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Characterization of the Thermoelectric Coolers and Fatty Acid as a Phase Change Material of the Portable Box Cooler

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ABSTRACT

The utilization of portable box coolers (PBC) for traditional fishermen is quite popular in Indonesia. However, pure water's cooling medium is still limited to ice. With the development of PCM technology, the utilization of fatty acids began to be used. Likewise, the use of thermoelectric coolers (TEC) directly on PBCs has also been widely developed. In this study, a combination of utilization of PCM based on fatty acids, namely lauric acid, myristic acid, and stearic acid has been carried out with the addition of a TEC to PBC. The concentration of each use of fatty acids in pure water was 5 mg/L, and the use of pure water was also tested as a comparison. The PBC design was developed for this research and given a load of 5 watts lamps in each test. The study was carried out in two stages, firstly, the use of PCM without the use of TEC, and the second study was the combination of the use of PCM which was added with the use of a TEC. The results showed that using a fatty acid solution was able to maintain the air temperature in the PBC longer than using only pure water. The use of stearic acid solution produces the best performance which can be seen from the time it takes to maintain the air temperature in the PBC is the longest to reach the initial air temperature, which is 1,160 minutes, followed using myristic acid solution for 1,120 minutes, while the use of the lauric acid solution is only able to maintain air temperature in PBC for 1080 minutes. This can be caused by the melting point of stearic acid being higher than the use of myristic acid and lauric acid. However, these results show that they are better than pure water, which can only reach 900 minutes to maintain air temperature in PBC. Adding a TEC to PCM from fatty acids could extend the time to maintain the air temperature in the PBC by about 40 minutes. These results indicate that the use of these fatty acids as PCM media can work significantly in thermal energy storage.

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1. Introduction

Indonesia is an archipelagic country consisting of tens of thousands of islands and seas. As an archipelagic country, almost all islands are surrounded by oceans, this makes Indonesia have an ocean area of more than 60 percent of its area. This ocean area is used by most of the people who live on the coast to work as fishermen. Residents who live in remote areas where technology for fishermen is still minimal, use simpler technology to maintain the quality of their fish catches while at sea, such as traditional fishermen using ice placed in a box cooler to store fish. Likewise, some residents who do have a hobby of fishing in the sea, also use a box cooler that is used to store fish while at sea. For anglers who have good facilities, they will use a commercialized portable box cooler (PBC).

Some commercial PBCs use ice packs filled with water and certain material, such as silica gel, which acts as a phase change material (PCM). PCM is divided into three parts, namely solid-liquid, liquid-gas, and solid-gas. Among these types, solid-liquid PCM is the most widely used PCM as a thermal energy storage [1]. Several types of PCM have been developed such as organic, inorganic, and eutectic PCM. Organic PCM is generally divided into two, namely paraffin which mostly consists of a mixture of alkane bonds, and non-paraffin organic material which is often referred to as fatty acid [2]. Organic materials include congruent melting, self-nucleation, and usually non-corrosiveness to the container material [3]. Unlike conventional energy storage materials, PCM can absorb and release heat energy at near-constant temperatures [4]. Several types of acids, which are based on fatty acids, can in principle be used as media of PCM, such as lauric acid ($CH_3(CH_2)_{10}COOH$), myristic acid ($CH_3(CH_2)_{12}COOH$), and stearic acid ($CH_3(CH_2)_{16}COOH$). These acids have several advantages such as low prices and adequate market availability when used as PCM [5]. Chemically, the three fatty acids are stable, non-toxic, non-corrosive, and do not have to subcool during solidification and the volume changes tend to be small during the phase change process from solid to liquid [6]. Organic fatty acids are also easily produced from raw conditions from renewable vegetable and animal sources that do not pollute the environment, these organic acids are sold in solid and liquid forms and if they are solid, they need to be mixed with liquid with a certain concentration. PCM uses chemical bonds to absorb and release heat. Transfer of heat energy occurs when a material change from solid to liquid, or liquid to solid. This is called a change of state or phase [7]. PCM material undergoes a melting or solidification process at a certain temperature point and period. During the melting process, PCM will absorb energy from the surroundings while for solidification, PCM will release a large amount of heat energy to the surroundings while the temperature remains constant or varies within a small range. When PCM is cooled in the refrigerator, solidification will occur because PCM will release heat, then when PCM is used there will be the absorption of heat energy so that PCM will melt [8].

