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Development of Portable Blood Carrier Box Employing Thermoelectric Module by Using Oil Palm Empty Fruit Bunch Composites as Materials of Box

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ABSTRACT

The process of blood distribution from the proper storage before transfusion requires a cooling unit, which is able to maintain the temperature of the blood and ensure that it is not damaged before being transfused. In order to maintain the chemical and structural composition of the blood, it should be stored at a temperature of 2-6 °C and distribution carried at a temperature of 2-10 °C with a maximum transit time of 24 hours specifically for whole blood. The cooling method currently used is by placing an ice pack or ice in a blood distribution room therefore, a special room, which prevents ice from cooling down, is continuously required for cooling. This study aims to design, manufacture and test a box that may be used as a means of blood transportation, does not require a special room to cool the cold room and works continuously for 2 hours. The thermoelectric cooler was chosen as a cooler in the blood carrier box because of its small size which makes it possible to be operated in a limited space and at a DC voltage of 12. Elements Peltier with type TEC1-12706 was use as the thermoelectric cooler and composites with oil palm empty fruit bunches, which has a thermal conductivity value of 0.13 W /m was chosen as the material for the box. The test carried out resulted in the highest coefficient of performance (COP) value, namely 0.168. The test was carried out at a voltage variation and loading of 9 volts and 7 blood bags of 350 ml, respectively. The result shows that the box is able to maintain a blood temperature of 2.65 °C and at the variation of the voltage and loading of 12 volts and 7 bags of 350 mL, respectively, it was able to maintain the best blood temperature of 2.62 °C.

1. Introduction

Based on a decree issued by the World Health Organization (WHO), blood supply in an area should exceed 2% of the total population. In Indonesia, the total need for blood supply in accordance with the WHO provisions is 5,174,100 bags however, the available blood supply is only for 4,201,578 bags [1]. In 2016, some blood were obtained from 281 Blood Transfusion Units although, an increase in the number of donors was reported yearly from 2007 to 2016 but had not yet fulfilled the blood

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supply needs in Indonesia as seen in Table 1. The data indicates that Indonesia is still in need of blood supply of over 972,522 bags [1].

Table 1
Number of blood donations in Indonesia 2007-2016 [1]

Years	Total donation	Voluntary donation	Family donation	Paid donation
2007	1.746.590	1.420.910	325.680	
2008	1.718.470	1.416.370	302.104	
2009	1.742.150	1.444.390	297.753	
2010	2.083.580	1.764.280	318.789	507
2011	2.310.720	1.954.600	345.874	10.547
2012	2.538.310	2.121.740	416.447	25.089
2013	2.722.750	2.306.700	403.470	12.581
2014	3.054.740	2.633.340	414.333	7.070
2015	3.370.930	3.034.900	330.913	5.118
2016	3.252.077	2.983.534	261.087	7.456

Due to this condition of insufficient blood supply, the distribution of blood to a place has become a way to meet the blood needs of the population. This is because it is not certain that the population's need for certain blood types is available at the Hospital Blood Bank or at the Blood Transfusion Units around the area where they live. Therefore, an adequate media is needed in the distribution to maintain the condition of the blood at a temperature of 2-10 ^{o}C in which it is still in good condition for use [2]. The cooling method currently used is by placing ice packs or ice cubes in the blood distribution room [3]. This indicates that the existing cooling requires space in a cooling room where ice cubes do not cool continuously compared to Peltier elements which are able to always cool as long as they are given electric power [3]. In addition, thermoelectrics were used based on several reasons such as efficient cooling at low prices [4], has been tested for cooling in box rooms [5] and may be used as portable cooling [6].

In addition to cooling, the distribution media requires innovation from the Box material used. This is carried out to maximize temperature maintenance. The existing box material is made of plastic, which is a synthetic material with thermal conductivity of 0.4 W/m.K [7]. Therefore, the use of plastic materials may be replaced with materials that are more environmental friendly and have a lower thermal conductivity value such as composites with oil palm empty fruit bunches which has a thermal conductivity value of 0.13 W/m.k [8]. In Indonesia, oil palm empty fruit bunches of waste from 2015 to 2019 exceeded 7 tons yearly [9].

In this study, blood carrier boxes were designed and made based on the use of the system and the characterization of the thermoelectric cooler [10,11]). Insulation and aluminum foil were used as a medium to reduce energy loss [12,13] and their box capacity based on blood loss conditions [14].

