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Effect of a Heat Exchanger on COP of a Thermoelectric Cooler Powered by Solar Panels

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ABSTRACT

COP (coefficient of performance) of a thermoelectric cooler so far is still less than 1. Some efforts have been conducted to improve the COP. Adding a heat exchanger is suspected to be able to improve COP. This study tried to investigate the thermoelectric cooler with and without a heat exchanger. This study aimed to know the effect of adding a heat exchanger on COP and to examine the cooler temperatures. The study used 1 thermoelectric module, a small pump, a heat exchanger, and a cooler box with a size of 40.8 cm x 32.6 cm x 53.8 cm. The experiments were conducted for 14400 s. The cooler box was filled with clean water. The power used in this study was obtained from solar panels. The results indicated that using a heat exchanger could increase COP by about 48% and the cooler temperature could decrease by 7.4 - 9.1%.

Keywords:
Thermoelectric cooler; heat exchanger;
COP; cooler temperature

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1. Introduction

Thermoelectric coolers (TEC) are now used in several demands such as portable cooling system, small cooling system, and drinking water cooler, vaccine cooler and small refrigerators. However, TEC has a weakness. Its COP is very low, even lower than 1. Secondly, its capacity is also small which is why TEC cannot be used for a large cooling system. For small cooling and portable devices, TEC becomes the choices though. Therefore, the lower COP is challenging the researchers to improve it. Then the study on this field is still open widely [1].

There are many ways to improve the COP of TEC. Some researchers improve the COP by updating the thermoelectric module (TEM) material; others increase the COP by maximizing the heat removal units, and TEM installations or applications.

From material viewpoints, performances of TEM can be increased significantly as reported by Sulaiman *et al*., [2]. Moreover, the quality of the TEM material depends on several parameters, e.g. Seebeck coefficient, electrical conductivity, thermal conductivity, and absolute temperature, while the TEM efficiency depends on the figure of merit [3]. To know some materials for TEM, Figure 1

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provides a figure of merit for low and high temperatures. The highest figure of merit (ZT) described in Figure 1 belongs to Zn_4Sb_3. However, this material is for high temperatures. According to Luo *et al.* [4], there is a material that has a maximum ZT of 1.8., which is higher than that in Figure 1. This material is BiSbTeSe. Nevertheless, the improvement of TEM material needs years though.

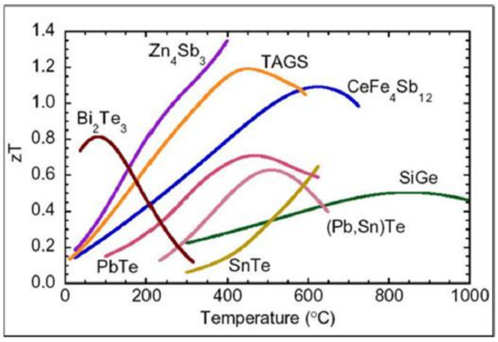

Fig. 1. Figure of merit (ZT) for several TEM materials [3]

Installations of TEM module on an application TEC device hold important roles. When the TEC is not installed properly, the TEC cannot absorb the heat optimally. Consequently, the TEC device cannot be cold [5]. Another important parameter is the heat removal unit. Many types of heat removal units have been investigated [5]. In [5], several heat removal units were studied, namely heat sink with a fan, heat pipe with double fans. They concluded that using heat pipe could increase COP significantly. However, when the power used for the heat pipe was considered, the heat sink with a fan was better. Till now, the effect of heat removal units on COP is still deteriorated or not clear yet. Some studies using heat sinks with a fan have been presented. The COP obtained from TEC applications that use a heat sink with a fan as the heat removal units varies from 0.002 - 0.86 as reported in [1, 5]. The devices that use heat removal units made of fluid heat exchangers have been also examined. The COP of using the fluid heat exchanger ranges from 0.1 - 1.2 as obtained by Mirmanto *et al.* [1] and Maral *et al.* [6]. However, some of the researchers used a close system and others used an open system of the working fluid. Using an open system can be more effective because the incoming working fluid has low temperatures, while using a close system may be less effective due to the working fluid temperature increases with time. That is why using a close system usually is accompanied by a heat exchanger. The weakness of the open system is that the working fluid line at the entrance and the end must be open and connected to the entrance and exit reservoirs. This needs long pipelines when the entrance and exit reservoirs are away from the thermoelectric cooler [7]. Therefore, this study concerns the effect of adding a heat exchanger on the COP of thermoelectric coolers with a close system. The crucial effect of adding a heat exchanger is studied with several clean water volumes placed inside the cooler box.

