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PAPER ACCEPTANCE NOTIFICATION

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Paper Title : Experimental study of thermoelectric cooler box using heat sink with u-shape heat pipe with methanol as working fluid
Paper ID : iCOMERA-Paper 191

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Experimental study of thermoelectric cooler box using heat sink with u-shape heat pipe and methanol working fluid

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Abstract. Thermoelectric refrigeration system is considered environmentally friendly because it does not use refrigerants which have huge potential damaging the ozone layer. In this experimental work, u-shape heat pipe with heat sink was charged with methanol working fluid with different filling ratios to observe its effect on the thermoelectric performance. The cooler box has 240 mm x 180 mm x 130 mm of inner dimension. 37,3 watt DC power supply supplied constantly to the thermoelectric module to performed cooling action. The result shows that methanol with 45% and 55% filling ratios has the maximum COP about 0.03881 and 0.03885 respectively. The filling ratio of 45% and 55% have lower cabin temperature, lower temperature difference between hot side and cold side and better performance (COP).

Keywords: thermoelectric cooler box, u-shape heat pipe, filling ratio, methanol, COP.

Introduction

Refrigeration is one of the important technologies that has wide range application from cryogenic temperature, food chain industries until residential applications. Mechanical based of vapour compression system is the most dominant usage system at refrigeration system. This system also has the highest coefficient of performance (COP) compare with other refrigeration system, such as absorption, thermoelectric and magnetic. However, the detrimental effect of refrigerant used by this system becomes a serious issue to the environmental.

Peltier or thermoelectric module is considered to become one of the pragmatic solutions for the environmental issues regarding the specific area of refrigeration. This kind of cooling system has fewer mechanical moving part, less friction and noise, no refrigerant needed, compact design and almost has free maintenance [1, 2]. Better temperature control for refrigerated area and it can be supplied with DC power become the special benefits of this cooling system. Many researchers agree that thermoelectric performance is low enough to compete with vapour compression system [2]. Nevertheless, it should be not considered as a huge shortcoming. In some application such as military, medical industries and aerospace, temperature stabilization is more important than just a low performance. Therefore, cooling systems use thermoelectric are still one of the top research interest in refrigeration for the next future.

A lot of study have been performed on evaluation about thermoelectric refrigeration performances. One of them studied by Min and Row [reference]. Their experiment showed the thermoelectric COP of 0.3-0.5 for cooling temperature at 5°C with outside environment at 25°C [3]. Dai et al. also found almost the same magnitude of COP for thermoelectric refrigerator with power supplied from photovoltaic module and battery [4]. Vián and Astrain proposed a thermoelectric refrigerator with two different heat exchanger based on the principle of thermosyphon. One of them using technology of capillary lift and the other using motionless part. They claim 66% increase in COP if compare it with thermoelectric refrigerator with conventional finned heat sink [5]. Jugsujinda et al. [6] investigated a thermoelectric cooler box with 0.022m^3 cabin volume. They claim temperature decreased of the cooler box from 30°C to -4.2 °C for 60 minutes with 3.5 ampere of current supply. They showed the COP of thermoelectric of 0.22 which generated using 40.46 watt power supplied [6]. Gökçek et al. performed an experimental study of a thermoelectric cooler box with water mini-channel as the cooling device of thermoelectric hot side [7]. The performance of thermoelectric refrigeration using two different type of heat sink was investigated by Mirmanto et al. Both of them serves as cooling device for the hot side of thermoelectric module. The device were heat sink fin with fan and heat sink heat pipe with double fan. They conclude that the heat sink fin was more reliable when it is considered about energy consumed [8]. Mirmanto et al. [9] also studied the performance of thermoelectric refrigeration with different positions of peltier module. The volume of cooler box was 4.891 litre with the insulation wall around 50 mm. Inside the box they put 360 ml of water as product load. They found that best positioned of thermoelectric device was on the wall [9].

Heat sink with u-shape heat pipe has been widely used as processor cooling device in personal computer or desktop. As a latent passive cooling, heat pipe is much more efficient than a conventional heatsink or even a water cooling. Many research also has been performed with heat pipe as a cooling device to many applications [10-16]. In thermoelectric refrigeration, heat pipe usually applied as thermal management for the hot side. Better performance of TEC was achieved if the temperature of hot side can be reduced to desired level with the use of heat pipe. In fact, the heat pipe performance depends on it's working fluid ratio or filling ratio [17]. Therefore, in this work methanol working fluid was injected to heat sink with u-shape heat pipe in different filling ratio and applied it at hot side of thermoelectric cooler box. The objective of the research was to find the performance of thermoelectric cooler box.

