_{rad}$ [18]

$q' = h\pi D(T_s - T_\infty) + \varepsilon\pi D\sigma(T_{s,2}^4 - T_{sur}^4)$

$$q' = (1.89W/m^2K)(\pi)(0.127m)(31-30)°C +$$
$$(0.85)(\pi)(0.127m)(5.67x10^{-8}W/m^2K^4)(304^4 - 303^4)K^4$$

$q' = 2.90W/m$

4.3.4.4 Energy Saved

Heat Saved = Heat loss without insulation – Heat loss with insulation

Heat Saved = 158.29 W/m – 2.90 W/m = 155.39 W/m

By applying oil palm mesocarp fiber as thermal insulation to the condenser pipe, we can save the amount of energy required for 155.39 W/m of heating.

In most palm oil mills, the boiler used is the model "Vickers Babcock TW16" and it operates at 21 bar gauge, and produces 21 tonnes of steam per hour at saturation temperature. In normal operation, palm fiber and palm shell fed into the boiler are 6.5 tonnes (6500 kg) and 2.25 tonnes (2250 kg) per hour respectively [21]. However, by applying insulation to the condenser pipe, the amount of fuel can be reduced.

Heat saved

Heat saved = Heat saved per length x length of the condenser pipe

Heat saved = 155.39 W/m x $\boldsymbol{x}$ m

Where

$\boldsymbol{x}$ = length of condenser pipe

Heat saved = 155.39$\boldsymbol{x}$ W

For every 1 meter of condenser pipeline, savings of energy rate = 155.39 W

Fuel saved

Fuel saved = Heat saved / higher heating value

Fuel saved = 155.39$\boldsymbol{x}$ W / 15 kJ/kg

Fuel saved = 37.29$\boldsymbol{x}$ kg /hr

For every 1 meter of condenser pipe, savings of fuel = 37.29 kg/hr

Energy rate available

Energy rate available = Biomass mass rate x higher heating value

Energy rate available = 8750 kg/hr x 15 kJ/kg = 131250 kJ/hr

Energy rate available = 131250 kJ/hr = 36458.33 W

Energy rate reduced

Energy rate reduced = Energy rate available – Heat saved

Energy rate reduced = (36458.33 – 155.39$\boldsymbol{x}$) W

Fuel reduced

Fuel reduced = Energy rate reduced / higher heating value

Fuel reduced = (36458.33 – 155.39$\boldsymbol{x}$) W / 15 kJ/kg

Fuel reduced = (8750 + 37.29$\boldsymbol{x}$) kg /hr

By applying insulation to the condenser pipe, the energy rate that can be saved for every 1 meter is equal to 155.39 W, and the fuel that can be saved for every 1 meter is equal to 37.29 kg /hr.

By applying insulation to the condenser pipe, the energy rate that can be reduced is equal to (36458.33 – 155.39$\boldsymbol{x}$) W, where $\boldsymbol{x}$ = length of condenser pipe and the fuel that can be reduced is equal to (8750 + 37.29$\boldsymbol{x}$) kg /hr.

CHAPTER 5

CONCLUSION

5 CONCLUSION

As a conclusion, from the results of the test performed using the Thermal conductivity of Building and Insulating Material Unit B480, the thermal conductivity of the oil palm mesocarp fiber is decrease as the packing density increase. With a high packing density, the thermal conductivity of the oil palm mesocarp fiber will become very low and become more suitable and efficient as thermal insulating material. At the packing density of 155.27 kg/m^3, the average thermal conductivity is 0.063 W/mK which reflect the low thermal conductivity of the material. Usually the thermal insulating materials have the thermal conductivity of less than 0.1 W/mK [22]. The oil palm mesocarp fiber's thermal conductivity is in this range thus qualified them as a good thermal insulating material. By knowing the thermal conductivity of the oil palm mesocarp fiber, the suitability of this fiber as thermal insulating material can be determined thus can contribute to the way of how to manage the abundantly oil palm waste material. For the energy conservation the right thickness of the thermal insulation is important in order to reduce the heat loss from a system. By improving the energy conservation, savings can be achieved in term of the fuel cost needed to recover the loss. From the calculation, the thermal insulation thickness needed for the energy conservation of condenser pipe is 0.17 m for the hot water temperature of 65 °C, surface temperature of 31 °C, and the ambient temperature of 30 °C. By applying insulation to the condenser pipe, the energy rate that can be saved for every 1 meter is equal to 155.39 W, and the fuel that can be saved for every 1 meter is equal to 37.29 kg /hr. This can be done by the oil palm manufacturers in order to solve two problems which are the abundantly oil palm waste material and conservation of energy in their mill.