2. Methodology

A thermoelectric cooler with a size of 40.8 cm x 32.6 cm x 53.8 cm has been investigated. The TEM used was TEC2-25408 (single). The heat removal unit utilized was a mini-pin fin and the working fluid was clean water. The schematic diagram of the experiment is shown in Figure 2, while the electrical circuit is described in Figure 3. The apparatus consists of a cooler box, TEM, mini pin fin, pump, heat exchanger, battery and two solar panels. Moreover, the working fluid circuit is indicated in Figure 4.

Solar panels gave electrical power to the battery. From the battery, the electrical power flowed to the TEM, pump and small radiator or heat exchanger. All power required was provided by the buttery supplied by solar panels. The electrical power employed was measured using a digital

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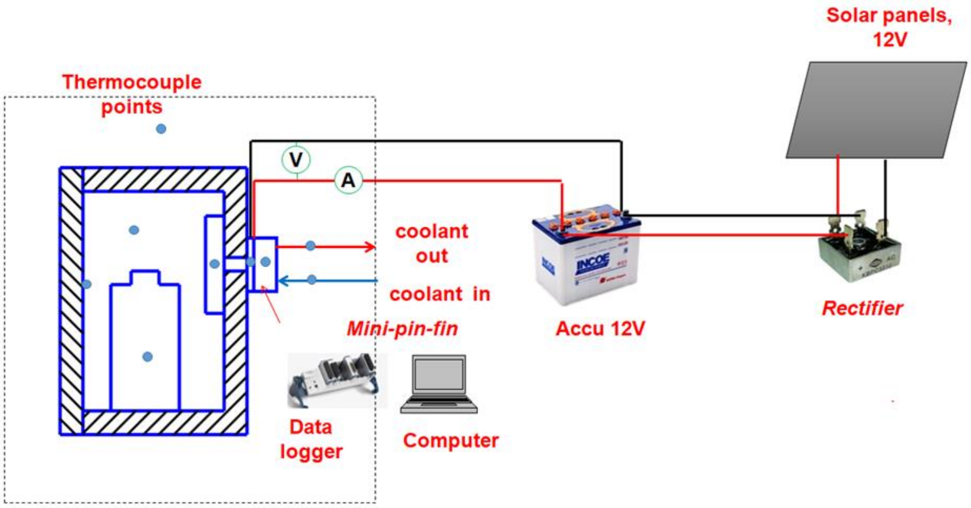
Volume 79, Issue 1 (2021) 1-8

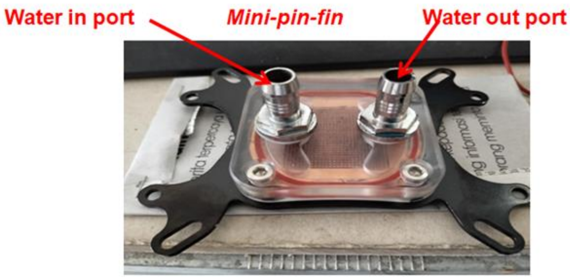
multimeter (a Vichy Vc8145). The accuracy of ampere and volt measurements was ± 0.1% reading and ± 0.05% reading. The power used by the system ranged from 60.4 to 90 W.

All thermocouples were calibrated in an oil bath equipped with a heater and PID so that the calibration temperature could be set at a certain value and constant. From calibrations, the uncertainty obtained was ± 0.2°C. The thermocouples used were K-type and connected to NIDAQmx 9714. The thermocouples were placed on the cooler box walls, on bottles, in water inside the bottles, in the inlet and outlet of the mini pin fin, in inlet and outlet of the heat exchanger, and an environment.

The clean water as the working fluid was circulated using a DC pump. The water circulates from the reservoir, through a mini pin fin, pump, flowmeter and finally, it was back again to the reservoir. The pump was placed after the mini pin fin so that heat coming from the pump did not influence the water flowing through the mini-pin fin. The water mass flow rate was measured using a flowmeter FLR1000 with an accuracy of ± 1% reading.



