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PRELIMINARY DESIGN OF THERMOELECTRIC COOLER BOX FOR MUD CRAB (SCYLLA)

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ABSTRACT

Mud Crab (Scylla) is a species of crab that is popular seafood that can be easly found in Indonesia, especially in Sumatera Island. Unlike crab, mud crab can preserve at fishing spot before transportes and distributed. Conventional preservation of mud crab uses block ice to reach -20ºC temp in cooler box which is heavy and contribute most on fishing boat. Block ice load is more than 60% of a cooler box and can be easly melt due to inproper handling. Therefore, a more modern method which lighter and lower energy consumption is needed. Preliminary cooler box design with thermoelectric module is conducted. Thermoelectric based system, which is light, saves electricity and does not require a large area on this cooling technology design is expected to provide data and analysis results that help cooler box designers to produce the best performance. The designed cooler box has the need to use it to store seafood such as mud crabs (Scylla). By using a thermoelectric cooling system, the power that can be generated by the thermoelectric module (TEC1-12706) is 56.27 W, the maximum power that generate is 272.5 W, and the power required if the object being cooled is mud crabs (scylla) of 3186 W and requires 17 thermoelectric modules to cool a cooler with a capacity of 30 liters.

Keywords: *Thermoelectric, Mud Crab, Cooler Box*

1. INTRODUCTION

To be consumed properly, seafood must be stored using a device or tool that can maintain the temperature of the seafood itself up to -20°C, including using a cooler box. Cooler box is a tool that is commonly used as a place to store objects, samples, objects, or materials that require low temperatures in the storage process. The cooler box that is commonly encountered is a conventional cooler box that still uses a forced cooling system, namely by using crushed ice chunks. This kind of forced cooling system is of course starting to become irrelevant for use because this kind of forced cooling system certainly reduces efficiency in terms of energy use, storage capacity, and the net weight of the cooler box when it is filled with live material.

Responding to these weaknesses, the cooler box is applied with a thermoelectric cooling system which is used because thermoelectric devices have light weight and have small dimensions. In addition, thermoelectric is also a power generator that does not require a large amount of power for one device [1]. The thermoelectric cooler box that released by a brand called Mobicool has a power consumption in eco mode at 8,50 Watt. However, this consumption value is the lowest value they can reach to saves more energy and electricity and the cooler box are used to storage some food and beverages for camping or any other outdoor activities that needs a cool food and beverages besides it used to be a portable fridge. This research is going to observe what it would be if the main object for storing and cooling is seafood, especially mud crabs.

The application of a thermo-electric generator is one of the cooling systems used to cool the cooler box. The main advantage of the thermoelectric cooling system is that this cooling system is light in weight, the dimensions of 1 module are small, and it does not require a large amount of power to supply one module [1]. This research will discuss the power requirements and the number of thermoelectric modules to cool a cooler box with a capacity of 30 liters.

2. RESEARCH METHOD

This research is a start of designing a cooler box that has a goal to calculate how much power do we need to supply the thermoelectric cooler to cool a 30 litre capacity cooler box, how much power do we need to cool the box with the cooling load, and how much thermoelectric module that needs to cool the box. The target for temperature in this research is -20°C from the ambient temperature that is 25°C. Also in this research, we'll need some process that projected in a flowchart explain what and how we do the research. The process of this research shown in Fig 1. below:

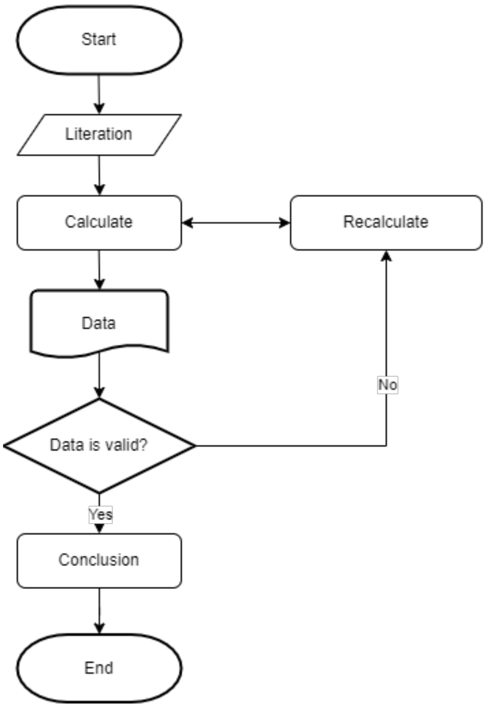

Figure 1. Research's Flowchart

Crabs

Mud crabs of the genus Scylla are characterized by an oval carapace shape in the front on the long side, there are 9 spines on the left and right sides and 4 others between the two eyes. The species under this genus can be distinguished from their morphological and genetic appearance. All the important organs of the body are hidden under the carapace. Limbs stem from the cephalus (chest) sticking out on the left and right of the carapace, namely 5 pairs of legs [2].

The first pair of legs is called a cheliped (claw) which acts as a tool for holding and carrying food, digging, opening shells and also as a weapon in facing enemies, the fifth pair of legs is shaped like a fan (flat) functions as polygon-patterned swimming legs and the rest of the pairs of legs as a foot. On the chest there are digestive organs, reproductive organs (gonads in females and testes in males). Part of the body (abdomen) folded tightly under (ventral) of the chest. At the end of the abdomen it opens to the digestive tract (rectum) [2].

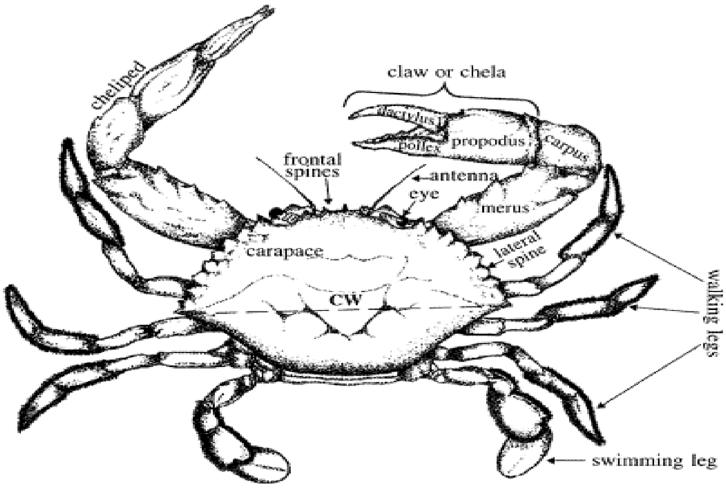

Figure 2. Mud Crab Body Parts

Insulation System

As the times progress, energy becomes valuable [3]. Therefore, reducing wasted energy in the energy sector such as building vehicles, especially in cooling is one way to optimize energy use [4][5]. Thermal insulation is a material or combination of materials that slows down the rate of heat flow by conduction, convection and radiation when properly applied [6].

Figure 3. Illustration of an Insulator
Source: https://www.alibaba.com

One tool that requires thermal insulation is a cooler box. Cooler box is a tool with a cooling system with a function to cool objects in the form of inanimate objects or living things in a closed cycle. The advantages of using thermal insulation in life, especially in cooler boxes, are as follows:

- Reducing the use of cooling systems or reducing excess power usage.

- Reducing the costs incurred to supply power to the cooling system.
- Maintain the thermal conditions in a room, enclosure, or system.4. Can be a material that dampens high sound intensity, and
- Prevent air leakage in a closed cycle system.

Thermoelectric Cooler (TEC)

A thermoelectric cooler is a device that works by using the Peltier effect to produce heat flux. The resulting heat flux comes from two combined Peltier elements which have different base materials. These two elements are known as P-type semiconductors and N-type semiconductors. Thermoelectric coolers are an alternative technology to compressor coolers which compress refrigerant into vapor, and when compared to compressors, thermoelectric coolers tend to be relatively more environmentally friendly and durable [7].

