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Analysis of Heat Transfer of Hybrid Refrigeration: Vapour Compression Refrigeration (VCR) and Thermoelectric Cooling (TEC)

Hybrid Mini-cooler is combining the conventional refrigeration and thermoelectric cooler. The conventional refrigeration uses R-134a as working fluid and generated by using electricity from thermal power whereas TEC is generated by using solar panel. This research consists of two methods, those are mini-cooler generated by using thermal power and solar panel. The result shows the inside temperature of mini-cooler which generated by using conventional electricity around 22 °C whereas the temperature on evaporator wall reaches 7 °C. Whereas the mini-cooler which is generated by solar panel through TEC shows increasing wall evaporator temperature rapidly since conventional refrigeration system is already Off whereas the room inside of mini-cooler does not shows increasing temperature rapidly.

Keywords: heat transfer, hybrid mini-cooler, thermoelectric cooling, vapour compression refrigeration, R-134a refrigerant, temperature.

Introduction

Heat transfer phenomena is one of the persistent topics of research especially in refrigeration system. Conventional refrigeration system or vapor compression refrigeration VCR uses refrigerant working fluid to generate the cooling. This system shows high Coefficient of Performance COP. In Indonesia, refrigerator highly depends on the state electricity company (thermal power) which the dependence on state electricity company brings about some

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consequences such as power outage due to electricity maintenance and repairs. The power outage automatically affects home electronics such as the home scale refrigerator. Some use solar panel to cope the power outage. But the problem appears since the efficiency of solar panel is quite low and this leads a challenging for applying solar panel to generate high power electronics such as compressor of refrigerator. This issue leads to conduct research by combining vapor compression refrigeration VCR by using electricity company and thermoelectric TEC which the TEC is generated by using solar panel and this mode is used to cope the power outage.

Remeli et al. [1] conducted research on Peltier cooling in a Mini Cooler. Data collection was carried out by measuring the ambient temperature, the inlet and outlet air temperatures, and the hot and cold temperatures of the Peltier. The difference between the research and simulation data is approximately 1%, showing that the mini cooler can reduce the temperature by up to 10°C from the initial temperature, and the temperature at the hot end reaches 45 °C. The greater the temperature gradient, the better the Peltier performance. The resulting COP is 0.5 with a heat transfer rate of 25 W. The study noted several considerations, such as the recommended heat sink, which uses a heat pipe heat sink with a high-performance Peltier and a high-conductivity heat sink.

Gao et al. [2] conducted research on a two-level TEC (Technical Equipment) to achieve optimal temperature reduction. Pulse currents were applied to the hot and cold parts of the two TEC levels. This research resulted in the two-level TEC producing lower temperatures and longer operating times. Wang et al. [3] conducted research on a TEC using an electrodynamic mechanism. Some electronic devices experience increased heat during use, which affects their performance. Heat dissipation is necessary for electronic devices to function properly. Equipment cooling using a combination of TEC and Corona Wind Cooling (CWC) is carried out based on the Second Law of Thermodynamics, namely minimizing entropy sources. Research results show a better cooling effect with a high COP by installing the CWC on the hot side. The operating temperature in this study was < 80 °C with a moderate input power, making this circuit suitable for equipment with a high heat flux. Huang et al. [4] conducted research on a small-scale cooling system using TEC. The control system used was Proportional Integral Differential (PID) using the MAX1978 control chip to control the closed-loop cooling system. The controllable temperature ranged from 5 to 55°C with an accuracy of 0.5 °C. This system offers several advantages such as low power consumption, noiselessness, and pollution. Khalida et al. [5] conducted research on combustion engine by using TEC to increase O_2 to optimize performance. This research shows that TEC could increase performance for low velocity but for high velocity TEC does not work well due to TEC needs more time for cooling air.

Tian et al. [6] conducted research on the performance of TEC as a cooling system, specifically air-water cooling. Data collection was carried out on air flow, room temperature, power, etc. Analysis was carried out on the operating costs of the system. The TEC cooling system costs around 0.7 to 1.4 dollars for every 1 kWh. Optimal requirements are at an input power of 23 W where the resulting costs are minimal.