2. Methodology

2.1 Box Design

The box was designed by first calculating the thickness of the wall using the thermal conductivity value where the empty palm oil fruit bunch composite is used as a wall material, using Eq. (1) and (2) [15].

$$x = \frac{\mathrm{k}}{\mathrm{h}} \tag{1}$$

where x is the wall thickness (m), k is the thermal conductivity (W/m.K) and h is the Air Layer Coefficient (W/m^2.K)

$$\mathrm{h} = \frac{k_f}{L_c} Nu \quad (2)$$

where k_f is the conductivity of the fluid, L_c is the Characteristic Length (m) and Nu is the Nusselt number.

The Nusselt number is differentiated according to the position of the dimensions in contact with air. Its characteristics may be obtained by Eq. (3) [16].

$$\text{Vertical Position: } Nu = \left[0{,}875 \frac{0{,}347 Ra_L^{\frac{1}{6}}}{\left[1+\left(\frac{0{,}492}{Pr}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}} \right]^2 \quad (3)$$

where Ra_L is the Rayleigh number and Pr is the Prandtl number

$$\text{Horizontal Position with Hot Top Side: } Nu = 0{,}54\ Ra_L^{\frac{1}{4}} \quad (4)$$

$$\text{Horizontal Position with the Lower Side of the Heat: } Nu = 0{,}27\ Ra_L^{\frac{1}{4}} \quad (5)$$

2.2 Cooling System Design

The cooling system was first designed by calculating the cooling load of the blood carrier box which comes due to the heat from the stored blood (product load) and the heat from the environment entering the container. The cooling load of blood in the blood carrier box is whole blood, using the following equation to calculate the load value of the product [17]

$$Q_{product} = \frac{\mathrm{m.Cp.\Delta T}}{\Delta \mathrm{t}} \quad (6)$$

where $Q_{product}$ is the product cooling load (watts) and Cp is the specific heat (J.kg/K).

Heat enters to the blood storage chamber through the side wall and its transfer transmission in the container may be seen in Figure 1.

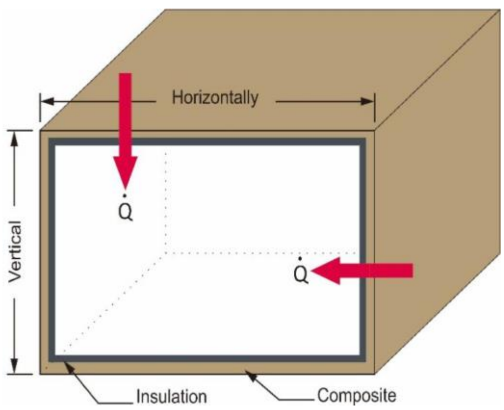

Fig. 1. Heat transfer schematic on box

The heat that enters to the blood storage chamber from the temperature difference through the walls of the box is a transmission load ($Q_{transmission}$) and the thermal resistant of wall may be seen in Figure 2.

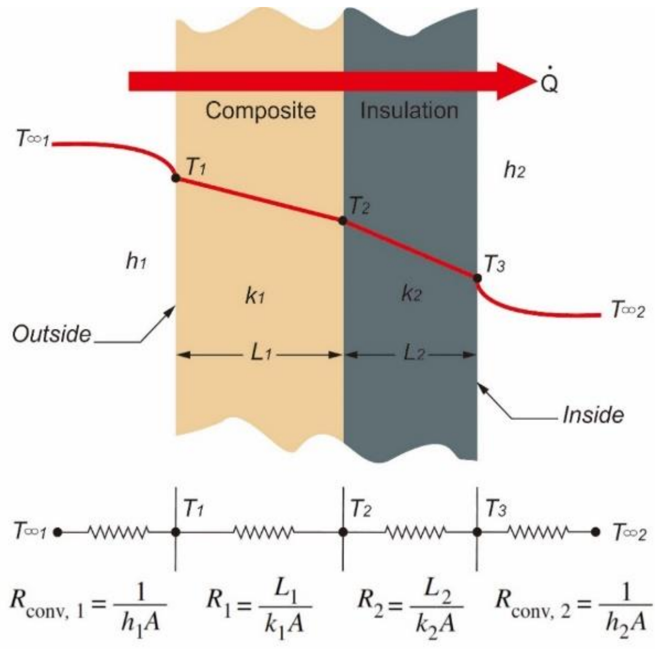

Fig. 2. Thermal resistance of wall

The cooling load may be obtained using the following equation after the product load and transmission load are obtained.

$$Q_{load} = Q_{transmission} + Q_{product} \quad (7)$$

where Q_{load} is the total of cooling load.

