Heat Transfer Characteristics of Paraffin in Staggered Fins Heat Exchanger for the Cooling Process to Room Cooling Applications

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IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: M Irsyad *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **520** 012009

View the article online for updates and enhancements.

IOP Conf. Series: Earth and Environmental Science **520** (2020) 012009 doi:10.1088/1755-1315/520/1/012009

Heat Transfer Characteristics of Paraffin in Staggered Fins Heat Exchanger for the Cooling Process to Room Cooling Applications

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Abstract. The night air temperature which is below or equal to the temperature of human thermal comfort is very potential to be used to help reduce the thermal load of the room. This utilization can help minimize the electrical energy consumption of air conditioning systems. Phase change material (PCM) can be used to utilize the potential of cold air at night as latent heat thermal energy storage (LHTES). One model of the application of PCM is the heat exchanger. PCM fills one part of the heat exchanger. The characteristics of heat transfer need to be known so that it can know the cooling rate and the time required in the process. The variable used in this study is the inlet air velocity. In this research, a staggered fins-type heat exchanger which contains PCM with paraffin material is used in the cooling process. The results showed that an increase in speed would accelerate the cooling rate. At a velocity of 3 $m.s^{-1}$, the average cooling rate of the PCM mass unity was 6.4 $^{o}C.hr^{-1}.kg^{-1}$. With this rate of cooling, the potential for cold night air for about two to three hours can be utilized for the PCM freezing process.

1. Introduction

Paraffin is one of the materials used as a store of thermal energy and is known by which the phase change material (PCM). Paraffin is an organic PCM which has high latent heat, which ranges from 82.7 - 257 kJ/kg [1,2]. Paraffin also has a wide temperature change temperature range of -57 ^{o}C to 71 ^{o}C and is influenced by the number of carbon atoms [2,3]. Other thermal properties that support the use of paraffin as PCM are having specific heat and relatively high thermal conductivity namely: 2.1 $kJ.kg^{-1}.K^{-1}$ and 0.21 $W.m^{-1}.K^{-1}$ [4,5]. Paraffin is a material that is easily obtained at low prices. Paraffin is applied for heating and cooling processes. Some research results show that paraffin as PCM can reduce the thermal load of the room, reduce the thermal conductivity of walls and reduce the electrical energy consumption of buildings.

To obtain thermal comfort in the activities and breaks in the room have been used air conditioner (AC). However, the use of this tool has an impact on a significant increase in building energy consumption. AC energy consumption in commercial buildings ranges from 38 % - 65 % [6,7,8,9]. The amount of AC electrical energy consumption is affected by the cooling load of the room. The cooling load of this room comes from the thermal energy generated by humans, lamps and other electrical equipment in the room. Also, thermal energy is coming from the walls, windows, and roofs that come from solar radiation. This high energy consumption has driven energy efficiency efforts in air conditioners both by increasing equipment efficiency, as well as reducing the cooling load of the room. One effort that has been investigated is the use of PCM to reduce the cooling load of the room.

Tropical regions such as Indonesia have the potential for relatively cold night air with an average minimum temperature below human thermal comfort temperature [10]. This potential can be utilized to reduce the thermal load of the room during the day by utilizing PCM as thermal energy storage. The potential for cold night air is used to cool down the PCM so that the phase changes become solid. During the day PCM is used to absorb the thermal energy of the room so that the material change become liquid again. By experiencing the phase change PCM can release and absorb thermal energy much higher than without phase change because it involves latent heat. Based on this, it is necessary to research the use of paraffin as a PCM in heat exchangers and the potential for the cold air at night air to cool the room. This research is focused on the heat transfer characteristics of the heat exchanger containing PCM in the cooling process.

2. Materials and Experiment

This research is an experimental study on a staggered fins type heat exchanger containing PCM to determine its heat transfer characteristics. The material used as PCM is paraffin.

2.1. Materials

Paraffin is used as commercial paraffin which is the result of mixing paraffin wax with solid and liquid phases. Paraffin wax has a melting temperature of 56 ^{o}C equivalent to Paraffin C26. Whereas liquid Paraffin has a temperature of -10 ^{o}C equivalent to Paraffin C12. The composition of the two suitable raw materials is obtained when the paraffin mixture has a freezing temperature reaching 20 ^{o}C.