In this study, the hybrid vapor compression-TEC refrigerator is designed and analyzed to understand the heat transfer of refrigerator especially when the transition between VCR and TEC mode. The data of VCR and TEC is collected separately which is encompassed by temperature, heat rate etc. The VCR system uses R-134a as working fluid since R-134a is widely used in Indonesia whereas the TEC uses TEC 12706.

Methods

This research is conducted by using Mini-cooler 50 x 50 x 50 cm with a TEC on left and right sides. The mini-cooler is equipped by evaporator, condenser, compressor, expansion valve etc. Whereas the working fluid is R-134a and the used TEC is commercial TEC 12706. The solar panel is used to generate TEC and the capacity is 100 Wp. The Figure 1 below is schematic diagrams of hybrid refrigeration.

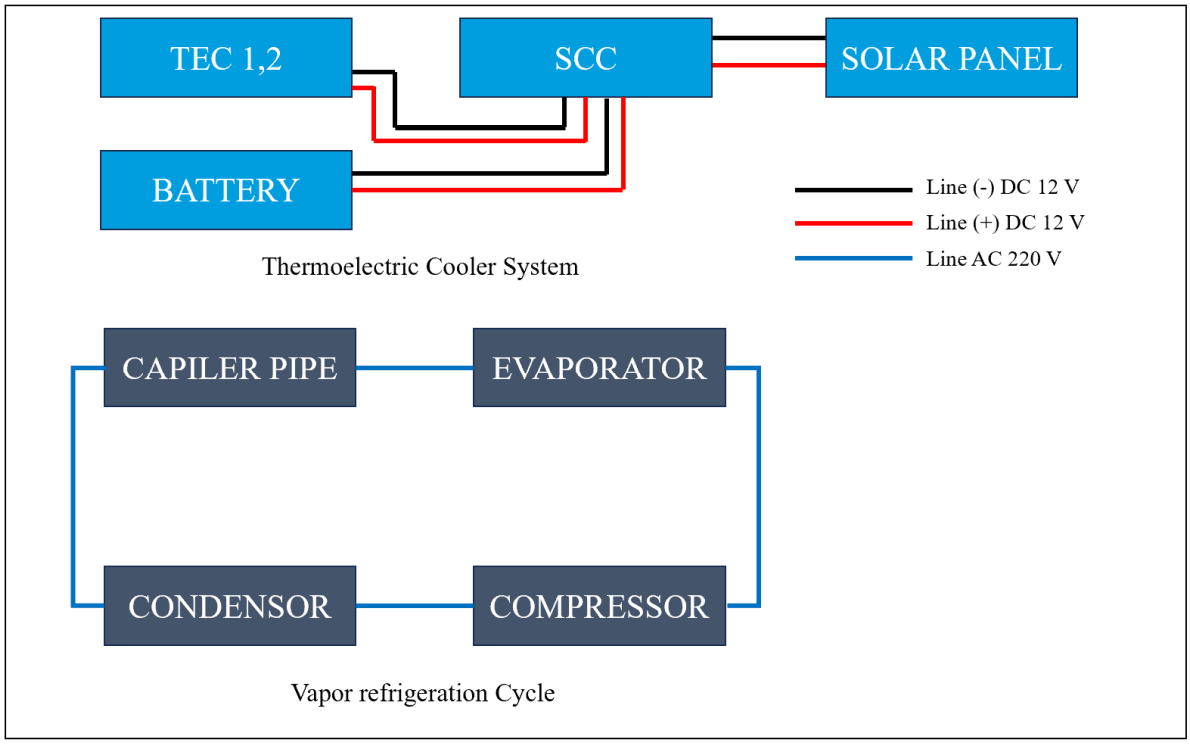

Fig. 1. Schematic diagram of Hybrid Refrigerator

The requires heat load is determined by using the heat transfer law as in Equation 1. In this equation, $\dot{m}$, $c_p, \Delta T$ is the mass of fluid, specific heat and temperature. Peltier consists of two different parts, namely the cold side and the hot side. This occurs due to seebeck effect since the electric current passing through the peltier. The heat produced on the hot side and the cold side can be calculated using equations 2 and 3. $\dot{q}_c$, $\dot{q}_h$, α, I, R_p, R is heat on cold and hot sides, seeback effects, current, thermal resistance and electrical resistance, respectively.