The amount of thermoelectric cooler and power supplied to the blood carrier box may be calculated with some supporting data for the thermoelectric cooler [18] which is a Seebeck coefficient (Sm), heat conductance (Km), electrical resistance (Rm) and power. Electric is measured in Watts (We) and Power Absorbed in Cooling in Watts (Qc). Furthermore, the parameters obtained are substituted to Eq. (8) to determine the quantity of thermoelectric cooler (n).

$$\mathrm{n} = \frac{Q_{load}}{Q_C} \quad (8)$$

2.2 Composite Wall Material Manufacturing
2.3.1 Material

The composite material on the box wall is a combination of oil palm empty fruit bunch (OPEFB) and epoxy resin as reinforcement and matrix, respectively. In this study, the Oil palm empty fruit bunch (OPEFB) used were obtained from PTPN V Sei Galuh Riau and the epoxy resin used was produced by PT. Brataco Chemika. Furthermore, the size of the oil palm empty fruit bunch (OPEFB) was 30 mesh particles, matrix epoxy resin 555 A and epoxy hardener EPH 555 B with a ratio of 2:1. Based on the calculations carried out, the required flexural strength is 4.08 MPa. Table 2 are shows the comparison of the flexural strength of composites from oil palm empty fruit bunches from several researchers and all of these composites met the requirements as material of box.

Table 2
Comparison of the flexural strength of composites from empty oil palm bunches

Material	Testing Standard	Flexural Strength (MPa)	Reference
Oil palm empty fruit bunch (OPEFB)	JIS K6781	30.216	Fatra, 2016 [19]
Oil palm empty fruit bunches (OPEFB) + Zinc Oxide (ZnO)	ASTM D790-92	10.01	Adlie, 2019 [20]
Oil palm empty fruit bunches (OPEFB) + Epoxy	ASTM D790	46.46	Result of this research

3. Methods of Making Composites

The particles of oil palm empty fruit bunches measuring 30 mesh as reinforcement were mixed with epoxy resin as a matrix with a volume fraction ratio (1:1), mixed until it became even. In addition, the mixture was poured into the mold as seen in Figure 3**.**

Fig. 3. Composite wall slabs before printing

Printing is carried out using a pre-made male-female steel mold, using compression molding with a pressure of 30 kg/cm^2. The results of the plate-shaped composite molding is seen in Figure 4**.** The plate-shaped composite was also formed into specimens and the bending test carried out according to the ASTM D 790 standard [21] which obtained a bending strength value of 46.46 MPa.

Fig. 4. Composite wall slab after printing

Composite walls only receive a load of 4.08 MPa from 2.45 L of blood (2.61 kg) as shown in Eq. (9) therefore, it is concluded that the composite material is suitable for use as a box wall and may proceed to the assembly process into a box. Blood carrier box made may be seen in Figure 5**.**

$$\sigma_b = \frac{\mathrm{Mc}}{I} \tag{9}$$

$$\sigma_b = \frac{(\text{F.x})(\frac{\text{h}}{2})}{\frac{1}{12}bh^3}$$

$$\sigma_b = 40{,}8\,\frac{\text{N}}{\text{cm}^2}$$

$$\sigma_b = 4{,}08\ \text{MPa}$$

where σ_b is the bending stress (MPa), *M* is the moment (N.cm), C is the center (cm) and *I* the moment of inertia (cm^4).

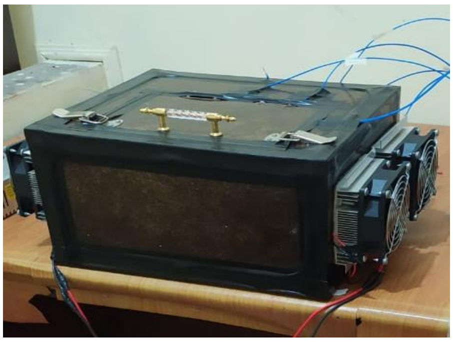

Fig. 5. Prototype blood carrier box

3.1 Testing Method

This study used an analytical method, with the initial blood temperature, number of blood bags as a cooling load and the stress as references in testing to calculate the coefficient of performance (COP) value for thermoelectric cooling. Based on the results of observations and calculations, it was discovered that the final temperature of the blood after being tested for variations for 2 hours and the coefficient of performance (COP) value for each variation of the test.