In a box cooler that uses PCM as a medium for storing fishery products, PCM will quickly melt if the ambient temperature is high enough or when the fishermen take a long time to go to the sea. Therefore, it is necessary to add other coolers, such as using a thermoelectric cooler (TEC) as a backup if the PCM is no longer able to cool the fish. On the other hand, many PBC development efforts use TEC directly. TEC is very influential on the performance of the box cooler [9]. TEC is an electric solid-state cooling component, in the cooling process TEC utilizes the Peltier effect, that is, when the electric current is in the same direction through a junction of two TEC materials produces a temperature difference at the connection [10].

Based on several studies on the use of PCM and TEC, in this study, the characteristics of the use of the two types of coolers, both PCM and TEC, that are used simultaneously on PBCs can be used by traditional fishermen as thermal energy storage media in storing their caught fish while at sea.

2. Methodology

This research has been carried out in two stages, firstly, the experiment is carried out on pure water, lauric acid, myristic acid, and stearic acid. The second step is to test the first type of PCM but is added with the use of a TEC. The experiment was carried out by manufacturing a PBC with an inner size of 370 mm × 245 mm × 265 mm. PBC walls are composed of aluminum foil on the inner of the PBC, then the styrofoam was added to the outer side of aluminum foil with a thickness of 20 mm, and plywood with a thickness of 8 mm is attached on the outside of the styrofoam, and the plywood directly functions as a PBC frame. To avoid condensate leakage, all plywood walls are covered with plaster [11]. The top of the PBC (cover) is made of the same material as the PBC wall, except in the middle of the PBC, a TEC type TEC1-12706 is installed. Two DHT-22-type temperature sensors are installed at 130.5 mm from the PBC cover. Loading on the PBC is carried out by installing a lamp with a power of 5 watts in a hanging position at 66.5 mm from the PBC cover. The PBC schematic can be seen in Figure 1.

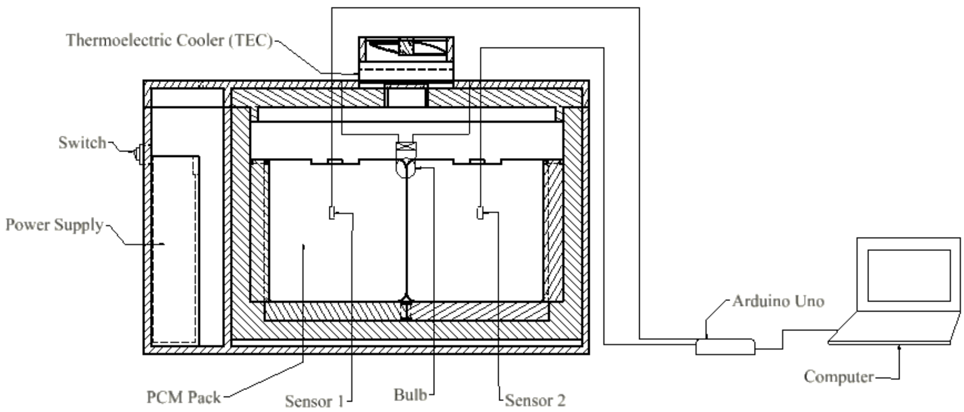

Fig. 1. A schematic design of the portable box cooler

Fatty acids used are powder types that are purchased commercially. The three types of acid are treated the same, namely by mixing each type of acid with as much as 5 mg, then put into a beaker glass. Pure water was added to the beaker glass until the volume of the beaker reached 1 L. Then, the solution was stirred using a magnetic stirrer for 15 minutes to achieve a homogeneous solution. The acid solubility in water affects the cooling performance of the PCM [12]. The homogeneous solution of each acid was put into a plastic pack of 150 mm x 150m x 25 mm, and the solution was put in a freezer for 24 hours. The frozen solutions are removed from the freezer, and they are arranged in the PBC. The number of packs included in the box is 8 pieces, with 2 packs put on wide walls, 1 pack on narrower walls, and 2 packs on the bottom of the box. The air temperature in the PBC is set during the experiment at the same initial temperature.