$$\dot{q} = \dot{m} c_p \Delta T \tag{1}$$

$$\dot{q}_c = \alpha IT - \frac{\Delta T}{R_p} - \frac{I^2 R}{2} \tag{2}$$

$$\dot{q}_h = \alpha IT - \frac{\Delta T}{R_p} + \frac{I^2 R}{2} \tag{3}$$

Result and Discussion

Hybrid minicooler data is collected by observing inside temperature of minicooler, temperature of hot and cold sides of TEC, current and voltage. The current passing through a single peltier is around 4.58 A while the voltage is around 11.7 V. The average temperature on the hot side is 29.8 ºC and in cold side is around –3.6 ºC which is reached in 340 second.

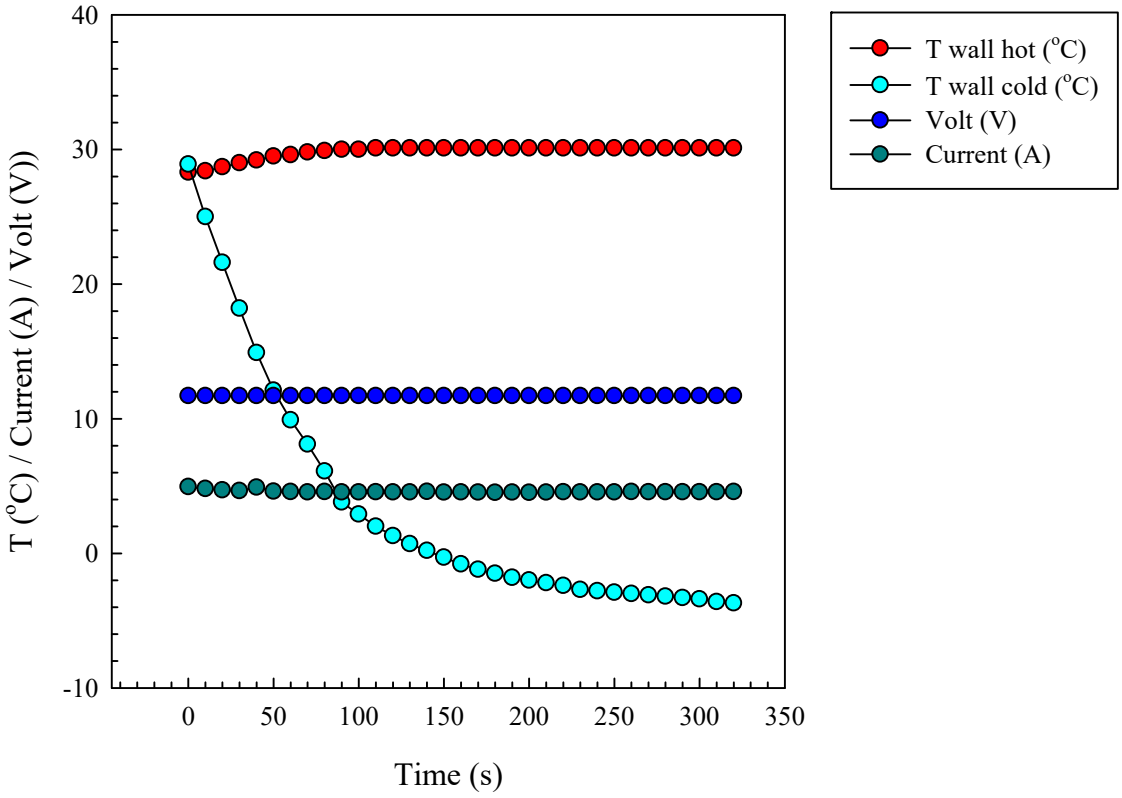

Fig. 2. Data of single TEC 1207

Based on these data, it could be seen that the wall temperature of hot side does not increase significant. Whereas the wall cold side temperature could reach temperatures below 0 ºC at short time. This occurs due to heat removal by the heat sink works properly. TEC 12706 has Seebeck coefficient 53 mV, electrical resistance 1.8 ohms, thermal resistance of 1.8 K/W, and thermal capacity 15 J/K [7]. These conditions are ideal for TEC 1207, while actual conditions may