2.2. Experiment

The initial stage of the research is mixing solid and liquid paraffin to obtain a suitable phase change temperature. To obtain this result a T-history test was performed. After obtaining a suitable paraffin composition, this mixture was tested for the type of compound and its amount of content using Gas Chromatography-Mass Spectrometry (GC MS) produced by Varian type Saturn CP-3800/2200MS.

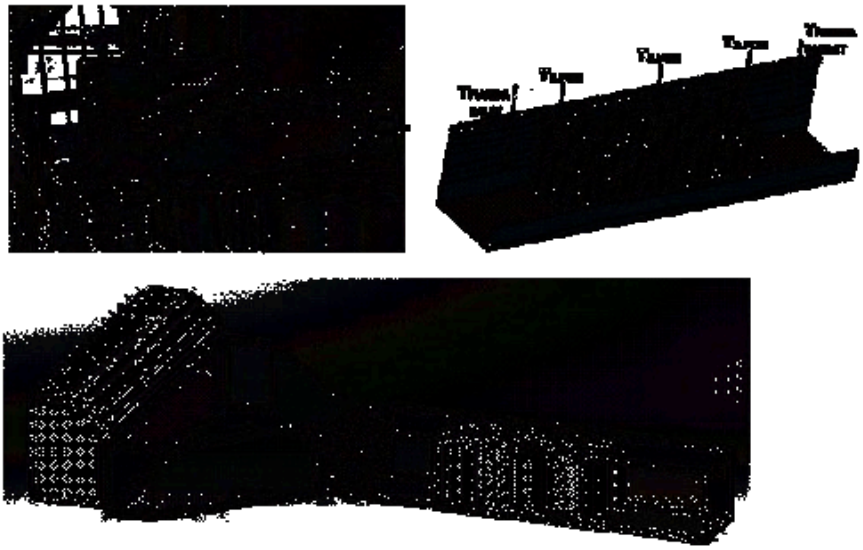

Figure 1. Photo and schematic of a staggered fins type heat exchanger.

In the second phase of research, two things were analyzed, namely the cooling rate and the rate of heat transfer. The parameters tested are the temperature of the incoming and outgoing air and the temperature of the PCM in the fins at three points as shown in Figure 1. This data is taken for the air temperature of 20 ^{o}C and several variations of velocity namely: 1 m.s^{-1}, 2 m.s^{-1}, and 3 m.s^{-1}. Air mass flow rates for each of these velocity are: 0.027 kg.s^{-1}, 0.057 kg.s^{-1} and 0.078 kg.s^{-1}. The temperature selection of 20 °C is the lowest possible ambient air temperature in several regions in Indonesia. PCM temperature data obtained from the cooling rate. From the PCM temperature data, the average cooling rate is calculated. The cooling rate is calculated as a cross-sectional area. Calculation of average cooling rate using Equation 1. While the data from the temperature of the incoming and outgoing air obtained the heat transfer rate at the heat exchanger using Equation 2. The total energy released by PCM is calculated using the energy balance equation assuming no heat goes into in a system that is the energy absorbed by air equal to the energy released by PCM, as shown in Equation 3. This data is then used to predict the percentage of the mass of PCM solids formed using Equation 4.

$$\dot{T} = (T_a - T_o)/(t_a - t_o) \quad (1).$$

$$\dot{Q}_{udara} = \dot{m} C_p dT \quad (1).$$

$$Q_{udara} = Q_{PCM} \quad (3).$$

$$Q_{PCM} = (\Delta x_s) m C_{ps} dT + (\Delta x_{sl}) m L + (\Delta x_l) m C_{pl} dT \quad (4).$$

The notation used in Equation 1 to Equation 4 is as follows: $\dot{T}$ is the cooling rate (°C.min^{-1}). T is Temperature °C) and t is time (min) with subscript notation a and o indicating the end and initial conditions. $\dot{Q}$ is the rate of heat transfer (Watt). $\dot{m}$ is the mass flow rate (kg.s^{-1}). C_p is the specific heat (kJ.kg^{-1}.K^{-1}). ΔT is the temperature difference (K). Q is total energy (kJ). m is mass (kg). Δx is the percentage of mass with subscript notation s for solid-phase, l for the liquid phase and sl for phase change (%).