The blood carrier box cooling system consists of several main components which includes the peltier element, cold and heat sinks and fan as a means of converting electricity into temperature changes, as mediums for absorption and release of heat in the cooling process and to accelerate the absorption and release of heat, respectively. Thermoelectric coolers are assembled in parallel to ensure that each circuit is supplied with the same voltage and divides the current from the power supply equally across four thermoelectric coolers. The advantage of a parallel circuit is that a damage in one series has no effect on the other series [22].

The measuring instrument used in testing the blood carrier box consists of 6 K-type thermocouples, each of which are used to measure the box's ambient temperature, spare wall temperature, heat and cold sink temperatures, box room temperature and blood. OMEGA TC-08 USB data logger which was used as a signal converter was obtained from the thermocouple to be forwarded to the computer and the watt meter used to measure the power consumption, voltage and current of the blood carrier box.

This study aims to determine the performance of the blood carrier box prototype. The blood carrier box was made and tested by loading 7 blood bags with 350 ml volume each with a voltage of 12 volts. Figure 6 show the experimental setup scheme used to test blood carrier box performance.

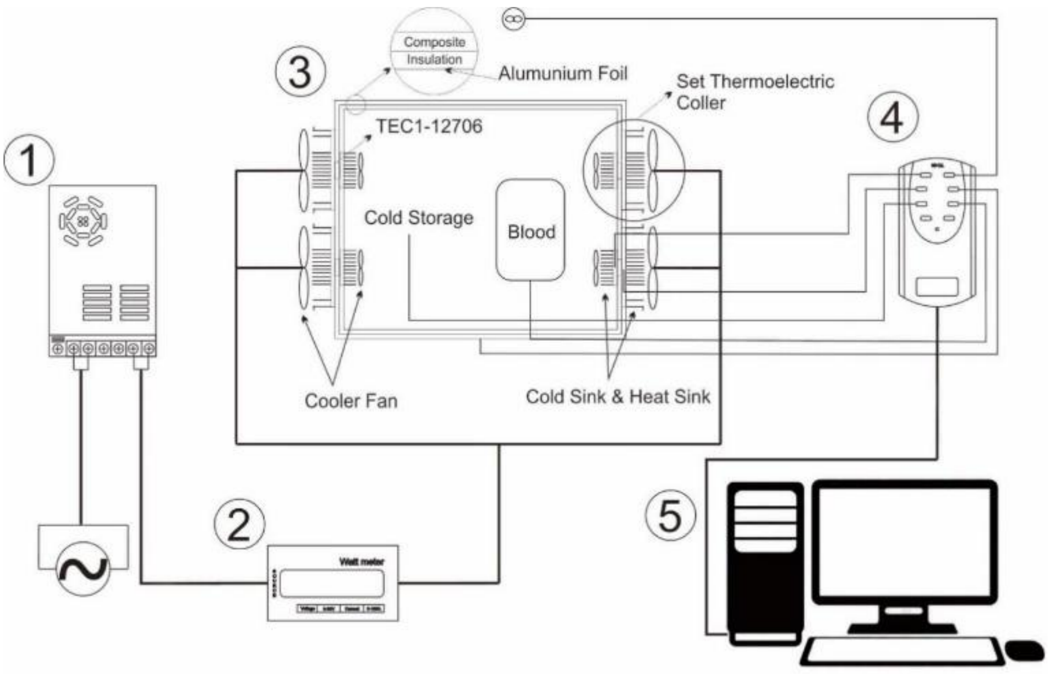

Fig. 6. Set-up experimental scheme: 1. Power supply; 2. Watt meter; 3. Blood carrier box; 4. Data logger omega tc-08; 5. Computer

The characteristics of the thermoelectric cooler may be determined using manufacturing data from Type TEC1-12706 and by calculating the Seebeck Coefficient (S_m), Heat Conductance (K_m), Electrical Resistance (R_m), Electric Power (We), Heat input (Q_c) and Coefficient of Performance (COP) [18].