Method and Material

Heat sink with u-shape heat pipe was used as a cooling device for the hot side of TEC. The heat pipe was injected with methanol working fluid before installed at the hot side. The injected filing ratio (FR) of working fluid was 30%, 45%,55%, and 85%. Figure 1(a) shows the filling system for charging the working fluid into the heat pipe. Red circle at the picture pointing the heat pipe position in filling system rig. Back filling method was used to charge the working fluid as we do in our previous work [12]. Figure 1(b) show the picture of heat sink heat pipe which already charged with methanol working fluid. Figure 2 show the schematic diagram of experimental research. The test-bed consisted of a cooler box with a thermoelectric module, a heat sink heat pipe with a fan, a cold sink with a fan, power supply units, a dc power meter, and a set of temperature loggers. The cooler box has 240 mm x 180 mm x 130 mm of inner dimension. The material of box was made from polyurethane with 40 mm of thickness. TEC1-12706 was used as peltier module and attached at side of the wall. The module was attached tightly with a cold sink, copper block and heat sink using

screws as shown in figure 2. The cooper block was used to connectead the hot side of TEC with the heat sink. It has dimension 40 mm x 40 mm x 35 mm. All the contact resistance was minimized with thermal paste with 1.97 $Wm^{-1}K^{-1}$ of thermal conductivity. The material of heat sink with u-shape heat pipe was made from aluminium and copper. DC fan with a dimension of 92 mm x 92 mm x 25 mm was attached at heat sink to increased heat rejected from condenser part of heat pipe. At the cold sink, a smaller dc fan was attached with a dimension of 40 mm x 40 mm x 15 mm.
DC power meter PZEM-017 was used to measure the electricity consumption of peltier module with measurement error of 1%. meanwhile, the DC fan power consumption was measured using digital multimeter. The temperatures were measured by type-K thermocouples connected to data acquisition device (NI 9213 and NI 9274). Six thermocouples (C1, C2, C3, C4, C5, and C6) are used specifically to measure the cabin temperature which then calculated it as average temperature in the data analysis. The rest are attached at hot side and cold side of peltier module, inner and outer walls, and the ambient temperature of cooler box. In this experiment the power supplied to the thermoelectric module was set constant at 4,5 ampere and 12 Volt for each filling ratio of methanol working fluid. Also, there was no product load within the cooler box excepted air solely to shorten the experimental times. The ambient temperature was set constant at 25 °C with air conditioning system.

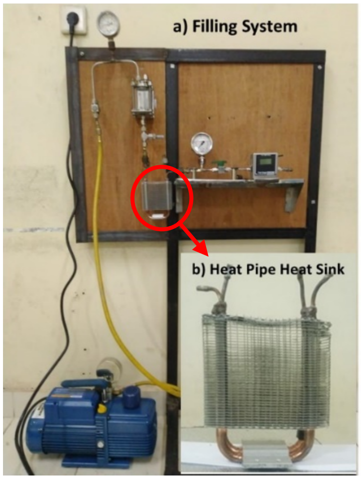

Figure 1. Mechanism of injected fluid into the heat pipe. a) Filling system, b) heat pipe which already injected with methanol working fluid.

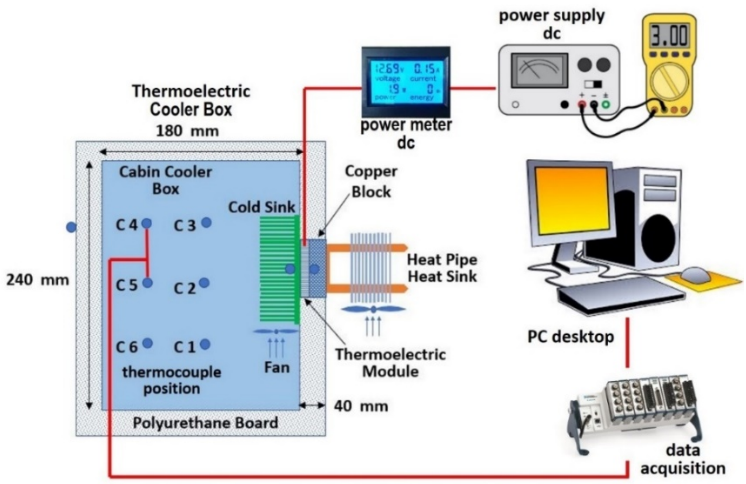

Figure 2. Schematic of experimental setup

The objective of this work is to investigate the cooling performance (COP) of thermoelectric with heat pipe heat sink as the hot side cooling using methanol as the working fluid. The calculation of COP of a thermoelectric cooler box is based on the conventional COP of refrigeration. That is, the total of cooling capacity divided by the total power consumption of the equipment. This method also verified and implemented by other researchers [1, 5, 7, 9] The equations is defined as follow:

$$COP = \frac{\dot{Q}_T}{P_{total}} \tag{1}$$

$$\dot{Q}_T = \dot{Q}_a + \dot{Q}_c + \dot{W}_{inner\,fan} \tag{2}$$

$$P_{total} = P_{heat\,sink\,fan} + P_{TEC} \tag{3}$$

$$\dot{Q}_a = \frac{dE}{dt} = m_a c_{p,a} \frac{dT}{dt} \tag{4}$$

$\dot{Q}_T$ (watt) is total of cooling capacity of thermoelectric cooler box and P_{total} (watt) is the total power consumes of cooler box. Equation 2 shows that $\dot{Q}_T$ is sum of $\dot{Q}_a$,$\dot{Q}_c$ and $\dot{W}_{inner\,fan}$. $\dot{Q}_a$is cooling load from the air inside the cabin, $\dot{Q}_c$ is transmission load through the wall, $\dot{W}_{inner\,fan}$ is heat generation from cold sink fan. Gökçek et al. calculated this heat generation using the rate of electrical power consumption [7]. Equation 3 computed the total power consumes. It consist of the power consumed by heat sink fan (outer fan) and Peltier module. In equation 4, m_a is the mass of air (kg), $c_{p,a}$ is the specific heat of air (J kg^{-1} K^{-1}), *dT·dt^{-1}* is the temperature gradient per unit time. Transmission load ($\dot{Q}_c$) or heat flow entering the inside cooler box is calculated with equation below.

$$\dot{Q}_c = A \cdot U \cdot (T_{amb} - T_{cabin}) \tag{5}$$

where *A* is the total of heat transfer surfaces (m), *U* is the overall heat transfer coefficient (Wm^{-2} °C^{-1}), T_{cabin} is the average temperature of cabin (C1 until C6) and T_{amb} is the environment temperature. The overall heat transfer coefficient can be calculated as below:

$$U = \frac{1}{\frac{1}{h_{int}} + \frac{L}{k_{wall}} + \frac{1}{h_{ext}}} \tag{6}$$

Where h_{int} is the heat transfer coefficient at inner surface of cooler box, h_{ext} is heat transfer coefficient at outer wall surface, L is the wall thickness and k_{wall} is the thermal conductivity of polyurethane. Equation 7 and 8 are correlation given by Parmelee and Huebscher [5, 7] for calculate the heat transfer coefficient at the inner surface.

$$Nu = 0{,}664 \cdot Pr^{1/3} \cdot Re^{1/3} \tag{7}$$

$$0{,}6 \le Pr \le 50$$

$$Re < Re_{x,c} \approx 5 \times 10^5 \tag{8}$$

Results and Discussion

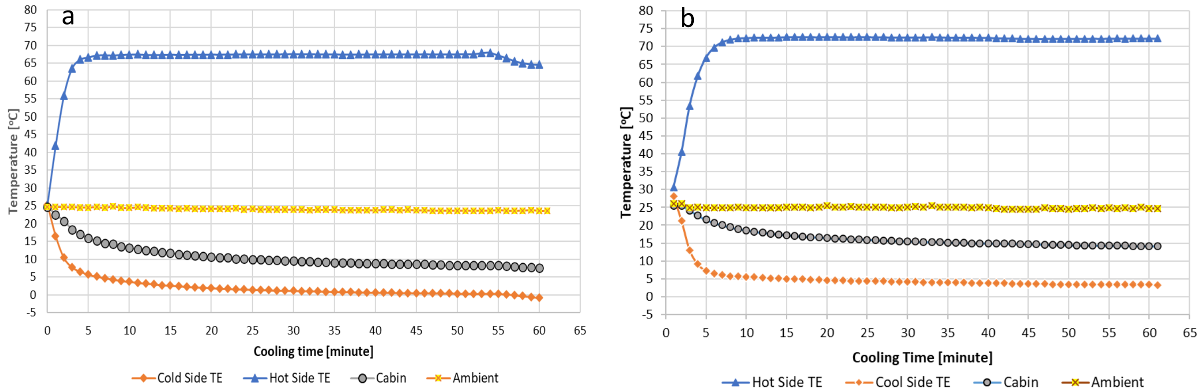

Figure 3. Temperature of thermoelectric cooling respect to time with (a) 45% Filling Ratio (b) 85% Filling Ratio