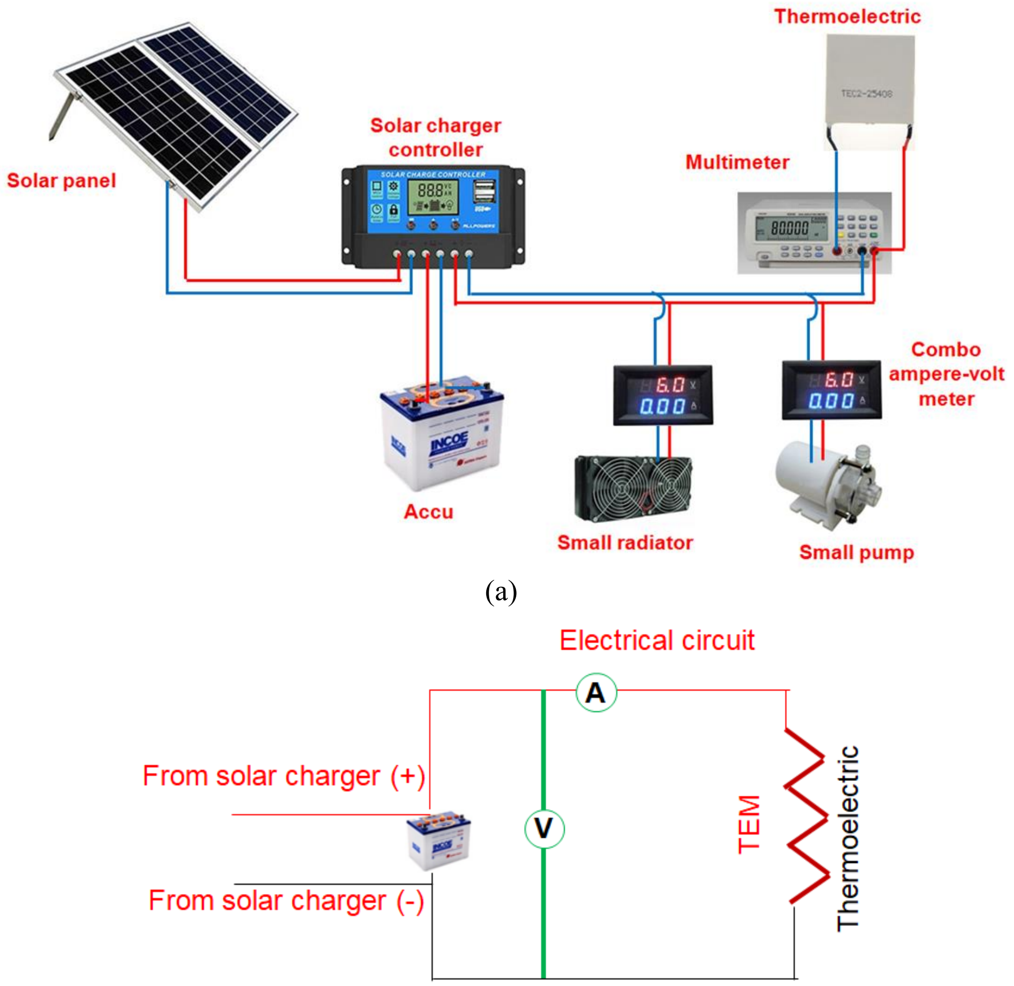
(a)



(b)

Fig. 2. Schematic diagram of the apparatus; (a) cooler box and water flow lines, (b) mini-pin fin unit

In this study, the cooler box was filled with clean/ drinking water in bottles. The number of bottles was varied ranging from no bottle to 4 bottles. Each bottle contained 1500 ml of water. Therefore, the volume of water varied was 0 ml, 3000 ml, and 6000 ml.