The staggered fins type heat exchanger has 39 fins arranged in zig-zag with several lines are 11 on the channel with a cross-section size of 100 x 150 mm. Odd lines number 4 fin and even number 3 fin. Fin is made of hollow aluminum with a size of 1 x 0.5 inches with a height of 150 mm. The distance between fins is the number of hollow used is 39 pieces. The gap distance between fins in the same line is 0.5 inch and the gap distance between lines is 1 inch. The total heat transfer surface area of the heat exchanger is 0.45 m^2.

3. Result and Discussion

The paraffin test results to obtain a paraffin mixture that has a phase change temperature that matches the temperature of the cold air is with a composition of 95.5 % liquid paraffin and 4.5 % solid paraffin. The T-history test results obtained freezing and melting temperatures as shown in Figure 2. In this method, the freezing temperature is determined by visualization. Freezing starts at 28 °C which is shown by the formation of small lumps in white, while the liquid is still clear. The overall PCM color change becomes white and paraffin does not move when tilted occurs at a temperature of 21 °C. This temperature is considered as the final freezing temperature. This temperature is considered as the final freezing temperature. In the melting process, paraffin starts to melt at 22 °C and ends at 28 °C.

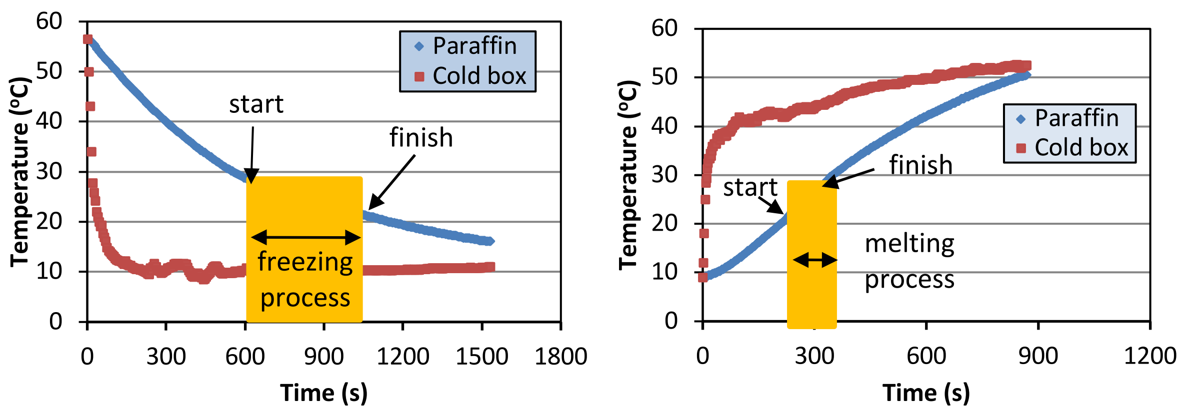

Figure 2. T-History test of paraffin in freezing and melting process

The types of compounds contained in this paraffin mixture obtained from the GC MS test results are shown in Table 1. The dominant compounds are 17-Pentatriacontane with 18.28 %, Pentatriacontane with 17.88 %, Tetrapentacontane, 1, 54-dibromo- with an amount of 14.87 %, 1-Hexacosene with an amount of 13.74 % and 12.65 %.

