

Thermal properties of corn husk fiber as insulation for flat plate solar collector

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Abstract

In order to reduce solar collector cost, heat loss of collector system and improve collector efficiency, the development of thermal insulation is a significant factor. In this research, local agricultural residue, corn husk fiber, is experimentally investigated to be a suitable insulation material for flat plate solar collector. Thermal conductivity, thermal resistance and thermal deterioration, of corn husk fiber have been determined. Factors affecting thermal conductivity, which include density, level of urea formaldehyde and paraffin, were examined. Additionally, collector testing to compare thermal performance between corn husk fiber and conventional fiber glass insulation material has been performed. It was found that $F_R(\tau\alpha)_e$ and $F_R U_L$ for corn husk fiber and fiber glass are 0.49 and 0.47, respectively and 7.73 and 9.85 W/m².°C, respectively. Cost evaluation for both insulation materials was done, which indicated that cost of corn husk is lower than that of fiber glass. The results showed that corn husk fiber is technically and financially more suitable insulation material than fiber glass.

Keywords: *insulation material, thermal property, flat plate solar collector, collector efficiency*

1. Introduction

Currently fiber glass or glass wool is mostly used as insulation material for flat plate solar collector, which has thermal conductivity ranging from 0.035 to 0.045 W/m.K [1]. Thermal insulation which is used to minimize heat loss of the system is one of the factors having reasonable influence on the performance of flat plate solar collector. The development of materials with better thermal insulation properties than fiber glass insulation is an effective way to improve the performance of the flat plate solar collector.

Thailand imports fiber glass materials on an average of 4.1 billion Baht per year [2]. Being an agricultural country it produces a large amount of agricultural residue every year. The agricultural residue composed of groups of cellulose is the one which is quite suitable for thermal insulation production. Several cellulose fibers from agricultural residue such as durian peel and coconut coir [3 - 4], coconut and sugarcane fibers [5], cotton stalk fiber [6], pineapple leaves [7], coconut husk and bagasse [8], rice straw [9], oil palm [10-12] and narrow-leaved cattail fibers [13] have been used as thermal insulation materials in buildings(in walls and ceilings).

In 2013, corn cultivated area was 1,179,123.2 hectare in Thailand and yielded 4,984,663 ton [14]. Corn husk is one of the local agricultural residues, which has no other utilization except animal food in a limited quantity. From previous research works, we came to know that corn husk fiber has never been investigated as insulation material for flat plate collector. Therefore, in this research, corn husk is selected to be used as thermal insulation for the flat plate solar collector. Experiment for determining thermal properties of corn husk was performed and thermal performance of flat plate collector using corn husk fiber as insulation material was determined and compared with collector system using fiber glass.

2. Preparation of raw material

Corn husk used in this research was collected from Northeastern region of Thailand after harvesting corn crop. Husk fibers were reduced to smaller particle sizes with grinder as shown in Figure 1 (a). Afterwards the corn husk particles were pretreated by soaking with 10% NaOH solution to improve the corn husk fiber as shown in Figure 1 (b). In addition, quantity of fiber has been evaluated by proximate analysis.



Figure 1 Characteristic of corn husk (a) Smaller particle size by a grinder
(b) Corn husk fiber after pretreatment with 10% NaOH solution

Pretreatment of corn husk with 10% NaOH solution at various reaction times yields different fiber percentages. This shows reaction time has an affect on fiber quantity as shown in Table 1.

Table 1 Percentage of crude fiber of corn husk fiber after pretreatment with 10% NaOH at various reaction times

Corn husk	Crude Fibers (%)
Non-pretreatment	33.03
Pretreatment with 10% NaOH for 30 minutes	39.49
Pretreatment with 10% NaOH for 45 minutes	39.95
Pretreatment with 10% NaOH for 60 minutes	44.54
Pretreatment with 10% NaOH for 90 minutes	44.72

As appeared in Table 1, during pretreatment of corn husk with 10% NaOH, ranging reaction times from 30 to 90 minutes, it is found that sodium hydroxide solution affects fiber quantity in terms of reaction time when compared with the specimen without pretreatment. This results in destroying bond between various fibers such as cellulose, hemicellulose and others which causes fiber quality to be improved. However, total reaction time for 60 minutes is selected because there is only marginal difference between 60 and 90 minutes results. Chemical composition of corn husk with and without pretreatment can be seen in Table 2.