(b)

Fig. 3. Schematic diagram of the electrical circuit; (a) electrical lines, (b) electrical flow measurement

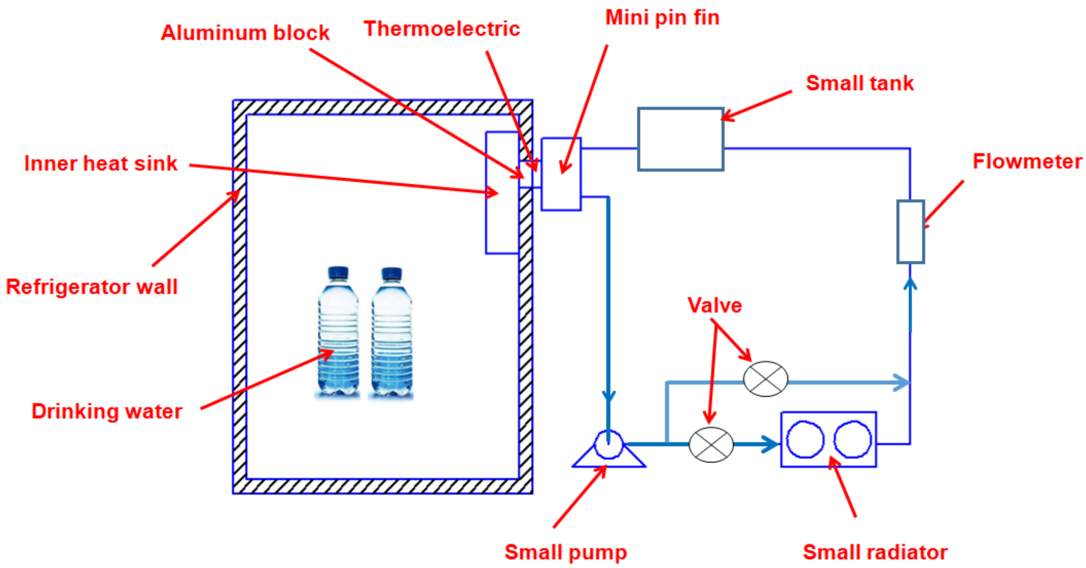


Fig. 4. Working fluid circuit (water flow measurements). The small radiator is the heat exchanger

To analyze the experimental data, some equations are given as follows. The heat inside the cooler box should be removed. The heat comprised of heat from water, bottle and air inside the box. Additional heat came from the ambient through the cooler box walls. This heat was called conduction heat. The heat from the water, bottle and air can be estimated using the equations below.

$$E_{w(i)} = m_w c_{(i)} \left(T_{w(i)} - T_{w(i-1)}\right) \quad (1)$$

$$Q_w = \frac{\sum_1^n E_{w(i)}}{t_{(n)}} \quad (2)$$

E is the energy (J), m_w is the water mass (kg), c_p is the specific heat (J/kg°C), and T_w is the water temperature (°C), Q_w is the heat rate coming from the water (W), t is the time during experiments performed, and i to n is the time segment. The energy and heat rate coming from bottles and air can be predicted using equations (1) to (2) by replacing the subscript *w* with *b* and *a*. Equations (1) to (2) are available in Mirmanto *et al.* [1, 5, 7] and some textbooks such as Holman [8], Incropera *et al.* [9].

The heat from ambient coming into the box through the box walls can be computed using equations (3) and (4) that can be obtained in Holman [8] and Incropera *et al.* [9]. It is expressed as

$$E_{k(i)} = k_T A \frac{\left(T_{wo(i)} - T_{wi(i)}\right)}{L} \left(t_{(i)} - t_{(i-1)}\right) \quad (3)$$

$$Q_k = \frac{\sum_1^n E_{k(i)}}{t_{(n)}} \quad (4)$$

k_T is the thermal conductivity of the walls (W/m°C), A is the heat transfer area (m^2), k indicates conduction mode. The total heat rates, Q_c, that indicate the cooling load or heat that must be removed from the cooler box can be calculated using equation (5).

$$Q_c = Q_w + Q_b + Q_a \quad (5)$$

Q_b is the heat rate from bottles (W), and Q_a is the heat rate from the air (W).

To know the performance of the cooler box, COP (coefficient of performance) must be calculated. This parameter was also used by several researchers, e.g. Mirmanto et al. [1], Jugsujinda *et al.* [10], Gillott *et al.* [11].

$$COP = \frac{Q_c}{P} \quad (6)$$

P is the power given to the TEC or system, which can be estimated as:

$$P = VI \quad (7)$$

V is the DC voltage (volt), and I is the DC (ampere). In this study, the Q_c and COP are the focus for with and without heat exchanger.