In the absence of TEC, the experiment is conducted when the power supply is turned off. Furthermore, for each material used in this test, the initial air temperature in the PBC is recorded, and the air-cooling process occurs and waits for the air temperature in the PBC to rise again. The experiment stops when the PBC's air temperature has reached its initial air temperature. The recording of air temperature in the PBC is carried out every 20 minutes using a temperature sensor controlled by Arduino Uno to obtain accurate data for each test. The same process is also carried out with simultaneous testing between the use of PCM and a TEC. As described earlier, all tests were carried out by providing a lamp power load of 5 watts. When the experiment is conducted with a TEC, the power supply (AC-DC converter) will be turned on to operate a TEC.

3. Results

The experimental results will be presented in two sections, firstly, to observe the characteristics of the use of fatty acids solution as a PCM in PBC and to observe the character of the use of pure water as a comparison. Furthermore, the effect of using a TEC will be discussed later for each use of pure water and fatty acids.

The addition of fatty acids into pure water to become an acid solution can maintain the air temperature in the PBC longer at low temperatures this is due to the melting temperature range of PCM for refrigeration applications lying within the thermal comfort range [13]. The stearic acid solution was able to withstand the air temperature in the PBC for 1,160 minutes to return to the initial air temperature, i.e. 26.3 °C. The use of myristic acid solution was able to hold the air temperature in the PBC for a shorter period, which was about 1,120 minutes. While the use of lauric acid solution has the worst performance of the other two acid solutions, which is for 1,080 minutes. In contrast, the use of pure water results in the air temperature in the PBC returning to its initial temperature in around 900 minutes or 15 hours, as shown in Figure 2. This can be caused that stearic acid has the highest melting point, compared to other acids, and the acid that has the lowest melting point is lauric acid, therefore, these properties may cause the stearic acid solution can maintain the air temperature in the PBC longer compared other acids [14,15]. As indicated in Figure 2, we also can observe that myristic acid increases the air temperature in the PBC more slowly than pure water and lauric acid but increases the air temperature more rapidly than stearic acid [16]. In general, these results can also indicate that the use of these fatty acids can be used as PCM media for thermal energy storage.

In Figure 2, it can also be seen that in the first 40th minute there was a very sharp decrease in air temperature in the PBC, especially when using stearic acid and myristic acid solutions which could reach 0.4 °C and 0.1°C, respectively. The use of lauric acid solution can reach the lowest temperature of 2.0 °C, and the lowest air temperature in PBC is achieved by pure water at a temperature of 2.9 °C.

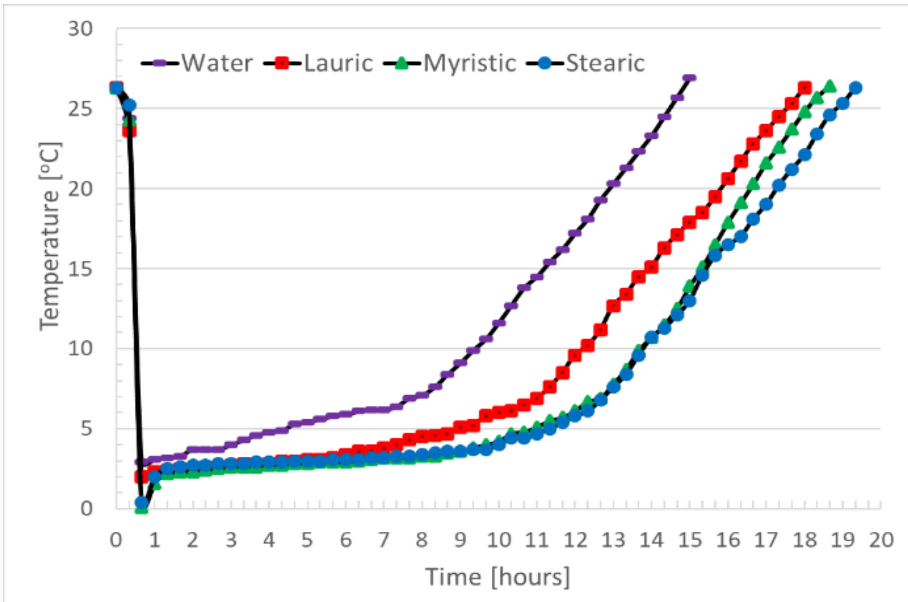

Fig. 2. The air temperature profile in the PBC of the various PCM and pure water

In the second experiment, the addition of a TEC on the PBC can also increase the time in which the air temperature in the PBC can last longer for all fluids used before the air temperature rises