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APPENDICES

Appendix A: Turbine Vapor Cycle on T-h Diagram

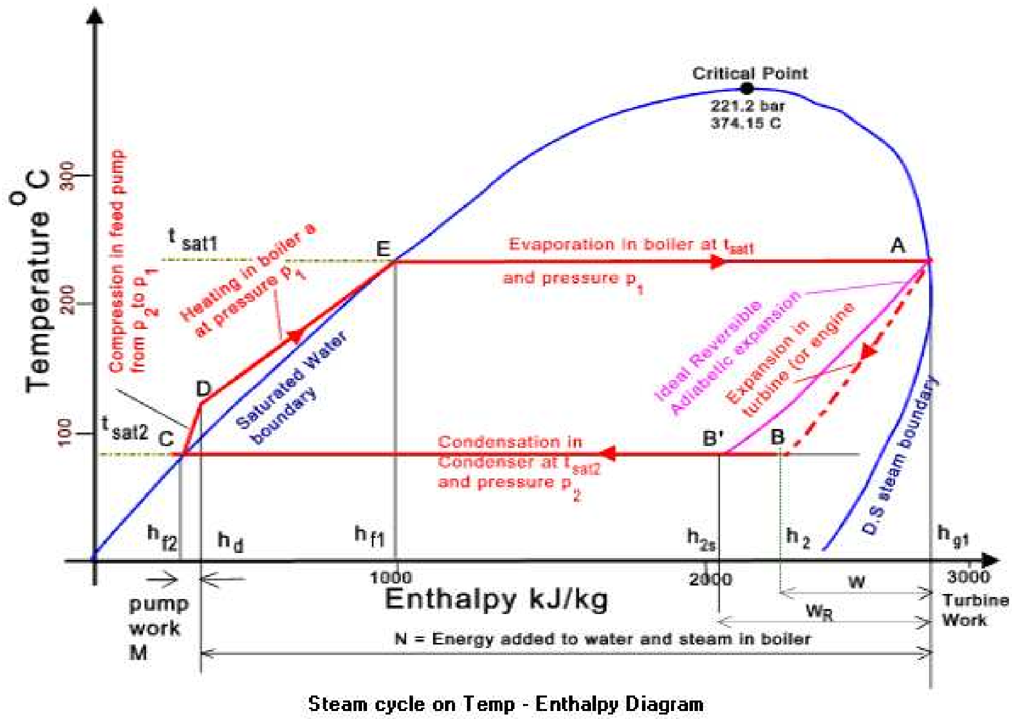

Figure 13.0: Turbine Vapor Cycle on T-h diagram

Appendix B: Experiment Procedure

1. The samples FPISB Kilang Sawit Neram (oil palm mill Neram) are measured into 5 different weights which are 100g, 120g, 125g, 140g, and 160g to get different packing density.

2. The unit is switched on at the main unit.

3. Ensure that there is no specimen in the plates. Place both of the silicon mats onto the cold plate. The lid is close and the two clasps are secured.

4. The screw handwheel is rotated anticlockwise to lower the hot plate assembly down onto the heat flowmeter plate. The turning is stopped at the point when the green 'Test Position' lamp illuminates. This should be repeated a few times and an average reading taken.

5. The screw handwheel is turned clockwise in order to lift the hot plate assembly. It should be brought to a position, such that the height between the horizontal lifting bar and screw cup lid is greater than the thickness of the specimen.

6. The lid of the box is opened and one of the silicone mats is placed onto the cold plate (See Figure 14.0).

Figure 14.0: A silicone mat is placed onto the cold plate

7. The wooden frame of 27.8 cm x 27.8 cm x 1 cm is placed above the silicon mat (See Figure 15.0). The purpose of this wooden frame is to hold the specimen during the test.

Figure 15.0: A wooden frame is placed on the silicon mat

8. The first specimen which is the oil palm mesocarp fiber with 100g in weight is put into the wooden frame (see Figure 16.0). The specimen is carefully spread in order to cover all the surface of the cold plate in order to make sure that all the heat will be insulated from the hot plate when the lid is closed.

Figure 16.0: The oil palm mesocarp fiber is spread to fill the wooden frame

9. Another silicone mat is placed onto the oil palm mesocarp fiber in order to cover all the fiber and distributed the pressure fairly when the lid is closed (See Figure 17.0).

Figure 17.0: Another silicone mat is put onto the oil palm mesocarp fiber

10. The lid is closed and the two clasps at the front are secured (See Figure 18.0).

Figure 18.0: The lid is closed and the handwheel is rotated

11. The screw handwheel is turned anticlockwise to lower the hot plate assembly to the specimen. The hot plate will touch the specimen and as the handle is turned further the whole assembly will move down on the four supporting springs. The handle is turned until the green test position lamp illuminates to denote that correct pressure has been applied. The new dial reading is noted. The handwheel

is turned to raise and lower the plate a few times and the average dial reading is taken.

12. The original dial reading is subtract (no specimen) from the new reading (with specimen). The value is multiplied by 2.5 (the screw thread pitch) to give the thickness of the specimen under test in mm.

13. The hot plate temperature (T_1) set point is set on the controller to the desired level. In this test, the testing temperature is set to the 60°C.

14. The coolant supply is turned on.

15. The cold plate temperature (T_2) and the milivolt output (HFM) is allowed to stabilize.

16. At each sample interval, the values of T_1, T_2, and the heat flowmeter output is noted. The mean temperature ($T_m = (T_1 + T_2) / 2$) and the temperature difference (dT) between T_1 and T_2 are then calculated. By using the sets of calibration constants (k1 to k6) supplied in the unit in the lambda equation, the thermal conductivity are then determined.

    Thermal conductivity formula

    $$\lambda = \frac{l_s \text{ x } [(k_1 + (k_2 \text{ x } T_m)) + ((k_3 + (k_4 \text{ x } T_m)) \text{ x HFM}) + ((k_5 + (k_6 \text{ x } T_m)) \text{ x HFM}^2)]}{dT}$$

17. To calculate the value of the specimen thermal resistance, R, the specimen thickness is divided by the thermal conductivity.

18. Then, the test is repeated again by using other samples of different weight from FPISB Kilang Sawit Neram (oil palm mill Neram).