Figure 3 shows the temperature performance of the TEC cooler box for the 45% and 85% of filling ratio. The temperatures trend shown in figure are cabin temperatures, cold side and hot side temperatures and ambient temperature. The obtained temperature trend has the same pattern as the previous experimental work [6-9, 18]. Lower cabin temperature is achieved by 45% of filling ratio if compared with 85% of filling ratio. The low cabin temperature obviously related to the achievement of a lower cold side temperature at filling ratio of 45% which is around 0°C. Meanwhile, at filling ratio of 85%, the cold side temperature only reaches 5°C. The lowest temperature of hot side also is achieved by 45 % of filling ratio as a result of lower thermal resistance between the hot side of Peltier module and the heat sink heat pipe. Higher heat absorbed at the hot side using 45% filling ratio of working fluid.

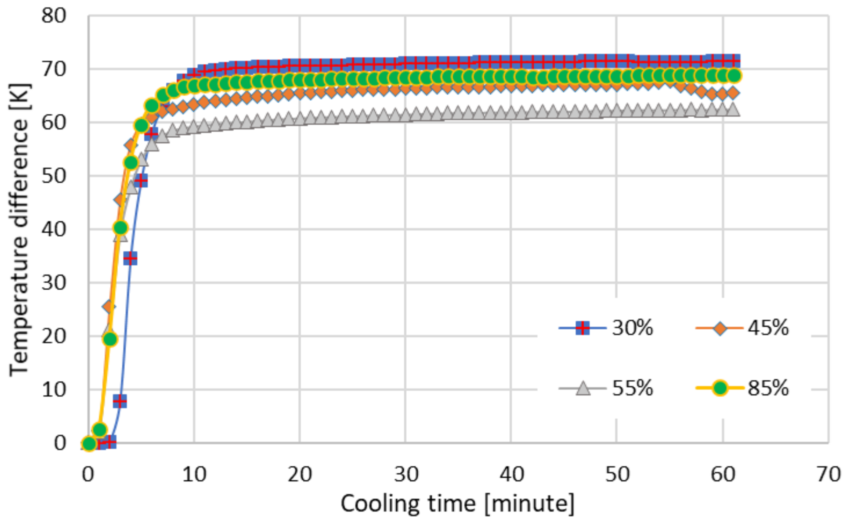

Figure 4.Temperature difference between hot and cold side of TEC

Figure 4 shows the comparison of temperature different (TD) between hot and cold side of TEC. Temperature differences higher than 50 K were observed at all filling ratios of methanol working fluid. The lowest temperature difference is clearly visible at the fill ratio of 55%. While the filling ratio at 30% shows the highest temperature difference among all. From the manufacturer datasheet of thermocouple, we could see that lower cooling capacity results from higher TD. Therefore, 30% of filling ratio has the lowest cooling capacity if we considered the temperature different of the hot and cold side peltier module. Furthermore, the highest cooling capacity achieved at 55% of filling ratio. This experimental result can still be improved in the future work.

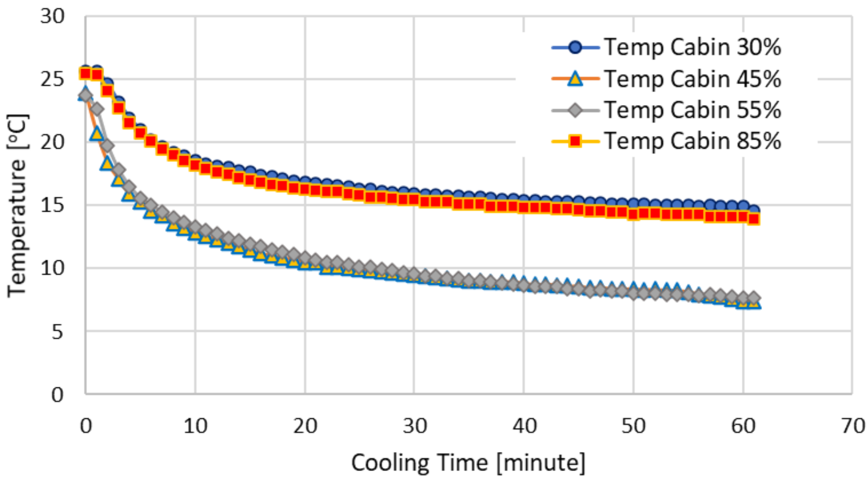

Figure 5. Temperature cabin of thermoelectric cooler box for different filling ratio

Figure 5 shows the cabin temperature of thermoelectric cooler box for each filling ratio (FR). Lower cabin temperatures showed at 45% and 55% of filling ratio compared with 30% and 80%. Temperatures of 7.36 °C and 7.70 °C were achieved at filling ratios of 45% and 55%, respectively. The lower cabin temperature also means better performance of extracting heat load within the box to the ambient. This also means that at 45% and 55% of filling ratio has the total thermal resistance which could transfer more heat from cabin to the outside of the system.