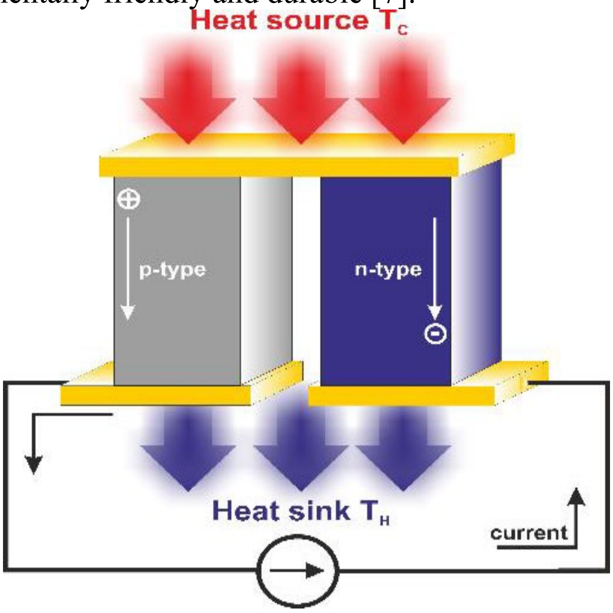

Figure 4. Basic Scheme of Thermoelectric Principles
Source: https://simpliphy.org/

The thermoelectric cooler structure consists of two semiconductors with different materials. The P-type semiconductor acts as a positive side and the N-type semiconductor acts as a negative side. The two semiconductors are positioned in parallel thermally and the ends of the two semiconductors are joined by a copper plate and the semiconductor circuit is clamped with the two ceramic cross-sections on either side of the semiconductor. The most often used material for thermoelectric's semiconductors is Bismuth Telluride (Bi2Te3) [7].

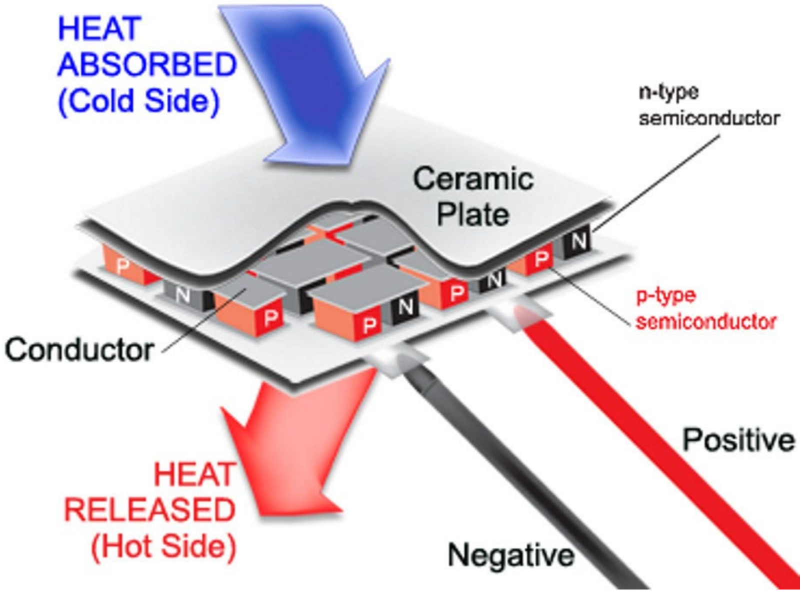

Figure 5. Scheme and How Thermoelectric Works
Source: [8]

Thermoelectric module that used in this paper is TEC1-12706 which has a technical specification below:

Table 1. TEC1-12706 Technical Specification
Source: [9]

Model	TEC1-12706
Dimension	40 × 40 × 3.7 mm
ΔT_{max}	>62 ◦C
Internal Resistance	2.0–2.2 Ω
Voltage	DC 12 V
Working Condition	55–83 ◦C
V_{maks}	DC 15.5 V
Storage Condition	40–60 ◦C
I_{maks}	6 A
Single Weight	23g
Working Current	4.5 A – 5 A
Qc_{maks}	60 W
Pacakging Process	704 silicone seal
Life Expectance	>300,000 h

