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Utilization of outdoor units as freshwater freezing machines on various masses of salt solution

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ABSTRACT

The effect of solution mass on freezing the freshwater using an AC outdoor unit was investigated. The AC outdoor capacity was ½ PK and the evaporator to absorb the heat from the freshwater was designed in the form of a square spiral placed in a freezing box. The outdoor used R32 as the working fluid. The solution mass variations were 10 kg, 12 kg and 14 kg. The freezing box was filed with saline solution with a concentration of 20%. The mass of fresh water that was frozen was wrapped in plastic with a mass of water per package of 500 grams. The total mass of the freshwater was 10 kg. The results show that the fastest freezing time occurs at a mass of 10 kg of salt solution with a freezing time of 3.5 hours and the longest freezing time is at a mass of 14 kg of solution with a freezing time of 6 hours. The highest total heat flow rate is 554 W found in the variation of 10 kg solution mass. The AC outdoor unit is very effective to be used as a freezing machine with an EER of 5.8.

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1. PENDAHULUAN

According to Fuad and Putra (2016) refrigeration machines such as refrigerators, air conditioners, freezers and so on have become a basic need for people both in urban and rural areas. In Indonesia, which has a tropical climate, refrigeration machines are often used in daily life. Gunawan et al. (2014) explained that a refrigeration machine (refrigerant) is a tool used to transfer heat from the room to the outside of the room to make the temperature of the object/room lower than the temperature of the environment so as to produce a cold temperature/temperature.

The development of technology in the field of refrigeration has started a long time ago. One example of the application of technology development in the field of refrigeration is the manufacture of ice cubes. Ice cubes are an indispensable commodity because they are used for cooling and preserving food and beverages. The use of ice cubes is a fairly cheap medium when compared to other media. Ice cubes have various types, the most widely made type is block-shaped ice cubes. Ice cubes are needed in various business fields, such as restaurant businesses, cafes and fisheries. Nevertheless, the available refrigeration machines take a long time to make ice cubes. The refrigerator, for example, takes 18 to 24 hours to make ice cubes in the freezer. The longer the process of making ice cubes, the greater the energy used. This bias causes the price of ice cubes to be high.

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In general, fishermen get ice from freezers or household refrigerators which cost Rp. 1500/kg. This condition forces fishermen not to catch large quantities of fish. Given these conditions, then the development and application of ice cube making machine equipment was carried out which will help solve the problem of ice cube limitations. Steam compression method ice cube making machine can be made with a cheap power source, easy to make and operate, and can be easily moved as explained by Jilan et al., (2021).

Outdoor air conditioner machine is a component of air conditioner engine used to cool the room. Indeed, outdoor air conditioning machines require quite high electricity because they work at high pressure. Meanwhile, the refrigerator is also to cool things, but with low pressure so that the electrical power used is quite low, around 70 W to 120 W depending on the size of the refrigerator. Based on the performance of the air conditioner and refrigerator, it is very possible to make a low-power ice cube maker cooling machine, namely using outdoor components of the air conditioner that are operated at low pressure.

There is already an ice cube making machine using this outdoor air conditioner, namely on Youtube which is made only with an estimate such as installing an air conditioner. The engine showed an extraordinarily fast ability to cool fresh water of the same mass. Because of this, this machine is very interesting to study or research.

Several studies related to the making of ice cubes have also been available in open literature such as research by Nugroho, et al. (2016), Lubis (2017), Akhyar (2022) and Pramudantoro and Sunanto (2023). Nugroho, et al. (2016) conducted an experimental study on the use of fish cooling media in the form of wet ice and ice packs as an effort to improve the performance of fish storage areas caught by fishermen. The experiment was carried out in two stages, namely with air load, then continued with the heat load of fish for each cooling medium in a different styrofoam box. From the results of this experiment, it was obtained that the freezing point of ice packs was reduced by a maximum of -12.3°C using a household freezer with a ratio of 1:5 alcohol to water, and it was proven that ice packs were able to keep the body temperature of fish at -1.3°C, compared to wet ice which was already at 5.4°C at the 6th hour. Lubis (2017) conducted a study on construction design manufacturing on small ice cube machines. By using components from the refrigeration engine, namely compressors, condensers, expansion devices, evaporators and R404 refrigerant as circulating working fluids to produce ice with a capacity of 1.35 kg with a freezing time of 2 hours. Akhyar (2022) conducted research on the design of an automatic evaporator with a cooling system using salt. The study used a 1 pk outdoor air conditioner with a mass of 10 kg of salt solution, where 8 kg of water and 2 kg of salt. The results showed that 16 bags of water took 120 minutes to freeze.