4. Results and Discussion

Testing is carried out by installing a thermocouple to measure the temperature of the box walls, environment, box room, blood, heat and cold sink. In this study, the tests carried out have resulted in various variations on temperature data on the blood carrier box. The thermocouple is connected to the OMEGA TC-08 data logger which is connected to a PC. This is to record the temperature changes that occur in the measuring object.

The test is run with a preparation of 30 minutes, followed by a test work 2 hours. A 30 minutes preparation is needed to adjust the temperature of the room to the lowest as possible. In addition, getting blood into the box is part of the preparation. The blood placed into the box has a temperature of 2^{o}C. According to the problem boundaries in this study, 2 hours work test was used with data recording carried out at an interval of 2 minutes. The test was carried out by varying the load and stress.

From the results of this study, it was discovered that room temperature and blood were at intervals of 2-10^{o}C, which was in accordance with the SOP for blood distribution from PERMENKES 2015 [2]. Furthermore, the obtained was converted into graphs in order to facilitate the process of comparing data. The following is a graph of the test data obtained from testing.

In Figure 7**,** there is a graph of blood temperature with a thermoelectric cooler at a given voltage of 9 volts. The first variation is the test at a temperature of 33^{o}C which continues to rise until the end of the test where the final blood temperature is 5.08^{o}C as seen in the graph. This is caused by the high temperature of the environment outside the box which forces it to enter the box and results in an increase in blood temperature inside the box. At the 33^{o}C environmental temperature variation, COP is 1.68 which is the biggest of the 2 other tests because the high environmental temperature loads the thermoelectric cooler to work deeper in order to absorb heat in the box. Furthermore, the second variation is testing at a temperature of 28°C, where the final temperature of the blood on the test is 3.8°C with a COP value of 1.62. The third variation is testing at a temperature of 26°C where the final temperature of the blood in the test is 2.7°C with a COP value of 1.60.

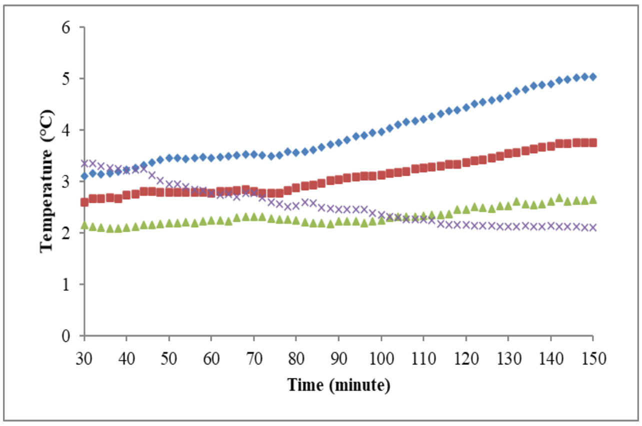

Fig. 7. Graph of load testing for 7 blood bags and unload at a voltage of 9 volt with variation of ambient temperature; 7 blood bags ◆ $T_{ambient}$ = 33°C, ■ $T_{ambient}$ = 28°C, ▲ $T_{ambient}$ = 26°C and unload χ $T_{ambient}$ = 33°C

In Figure 8**,** there is a graph of blood temperature with a thermoelectric cooler at a given a voltage of 12 volts. The first variation is the test at a temperature of 33°C, which continues to rise until the end of the test the final blood temperature is 4.7°C as seen in the graph. This is caused by the high temperature of the environment outside the box which forces it to enter the box and results in an increase in blood temperature inside the box. Furthermore, at the 33°C environmental temperature variation, COP is 1.58, which is the biggest of the 2 other tests because the high ambient temperature loads the thermoelectric cooler to work deeper in order to absorb heat in the box. The second variation is testing at a temperature of 28°C where the final temperature of the blood on the test is 3.7°C with a COP value of 1.56. In addition, the variation is testing at a temperature of 26°C, where the final temperature of the blood in the test is 2.6°C with a COP value of 1.50.