Table 2 Chemical composition of corn husk

Chemical composition	% (By dry weight)	
	Non-pretreatment	Pretreatment
Cellulose	47.00	61.37
Hemicellulose	43.96	19.93
Lignin	4.13	2.23
Ash	2.93	12.48

Table 2 shows the percentage of the corn husk fiber soaked in 10% NaOH solution for 60 minutes, the percentage of cellulose is increased while percentage of hemicellulose and lignin is decreased because the amount of starch is removed and structure of hemicellulose is destroyed, while cellulose is the major part for producing fiber insulation board.

3. Thermal Properties of Corn Husk

Effective thermal properties of the insulation material namely thermal conductivity (k) and the thermal resistance (R) can be determined at room temperature and normal pressure in the steady state. The basic principle of operation is to create one-dimensional axial heat flow through the specimen using the Fourier's equation of heat conduction by following the equation (1) and thermal resistance can be calculated from equation (2).

$$q_{cond} = -kA \frac{dT}{dx} \tag{1}$$

Where q is the steady-state heat flow (W/m^2), k is the thermal conductivity ($W/m.K$), A is the area of the specimen (m^2) and $-dT/dx$ is the temperature gradient (K).

$$R = \frac{\Delta T}{q/A} \tag{2}$$

The corn husk fiber insulation board is formed by spraying with urea formaldehyde resin as a binder adhesive and paraffin as a moisture resistant. The duration of cold insulation compression was 8 hours for a thickness of 10 mm, as shown in Figure 2.



Figure 2 Specimen of corn husk fiber insulation board

Structure of the corn husk fiber insulation board is determined by Stereo microscope of 50x. It was found that the characteristics of untreated corn husk were smooth and dense in mat as shown in Figure 3 (a), whereas after pretreatment they were disorganized with increased porosity or voids as shown in Figure 3 (b). This difference was produced by sodium hydroxide solution after reaction with fibers resulting in high cellulose purity, showing that pretreatment of corn husk helps to obtain good properties for being thermal insulation.

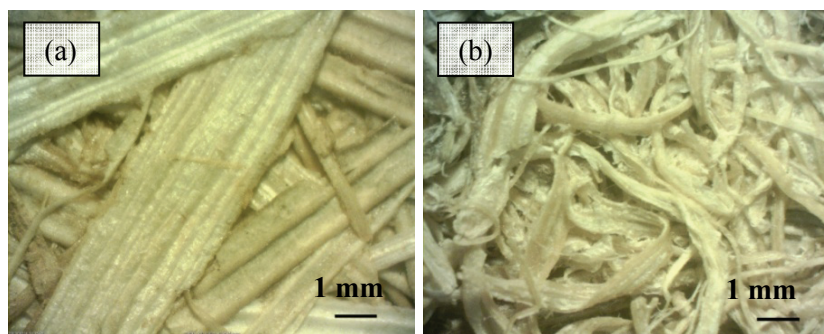


Figure 3 Structure of the corn husk fiber insulation
(a) Non-pretreatment (b) Pretreatment with 10% NaOH solution

Table 3 Various Parameters obtained from determining thermal property

Type of insulation	Density (kg/m ³)	Moisture content (%)	Thermal conductivity, <i>k</i> (W/m.K)	Thermal resistance, <i>R</i> (m ² .K/W)
Corn husk fiber insulation at density 100 kg/m ³	112	12.05	0.0289	0.3457
Corn husk fiber insulation at density 200 kg/m ³	223	12.28	0.0287	0.3488
Corn husk fiber insulation at density 300 kg/m ³	329	13.18	0.0306	0.3269
Corn husk fiber insulation at density 400 kg/m ³	428	14.03	0.0316	0.3161
Corn husk non-pretreatment insulation	214	3.82	0.0312	0.3203
Fiber glass insulation	60	-	0.0327	0.3060

Table 3 shows thermal conductivity of corn husk insulation and fiber glass insulation. The experiment result shows that thermal conductivity of different densities of corn husk with pretreatment ranges from 0.0287 to 0.0316 W/m.K and for untreated 0.0312 W/m.K, while that of fiber glass insulation is 0.0327 W/m.K. As these values are less than 0.25 W/m.K can safely be used as insulation material [1].