Pramudantoro and Sunanto (2023) conducted a study on the analysis of the effect of salt content variations on the freezing process in a 40 L ice cube machine using a 1 PK compressor. This study aims to determine the effect of salt content variations on the performance of ice cube making machines, with 3 tests, namely with salt content concentrations of 30, 40, and 50% in 40 liters of water in a 4-hour test using R22 refrigerant. The results of the research are known that the higher the percentage of salt content in the ice cube freezing machine system, the lower the cabin temperature results obtained, thus accelerating the ice cube freezing process.

Some of the researchers above already use outdoor air conditioning machines but the research was carried out with variations in the type of load, cube ice test, and salt solution concentration used. The speed of ice formation is also influenced by the number of solutions, so on this occasion the influence of the mass of the solution on the speed of ice cube formation will be studied. The machine used is to utilize used outdoor with a power of 0.5 PK.

2. METODE PENELITIAN

The method used in this study is an experimental method. Where this type of research method can be used to test a new treatment or design by comparing one or more test groups with treatment and no treatment. Tools and materials are prepared in advance so that there is no confusion in looking for tools and materials at the time of research. The equipment and materials used in this study include outdoor, evaporator, cooler box, thermocouple, water pump, barometer, R-32 refrigerant, digital scale, coarse salt, 500 g ice plastic, and fresh water. The variables tied to this study are the temperature of the solution and the freezing time. Meanwhile, the temperature of frozen water is assumed to be the same as the temperature of the solution. The independent variables in this study were the mass of salt solution of 10 kg, 12 kg and 14 kg.

The method of data collection can be done starting when the machine has not been started, then the ambient temperature and the temperature of the solution in the cooler box are recorded as zero seconds after the machine is operated. Then make sure the temperature of the solution in the cooler box is around 25°C, then put 20 bags of 10 kg of fresh water and turn on the water pump to circulate the solution. So that no heat enters from the air, the cooler box is closed. Turn on the compressor while every 30 minutes check the solution temperature, ambient temperature, compressor and pump energy, and check whether the fresh water has completely frozen. The experiment will be stopped if all fresh water has become frozen or completely frozen.

All temperatures were measured using a K-type thermocouple connected to a data logger with an uncertainty of ± 0.5°C. Meanwhile, ambient temperature, ambient pressure and environmental RH are measured using a digital Thermo-hygro-barometer. The mass of frozen water and the mass of the solution were measured using a digital kitchen scale with a resolution of 1 g. The evaporator used is made of 1/4 in copper pipe that is formed in a rectangular winding as shown in figure 1. The evaporator is placed in a cooler box containing salt water with a concentration of 20%. The variation in the mass of the solution used was 10 kg, 12 kg and 14 kg with the same concentration of 20%. The cooler box used is shown in figure 2 which is made of plastic with a cavity on each wall and a cavity filled with air as an insulator.