Thermoelectric equations below are usd to predict Qc and Qh of the TEC itself:

$$Q_c = \alpha I T_c - 0{,}5 I^2 R - K(T_h - T_c) \quad (1)$$

$$Q_h = \alpha I T_h + 0{,}5 I^2 R - K(T_h - T_c) \rightarrow Q_h = Q_c + P_{in} \quad (2)$$

Where, Qc is the heat absorbed by the thermoelectric cold side (W), Qh is the heat transfer rate rejected from the thermoelectric hot side (W), α is the Seebeck effect (W/AoC), I is the current (A), V is the input voltage (V = α (Th–Tc) + IR), R is the thermoelectric resistance (Ω), and K is the thermoelectric conductance (W/ºC).

When there is a temperature difference between the hot and cold sides of the thermoelectric module, the output power generated by the thermoelectric is:

$$P = \frac{\Delta T^2 \alpha_m^2 R_L}{(R_L + R_{in})^2} \tag{3}$$

T_h and T_c represent the hot and cold side temperatures of the TEG module; α_P and α_N are the Seebeck coefficients of P and N type semiconductors; △T is the temperature difference between the hot side and the cold side TEG; αm is the semiconductor Seebeck coefficient; Rin and RL are the internal and external resistances. The current flowing through the RL resistance circuit can be calculated using the equation:

$$P_{max} = \frac{\Delta T^2 \times \alpha_m^2}{4R_{in}} \tag{4}$$

In order to find required power for cooling mud crabs in cooler box, the calculation will be based on Law of Conservation of Energy. The variables in the energy conservation equation are specific heat, mass, and temperature change. Specific heat is one of the variables in the Law of Conservation of Energy. Specific heat is needed to calculate the power needed by the cooler box to cool the mud crabs. The specific heat of mud crabs is shown in table 4 below:

Table 2. Specific Heat of Crab
Source: https://www.engineeringtoolbox.com/specific-heat-capacity-food-d_295.html

Type of Animal	C_p above freezing $\left(\frac{kJ}{kg°C}\right)$	C_p below freezing $\left(\frac{kJ}{kg°C}\right)$
Crab	3,54	1,72

Then, the average mass of adult mangrove crabs is shown in table 5 below:

Table 3. Mass and Dimension of a Crab
Source: [10]

Type of Animal	Mass (gr)	Size/Dimension (mm)
Crab	1500	230

The energy conservation equation used to calculate the required power is calculated using the following equation:

$$Q = m_{kepiting} \times C_p \times \Delta T \tag{7}$$

Where m is mass of mud crab (kg), Cp is specific heat of mangrove crab (kJ/(kg°C)), and ΔT is desired temperature change.

3. RESULTS AND DISCUSSIONS

THERMOELECTRIC CALCULATION

Based on the technical properties of TEC1-12706 as shown on table 3, the power produced by a single thermoelectric can be calculated from Eq. (5) and shown as below:

$$P = \frac{\Delta T^2 \alpha_m^2 R_L}{(R_L + R_{in})^2} = \frac{318\ K^2 \times 0{,}07\ {}^{V}/_{K}{}^{2} \times 2{,}3\Omega}{(2{,}2\Omega + 2{,}3\Omega)^2} = 56{,}27\ W$$

And for the calculation of the maximum power that can be produced by a single TEC1-12706 will be using the formula from Eq. (6) and can be defined as below:

$$P_{maks} = \frac{\Delta T^2 \times \alpha_m^2}{4R_{in}} = \frac{318\ K^2 \times 0{,}07\ {}^{V}/_{K}{}^{2}}{4 \times 2{,}2\ A} = 272{,}5\ \mathrm{W}$$