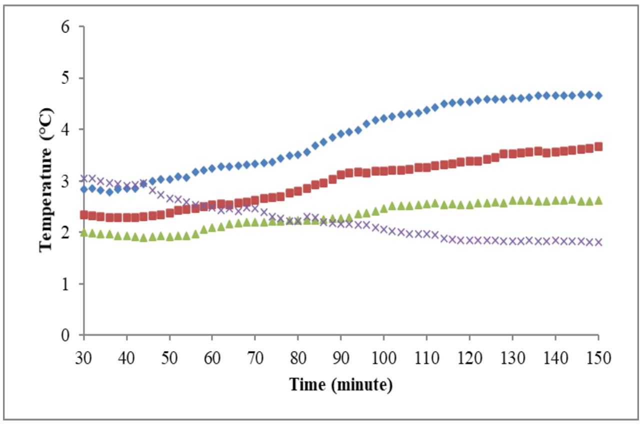

Fig. 8. Graph of load testing for 7 blood bags and unload at a voltage of 12 volt with variation of ambient temperature; 7 blood bags ◆ $T_{ambient}$ = 33 °C, ■ $T_{ambient}$ = 28 °C, ▲ $T_{ambient}$ = 26 °C and unload X $T_{ambient}$ = 33 °C

In Figure 9, there is a blood temperature graph with a thermoelectric cooler given at a voltage of 12 volts an ambient temperature of 33°C. The first variation is the unload test seen in the graph that continues to fall until it gets to the end of the test where the final blood temperature is 1.8°C. This is caused by the continuous cooling provided by the thermoelectric cooler in the box room.

The second variation is the test with 4 blood bags, which continues to rise until at the end of the test the final blood temperature is 5.5°C as seen in the graph. This is because the cooling provided by the thermoelectric cooler continuously in the box room is unable to maintain the initial temperature of the blood when it is entered. The third variation is the test with 7 blood bags, which continues to rise until the end of the test the final blood temperature is 4.7°C as seen in the graph. The final temperature obtained is lower Compared to the 4 blood bags variation because in the 7 blood bags variation it is better to maintain its temperature at the beginning of the test.

To find out the criteria for the COP value obtained, a comparison was made with studies related to the box with other thermoelectric coolers. The comparison results are shown in Table 3.

From Table 3, it may be seen that the highest and lowest COP values based on testing are 0.19 and 0.103, respectively. Based on these data, the COP value obtained from the study was 0.168 which indicates that the blood carrier box made had good performance.

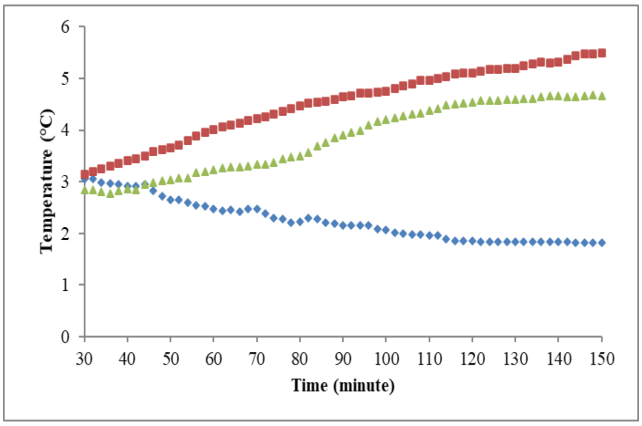

Fig. 9. Graph of load testing for unload, 4 blood bags and 7 blood bags and at a voltage of 12 volt with ambient temperature 33°C; ◆ = Unload, ■ = 4 Blood bags and ▲ = 7 Blood bags

Table 3
Comparison of COP with related research

No	Reference	COP
1	Lal, 2017 [4]	0,17
2	Mirmanto, 2018 [5]	0,19
3	Midiani, 2019 [23]	0,103
4	Result of this research	0,168

4. Conclusion

From this study, a blood carrier box has been designed and made with a cooling component of peltier elements and composites made from oil palm empty fruit bunches with the dimensions of 306 mm x 256 mm x 163 mm for length, width and height, respectively. The thickness of the composite wall of oil palm empty fruit bunches applied to these dimensions is 6 mm for the vertical position and 7 mm horizontally on the top side and 15 mm for the wall with a horizontal position at the bottom of the box. The need for Peltier elements was 4 sets with the required power of 282.35

watts. However, the test shows that the Peltier element only uses 14 amperes with a voltage of 12 volts, which is 168 watts therefore, the power required by peltier element under real condition is different from theoretical.

After testing, it was discovered that the blood carrier box was able to maintain the blood temperature according to the distribution standards of 2-10^{o}C. This is seen in the test results in which the blood carrier box with an input voltage of 9 volts, had the highest temperature of 5^{o}C with a COP value of 1.68 and the test with an input voltage of 12 volts had a temperature of 4.7^{o}C with a COP value of 1.58.

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