different. By using Ohm's law, and the resistance obtained is approximately 2.5 ohms. The image below is a schematic of TEC 12706 and the TEC parameters can be used to calculate the heat rate on the hot and cold sides.

After understanding several parameters from the data collection, the next step is to calculate the Peltier heat rate on the cold and hot sides. The heat rate on the hot side shows

almost the same value as the heat rate on the cold side due to equilibrium. Heat rate shows higher when the difference of hot and cold temperatures is higher. Based on Kukov's [7] statement which stated that ideally the Peltier 12706 has a resistance of 1.8 ohms, but based on direct measurements, the resistance is around 2.5 ohms. This leads heat rate difference between ideal and real conditions arounds 33%. Figure 4 shows the heat rate increases suddenly when the ΔT around 15 °C. This occurs due to a surge in electrical current and the recorded current at ΔT=15 °C is around 4.9 amperes whereas average electric current is around 4.5 amperes.

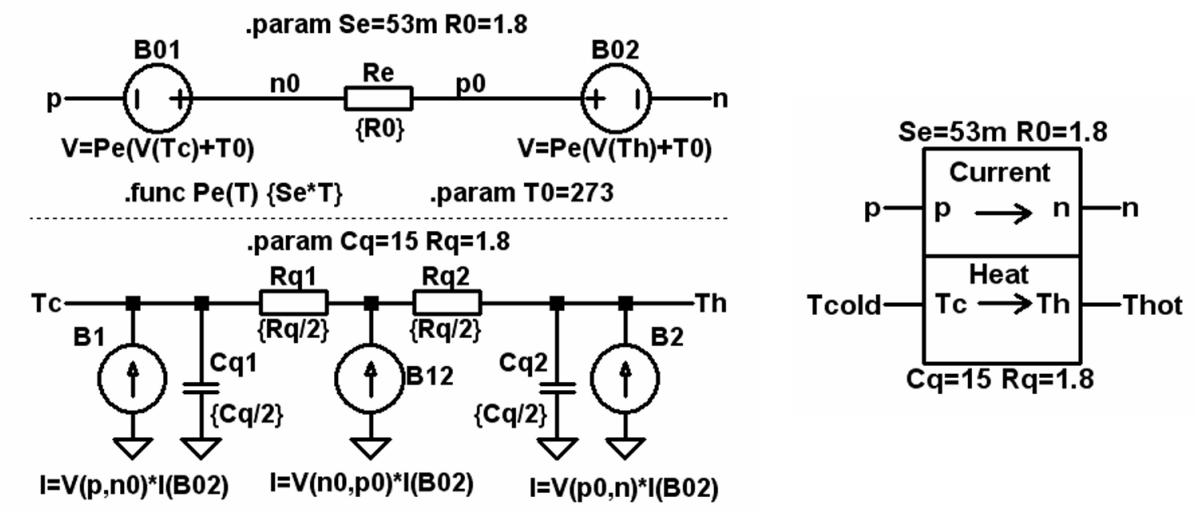

Fig. 3. Parameters of TEC 12706 [7]