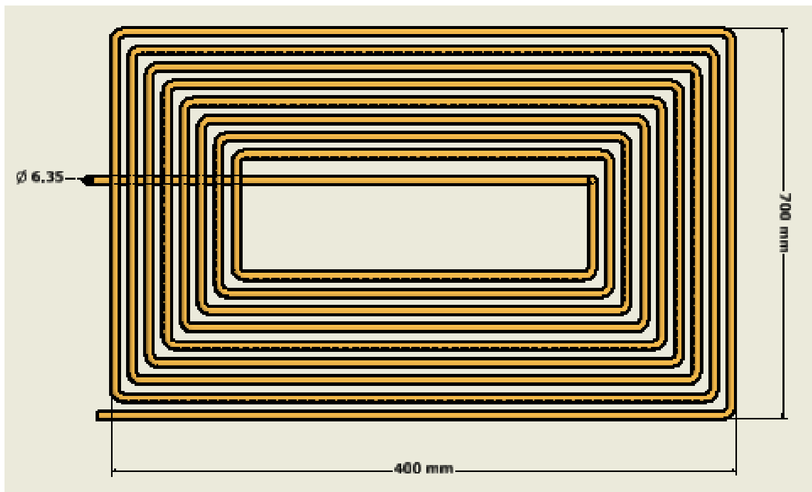

Figure 1. Rectangular winding evaporator

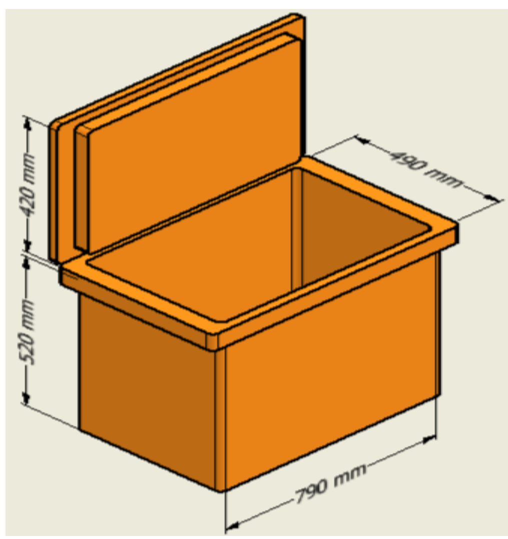

Figure 2. Design cooler box

The refrigerant flow scheme or flow is shown in Figure 3 where the refrigerant flows through several components such as condensers, capillary pipes, evaporators, accumulators, compressors. Capillary pipes, condensers and compressors become one unit called outdoor.

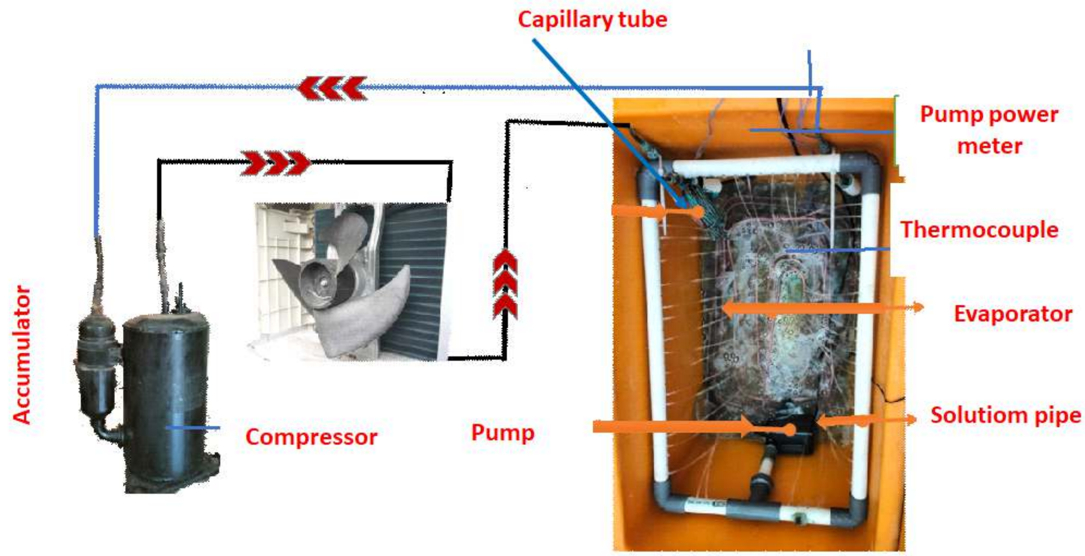

Figure 3. Refrigerant line scheme

The compressor works to increase the refrigerant pressure from low pressure inside the evaporator to high pressure inside the condenser. From the compressor, this refrigerant flows to the condenser, which because the temperature is high, the temperature of the refrigerant vapor also becomes high. In the condenser, pressurized and high-temperature refrigerant vapor is condensed into a refrigerant liquid and the heat from the refrigerant is discharged into the environment. From the condenser, the refrigerant enters through the capillary pipe where the refrigerant pressure drops so that the temperature drops and enters the evaporator. This heat-absorbing unit (evaporator) absorbs heat from the salt solution so that the solution cools and cools the fresh water for a certain time so that the fresh water becomes frozen.

