Biomedical and Mechanical Engineering Journal (BIOMEJ)
e-ISSN: 2776-1983, p-ISSN: 2829-5242
Vol. 4, No.1, May 2024, pp 20-26

Cooling Machines Design and Its Coefficient of Performance Calculations

P D Safitri[1,*], A Hidayat, H A Geralfine[1], D Y Nugraha[1], N A Tasya[1]
F H R Nurrokhim[1], I A Fayrezzi[1], I Habibullah[1], W Saputro[1], R D Issafira[1]
[1]Department of Mechanical Engineering, Faculty of Engineering, University of Pembangunan Nasional Veteran Jawa Timur, 60294, Indonesia

*Corresponding e-mail: 21036010033@student.upnjatim.ac.id

Abstract. A cooling machine is an energy conversion machine that is used to transfer heat from a high temperature hot reservoir to a higher temperature hot reservoir by adding work from outside. In clear terms, a cooling machine is equipment used in the process of cooling a material (fluid) so that it reaches the desired temperature and humidity, by absorbing heat from the material (fluid) that will be conditioned, or in other words absorbing heat (heat) from a cold reservoir. and given to the hot reservoir. The method used in this experiment is a quantitative method where we collect data and then process the data to get the Coefficient of Performance (COP) value. the average temperature in the 5th minute was 24.7 ˚C, in the 10th minute it was 22.34 ˚C, in the 15th minute it was 21.66 ˚C, in the 20th minute it was 21.42 ˚C, at the 25th minute it was 21.32 ˚C, and at the 30th minute it was 21.2 ˚C. COPmax data above the 5th minute to the 10th minute there is a temperature decrease of 5.74%, where the temperature decrease is the highest temperature speed decrease compared to other minutes because the series of tools working in the first 5 minutes has a temperature decrease speed of the minute temperature.

Keyword: refrigeration system; Cooling Machine and Coefficient of Performance.

1. Introduction

A cooling machine is an energy conversion machine that is used to transfer heat from a high temperature hot reservoir to a higher temperature hot reservoir by adding work from outside. In clear terms, a cooling machine is equipment used in the process of cooling a material (fluid) so that it reaches the desired temperature and humidity, by absorbing heat from the material (fluid) that will be conditioned, or in other words absorbing heat (heat) from a cold reservoir. and given to the hot reservoir. The cooling machine is an inseparable part of current technological advances. Refrigeration machines are part of the application of thermodynamics science which is used in various fields. Not only in daily life but also in various industries, such as refrigerators, water coolers or air conditioners in cars.

There are several types of Cooling Machines, First is Vapor Compression Cycle Refrigeration Machine This machine uses a compressor to increase the pressure of the refrigerant vapor from the evaporator and then pushes it into the condenser so that it can be easily condensed. The cycle in this engine almost uses the opposite of the Carnot cycle, the comparison is that this cycle uses a valve which produces an isoenthalpy pressure drop.

Biomedical and Mechanical Engineering Journal (BIOMEJ)
e-ISSN: 2776-1983, p-ISSN: 2829-5242
Vol. 4, No.1, May 2024, pp 20-26

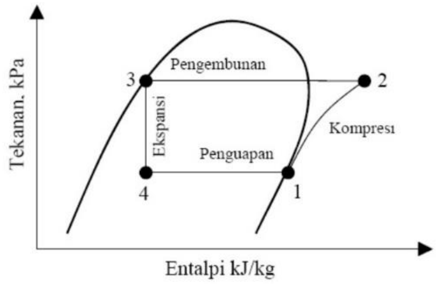


Figure 1. Actual and Standard Cycle of Refrigeration System

The performance of cooling machine with a vapor compression refrigeration cycle are as follows: The working fluid is compressed in the compressor from state level 1 to state level 2, at this high pressure the working fluid is condensed in the condenser to state level 3 and then expanded with an expansion valve to state level 4 and evaporates in the evaporator back to state level This cooling system consists of several main tools that are essential for the vapor compression process to occur, namely Compressor functions to increase the refrigerant pressure. Condenser's function is to cool or condense the refrigerant, meaning heat is discarded in the condenser. Expansion valve functions to expand the refrigerant with constant enthalpy and no heat is absorbed or dissipated in the expansion process to reduce the refrigerant pressure. Evaporator functions to heat or evaporate the refrigerant, meaning that heat is absorbed by the refrigerant, resulting in a cooling effect on the surrounding environment.