3. Results

Before presenting the performance of the experimental cooler box, several recorded temperatures are given. They are shown in Figure 5 for three cases. Figure 5 depicts that cooler box temperatures with a HE are lower than those without a HE. For case A, the cooler box temperatures are lower than that of case B, where for case A and case B, the experiments were run without water inside the cooler box. The temperatures for case C are higher than that for case A and case B. This was due to the adding of 3000 ml water inside the cooler box. As also found by Ramdan [12], Mirmanto *et al.* [13], that when some goods were put into the cooler box, the cooler box temperatures increased. Moreover, increasing the mass of the goods also increased cooler box temperatures. Cases A, C and E indicate that adding the water volume increases the cooler box temperature. Similarly, for case B, D, and F, the cooler box temperatures increase with the increase in water volume. This phenomenon was due to the heat capacity of the TEM. The TEM has a maximum capacity for absorbing heat. When it has reached the maximum capacity, the TEM cannot absorb more heat inside the cooler box. Consequently, the cooler box temperatures rise.

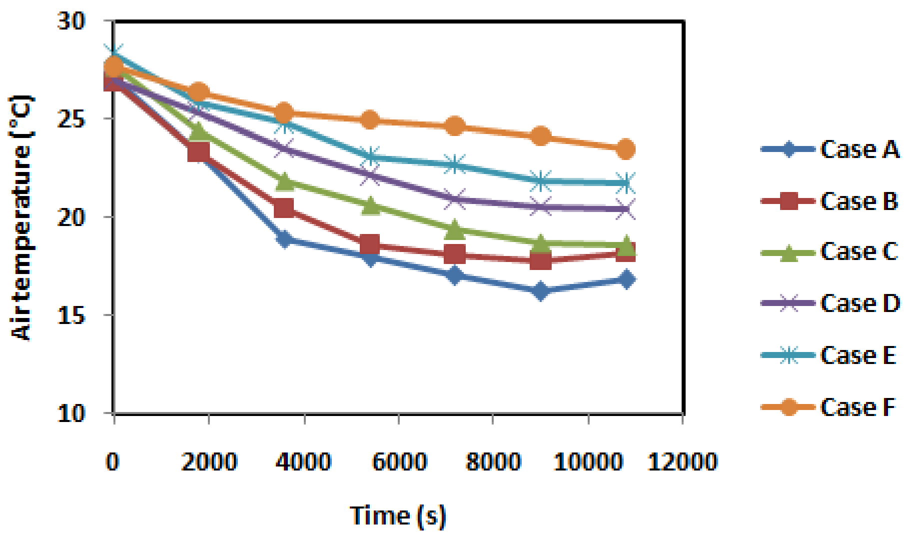


Fig. 5. Air temperatures inside the cooler box versus observation time

Parameter Q_c or cooling load can be used as an assessment of the cooler box performances. When the cooler box can absorb much heat means that the cooler box performance is good. Figure 6 describes the Q_c for all cases.

In Figure 6, the trends of COP increase with the increase in water volume. When the cooler box was empty, Q_c was small and when the cooler box was filled with water, Q_c raised. This phenomenon was also found by previous researchers such as Ramdan [12], Girawan and Aryanto [13], Mirmanto *et al.* [14], and Saputra [15]. However, for 3000 ml and 6000 ml of water placed inside the cooler box, the Q_c lines were not clear. Mainil *et al.* [16] found different thing from this study. They stated that increasing the cooling load needs a longer time for cooling the goods inside the cooler box. This could occur when the maximum capacity of the TEC (thermoelectric cooling) had not been achieved yet. When the maximum capacity of the TEC was only 60 W and the goods inside the cooler box released more than 60 W, the cooler box temperatures increased. They touched each other or there was a deterioration of Q_c. Nevertheless, the effect of the heat exchanger is significant. For case C the Q_c is higher than that for case D. Similarly, for case E, the Q_c is also higher than that for case F.