The total heat absorbed on the thermoelectric cold side is calculated using Eq. (1). The result is shown as below:

$$Q_c = -0{,}07 \times 5A \times 2{,}2°\mathrm{C} - 0{,}5(5A)^2 2{,}3\Omega - 1{,}37(53°\mathrm{C} - 2{,}2°\mathrm{C})$$

$$Q_c = -11{,}276W$$

And by using Eq. (2), the calculation of heat transfer rate rejected from the thermoelectric hot side, is shown as below:

$$Q_h = -210{,}84\ W + 50\ W$$

$$Q_h = -61{,}276\ W$$

REQUIRED COOLING POWER WITH LOADS INSIDE

In order to calculate the required cooling power, the maximum number of crabs that can be stored inside the cooler box needs to be find first. And the result can be seen as below:

Table 4 Dimension or Size of Adult Mud Crabs
Source: [10]

Crabs gender	Dimension		
	Length (mm)	Wide (mm)	Thickness (mm)
Male crabs	40 – 89	59 - 128± 50	40 - 50
Female crabs	32 - 91	53 – 122± 50	40 -50

From table 6 above, the volume of a crab can be found and the maximum number of crabs can also be found. By assuming the shape of the crab as a rectangular prism, the volume of a male crab and female crab are shown:

$$V_{male} = 89 \times 178 \times 50 = 792100\ mm^3 \rightarrow 792{,}1 cm^3$$

And for the female crabs has a volume as shown below:

$$V_{female} = 91 \times 172 \times 50 = 782600mm^3 \rightarrow 782,6cm^3$$

And by dividing the box volume with the crab volume, the maximum number of crabs (n) can be predicted as:

$$n_{total} = \frac{V_{box}}{V_{male}} = \frac{30.000cm^3}{792,1cm^3} = 37,87 \rightarrow \pm 38 \text{ crabs}$$

or

$$n_{total} = \frac{V_{box}}{V_{female}} = \frac{30.000cm^3}{782,6cm^3} = 38,33 \rightarrow 38 \text{ crabs}$$

Based on table 4 and Eq. (7) that has been stated before, the required cooling power can be predicted or calculated. However, the specific heat of crab is differentiated as Cp above freezing point and Cp below freezing temperature, as seen on table 4. This means the calculation will be done twice, as crabs have different Cp based on freezing point.
For cooling crabs above freezing temperature (0°C - 25°C), the estimated required power is:

$$Q_{total\ TEG} = (n_{total} \times m_{kepiting}) \times C_p \times \Delta T = (38 \times 1{,}5kg) \times 3{,}54\ {}^{kJ}/_{kg°C} \times 25°C = 3982{,}5\ W$$

And for cooling crabs below freezing temperature (0°C – (-20°C)), the estimated required power is:

$$Q_{total\ TEG} = (n_{total} \times m_{kepiting}) \times C_p \times \Delta T = (38 \times 1{,}5kg) \times 1{,}72\ {}^{kJ}/_{kg°C} \times -20°C = 3186\ W$$

To meet the required cooling power, the quantity of thermoelectric needs to be defined. The quantity of thermoelectric modules (n_{modul}) can be defined by dividing total required cooling power (Q_{total}) with maximum power produced by a single thermoelectric module (P_{maks}).
Number of thermoelectric modules needed for cooling above freezing temperature (0°C - 25°C):

$$n_{modul} = \frac{Q_{total}}{P_{maks}} = \frac{3982{,}5\ W}{272{,}5\ W} = 15 \text{ pieces}$$

For cooling below freezing temperature (0°C – (-20°C)), the number of thermoelectric modules is:

$$n_{modul} = \frac{Q_{total}}{P_{maks}} = \frac{3186\ W}{272{,}5\ W} = 17 \text{ pieces}$$