Absorption Cooling Machine This cooling machine uses two types of refrigerant, namely primary refrigerant as a cooling agent and secondary refrigerant as a heat binding agent / which carries the primary refrigerant to the generator. The evaporator absorbs heat from the system, captured by the primary refrigerant in the form of low pressure steam. Next, the primary refrigerant is absorbed into the absorber which contains secondary refrigerant which has more viscosity. This aims to bind the primary refrigerant which is in the vapor phase so that it can be flowed by the pump to the generator. The generator produces energy to turn on heating components (such as a heater) to produce heat which is used to release the primary refrigerant with the secondary refrigerant. The primary refrigerant can be separated from the secondary refrigerant because of the volatile nature of the primary refrigerant, then the primary refrigerant continues its cycle to the condenser releasing its heat into the environment. After leaving the condenser, the liquid phase of the refrigerant passes through the expansion valve, here the pressure and temperature of the refrigerant are lowered until it reaches the evaporation temperature and pressure by means of atomization.

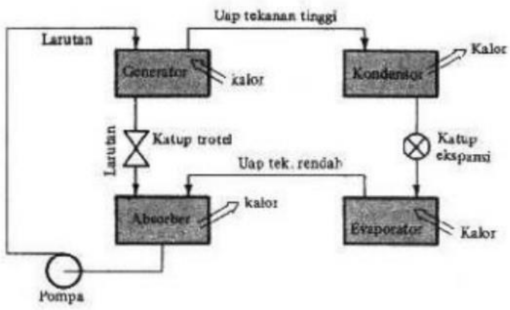


Figure 2. Refrigeration System Part

Secondary refrigerant, which has a higher viscosity than the primary refrigerant, circulates from the generator to the throttle valve which then returns to the absorber. The secondary refrigerant absorber still has a high temperature. In the absorber there is a heat release process which functions to absorb the primary refrigerant vapor that comes out of the evaporator due to the pressure difference which in the absorber is lower than the evaporator pressure.

2. Method

The Coefficient of Performance (COP) is a key metric used to evaluate the efficiency of a refrigeration system. It essentially measures the amount of cooling produced (refrigeration effect) in relation to the energy input (electrical power consumption). This paragraph will outline the procedure for calculating the COP of a simple Peltier refrigeration system using readily available materials. The first step involves gathering the necessary tools and materials. These include a Styrofoam box, a Peltier cooler module, a heatsink, an axial fan, a 12V power supply, thermometers for measuring both hot and cold side temperatures, and a data recording tool like a notepad or spreadsheet. The dimension for the refrigeration cooling system are shown in Figure 3 below.

