Thermal Performance of Oil Palm Fibre and Paper Pulp as the Insulation Materials

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Abstract – Energy consumption for residential use in Malaysia is keep increasing yearly in order to maintain the internal thermal comfort of the building. Roof insulation material plays a vital role in improving the thermal comforts of the building while reduce the cooling load of the building. Oil palm industry in Malaysia had grown aggressively over the past few decades. Tons of oil palm waste had produced during the process such as empty fruit bunch fiber. Another waste material that available and easy to obtain is paper. Paper is a valuable material that can be recycled. Waste paper comes from different sources such as newspaper, office and printing papers. This study will take advantage of the available resources which could contribute to reduce the environment impact. The aim of this study is to investigate the thermal performance of roof insulation materials using mixture of oil palm fiber and paper pulp with different ratio and thickness. This study found that the thermal performance of the paper pulp is slightly better compare to the oil palm fiber. Thermal conductivity of the particle board reduces around 4.1% by adding the 10% of paper pulp into the total density of the particle board. By adding 75% of paper pulp, the thermal conductivity of the particle board could be reduced to 24.6% compare to the oil palm fiber board under the similar condition. Therefore, from this study, it could be concluded that paper pulp has high potential to be used as a building insulation material.

***Keywords*:** Thermal Performance, Thermal Conductivity, Paper Pulp, Oil Palm Fiber, Bio-degradable Insulation Materials

I. INTRODUCTION

NOWADAYS, people are very concern on sustainable development in order to ensure the environment could be inherited to the next generation. According to the United Nations Brundtland Report (1987), the sustainable development had been defined as development that meets the need of the current situation without compromising the ability of future generations to meet their own needs [1]. The purpose of the implementation of sustainable development is to ensure that the environment is preserved and the natural resources can be retained for the future generations. The life quality of the citizens and the access of the dependable source of energy can be improved by implementing the sustainable development. In the meantime, it is also promoting the economic growth and climate change mitigation.

The industrial sectors in Malaysia consume the most energy (43%) compare to the transportation sector shows the second highest (36%) and the residential sector comes in third place with 14% energy consumption [2]. The energy consumption is directly proportional to the population growth. As population in Malaysia keep increasing, larger space is needed to accommodate the new residents. If the development could not be sustained, the energy usage will increase due to the increment of the population. These will result in the environmental pollution such as air pollution, water pollution, sound pollution and etc.

On the global average, buildings contribute 30% of CO2 emissions and consumed 30% of natural resources and produce 30% to 40% of land filled waste, which contribute significantly to the global warming [3]. It is also essential to reduce the environmental impact caused by the construction industry. These challenges can only be achieve through the innovation or the implementation energy-efficient technologies.

Cooling system and lighting consume the most energy compare to others housing appliance [4]. The design of the building envelopes and material used play an important role in reducing the energy consumption of the building. Compare to the walls, roof exposed more towards solar radiation. Referring to climate factors of Malaysia and the duration of roof exposure to solar radiation is longer compare to walls.

Some passive building envelope design could be implemented in the region like Malaysia. The implementation of the

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passive design can achieve the effect of cooling of the building significantly thereby increase the comfort level of the occupants [5]. However, the implementation of the thermal insulation and special types of building materials also had increased drastically in these recent years no matter in hot or cold climates [6].

Energy efficiency can be achieved by designing suitable roof insulation material, depends on the local climate. Different material has different thermal properties. In hot and humid climate country like Malaysia, the most suitable roofing material is the materials that would reduce or reflect the solar radiation. This is to keep the internal temperature of the building to the minimum level. Roof insulation plays very important roles in reducing the solar radiation and most of the roof insulations in the market are made of inorganic material with low thermal conductivity that could not be composed naturally. The inappropriate insulating materials can be harmful to the human health by pollute the indoor environment such as emissions of toxic gas and particle [7].

The energy usage for cooling the building can be reduces by installing the thermal insulation within the walls or roofs [8]. However, maintaining the suitable thermal comfort of a building is a great challenge to the engineers nowadays. Different climate need different type of roof insulation material in order to achieve the ideal thermal comfort. In hot humid climate like Malaysia, it is vital to reach the optimal thermal comfort for the occupants by installing low thermal conductivity roof insulator. According to Sadineni et.al [5], about 60% of the thermal energy leakage occurs through the roofs, and the roof insulation plays an important role in reducing the cooling loads of the building.