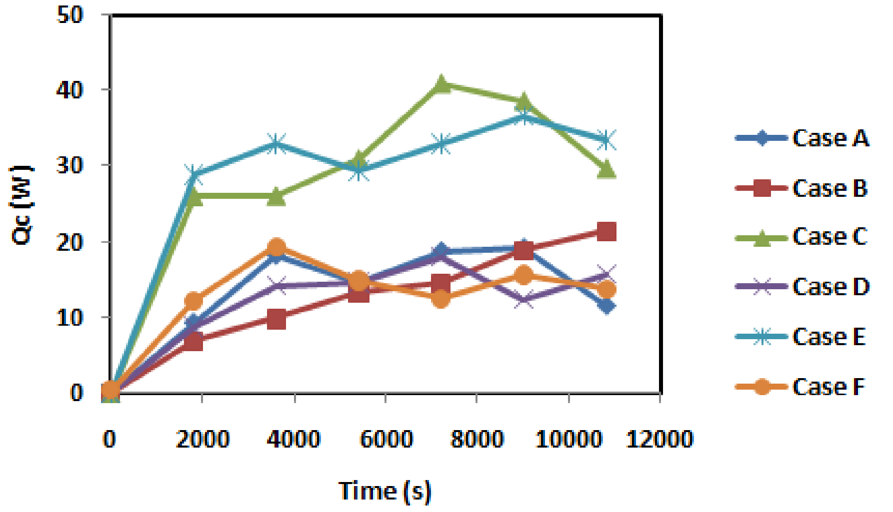


Fig. 6. Cooling capacity versus observation time

The last parameter investigated is COP, which is the real assessment of the thermoelectric cooler box performance. The experimental COP is presented in Figure 7. For high water volume, the COP deteriorates. The COP of 3000 ml and 6000 ml cooler box is almost the same. However, the optimum thermoelectric cooler box based on the experimental assessments is the cooler box with 3000 ml water volume. Despite the higher COP, it has also lower cooler box temperatures. As the *Qc* is higher for case C and E, the COP for both is also higher than others in this particular study.

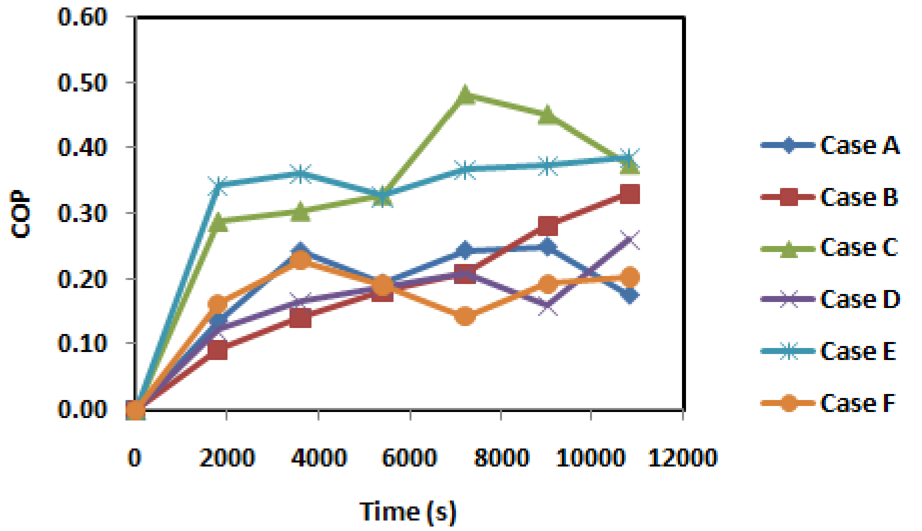


Fig. 7. COP versus observation time

4. Conclusions

Experiments to examine the effect of the heat exchanger on Q_c and COP were conducted. Some remark findings are as follows. Heat exchanger greatly affects the performance of the thermoelectric cooler box for heat removal unit made of mini pin fin flowed with water. Using a heat exchanger the maximum COP gained is about 0.5, while without a heat exchanger the COP found is around 0.4. The water volume as the goods placed inside the cooler box determines the Q_c and COP of the cooler box. At higher water volumes, the effect of water volume becomes deteriorate. Using a heat exchanger increases COP by about 48% and the cooler temperature decreases by 7.4 - 9.1%. Therefore, a heat exchanger shall be used when the heat removal unit utilizes a fluid circuit in a close loop.