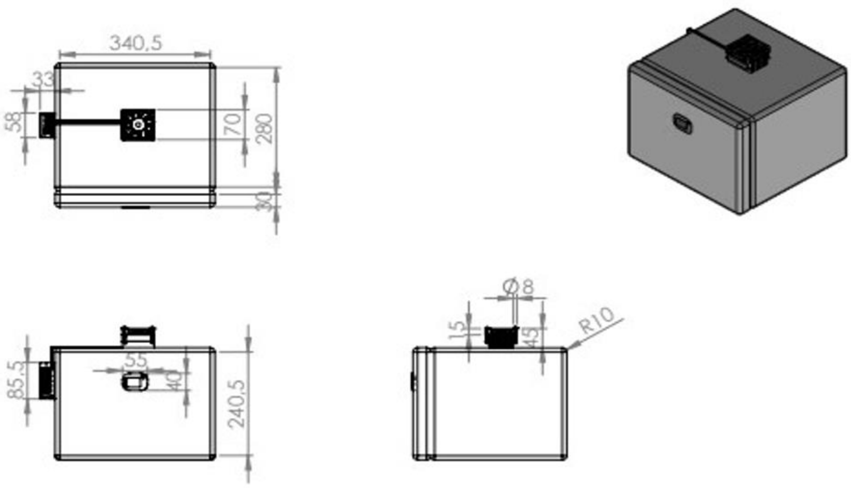


Figure 3. Dimensions of the Cooling Machine

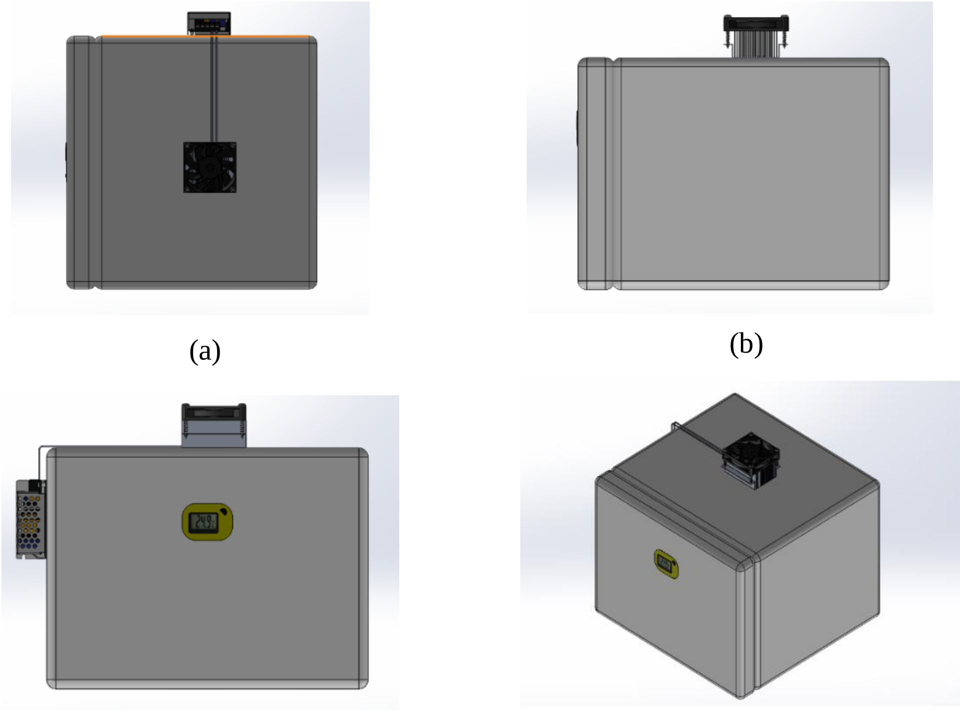
Once the materials are acquired, the styrofoam box was modified to accommodate the Peltier module, heatsink, and fan. This involves creating a hole in one side of the box. The size of the hole should be appropriate to securely mount the heatsink and allow for sufficient airflow from the fan. The Peltier module is then positioned inside the box, with one side facing the interior and the other facing the external environment. The heatsink is attached to the exposed side of the Peltier module, and the axial fan is mounted on the heatsink to facilitate heat dissipation. The next step involves connecting the electrical components. The Peltier module typically comes with two wires representing the positive and negative terminals. These wires are carefully connected to the 12V power supply, ensuring proper polarity. Then, a cable and plug are installed to connect the power supply to a standard wall outlet. The design view shown on Figure 4 below.