This study also examines the various factors such as density, urea formaldehyde resin level and paraffin level which affect thermal conductivity.

3.1 Effects of density on thermal conductivity

As shown in Figure 4, specimens consisting of urea formaldehyde resin at 30% and paraffin at 1% are studied to estimate effect of density on thermal conductivity. Low ranging densities of 100, 200, 300 and 400 kg/m³ were studied. These values were selected as in [15].

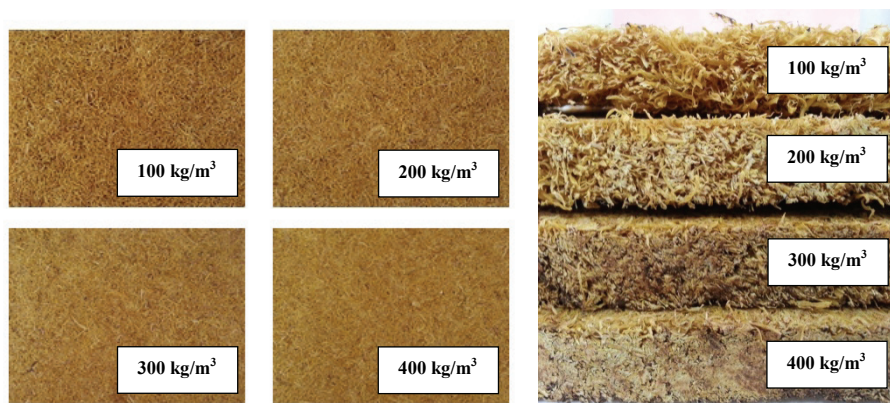


Figure 4 Corn husk fiber insulation at density of 100, 200, 300 and 400 kg/m³

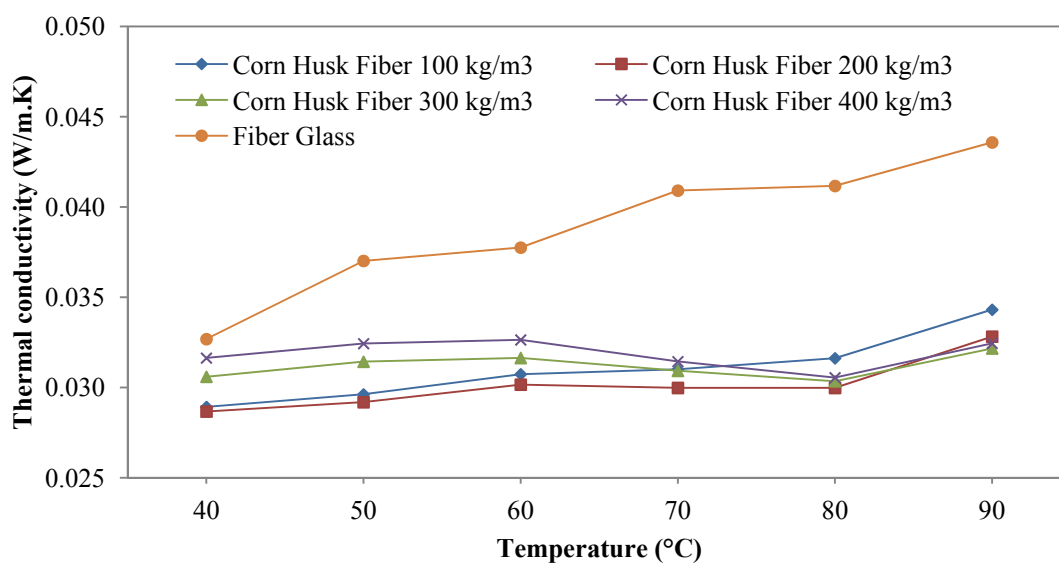


Figure 5 Thermal conductivity of corn husk fiber at different densities and fiber glass for varying temperatures