Table 1. List of name and composition of compounds from paraffin

No	Rt	Mw	m/z	Name of Compound	R. Match	F. match	% Prob	Area	% Area
1	11.522	422	57	Triacontane	785	723	26.76	16970000	6.66
		492	57	Pentatriacontane	745	710	20.69		
2	13.035	914	57	Tetrapentacontane,1, 54-dibromo-	719	710	23.49	37870000	14.87
3	14.531	492	57	Pentatriacontane	767	737	26.32	45530000	17.88
		592	57	1-Hentetracontanol	737	726	21.06		
4	16.005	490	57	17-Pentatriacontane	741	731	28.6	46540000	18.28
		508	83	1-Pentatriacontanol	738	709	26.7		
5	17.431	364	43	1-Hexacosene	769	753	27.54	34990000	13.74
		492	57	Pentatriacontane	762	718	24.76		
6	18.864	364	43	1-Hexacosene	725	715	25.17	32200000	12.65
		914	57	Tetrapentacontane,1, 54-dibromo-	737	707	21.31		
7	20.285	296	57	Octadecane,1-(ethenyloxy)-	735	721	23.15	18690000	7.34
		268	82	Oxirane,hexadecyl-	744	720	23.03		
8	21.83	392	57	Cyclooctacosane	769	729	21.45	13750000	5.40
		324	43	4-methyldocosane	736	727	20.78		
9	23.648	392	57	Cyclooctacosane	784	733	25.16	4050000	1.59
		324	43	4-methyldocosane	741	729	24.58		
10	25.937	364	43	1-Hexacosene	778	753	29.43	2153000	0.85
		296	57	Octadecane,1-(ethenyloxy)-	740	708	21.45		
11	28.695	296	71	Phytol	734	715	23.79	1897000	0.74
		282	85	2(3H)-Furanone,dihydro-5-tetradecyl-	717	704	21.45		
				Total				254640000	100.00

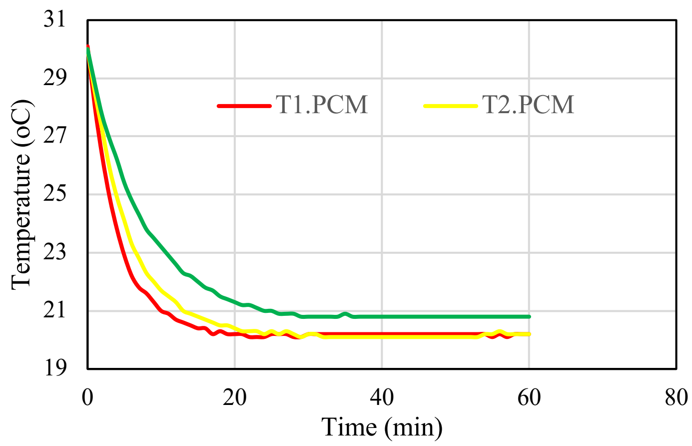

Figure 3. Graph of decrease in PCM temperature at an air velocity of 3 m.s^{-1}.

PCM temperature drop test was taken at three points, namely: fin on the first line ($T_{1.PCM}$), the fin on the 6th line ($T_{2.PCM}$), and fin on the 11th line ($T_{3\ PCM}$). The test results are shown in Figure 3 and show that $T_{1.PCM}$ has a faster cooling rate than $T_{2.PCM}$ and $T_{3.PCM}$. This is because of $T_{1.PCM}$ has a location that is directly facing the inlet air temperature while $T_{2.PCM}$ and $T_{3.PCM}$ has a location that is fartheraway from the inlet air temperature so that the air temperature has increased.

Figure 4 is a graph of the effect of air velocity on the PCM temperature drop. This graph shows that the greater the air velocity, the faster the PCM temperature decreases. This is because the air velocity is directly proportional to the mass flow rate. Also, an increase in air velocity increases the rate of convection heat transfer that occurs between the air and the fin surface. However, as the process of PCM temperature decreases the temperature difference between air and PCM decreases so that the effect of air velocity on PCM temperature decreases becomes insignificant. After 60 minutes of cooling, the final PCM temperature for these three speeds is not much different.