19. The step 3 – 18 is repeated for the samples from FPISB Kilang Sawit Kerteh (oil palm mill Kerteh).

20. The density can be measured by dividing the mass to the volume.

21. All the data will be organized into a table.

Appendix C: Error Calculation

- Standard deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x)^2}{N-1}}$$

Where

σ = standard deviation

x_i = data

x = mean value

N = number of data

- Variance

$$\sigma^2 = \frac{\sum_{i=1}^{N}(x_i - x)^2}{N-1}$$

Where

σ^2 = variance

x_i = data

x = mean value

N = number of data

- <u>Standard error of the mean</u>

$$\sigma_x = \frac{\sigma}{\sqrt{N}}$$

Where

σ_x = standard error of the mean

- Uncertainty Analysis

The uncertainty is calculated by using the calibration error.

Appendix D: Final Year Project Milestone

FYP 1

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topic														
2	Preliminary Research Work														
3	Submission of Preliminary Report														
4	Consult with technician regarding on using the laboratory equipment														
5	Picking oil palm waste material (fiber)														
6	Test for thermal conductivity														
7	Submission of Progress Report														
8	Seminar														
10	Submission of Interim Final Report Draft														
11	Oral Presentation								During Study Week						

Figure 19.0: Milestone of Final Year Project 1

FYP 2

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Picking oil palm waste material (fiber)														
2	Test for thermal conductivity														
3	Submission of progress Report I														
4	Submission of progress Report II														
5	Seminar														
6	Designing thermal insulation for steam pipe														
7	Poster preparation														
8	Poster exhibition														
9	Submission of Dissertation Final Draft														
10	Oral Presentation	During Study Week													
11	Submission of Dissertation (Hard Bound)	7 days after oral presentation													

Figure 20.0: Milestone of Final Year Project 2

APPENNDIX E: Graph Of Normal Distribution For Thermal Conductivity Of Oil Palm Mesocarp Fiber

From the error calculation, the graph of normal distribution for thermal conductivity of oil palm mesocarp fiber can be constructed. Below are the graphs for each packing density:

Oil Palm Mill Neram

1. 100.18 kg/m^3

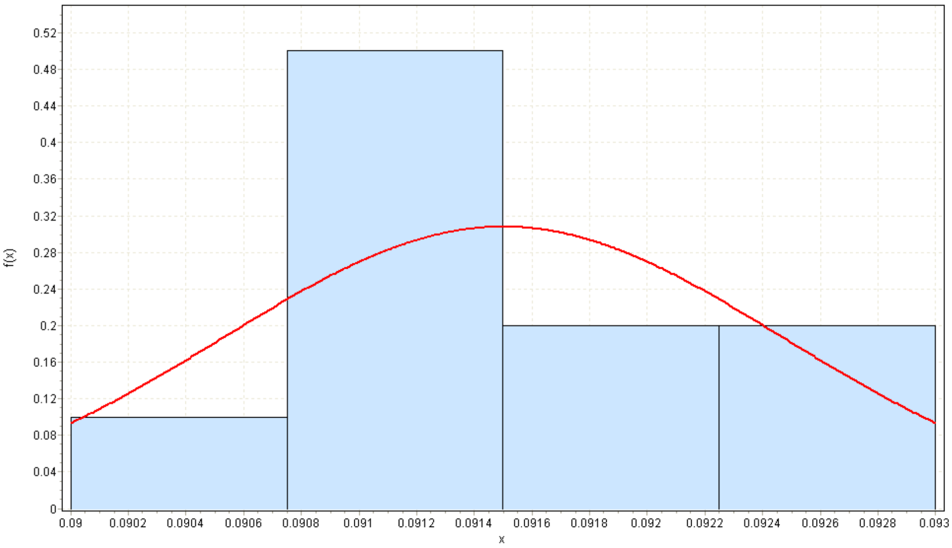

Figure 21.0: Normal distribution for packing density of 100.18 kg/m^3

Table 11.0: Descriptive Statistics for packing density of 100.18 kg/m^3

Statistic	Value
Sample Size	10
Range	0.003
Mean	0.0915
Variance	9.4444E-7
Std. Deviation	9.7183E-4
Coef. of Variation	0.01062
Std. Error	3.0732E-4
Skewness	0.45397
Excess Kurtosis	-0.51607

Percentile	Value
Min	0.09
5%	0.09
10%	0.0901
25% (Q1)	0.091
50% (Median)	0.091
75% (Q3)	0.09225
90%	0.093
95%	0.093
Max	0.093