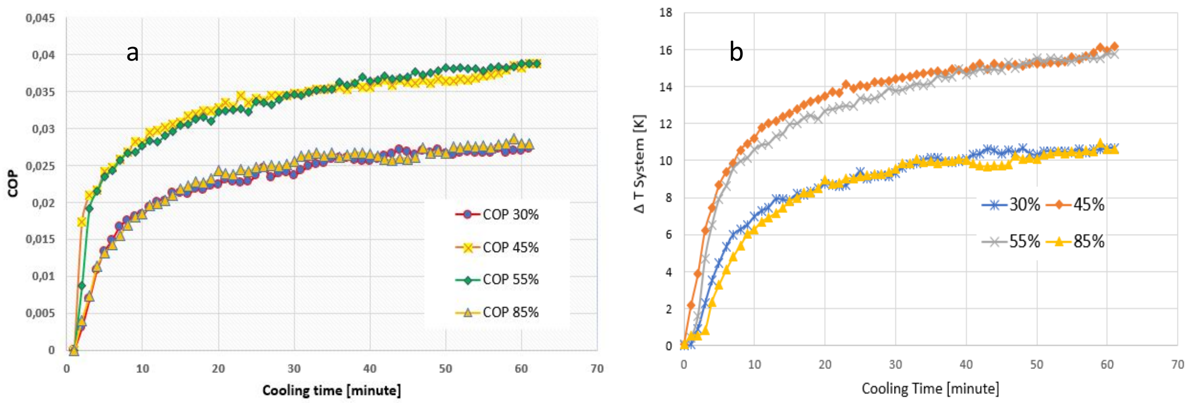

Figure 6 variation of: a) COP and b) ΔT system for different filling ratios of methanol working fluid.

COP is the standard parameter for the cooling system performance. Fig. 6a shows COP of the cooler box for all filling ratios which are calculated using the equation (1). All COP trends are increased sharply at the beginning, then after a few minutes, the curve begins to reduce it's the slope and prepared to steady. The graph shows that filling ratio of 45% and 55% has higher COP (0.03881 and 0.03885) compared with 30% and 85% of filling ratio due to higher cooling capacity ($\dot{Q}_c$). COP line of 45% and 55% almost coincide with each other from the beginning; likewise for the of 30% and 80% for a lower value. The finding COP curve is somewhat different from other researchers [7, 8] because of the significant quantity of $\dot{Q}_c$ among all parameters in equation 2. As mentioned in equation (1), COP is the ratio of $\dot{Q}_T$ and P_{total}, and $\dot{Q}_c$ is one of the component which has significant effect on the calculations. For this reason, figure 6b is added to shows the ΔT of the system for each filling ratio, which prove the significant effect of $\dot{Q}_c$. The temperature difference of system (ΔT system) was calculated from temperature ambient minus the average temperature of the cabin [7, 9]. Figure 6b shows that 45% and 55% of filling ratio have higher ΔT of system compared with 30% and 80%, which means higher $\dot{Q}_c$ for the same level of energy supply to the thermoelectric module. Higher ΔT of the system will result in the higher cooling capacity of the thermoelectric, thereby increasing the COP of the thermoelectric cooler box.

Conclusion

Thermoelectric cooler box using u-shape heat pipe with methanol working fluid has been experimentally investigated. The heat pipe was injected with different filling ratios of methanol working fluid to observe it's performance absorbing heat from the hot side of thermoelectric module. From the experimental data, the similar temperature trends are shown for all different filling ratios. The lowest temperature of hot side also is result of lower thermal resistance between the hot side of Peltier module and the heat sink heat pipe The temperature different of the hot and the cold side are higher than 50 K for filling ratios. Lower cabin temperatures, which is shows at 45% and 55% of filling ratio, is result of better performance of extracting heat load within the box to the ambient. The COP increased with time due to the increase of cooling capacity. The maximum COP of thermoelectric cooler box is about 0.03881 and 0.03885 for 45% and 55% FR respectively.

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