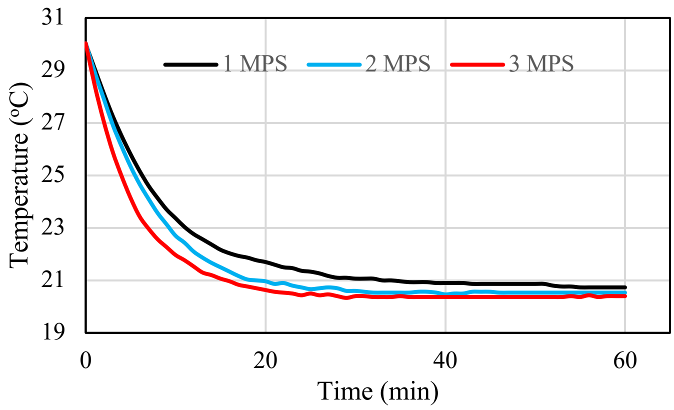

Figure 4. Graph of decrease in PCM temperature at an air velocity of 3 m.s^{-1}.

From the results of the PCM temperature drop test, the overall cooling rate can be calculated. The cooling rate in each test variation is shown in Table 2. The air velocity into the heat exchanger affects the PCM cooling rate. This is because the large air velocity can increase the rate of heat transfer so that the PCM temperature were reduced faster. In this test, the greatest cooling rate was 6.4 ºC.hr^{-1}.kg^{-1} at an air velocity variation of 3 m.s^{-1}.

Table 2. Cooling rate of paraffin in the staggered fins type heat exchanger

Air Temperature (˚C)	Cooling rate of Paraffin (ºC.hr^{-1}.kg^{-1})		
	1 m.s^{-1}	2 m.s^{-1}	3 m.s^{-1}
20	6.2	6.3	6.4

The energy needed in the cooling process for each velocity from the results of calculations using Equation 2 were: 93.9 kJ for 1 m/s, 124.8 kJ for 2 m.s^{-1} and 150.8 kJ for 3 m.s^{-1}. Increased air velocity improved the heat transfer. The energy needed to make the Paraffin phase change from liquid to solid with an amount of 1.5 kg is 228 kJ. The energy analysis released by PCM uses the energy balance equation assuming no heat comes out of the system. Using this method and Equation 4 can predict the mass concentration of PCM solids that are formed. From the calculation results, the percentage of solid mass formed to each velocity were 22.9 % for 1 m.s^{-1}, 35.3 % for 2 m.s^{-1}, and 45.7 % for 3 m.s^{-1}.

4. Conclusion

The difference in PCM temperature per row in the cooling process is not significant. Paraffin did not have subcooling. The biggest cooling rate occurs at 3 m.s^{-1} which is 6.4 ºC.hr^{-1}.kg^{-1}. The percentage of solid mass formed after 60 minutes for each air velocity were: 22.9%, 35.3%, and 45.7%. The largest amount of heat absorbed by air is 150.8 kJ. Based on this, paraffin is very potential to be developed by observing the temperature and velocity of cold air entering.

Acknowledgment
This research has been funded by Universitas Lampung with a research scheme: Superior Research Of Higher Education 2019.

References

[1] Al-Abidi A A, Mat S B, Sopian K, Sulaiman M Y, Lim C H and Abdulrahman 2012 *Renewable and Sustainable Energy Reviews* **16** 5802–5819
[2] Sharma S D and Sagara K 2005 *International Journal of Green Energy* **2** 1–56
[3] Zhou D, Zhao C Y and Tian Y 2012 *Applied Energy* **92** 593–605
[4] Zhang P, Ma Z W and Wang R Z 2010 *Renewable and Sustainable Energy Reviews* **14** 598–614
[5] Xia J, Hong T, Shen Q, Feng W, Yang L, Im P, Lu A and Bhandari M 2014 *Energy and Buildings* **78** 165–175.
[6] Saidur R 2009 *Energy Policy* **37** 4104–4113.
[7] Qua Y, Zhang Z, Wang H and Yang F 2017 *Procedia Engineering* **205** 2111–2117
[8] Happlea G, Wilhelm E, Fonseca J A and Schlueter A 2017 *Energy Procedia* **122** 313–318
[9] JICA Study on Energy Efficiency and Concervation Improvement in Indonesia (2007–2008)
[10] Irsyad M and Harmen 2017 *IOP Conf. Series: Earth and Environmental Science* **60** 012027