Figure 5 shows relationship of thermal conductivity of corn husk fiber for different densities and fiber glass at different temperatures. From Figure 5, it can be seen that when temperature and density increases, thermal conductivity increases as well. However, as density corresponds to porosity, increased porosity can transfer heat easier, such as at density of 100 kg/m³. While at density of 300 and 400 kg/m³, porosity of material is very little, resulting in higher thermal conductivity. From figure 6 it can be seen that thermal conductivity is lowest at density of 200 kg/m³, hence selected to prepare insulation material.

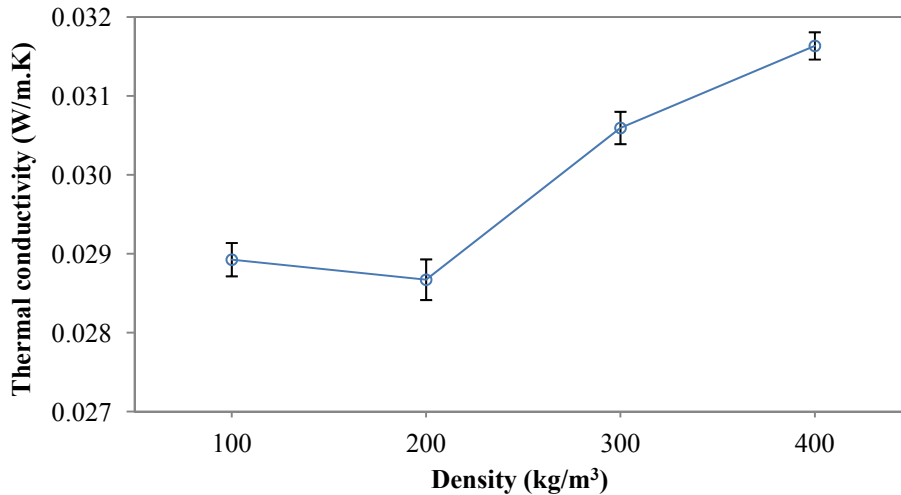


Figure 6 Thermal conductivity of corn husk fiber insulation as a function of board density

3.2 Effects of paraffin on thermal conductivity

Effect of different paraffin levels (1%, 3%, 5% and 7%) at a density of 200 kg/m³ on thermal conductivity of corn husk fiber was examined as shown in Figure 7.

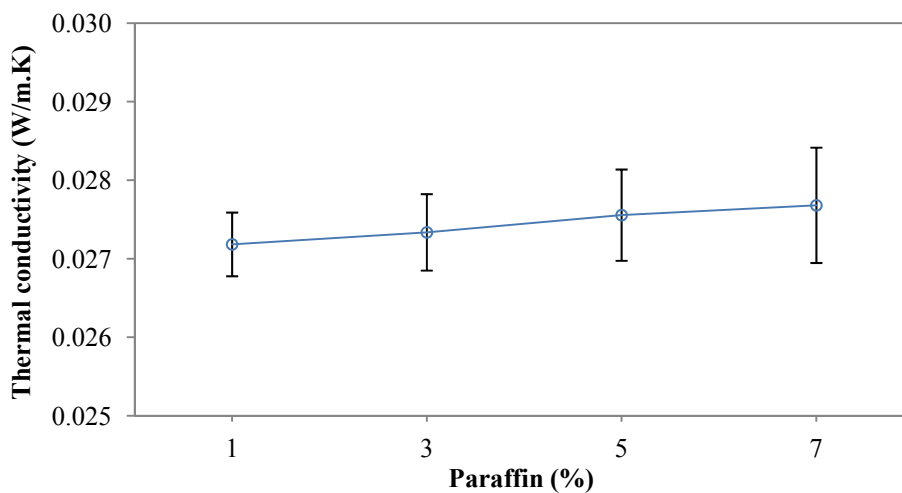


Figure 7 Thermal conductivity of corn husk fiber insulation as a function of paraffin content

Figure 7 shows that variation of paraffin levels ranging from 1% to 7% at a density of 200 kg/m³ does not affect thermal conductivity. Thermal conductivity was recorded constant at 0.028 W/m.K. Paraffin resists moisture absorption by the insulation board, as fibers and parenchyma are constituted from hemicellulose which has high ability to absorb moisture [4]. The moisture in the air causes the insulation to swell resulting in poor insulation.