Over the past few decades with the advancement of the technology, many inorganic low thermal conductivity material had been produced for building thermal insulation like foam glass, glass wool, Styrofoam and plastic foam [9]. Manohar [10] highlighted that these man-made materials would not disposed naturally in the dumping site. These inorganic materials take hundreds of years to decompose and it will also bring a long term impact to the environment. Although the inorganic insulation materials has their continuing economic profit but the materials is hard to dispose and dangerous to human health. Therefore, for this study, organic material oil palm fibre and paper pulp will be used to replace the inorganic thermal insulation materials. Paper is a valuable material that can be recycled. Disposable papers are available and easy to obtain. Waste paper comes from different sources such as newspaper, office and printing papers. Since, Malaysia is one of the largest oil palm production in the world, therefore, the amount of oil palm waste fiber in Malaysia is far exceeds present and future fiber requirements for production of particle board.

II. MATERIALS AND METHODS

The types of waste material chosen for this study are paper and oil palm waste fiber. Figure 1 shows the process that had been carried out to make a particle board. The moisture content of oil palm fibre was removed using oven dry. The unwanted substance such as Oil Plam Shell was removed by sieving process. The weights of the fibre and paper pulp were recorded to measure the density for the particle board. The resin Urea Formaldehyde (UF) was use in this study as the binder of the oil palm fibre and paper pulp. After the mixture is mixing well, the oil palm fibre and paper pulp was place into a wooden mold and ready for the pre-press and hot-press. The required duration of pressing is 1 minute for every 1mm at the temperature of 100oC. After that the sample was trim to 300mm x 300mm so that the particle board can fit into the B480 Heat Flow Meter Apparatus for thermal conductivity measurement.

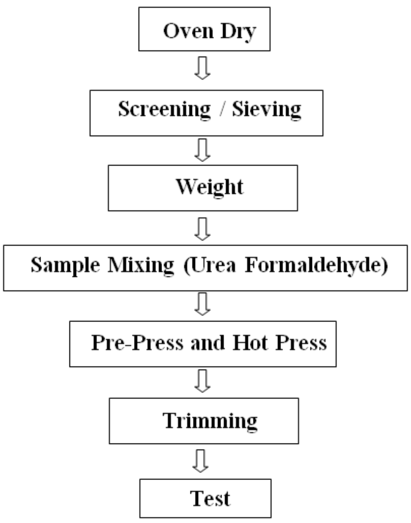

Figure 1: Summarize Process of Sample Preparation

A. Specific Gravity Test

The bulk density of oil palm fiber was determined from gravity measurements. The specific gravity of the oil palm fibers were measure using buoyancy test with water as the medium for immersion. Figure 2 shows the mass of the particle board mass is weighing in the air and in water by putting the sample into the sample holder. After the mass in the air is recorded, the sample holder will then immerse into the water, and the mass of the particle board in water was recorded.

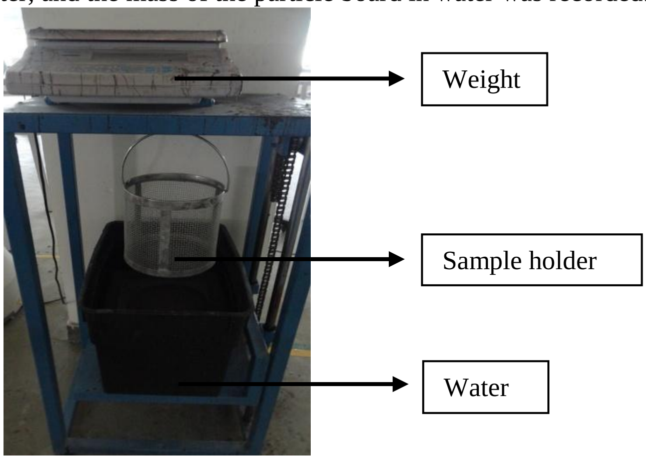

Figure 2: Buoyancy Test Machine

After the mass of the oil palm fiber in air and in water had determined, the bulk density could be calculates using Equation 1 and Equation 2.

Specific Gravity = (Mass in Air)/(Mass in Air - Mass in Water) (1)

Bulk Density = Specific Gravity x 1000 kg/m3 (Water Density at 24^{o}C) 2 (2)

B. Thermal Conductivity Test

B480 Heat Flow Meter is a ISO8301: 1991 recognized international standard equipment. The Hilton B480 unit is based on ISO 8301 and incorporates a heat flow meter. The sample was measured in accordance with British Standard 874: Part 2: 1986.

The particle board sample had been tested the thermal performance by using B480 Thermal Conductivity of Building and Insulating Materials as shown Figure 3. The sample is put within the hot plate and cold plate and the computer will calculate the heat flow meter (HFM), the thermal conductivity (K-value) can be determined after the HFM was obtained. The values of T_H, T_C and the heat flow meter output were taken after the steady state condition had been reached. The thermal conductivity is then automatically determined by computer program using Equation 3.