2. 103.51 kg/m^3

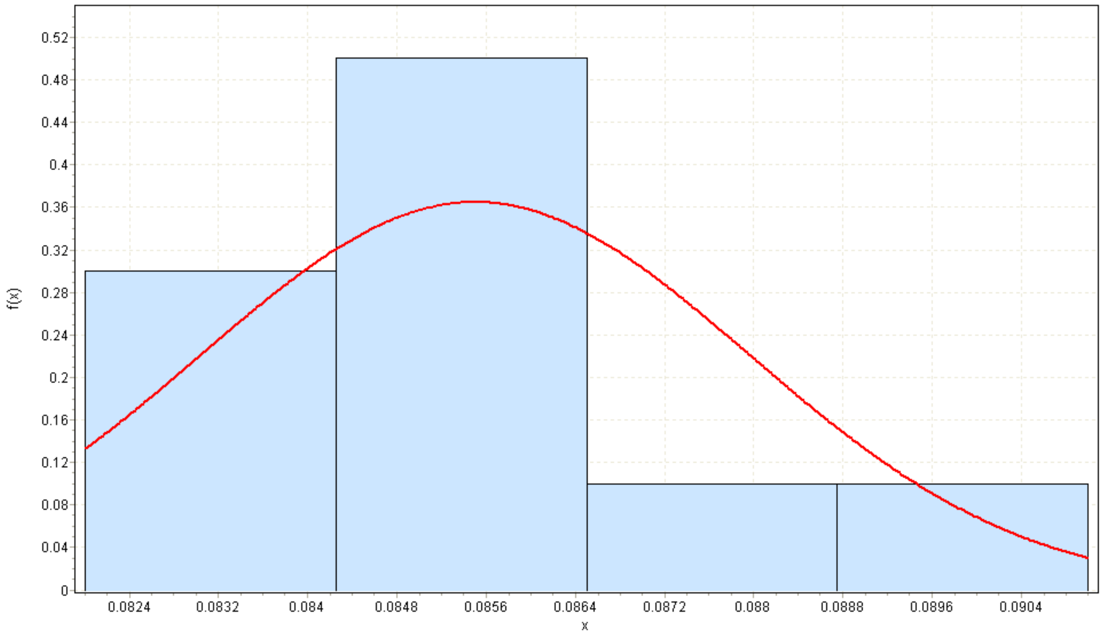

Figure 22.0: Normal distribution for packing density of 103.51 kg/m^3

Table 12.0: Descriptive Statistics for packing density of 103.51 kg/m^3

Statistic	Value	Percentile	Value
Sample Size	10	Min	0.082
Range	0.009	5%	0.082
Mean	0.0855	10%	0.0821
Variance	6.0556E-6	25% (Q1)	0.08375
Std. Deviation	0.00246	50% (Median)	0.0855
Coef. of Variation	0.02878	75% (Q3)	0.08625
Std. Error	7.7817E-4	90%	0.0906
Skewness	1.0066	95%	0.091
Excess Kurtosis	2.2948	Max	0.091

3. 107.83 kg/m^3

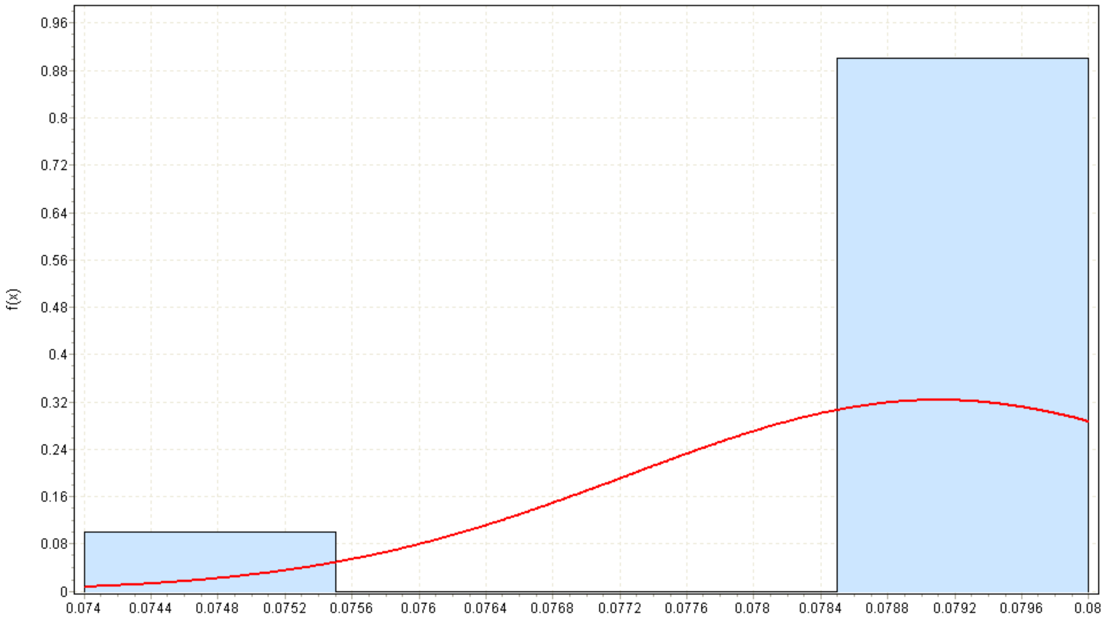

Figure 23.0: Normal distribution for packing density of 107.83 kg/m^3

Table 13.0: Descriptive Statistics for packing density of 107.83 kg/m^3

Statistic	Value
Sample Size	10
Range	0.006
Mean	0.0791
Variance	3.4333E-6
Std. Deviation	0.00185
Coef. of Variation	0.02343
Std. Error	5.8595E-4
Skewness	-2.8006
Excess Kurtosis	8.2596

Percentile	Value
Min	0.074
5%	0.074
10%	0.0745
25% (Q1)	0.079
50% (Median)	0.08
75% (Q3)	0.08
90%	0.08
95%	0.08
Max	0.08