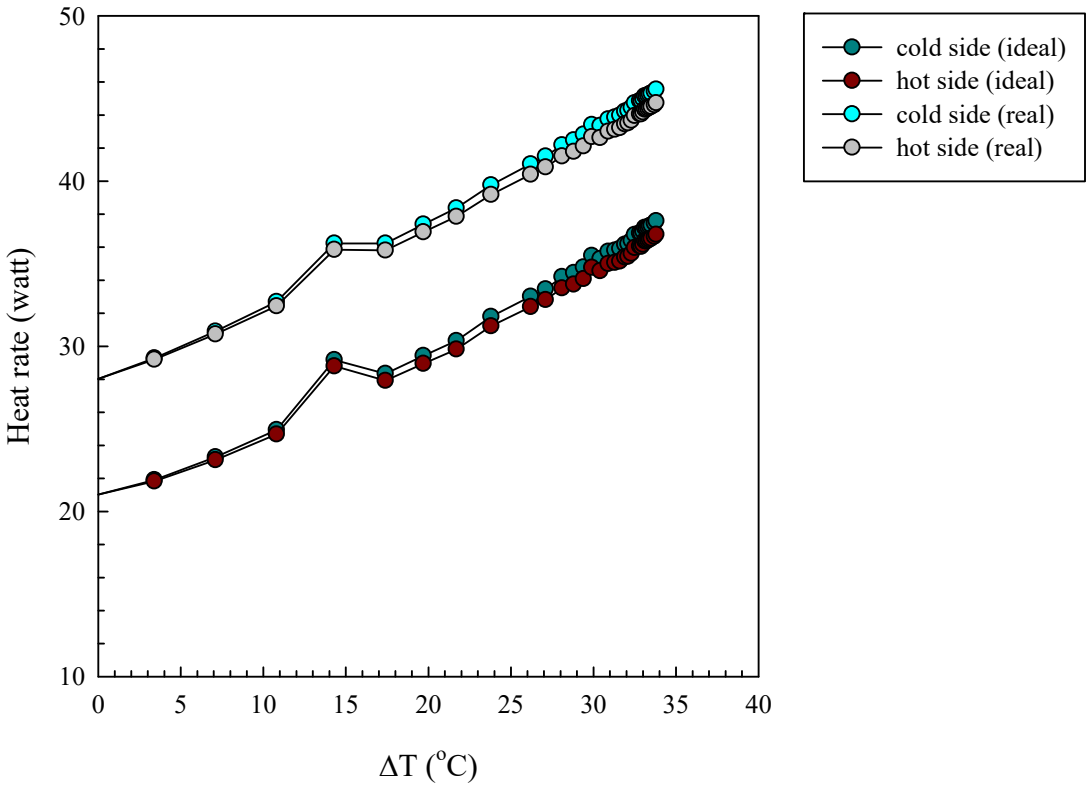

Fig. 4. Heat rate of TEC 12706

Figure 5 below shows the inside temperature of hybrid mini-cooler which is generated by conventional electricity (thermal power) and solar panel. In the beginning, the mini-cooler is generated by using conventional electricity and the average inside temperature reaches around 22 ºC whereas the temperature on evaporator wall reaches 7 ºC. The conventional Vapour Refrigeration System in the mini-cooler works well since the lowest temperature is reached in 150 seconds. But the heat transfer in inside mini-cooler room needs to enhance the since the temperature difference between wall evaporator and mini-cooler room is quite high.