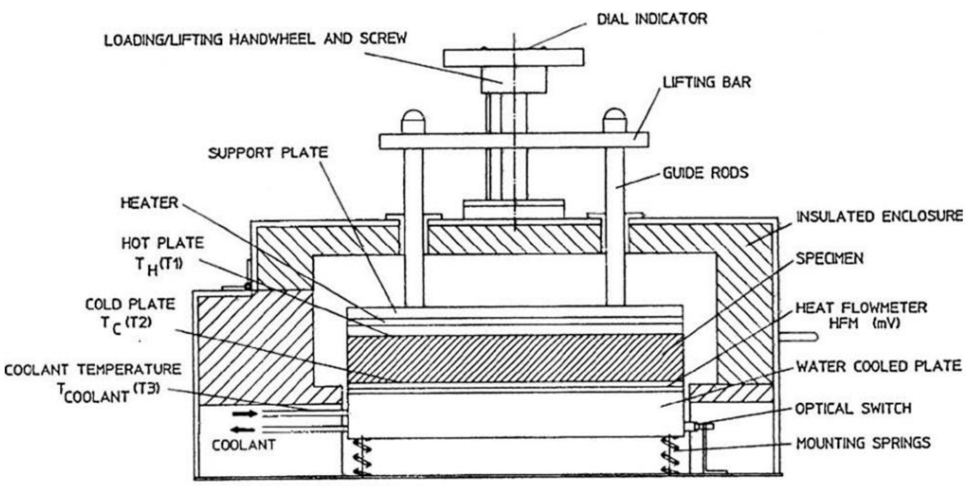

Figure 3: Cross-sectional Diagram of B480 Heat Flow Meter Apparatus (Source: P.A. Hilton Ltd)

$$\lambda = \frac{I_s \times \left[(K_1 + (K_2 \times T)) + \left((K_3 + (K_4 \times T)) \times HFM \right) + \left((K_5 + (K_6 \times T)) \times HFM^2 \right) \right]}{dT} \quad (3)$$

Where, l_s = Thickness of Sample (m)
T_1 = Upper Plate Temperature (^oC)
T_2 = Lower Plate Temperature (^oC)
dT = $T_1 - T_2$ (^oC)
T = $(T_1+T_2)/2$ (^oC)
HFM = Heat Flow Meter (mV)

Coefficients without the rubber mat,
K_1 = -30.7757
K_2 = 0.4721
K_3 = 3.2398
K_4 = -0.0101
K_5 = -0.0121
K_6 = 0.0003

C. Modulus of Flexural Test

Bending strength or so-called Modulus of Flexural was determined using the Flexural strength testing machine. The length of the support span used in this parameter was 200mm and 240mm for the width of the sample. After getting the maximum force, F_{max} from the testing machine, the Modulus of Flexural of the sample can be determine using Equation 4.

$$MOF = \frac{3F_{max}L}{2bd^2} \quad (4)$$

Where, F_{max} = Maximum force, N
L = Length of Support Span, mm
b = Sample width, mm
d = Sample thickness, mm

C. Particle Boards

Figure 4 shows the plan view and the cross section view of the 36mm particle board with 50% of paper pulp and 50% of oil palm fibre. The particle board is ready for HFM test, specific gravity test and Modulus of Flexural Test. Four particle boards had been fabricated at different percentage of paper pulp ratio. 10% of liquid Urea Formaldehyde of the total weight of the particle boards had been added and press at a 100^{o}C in the hot press machine for at least 12 minute, depends on the thickness of the particle boards. According to the resin manufacturer, the setting requirement for the Urea Formaldehyde was 100^{o}C and press for 1 minute for every 1mm. The thermal properties of the particle boards had been analyzed in this study.

Figure 4: Plan View and Cross Section of 36mm Particle Board (50% Paper Pulp and 50% of oil palm fibre)

III. Results and Discussions

A. Solid Density

From the data obtained from Table 1, the mean of the specific gravity of the oil palm empty fruit bunch was 0.7953. The solid density of the oil palm fiber empty fruit bunch was 795.3 kg/m^3. Solid density was calculated using Equation 2.

Table 1: Specific Gravity of the Oil Palm Fiber Empty Fruit Bunch

Specimen	Mass in Air (g)	Mass in Water (g)	Specific Gravity	Density (kg/m^3)
1	172.82	-42.88	0.8012	801.2
2	172.64	-47.12	0.7856	785.6
3	345.64	-87.34	0.7983	798.3
4	345.61	-86.94	0.7990	799.0
5	518.42	-140.14	0.7872	787.2
6	519.02	-137.88	0.7901	790.1
7	691.27	-169.80	0.8028	802.8
8	691.02	-172.38	0.7985	798.5

B. Thermal Properties

From Table 2 and Figure 5, the result shows that the paper pulp has slightly better insulation compare to the oil palm fiber. The 75% paper oil palm particle board shows slightly lower thermal conductivity 0.04158 W/mK at mean temperature of 20^{o}C compare to pure oil palm fiber particle board. According to previous study [11,12], it found that the materials that containing cellulose or so-called lignocellulosic fiber are good in acoustic and thermal insulation. Beside the oil palm fiber, paper is another lignocellulosic material that containing cellulose and it is the easiest materials that can be obtained. Lignocellulosic materials are non-expensive, accessible, renewable and fundamental resources of great human importance.