4. 129.39 kg/m^3

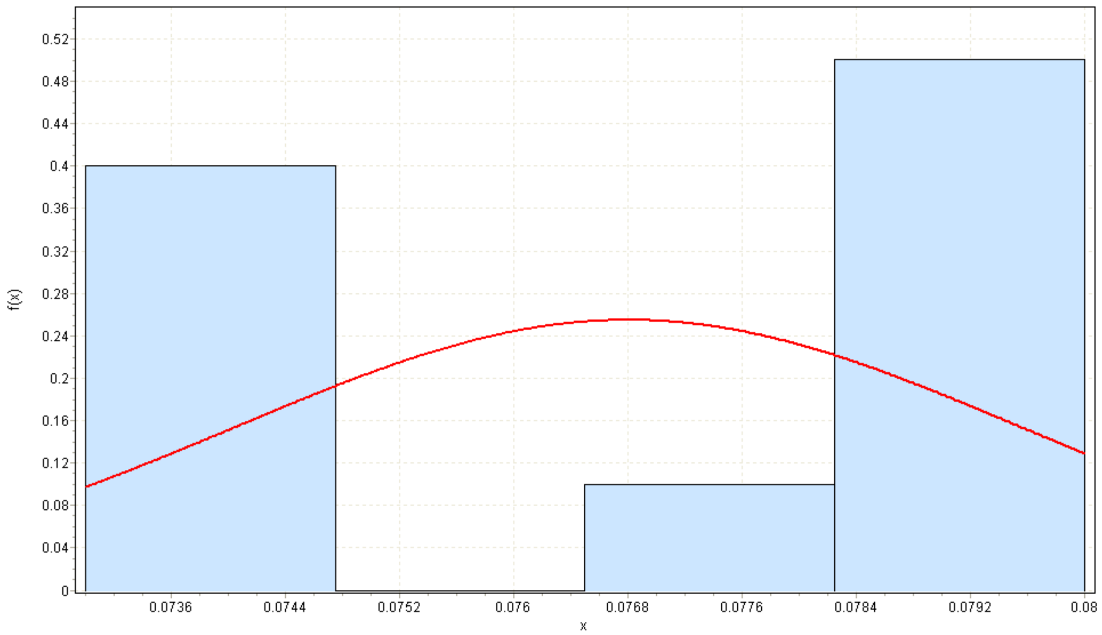

Figure 24.0: Normal distribution for packing density of 129.39 kg/m^3

Table 14.0: Descriptive Statistics for packing density of 129.39 kg/m^3

Statistic	Value
Sample Size	10
Range	0.007
Mean	0.0768
Variance	7.5111E-6
Std. Deviation	0.00274
Coef. of Variation	0.03569
Std. Error	8.6667E-4
Skewness	-0.30604
Excess Kurtosis	-2.0511

Percentile	Value
Min	0.073
5%	0.073
10%	0.0731
25% (Q1)	0.074
50% (Median)	0.078
75% (Q3)	0.079
90%	0.0799
95%	0.08
Max	0.08

5. 138.02 kg/m^3

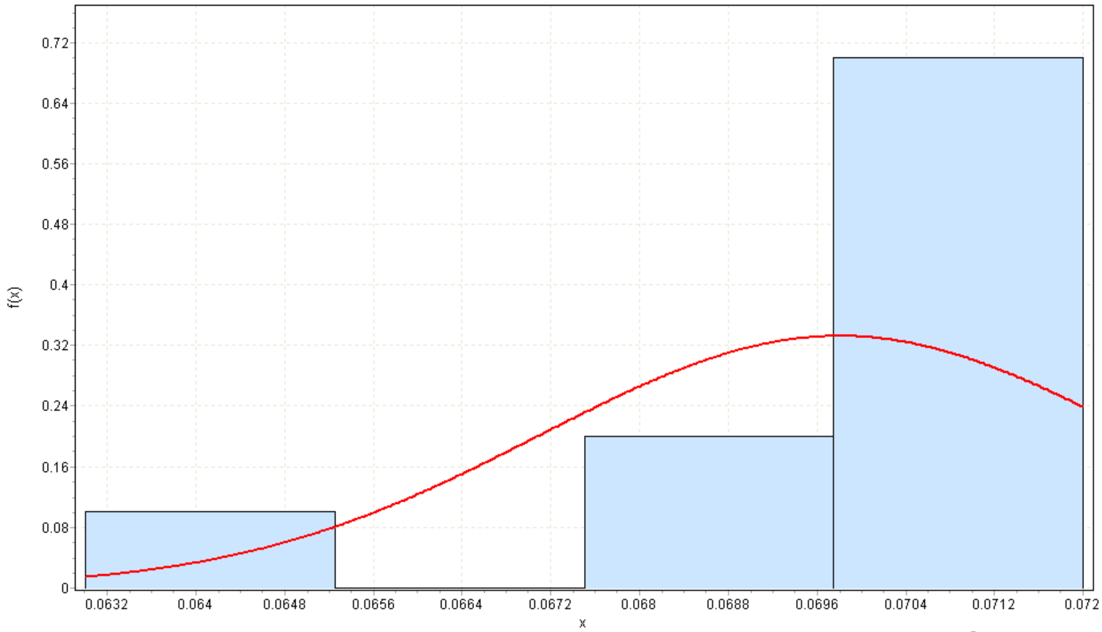

Figure 25.0: Normal distribution for packing density of 138.02 kg/m^3

Table 15.0: Descriptive Statistics for packing density of 138.02 kg/m^3

Statistic	Value
Sample Size	10
Range	0.009
Mean	0.0698
Variance	7.2889E-6
Std. Deviation	0.0027
Coef. of Variation	0.03868
Std. Error	8.5375E-4
Skewness	-2.0649
Excess Kurtosis	4.7157

Percentile	Value
Min	0.063
5%	0.063
10%	0.0635
25% (Q1)	0.06875
50% (Median)	0.071
75% (Q3)	0.07125
90%	0.072
95%	0.072
Max	0.072