3.3 Effects of urea formaldehyde resin on thermal conductivity

Effect of different urea formaldehyde resin levels (10%, 20%, 30% and 40%) at a density of 200 kg/m³ on thermal conductivity was determined as shown in Figure 8.

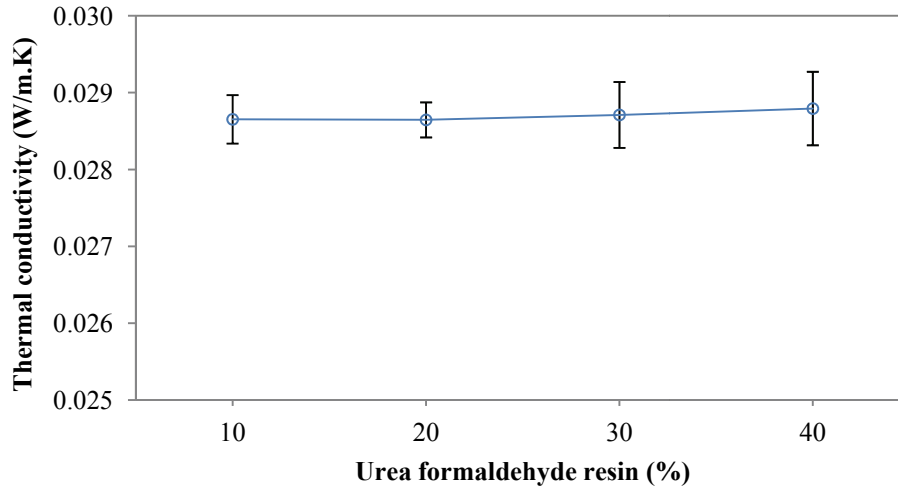


Figure 8 Thermal conductivity of corn husk fiber insulation at different urea formaldehyde resin levels

The results showed negligible variation in thermal conductivity at different urea formaldehyde levels ranging from 10% to 40% at the density 200 kg/m^3 . Type of adhesive affects the strength of the insulation [3]. The adhesive is a factor in increasing the strength of thermal insulation, can be expressed by the mechanical strength and dimensional stability of insulation, which makes note of the potential of applications.

3.4 Effect of the thermal deterioration

Temperature limitation is a factor affecting use of corn husk fiber insulation. This study aims to determine suitable temperature range of this type of insulation for applications. Thermal deterioration of the insulation material can be determined by simultaneous thermal analysis (TGA/DSC) technique, which is analyzed at conditions of temperature range of $30 \text{ }^\circ\text{C}$ to $750 \text{ }^\circ\text{C}$ and nitrogen gas is used as carrying gas at flow rate of 30 mm/Min . The result can be seen in Figure 9.