As the system assembled and powered, we can begin collecting data for COP calculation. It's crucial to allow the system to stabilize and reach thermal equilibrium before taking measurements. The experiment involves recording the temperatures at specific intervals, typically at 5, 10, 15, 20, 25, and 30 minutes. Two sets of temperature readings are required: the cold side temperature inside the Styrofoam box and the hot side temperature measured on the heatsink. It's important to use accurate thermometers and ensure consistent placement for reliable data. Once the data collection is complete, the COP calculation is proceed. The COP is expressed by the following formula

$$\text{COP} = \frac{Qc}{W}$$

Here, Qc represents the heat removed from the cold side (refrigeration effect), and W represents the electrical work input (power consumption). Calculating Qc requires some additional information. The specific heat capacity of the air inside the box and the volume of the box were also calculated. With these values, along with the temperature difference between the initial and final readings on the cold side, we can estimate the heat removed (Qc).

Biomedical and Mechanical Engineering Journal (BIOMEJ)
e-ISSN: 2776-1983, p-ISSN: 2829-5242
Vol. 4, No.1, May 2024, pp 20-26



(a) (b) (c) (d)

Figure 4. (a) Left, (b) Right, (c) Front, (d) Isometric View

The electrical work input (W) can be calculated by multiplying the voltage (12V) by the current (amps) drawn from the power supply. This information can be obtained using an ammeter connected in series with the Peltier module. By substituting the calculated values of Qc and W into the COP formula, we can determine the efficiency of the Peltier refrigeration system. A higher COP indicates a more efficient system, meaning it produces more cooling for a given amount of electrical energy consumed.

3. Result and Discussion

In this study, the aim of the portable mini refrigerator observation is to observe the average temperature at the 5th, 10th, 15th, 20th, 25th and 30th minutes, where the initial temperature value is 30 ˚C. Based on the experiments that have been carried out, the independent variable in the portable mini refrigerator practicum is observation time for 30 minutes with data collection every 5 minutes. Meanwhile, the dependent variable is the average temperature every 5 minutes for 30 minutes. And the control variables in the experiment are initial temperature, power and current.

Table 1. Experiment Results

Time	Temp. 1	Temp. 2	Temp. 4	Temp. 5	Suhu 5	Rata-rata
5’	24,7	22,8	24,7	21	27	24,7
10’	23	20,9	23,1	19,2	25,5	22,34
15’	22,3	20,2	22,5	18,5	24,8	21,66
20’	22,1	20	22,2	18,2	24,6	21,42
25’	22	19,9	22,1	18	24,5	21,32
30’	21,9	19,7	22	17,9	24,5	21,2

$$COP_{(maks)} = \frac{Q_L}{Q_h - Q_L} = \frac{T_L}{T_h - T_L}$$

TL = Refrigerator Temperature
Th = Environmental Temperature

1. Time 5’

$$COP_{(maks)} = \frac{24{,}7°c}{29°c - 24{,}7°c} = 5{,}74$$

2. Time 10’

$$COP_{(maks)} = \frac{22{,}34°c}{29°c - 22{,}34°c} = 3{,}35$$

3. Time 15’

$$COP_{(max)} = \frac{21{,}66°c}{29°c - 21{,}66°c} = 2{,}95$$

4. Time 20’

$$COP_{(max)} = \frac{21{,}42°c}{29°c - 21{,}42°c} = 2{,}82$$

5. Time 25’

$$COP_{(max)} = \frac{21{,}32°c}{29°c - 21{,}32°c} = 2{,}77$$

6. Time 30’

$$COP_{(max)} = \frac{21{,}2°c}{29°c - 21{,}2°c} = 2{,}71$$

$$COP_{(actual)} = \frac{Q_L}{W}$$

Q_L = Cooling Load
W = Input Power Used (Thermoelectric)