Oil Palm Mill Kerteh

1. 118.30 kg/m^3

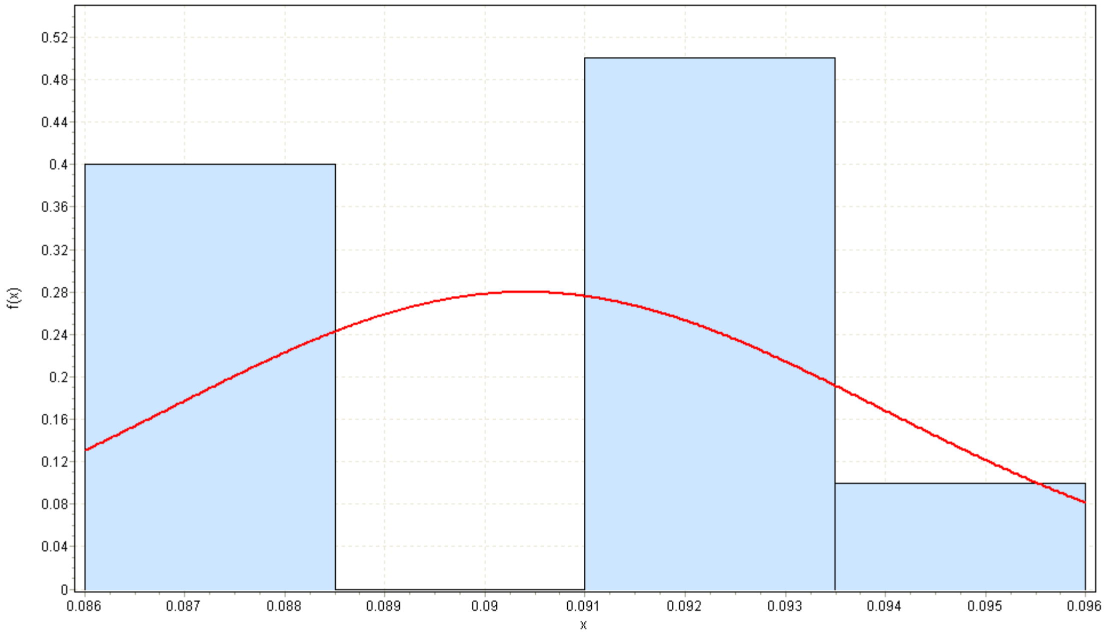

Figure 26.0: Normal distribution for packing density of 118.30 kg/m^3

Table 16.0: Descriptive Statistics for packing density of 118.30 kg/m^3

Statistic	Value
Sample Size	10
Range	0.01
Mean	0.0904
Variance	1.2711E-5
Std. Deviation	0.00357
Coef. of Variation	0.03944
Std. Error	0.00113
Skewness	-0.07944
Excess Kurtosis	-1.4872

Percentile	Value
Min	0.086
5%	0.086
10%	0.086
25% (Q1)	0.08675
50% (Median)	0.092
75% (Q3)	0.093
90%	0.0957
95%	0.096
Max	0.096

2. 120.77 kg/m^3

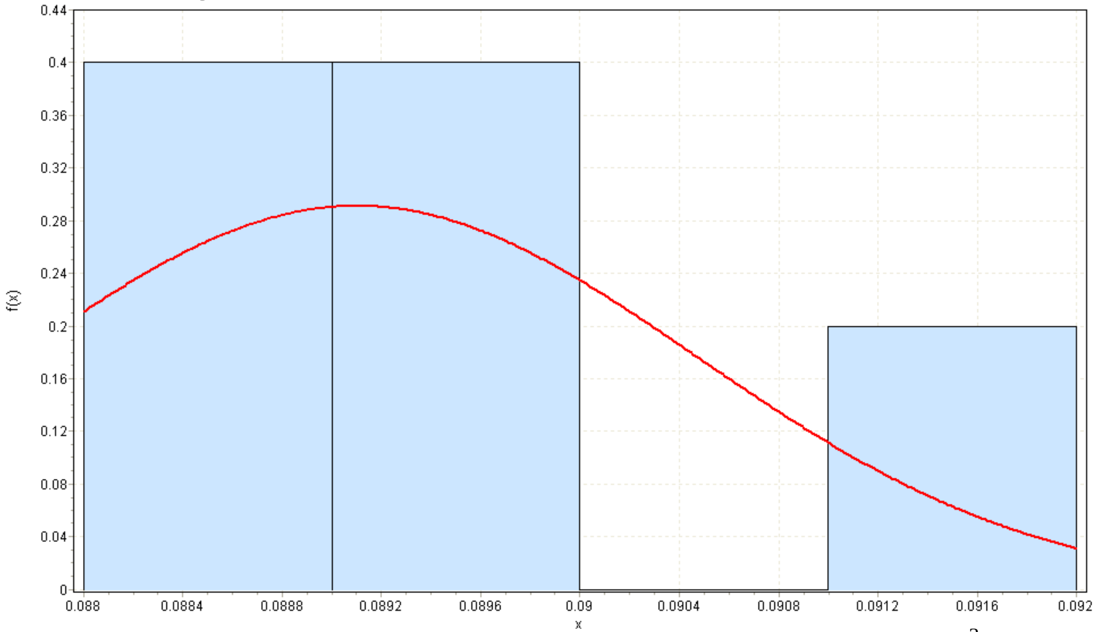

Figure 27.0: Normal distribution for packing density of 120.77 kg/m^3

Table 17.0: Descriptive Statistics for packing density of 120.77 kg/m^3

Statistic	Value
Sample Size	10
Range	0.004
Mean	0.0891
Variance	1.8778E-6
Std. Deviation	0.00137
Coef. of Variation	0.01538
Std. Error	4.3333E-4
Skewness	1.3991
Excess Kurtosis	1.2078

Percentile	Value
Min	0.088
5%	0.088
10%	0.088
25% (Q1)	0.088
50% (Median)	0.089
75% (Q3)	0.0895
90%	0.0919
95%	0.092
Max	0.092