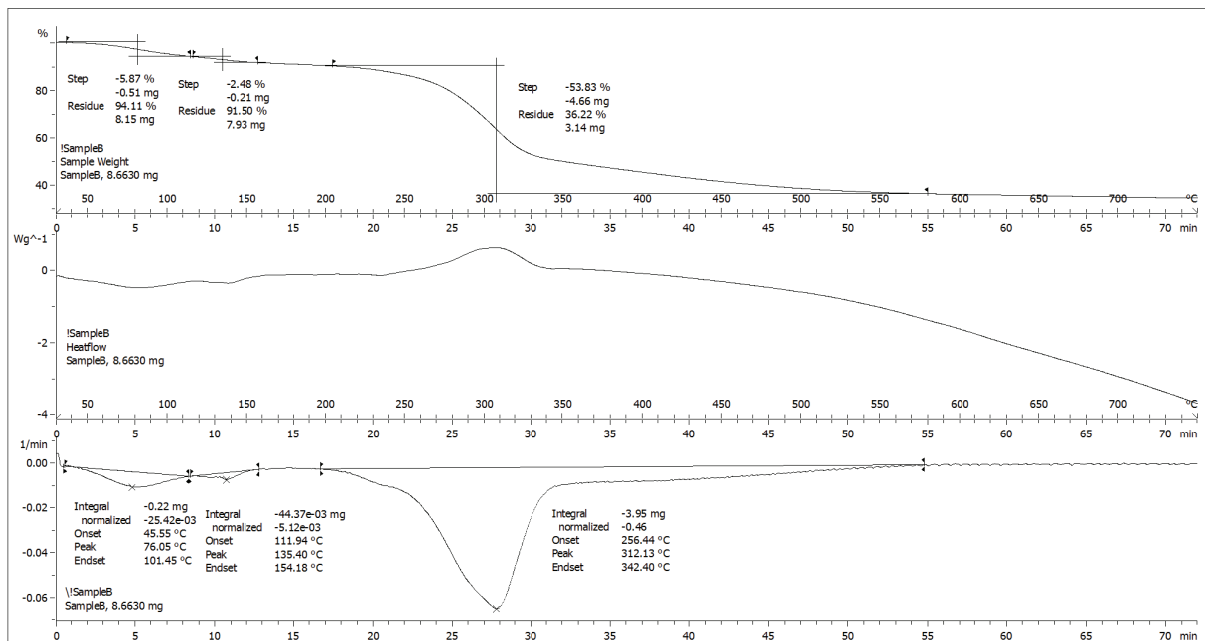


Figure 9 Thermal deterioration of corn husk fiber with TGA/DSC technique

Figure 9 shows the relation of weight loss with the rising temperature for corn husk fiber material. In the temperature range of 45.5 to 154.2°C, total weight loss is 8.5% because of vaporization of moisture. For temperature range of 256.4 to 342.4°C, total weight loss is 55.3% resulting from decomposition of material structure. This result corresponds with the findings in [16]. Cellulose materials are used as insulation having long lifetime as 5-10 years, depending on temperature [17, 18]. The above results also indicate that material under investigation possess high thermal stability, thus suitable to use as insulation for flat plate collector.

4. Performance of flat plate solar collector for different thermal insulations

After determining thermal properties of corn husk fiber, production of corn husk fiber insulation at optimal density of 200 kg/m³ was performed. In addition, flat plate collector using corn husk fiber as insulation material was fabricated and tested, in accordance with ASHRAE Standard 93-77, to determine collector thermal efficiency and thermal performance. Several parameters were collected including solar radiation intensity, G_t , ambient temperature, T_a , inlet, $T_{f,i}$ and outlet, $T_{f,o}$ water temperature and mass flow rate of water, \dot{m} . The collected data was analyzed in detail. Additionally, thermal performance of flat plate collector, using corn husk and fiber glass as insulation material was compared with each other. Instantaneous collector thermal efficiency (η) for two types of insulation materials is plotted with the term of $(T_{f,i} - T_a) / G_t$, as shown in Figure 10.