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again to the initial air temperature of the PBC. As can be seen from Figure 3, the time required to maintain the air temperature in the PBC using pure water reaches 1,000 minutes. The holding time of the air temperature in the PBC to reach the initial air temperature also can be identified to be 1,120 minutes and 1,160 minutes for the use of lauric acid and myristic acid solutions, respectively. Meanwhile, the greatest increase in time was achieved by using a stearic acid solution, which was 1,200 minutes, to maintain air temperature in the PBC to reach the initial air temperature. These are due to that the addition of a TEC can affect the melting time of the material used as PCM [9]. The average increase in time to maintain air temperature in PBC for all fatty acid solutions is about 40 minutes, while for the use of pure water, it can reach 100 minutes. This could be since the use of these fatty acids was able to maintain a plateau air temperature in the PBC for a longer period compared to the use of pure water, as can also be identified in Figure 4.

As shown in Figure 4, it appears that in the temperature interval from 2.5 °C to 3.5 °C there is a very small change in air temperature in the PBC (shown as the dashed lines). It can be seen in the figure that the temperature measurement becomes a plateau. However, the time to maintain the air temperature in the PBC varies according to the use of the fluid used. For example, the use of pure water is only able to maintain the air temperature in the PBC at intervals of 2.5 to 3.5 °C for only about 3 hours, as can be seen in Figure 4(a). While using lauric acid, myristic acid, and stearic acid solutions, as can be identified in Figure 4(a) to Figure 4(c), it appears that the air temperature in the PBC can be maintained almost stable for about 6 hours, 8 hours, and 10 hours, respectively. Again, these results show that using fatty acids as PCM for cooling systems can work significantly.

The addition of TEC to PBC can reduce the air temperature in PBC compared to the experimental results without the addition of TEC because the addition of a TEC cooler greatly affects the melting time of the PCM material, as also can be seen in Figure 4 [17]. In the first 40th minute, the use of pure water results in air temperature in the PBC can reach of 2.6 °C, as shown in Figure 4(a), in the use of fatty acids, namely in lauric acid solution the lowest air temperature reaches 1.6 °C, as can be seen in Figure 4(b), in the use of the myristic acid solution, as indicated in Figure 4(c), the lowest air temperature reaches 0 °C, and in Figure 4(d) we can identify that the air temperature in the PBC can reach 0.2 °C in the use of the stearic acid solution.

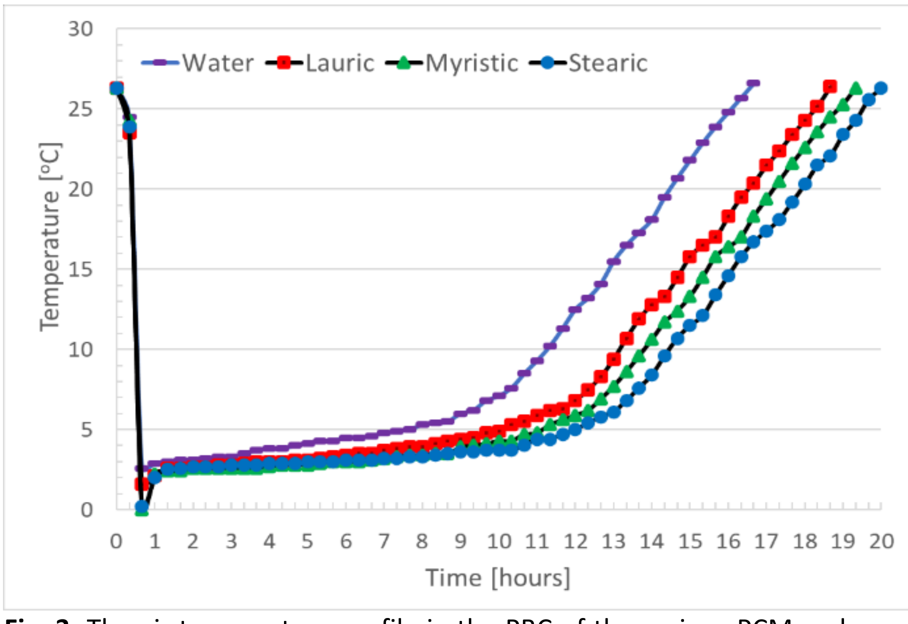

Fig. 3. The air temperature profile in the PBC of the various PCM and pure water with the addition of a TEC