3. 129.39 kg/m^3

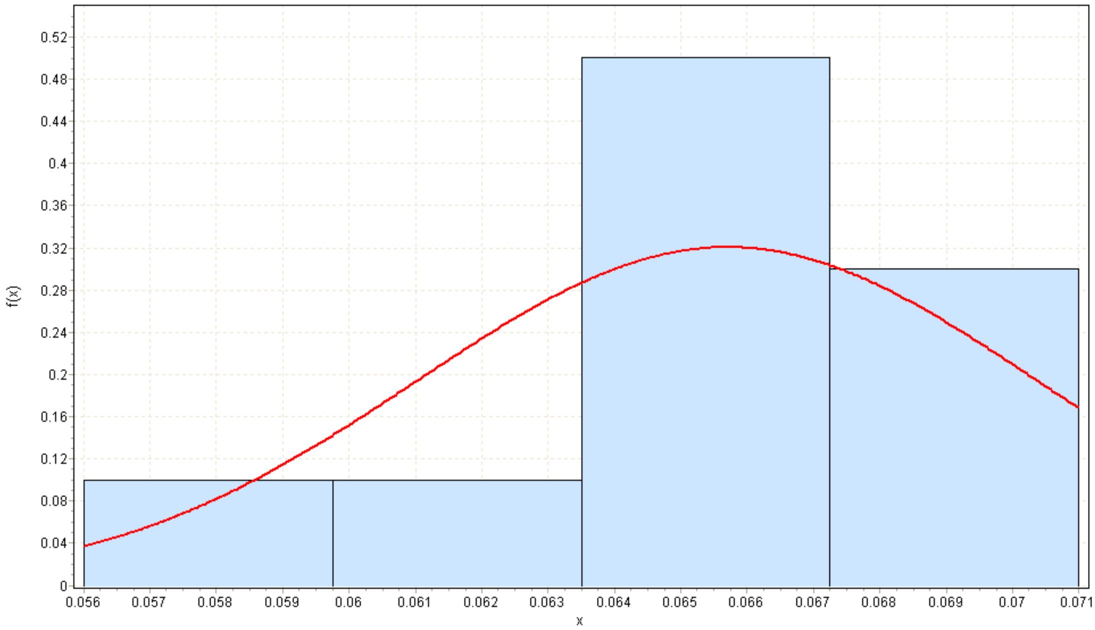

Figure 28.0: Normal distribution for packing density of 129.39 kg/m^3

Table 18.0: Descriptive Statistics for packing density of 129.39 kg/m^3

Statistic	Value
Sample Size	10
Range	0.015
Mean	0.0657
Variance	2.1789E-5
Std. Deviation	0.00467
Coef. of Variation	0.07105
Std. Error	0.00148
Skewness	-0.71316
Excess Kurtosis	0.90902

Percentile	Value
Min	0.056
5%	0.056
10%	0.0566
25% (Q1)	0.0635
50% (Median)	0.0655
75% (Q3)	0.071
90%	0.071
95%	0.071
Max	0.071

4. 154.04 kg/m^3

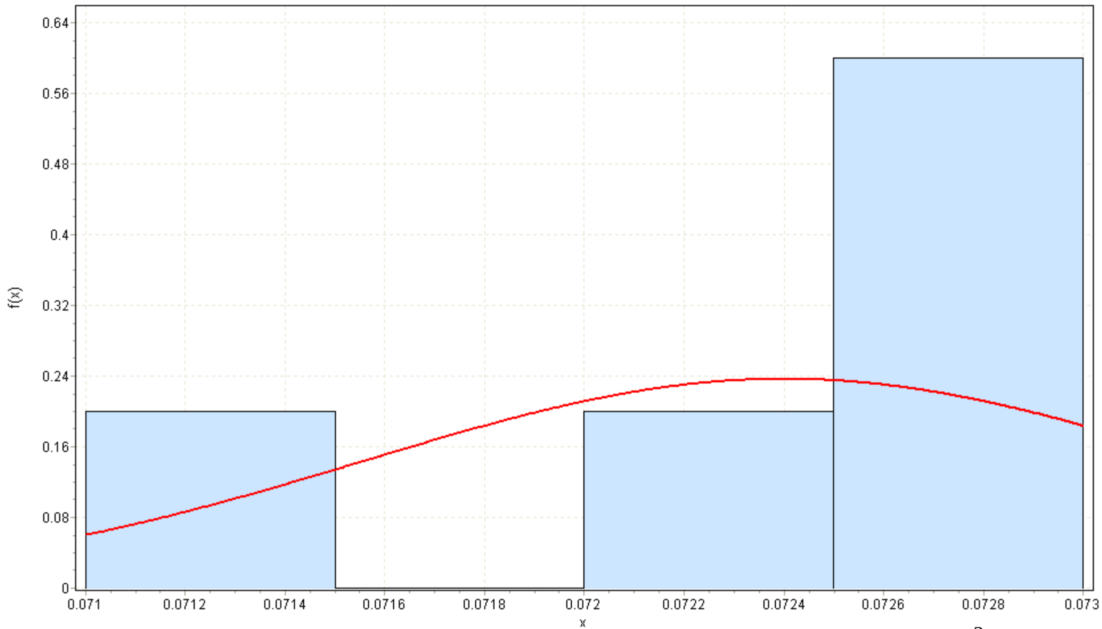

Figure 29.0: Normal distribution for packing density of 154.04 kg/m^3

Table 19.0: Descriptive Statistics for packing density of 154.04 kg/m^3

Statistic	Value
Sample Size	10
Range	0.002
Mean	0.0724
Variance	7.1111E-7
Std. Deviation	8.4327E-4
Coef. of Variation	0.01165
Std. Error	2.6667E-4
Skewness	-1.0006
Excess Kurtosis	-0.66546