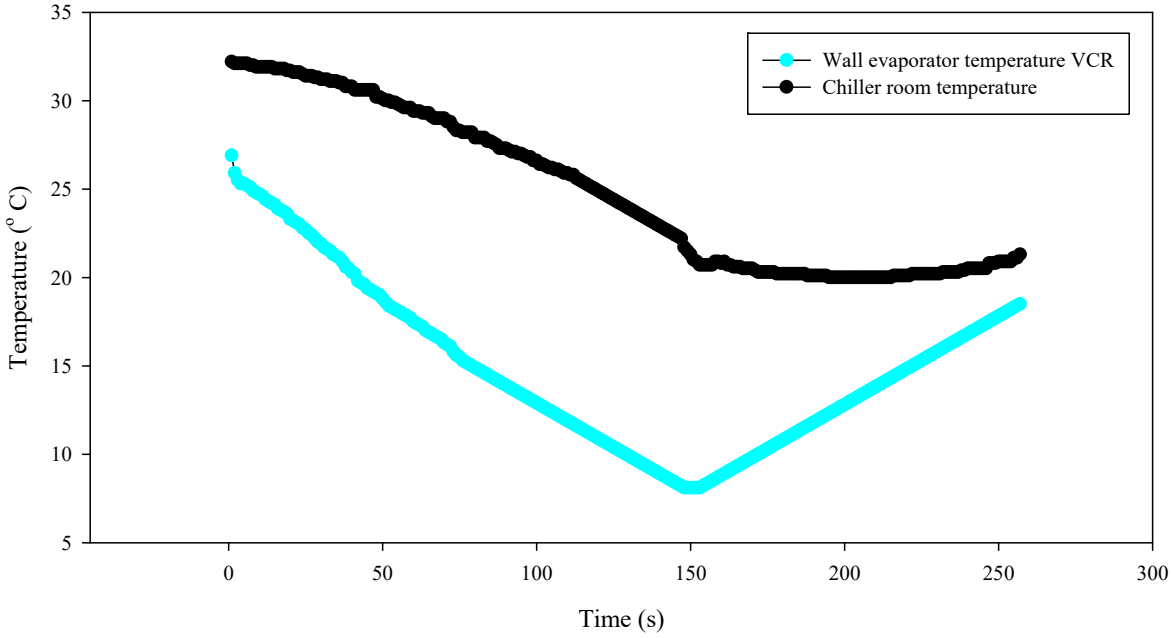

Fig. 5. Temperature of Hybrid Refrigerator

The next is mini-cooler which is generated by solar panel through TEC. The Figure 5 shows increasing wall evaporator temperature rapidly since VCR is already Off whereas the room inside of mini-cooler does not shows increasing temperature rapidly. The increasing wall evaporator temperature rapidly because the compressor off and leads rising heat and then increasing refrigerant temperature. This scheme should be considered since rising heat on compressor and may considering additional fans to cooling compressor.

Conclusion

In this research should be noted that improper operation of the TEC could cause the Joule effect, which is the appearance of heat on the cold side of the TEC. This is an undesirable condition where electrical energy produce hot temperature on cold side. This can occur if the heatsink and fan on the hot side are inadequate for heat dissipation. This hybrid refrigeration is generated by two modes, those are conventional VCR with R-134a as refrigerant and TEC. The VCR mode shows inside of refrigerator temperature reaches around 22 ºC and 7 ºC on evaporator wall. Whereas the second mode is generated by solar panel through TEC after shutting down the VCR system and this mode shows inside of refrigerator temperature still

reaches around 22 ºC but the evaporator wall temperature increases rapidly. This refrigeration needs higher performance of solar panel battery since the battery drains rapidly.

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Аналіз теплопередачі гібридного охолодження: парокомпресійне охолодження (VCR) та термоелектричне охолодження (TEC)

Гібридний міні-холодильник поєднує в собі звичайне охолодження та термоелектричний охолоджувач. Звичайний холодильний пристрій використовує

R-134a як робочу рідину та виробляє електроенергію з тепла, тоді як ТЕС генерується за допомогою сонячних панелей. Це дослідження складається з двох методів: міні-холодильник, що генерується за допомогою тепла та сонячних панелей. Результат показує внутрішню температуру міні-холодильника, який генерується за допомогою звичайної електроенергії, близько 22 °C, тоді як температура на стінці випарника досягає 7 °C. У той же час міні-холодильник, який генерується сонячною панеллю через ТЕС, демонструє швидке зростання температури на стінці випарника, оскільки звичайна холодильна система вже вимкнена, тоді як у приміщенні всередині міні-холодильника температура не зростає швидко.

Ключові слова: теплопередача, гібридний міні-холодильник, термоелектричне охолодження, парокомпресійне охолодження, холодоагент R-134a, температура