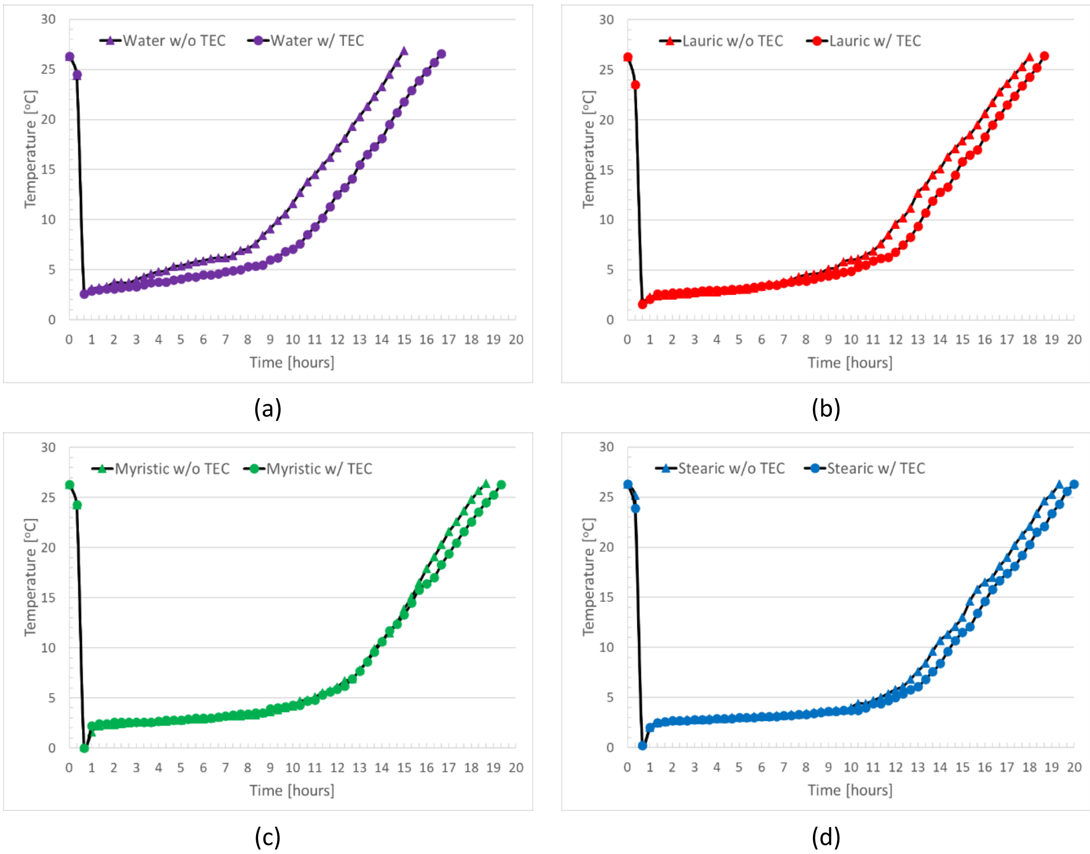

Fig. 4. The air temperature profile in the PBC (a) Pure water (b) Lauric acid solution (c) Myristic acid solution (d) Stearic acid solution

4. Conclusions

The use of fatty acids such as lauric acid, myristic acid, and stearic acid can be significantly performed as PCM media when used to maintain air temperature in PBC compared to using pure water only. However, due to these three types of acid having different characteristics, especially the melting point, their abilities are also different. The acid with the largest melting point can be concluded as a better PCM in cooling systems such as in the PBC. In this case, stearic acid is the acid that can maintain the air temperature in the PBC longest than other types of acids used as PCM in this study. Adding a TEC combined with the use of fatty acids as PCM simultaneously can result in better performance of the PCM in the PBC applications.

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