Percentile	Value
Min	0.071
5%	0.071
10%	0.071
25% (Q1)	0.07175
50% (Median)	0.073
75% (Q3)	0.073
90%	0.073
95%	0.073
Max	0.073

5. 155.27 kg/m^3

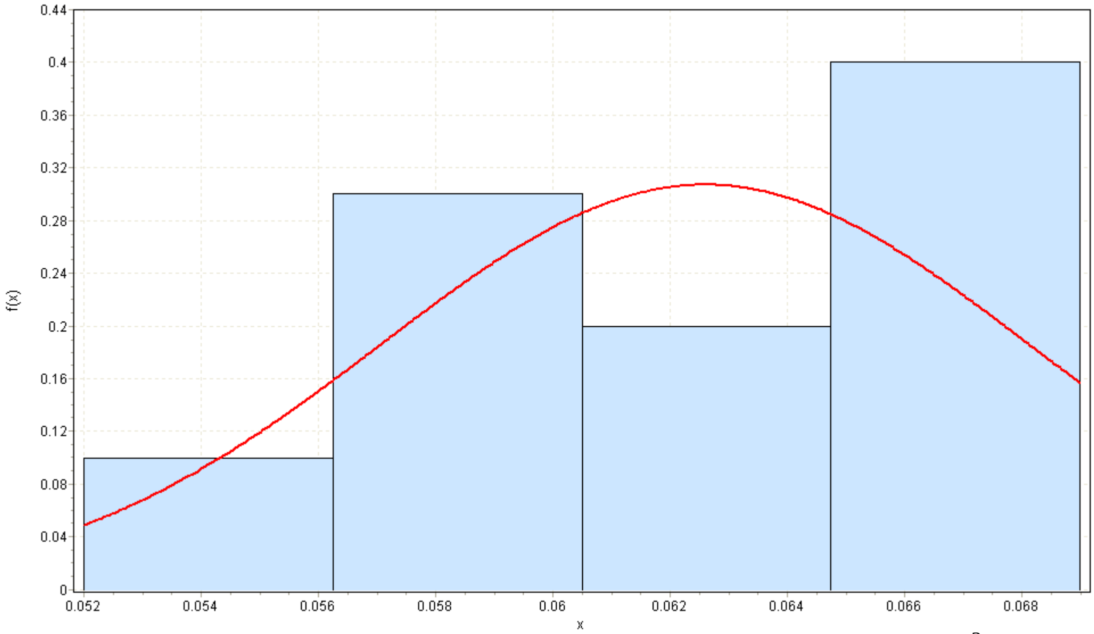

Figure 30.0: Normal distribution for packing density of 155.27 kg/m^3

Table 20.0: Descriptive Statistics for packing density of 155.27 kg/m^3

Statistic	Value
Sample Size	10
Range	0.017
Mean	0.0626
Variance	3.0489E-5
Std. Deviation	0.00552
Coef. of Variation	0.08821
Std. Error	0.00175
Skewness	-0.64687
Excess Kurtosis	-0.32866

Percentile	Value
Min	0.052
5%	0.052
10%	0.0526
25% (Q1)	0.058
50% (Median)	0.0635
75% (Q3)	0.068
90%	0.0689
95%	0.069
Max	0.069

Appendix F: Uncertainty Analysis

The uncertainty analyses of the thermal conductivity of oil palm mesocarp fiber were calculated using the methods of Kline and Mclintok (1953), Wheeler and Ganji (2004) and Taylor (1997).

1. The systematic uncertainty is calculated for the mean of the mean temperature, T_m. For example, given that the Thermal Conductivity of Building and Insulating Material Unit B480 have 10% accuracy. In this case for packing density of 100.18 kg/m^3, 10 % x 47.2 °C = 4.72 °C

2. To find random uncertainty, the standard deviation of thermal conductivity is required, and for packing density of 100.18 kg/m3, the standard deviation is 0.055 °C. The random uncertainty is then calculated for 95% confidence according to Students t distribution with a sample size of 10. The result is a random uncertainty of 0.055 x 2.26 = 0.1243 °C

3. Both the random and systematic uncertainties are combined using a root square sum calculation to give a total uncertainty for the thermal conductivity of :

   $$\sqrt{4.72^2 + 0.1243^2} = 4.72°C$$

4. The remainder of the variables which appear in the thermal conductivity calculation equation,

   $$\lambda = \frac{l_s x[(k_1 + (k_2 x T_m)) + ((k_3 + (k_4 x T_m))xHFM) + ((k_5 + (k_6 x T_m))xHFM^2)]}{dT}$$

   Are subject to the same analysis as in step 1 to step 3

5. The results are propagated through the heat transfer coefficient equation using the following formula

$$\sqrt{\left[\left(\frac{\partial\lambda}{\partial T_m}T_m\right)^2+\left(\frac{\partial\lambda}{\partial HFM}HFM\right)^2+\left(\frac{\partial\lambda}{\partial dT}dT\right)^2\right]}$$

Where,

$$\frac{\partial\lambda}{\partial T_m}=\frac{l_s x(k_2+k_4 HFM+k_6 HFM^2)}{dT}$$

$$\frac{\partial\lambda}{\partial HFM}=\frac{l_s x(k_3+k_4 T_m+2k_5 HFM+2k_6 T_m HFM)}{dT}$$

$$\frac{\partial\lambda}{\partial dT}=-\frac{l_s x[(k_1+(k_2 x T_m))+((k_3+(k_4 x T_m))x HFM)+((k_5+(k_6 x T_m))x HFM^2)]}{dT^2}$$

To give a final uncertainty (with 95%).