$$Q_L = m.C_{p.}\Delta T$$

1. Time 5’

$$Q_L = 0{,}0017kg \,.\, 1000\frac{j}{kg}°c\ (30 - 24{,}7)°c = 9.01$$

$$COP_{(actual)} = \frac{9{,}01}{12\ w} = 0{,}75$$

2. Time 10’

$$Q_L = 0{,}0017 \,.\, 1000\frac{j}{kg}°c\ (24{,}7 - 22{,}34)°c = 4.01$$

$$COP_{(actual)} = \frac{4{,}01}{12\ w} = 0{,}33$$

3. Time 15’

$$Q_L = 0{,}0017 \,.\, 1000\frac{j}{kg}°c\ (22{,}34 - 21{,}66)°c = 1{,}15$$

$$COP_{(actual)} = \frac{1{,}15}{12\ w} = 0{,}09$$

4. Time 20'

$$Q_L = 0{,}0017 \,.\, 1000 \frac{j}{kg} °c \,(21{,}66 - 21{,}42)°c = 0{,}4$$

$$COP_{(actual)} = \frac{0{,}4}{12\,w} = 0{,}03$$

5. Time 25'

$$Q_L = 0{,}0017 \,.\, 1000 \frac{j}{kg} °c \,(21{,}42 - 21{,}32)°c = 0{,}17$$

$$COP_{(actual)} = \frac{0{,}17}{12\,w} = 0{,}01$$

6. Time 30'

$$Q_L = 0{,}0017 \,.\, 1000 \frac{j}{kg} °c \,(21{,}32 - 21{,}2)°c = 0{,}204$$

$$COP_{(actual)} = \frac{0{,}17}{12\,w} = 0{,}01$$

As shown in Figure 5, The average temperature obtained in the 5th minute was 24.7 ˚C, in the 10th minute it was 22.34 ˚C, in the 15th minute it was 21.66 ˚C, in the 20th minute it was 21.42 ˚C , at the 25th minute it was 21.32 ˚C, and at the 30th minute it was 21.2 ˚C. Based on calculations from COPmax data above the 5th minute to the 10th minute, there was a temperature decrease of 5.74%, where the temperature decrease was the highest temperature decrease compared to other minutes because the series of tools working in the first 5 minutes had a temperature decrease speed. from the 5th minute temperature of 24.7 ˚C to the 10th minute average temperature of 22.34 ˚C. Meanwhile, the decrease in temperature from the 10th minute to the 15th minute was 2.95%. From the 15th minute to the 20th minute temperature, there was a decrease of 2.82%. For the temperature from the 20th minute to the 25th minute, the temperature decreased by 2.77%. Then from the 25th minute to the 30th minute, the temperature decreased by 2.71%.

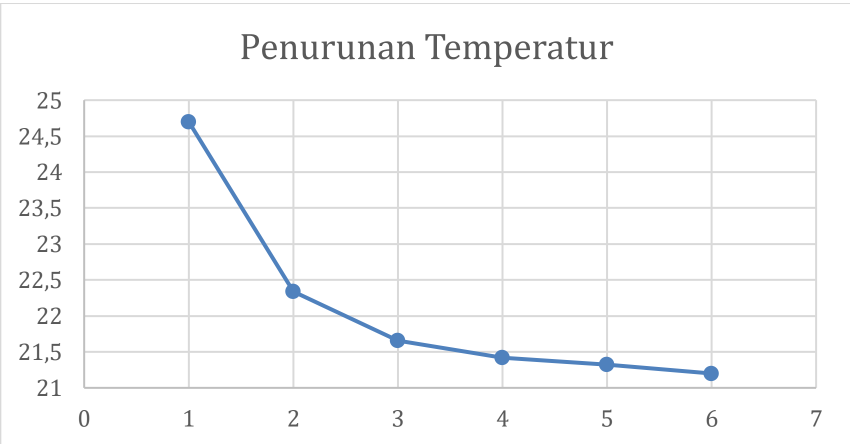


Figure 5. Temperature Evolution of Refrigeration Process

COPactual data calculations also showed a decrease where in the 5th minute it was 0.75%, in the 10th minute 0.33%, in the 15th minute 0.09%, in the 20th minute 0.03%, while in the 25th and 30th minutes the temperature starts constant with a decrease of 0.01%