REQUIRED COOLING POWER WITHOUT LOADS INSIDE

Based on the calculation result using Eq. 1, a single thermoelectric module can generate 56,27 Watt of power and a single thermoelectric module can generate 272,5 Watt of power. If we look at the result from calculating how much thermoelectric modules that we need for a cooler box with 30 litre of capacity, we can multiple the regular power output and the maximum power output with the total number of thermoelectric modul that needed. The result is:

$$Q_{without\ load} = P_{1\ module} \times n_{module} = 56{,}27\ Watt \times 17\ pieces = 956{,}59\ Watt$$

And the result for total power that needed without any loads inside is:

$$Q_{\text{without load}} = P_{\text{max}} \times n_{\text{module}} = 272{,}5 \text{ Watt} \times 17 \text{ pieces} = 4632{,}5 \text{ Watt}$$

4. CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS

Based on the results of the initial research above, it can be concluded that if the target of this research is how much power needed to cool the box into -20°C, the process of cooling food ingredients, especially seafood (seafood) requires greater power than the process of cooling food materials such as vegetables and fruits. It caused by the object is a mud crab, as we know that the crab spesific heat's value 3,54 kJ/kg°C. The power required with the capacity of the contents of the cooler box is directly proportional. The greater the capacity of the cooler box, the greater the power required. Based on the calculation results, a cooler box with a capacity of 30 liters requires 17 pieces of thermoelectric modules. The power needed to cool 1 adult mud crab ranges from 116.1 Watt to 237.6 Watt. With a total of 38 adult mud crabs filled in a cooler box with a capacity of 30 liters, the power needed to cool the box is around 3186 Watt.

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REFERENCES

[1] I. Rosyadi *et al.*, "Analisis perancangan cooler box berbasis termoelektrik terhadap varian penggunaan thermal paste, faktor lingkungan dan heatsink," *J. Ind. Serv.*, vol. 7, no. 1, p. 188, 2021, doi: 10.36055/jiss.v7i1.13040.

[2] Y. Heri, Sulistiono, and aries Asriansyah, *Pedoman Pemeriksaan/Identifikasi Jenis Ikan Dilarang Terbatas (Kepiting Bakau/Scylla Spp)*, vol. 53, no. 9. 2016.

[3] ASHRAE, *ASHRAE fundamentals (SI)*. 2017.

[4] Á. Lakatos, "Thermal insulation capability of nanostructured insulations and their combination as hybrid insulation systems," *Case Stud. Therm. Eng.*, vol. 41, no. November 2022, 2023, doi: 10.1016/j.csite.2022.102630.

[5] U. Berardi, "A cross-country comparison of the building energy consumptions and their trends," *Resour. Conserv. Recycl.*, vol. 123, pp. 230–241, 2017, doi: 10.1016/j.resconrec.2016.03.014.

[6] L. D. Hung Anh and Z. Pásztory, "An overview of factors influencing thermal conductivity of building insulation materials," *J. Build. Eng.*, vol. 44, 2021, doi: 10.1016/j.jobe.2021.102604.

[7] F. S. Gianita, "Kaji Eksperimental Portable Cool Box Menggunakan TEC1-12705 Cascade," *Tugas Akhir*, pp. 1–65, 2017, [Online]. Available: http://repository.its.ac.id/47585/

[8] K. Sztekler, K. Wojciechowski, and M. Komorowski, “The thermoelectric generators use for waste heat utilization from conventional power plant,” *E3S Web Conf.*, vol. 14, 2017, doi: 10.1051/e3sconf/20171401032.

[9] M. Mirmanto, S. Syahrul, and Y. Wirdan, “Experimental performances of a thermoelectric cooler box with thermoelectric position variations,” *Eng. Sci. Technol. an Int. J.*, vol. 22, no. 1, pp. 177–184, 2019, doi: 10.1016/j.jestch.2018.09.006.

[10] B. Widigdo, Rukisah, A. Laga, A. A. Hakim, and Y. Wardiatno, “Carapace length-weight and width-weight relationships of Scylla serrata in Bulungan District, North Kalimantan, Indonesia,” *Biodiversitas*, vol. 18, no. 4, pp. 1316–1323, 2017, doi: 10.13057/biodiv/d180405.