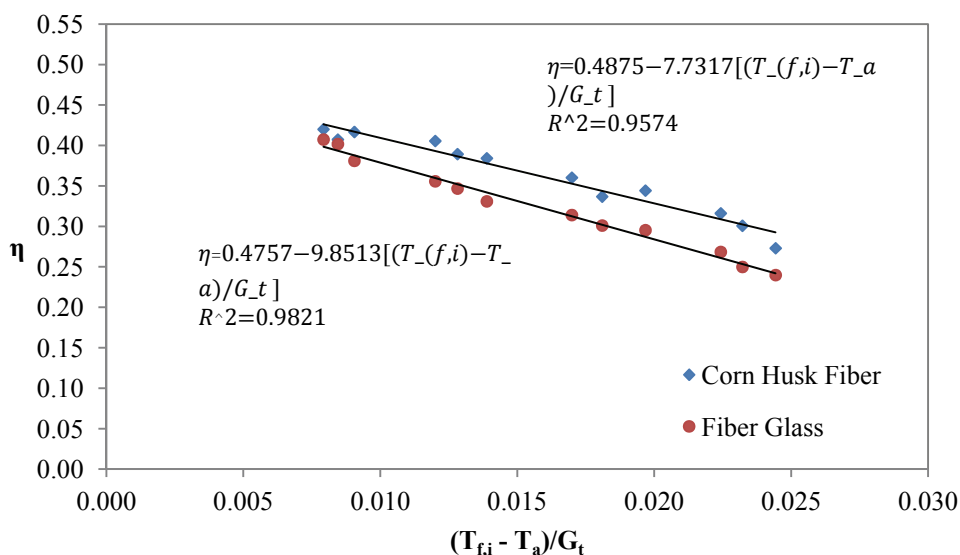


Figure 10 Relationship between collector thermal efficiency (η) and term $(T_{f,i} - T_a) / G_t$ for corn husk fiber and fiber glass as insulation

Collector using corn husk fiber as insulation was tested at solar radiation intensity ranging from 877 to 968 W/m², ambient temperature ranging from 26.4 to 28.5 °C and fluid inlet temperature ranging from 34.8 to 50.8 °C. From the plot of collector efficiency (η) and the term $(T_{f,i} - T_a) / G_t$, collector characteristics $F_R(\tau\alpha)_e$ and $F_R U_L$ are 0.49 and 7.73 W/m².°C, respectively. Additionally, collector using fiber glass as insulation was tested under solar radiation intensity ranging from 802 to 969 W/m², ambient temperature ranging from 26.9 to 30.7 °C and fluid inlet temperature ranging from 34.7 to 50.4 °C, $F_R(\tau\alpha)_e$ and $F_R U_L$ 0.47 and 9.85 W/m².°C, respectively, as shown in figure 10. This figure shows that corn husk fiber exhibits lower heat loss than fiber glass when used as insulation material for collector system. This is because thermal conductivity of corn husk fiber is

lower than fiber glass. Thus, it can be inferred that corn husk fiber is more suitable insulation material than fiber glass.

5. Production cost of Corn husk fiber insulation

From experimental comparison, thermal properties and performance of flat plate solar collector indicate that corn husk fiber yields better insulation quality than the commercial insulation, fiber glass. Corn husk fiber being agricultural residue has nominal cost, however commercial production will involve processing and other materials costs. Total production cost of corn husk fiber insulation at density of 200 kg/m^3 , dimension of $1.0 \times 1.0 \times 0.01 \text{ m}$, and by using urea formaldehyde resin and paraffin of 300 g/m^2 and 20 ml/m^2 , respectively is 3.7 US/m^2 . This cost is cheaper than that of fiber glass insulation, 5.1 US/m^2 .

6. Conclusion

This research work emphasizes on development of insulation material for flat plate solar collector, from local agricultural residue. Corn husk was selected to study because of its abundance in Thailand and negligible utilization. Preparation of corn husk insulation material for collector was performed. Pretreatment with sodium hydroxide can improve fiber to obtain suitable quality. Thermal properties of corn husk, which were experimentally examined, are thermal conductivity, thermal resistance and thermal deterioration. In order to obtain suitable thermal conductivity for corn husk insulation material, three factors affecting thermal conductivity, density, level of urea formaldehyde resin and paraffin, were varied to determine optimum conditions to fabricate insulation material. From experiment results, it was found that among the three investigated factors, only density affects thermal conductivity and optimal value is 200 kg/m^3 yielding low thermal conductivity of 0.0287 W/m.K and thermal resistance of $0.3488 \text{ m}^2\text{K/W}$. Collector testing was performed to compare corn husk fiber and fiber glass insulation material. Results indicated that corn husk fiber proved to be more suitable insulation material than fiber glass, with lower heat loss coefficient and higher optical efficiency. In addition, corn husk fiber insulation has lower cost of production when compared with fiber glass insulation. In view of this research corn husk fiber can be introduced as a new promising insulation material for collectors by the manufacturers in the near future.

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