The results show that the particle board with higher percentage of with paper pulp will decrease the K-value of the particle boards. This indicated that the higher the paper pulp added in the particles board, the lower the thermal conductivity of the particles board and within the range of acceptable thermal conductivity for insulation materials.

Table 2: Thermal Conductivity for Different Ratio of Oil Palm and Paper Pulp

Density (kg/m^3)	Paper Ratio (%)	Mean Temperature		
		20^{o}C	25^{o}C	30^{o}C
		K-value (W/m.K)	K-value (W/m.K)	K-value (W/m.K)
250	10	0.111	0.113	0.115
250	25	0.076	0.078	0.081
250	50	0.045	0.047	0.048
250	75	0.041	0.043	0.045

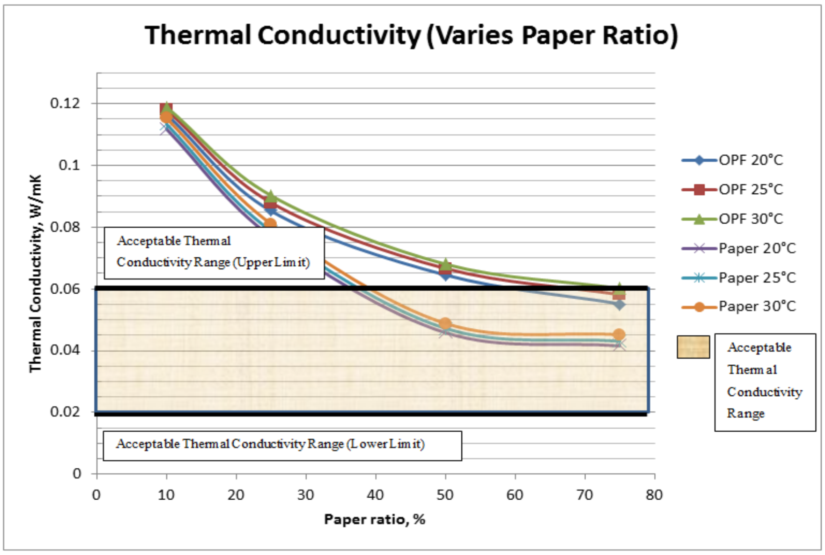

Figure 5: Relationship between Paper Pulp and Oil Palm Fiber

Table 3 shows that the existing insulation materials have higher thermal resistance compare to the oil palm particle board and the oil palm paper pulp particle board. Some modification of the particle boards had been made to achieve the thermal resistance of the existing insulation materials. By increasing the thickness of the particle board from 48mm to 150mm the thermal resistance can increase up to 2.73 m^2K/W for Oil Palm Particle Board ($250kg/m^3$).This result shows similar agreement with the study conducted by Al-Nasearawi [13] stated that the increasing of thickness will lead to the increment of thermal resistance of the materials.

Table 3: List of Thermal Conductivity and Thermal Resistance

Building Insulation Material	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^2K/W)
Glass Wool ($48kg/m^3$)	180	0.044	4.091
Stone Wool ($160kg/m^3$)	160	0.038	4.211
Sheep Wool ($160kg/m^3$)	215	0.054	3.981
Cellulose Fiber ($24kg/m^3$)	190	0.046	4.130
Hemp Fiber	165	0.039	4.231
Polyester Fiber	180	0.044	4.091
Wood Fiber	225	0.061	3.689
Cotton	170	0.040	4.250
Cork ($120kg/m^3$)	200	0.055	3.636
Oil Palm ($250kg/m^3$)	48	0.055	0.873
25% Oil Palm + 75% Paper ($250kg/m^3$)	48	0.042	1.154

IV. CONCLUSION

Thermal conductivity of the particle board had been reduced around 4.1% by increasing the percentage of paper pulp into the total density of the particle board. By adding 75% of paper pulp, the thermal conductivity of the particle board could be reduced to 24.6%. Therefore, from this study, it could be concluded that paper pulp has high potential to be use as an insulation material. The most important fact is the paper pulp is a biodegradable composite which will not bring any negative impact to the environment compare to the non-biodegradable insulation materials available in the market. By having insulation material in the building, the energy usage could be reduce and increase the energy efficiency of the building. On the other hand, energy efficiency building also gives less impact to the environment and enhances the quality of life of the occupants.

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