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References
[1] Mirmanto, M., Syahrul, S., Wirawan, M., Sayoga, I.M.A., Wijayanta, A.T., and Mahyudin, I. "Performance of a thermoelectric powered by solar panel for a large cooler box." *Advances in Science, Technology and Engineering Systems Journal* 5, no. 1 (2020): 325-333. https://dx.doi.org/10.25046/aj050141
[2] Amin, N.A.M., Basha, M.H., Majid, M.S.A., Nasir, N.F.M., and Zaman, I. "Cooling performance of thermoelectric cooling (TEC) and applications: A review." *MATEC Web of Conferences 225*, 03021 (2018). https://doi.org/10.1051/matecconf/201822503021
[3] Snyder, G.J., and Snyder, A.H. "Figure of merit ZT of a thermoelectric device defined from materials properties." *Energy & Environmental Science* 10, no. 11 (2017): 2280–2283. https://doi.org/10.1039/c7ee02007d
[4] Luoa, D., Wang, R., Yua, W., and Zhoub, W. "Performance evaluation of a novel thermoelectric module with BiSbTeSebased material." *Applied Energy* 238, no. 15 (2019): 1299-1311. https://doi.org/10.1016/j.apenergy.2019.01.139
[5] Mirmanto, M., Alit, I.B., Sayoga, I.M.A., Sutanto, R., Nurchayati, N., and Mulyanto, A. "Experimental cooler box performance using two different heat removal units: a heat sink fin-fan, and a double fan heat pipe." *Frontiers in Heat and Mass Transfer (FHMT)* 10, no. 34 (2018): 1-7. http://dx.doi.org/10.5098/hmt.10.34
[6] Maral, Y., Aktas, M., Erol, O., Ongun, R., Polat, F. "An examinaion about thermal capacities of thermoelectric coolers in battery cooling systems." *Journal of Engineering Research and Applied Science* 6, no. 2 (2017): 703-710.
[7] Mirmanto, Sutanto, R., Putra, D.K. "Unjuk kerja kotak pendingin termoelektrik dengan variasi laju aliran massa air pendingin." *Jurnal Teknik Mesin* 7, no. 1 (2018): 44-49.
[8] Holman, J.P. "Heat Transfer." *McGraw-Hill Education (India) Pvt Limited*, 2002.
[9] Incropera, F., DeWitt, D.P., Bergman, T.L., and Lavine, A.S. "Fundamentals of Heat and Mass Transfer." *6th Edition, John Wiley & Sons, Hoboken*, 2006.
[10] Jugsujinda, S., Vora-ud, A., and Seetawan, T. "Analysing of thermoelectric refrigerator performances." *Procedia Engineering* 8, (2011): 154-159. https://doi.org/10.1016/j.proeng.2011.03.028
[11] Gillott, M., Jiang, L., and Riffat, S. "An investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings." *International Journal Of Energy Research* 34, (2010): 776-786. http://doi.org/10.1002/er.1591
[12] Ramdhan, G. "Sistem Pendinginan pada Kulkas Termoelektrik dengan Variasi Pembebanan." *Skripsi, Jurusan Teknik Mesin, Fakultas Teknik*, Universitas Mataram, Mataram, NTB, Indonesia, 2016.
[13] Girawan, B.A., and Aryanto F. "Optimalisasi sistem pendingin berbasis termoelektrik berpendingin air." *Dinamika Teknik Mesin: Jurnal Keilmuan dan Terapan Teknik Mesin* 9, no. 1 (2019): 15-22. https://doi.org/10.29303/dtm.v0i0.253
[14] Mirmanto, M., Joniarta, I.W., Sayoga, I.M.A., Nurpatria, N., Padang, Y.A., and Yudhyadi, I.G.N.K. "Effect of water volume on a thermoelectric cooler box performance.", *Frontiers in Heat and Mass Transfer (FHMT)* 11, no. 17 (2018): 1-7. http://dx.doi.org/10.5098/hmt.11.17
[15] Saputra, Z. "Pengaruh heat exchanger terhadap unjuk kerja kotak pendingin termoelektrik dengan unit pembuang panas mini pin fin." *Skripsi, Jurusan Teknik Mesin, Fakultas Teknik,* Universitas Mataram, Mataram, NTB, Indonesia, 2020.
[16] Mainil, A.K., Aziz, A., and Akmal, M. "Portable thermoelectric cooler box performance with variation of input power and cooling load.", *Aceh International Journal of Science and Technology* 7, no. 2 (2018): 85-92. http://doi.org/10.13170/aijst.7.2.8722.