In the results of observing the average temperature, the temperature indicator is found on the heatsink which is assembled with a peltier, where the function of this device is to expand heat transfer. Heatsinks are made from aluminum or copper, these materials have a high conductivity value, so they are able to break down or release heat well. The work of the peltier is also assisted by a water block, where the function of the tool is as a liquid cooler. According to (Putri, D.A., 2020) liquid coolers are more efficient than air coolers (fans) because liquid coolers can remove the heat in the peltier . In accordance with the laws of thermodynamics, the thermal conduction rate is proportional to the temperature difference between the junction and the environment.

The series of tools in the first 5 minutes has fast tool performance in working, because the initial temperature decrease towards the 5th minute has a wide temperature difference. However, starting from the 10th minute, the device circuit began to slow down in reducing the temperature, because the power used was not working optimally. Thermoelectric performance is influenced by the input power received, the greater the power received, the lower the temperature speed resulting in a lower temperature.

4. Conclusion

1. In the observations from the data collection results, it was found that in the 5th minute to the 30th minute the temperature decreased where the room temperature in the cooling machine was initially 30°C, and continued to decrease in the 5th minute by 24.7 ˚C, in in the 10th minute it was 22.34 ˚C, in the 15th minute it was 21.66 ˚C, in the 20th minute it was 21.42 ˚C, in the 25th minute it was 21.32 ˚C, and in the 30th minute of 21.2 ˚C.

2. From the COPmax data above the 5th minute to the 10th minute, there was a decrease in temperature of 5.74%, where the temperature decrease was the highest temperature speed decrease compared to other minutes because the series of tools working in the first 5 minutes had a temperature decrease speed of temperature. the 5th minute was 24.7 ˚C towards the average temperature in the 10th minute of 22.34 ˚C. Meanwhile, the decrease in temperature from the 10th minute to the 15th minute was 2.95%. From the 15th minute to the 20th minute temperature, there was a decrease of 2.82%. For the temperature from the 20th minute to the 25th minute, the temperature decreased by 2.77%. Then from the 25th minute to the 30th minute, the temperature decreased by 2.71%. COPactual data calculations also showed a decrease where in the 5th minute it was 0.75%, in the 10th minute 0.33%, in the 15th minute 0.09%, in the 20th minute 0.03%, while in the 25th and 30th minutes the temperature starts constant with a decrease of 0.01%

References

[1] Putri, D.A., 2020. Perancangan Cooling System Untuk Box VSAT (Very Small Aperture Terminal) Menggunakan Arduino Uno. eJournal Mahasiswa Akademi Telkom Jakarta (eMIT), 2(2), pp.26-31.

[2] Fuad, A., 2016. Studi Eksperimen Pengaruh Panjang Pipa Kapiler dan Variasi Beban Pendinginan pada Sistem Refrigerasi Cascade. s.l.:Doctoral dissertation, Institut Teknologi Sepuluh Nopember Surabaya.

[3] Haq, A. H. J. a. A. A., 2017. Pengujian Kinerja Couple Thermoelektrik Sebagai Pendingin Prosesor. Prosiding SNATIF,, pp. 161-166.

[4] Mustofa, K. a. P. Y., 2021. Pengaruh Perubahan Dimensi Filter-Drier Dan Pipa Kapiler Terhadap Coefficient Of Performance (COP) Mesin Pendingin Kulkas 2 Pintu. Jurnal Teknologi Terapan, Volume 7 (1), pp. 8-12.

[5] Sulstiyanto, N., 2014. Pemodelan Sistem Pendingin Termoelektrik pada Moduk Superluminance LED. Jurnal EECCIS, Volume 8 (1), pp. 67-72