To process data or analyze experimental data, several equations are used, namely sensible heat transfer equations and latent heat transfer equations. Equation (1) shows the latent heat transfer of solution and fresh water written as:

$$\dot{Q}_{s1} = \dot{m}_w c_p \left(T_i - T_o\right) \quad (1)$$

$\dot{Q}_{s1}$ expresses the sensible heat transfer from fresh water to the evaporator (W) that occurs when the temperature drops from the initial temperature Ti to the temperature To. To is assumed to be equal to 0°C. $\dot{m}_w$ is the flow rate of freshwater mass (kg/s). As for the change of form from water to ice, the heat transfer is expressed by the latent heat equation and is written as:

$$\dot{Q}_l = \dot{m}_w h_{fg} \quad (2)$$

h_{fg} is an enthalpy for evaporation or condensation (J/kg). After the change of form and the formation of the essent, there is still a heat transfer from the ice to the evaporator which is also called sensible heat transfer which is written as:

$$\dot{Q}_{s2} = \dot{m}_w c_p \left(T_o - T_f\right) \quad (3)$$

Tf is the final temperature of the solution and ice (°C). Meanwhile, the salt solution only has a sensible heat transfer because the salt solution does not freeze. Therefore, the equation for determining the heat transfer of a salt solution is written as:

$$\dot{Q}_{so} = \dot{m}_l c_p \left(T_i - T_f\right) \quad (4)$$

$\dot{Q}_l$ is the rate of heat transfer from the salt solution to the evaporator (W). Then the performance of the engine (K) can be determined by the equation:

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$$K = \frac{\dot{Q}_t}{W_c + W_p} \tag{5}$$

Wc is the work of the inner compressor (W) and Wp is the work of the salt solution circulation pump (W), each of which in the experiment was measured using a digital power meter.

$$\dot{Q}_t = \dot{Q}_{s1} + \dot{Q}_l + \dot{Q}_{s2} + \dot{Q}_{so} \tag{6}$$

Equations (1) to (6) can be found in the research of Saputra (2024), Waasi (2024), and Jayeng (2024). EER or energy efficiency ratio, is a measure of the energy efficiency of air conditioning devices such as air conditioners (air conditioners). EER is calculated by dividing the cooling capacity (in BTU) by the electrical power consumed (in watts). The formula for calculating EER can be seen in Springer and German (2014) and is written as:

$$\text{EER} = \frac{\text{Cooling capasity}}{\text{Electrical power}} = \frac{\text{BTU/h}}{\text{Electrical power}} \tag{7}$$

3. RESULTS AND DISCUSSION

This study was to determine the influence of the mass of the salt solution on the duration of fresh water freezing, the total heat transfer from the water and the salt solution to the evaporator and the performance of the engine. The data obtained from the study for the mass of 10 kg, 12 kg and 14 kg of solution are shown in tables 1, 2 and 3.

Tabel 1. Hasil penelitian pada percobaan hari pertama dengan massa larutan garam 10 kg.

No.	Time (s)	T_{ling} (°C)	Freshwater mass freezed (kg)	T_{so}, Solution tempera ture (°C)	Comp ressor power Pc (W)	kWh	Pump power Pp (W)	Total kWh	Freshwater condition
1	0	23.5	10	25.5	0	0	0	0.00	Soft
2	1800	24.5	10	9.9	294.5	0.147	27.41	0.01	Soft
3	3600	26.2	10	0.4	296.9	0.296	26.72	0.02	Soft
4	5400	27.0	10	-6.0	296.7	0.445	26.35	0.06	Starting to freeze
5	7200	27.5	10	-9.8	294.7	0.589	26.11	0.10	Partially frozen
6	9000	28.1	10	-10.6	299.0	0.747	26.39	0.15	Partially frozen
7	10800	28.3	10	-12.2	300.1	0.900	26.51	0.21	Completely frozen

Tabel 2. Hasil penelitian pada percobaan hari pertama dengan massa larutan garam 12 kg.

No.	Time (s)	T_{ling} (°C)	Freshwater mass freezed (kg)	T_{so}, Solution tempera ture (°C)	Comp ressor power Pc (W)	kWh	Pump power Pp (W)	Total kWh	Freshwater condition
1	0	26.4	10	25.5	0.0	0.00	0.0	0.00	Soft
2	1800	27.4	10	12.5	301.0	0.15	26.3	0.01	Soft
3	3600	28.1	10	-2.1	300.4	0.30	25.6	0.02	Soft
4	5400	28.6	10	-7.3	295.7	0.44	25.3	0.05	Soft
5	7200	28.4	10	-11.3	298.6	0.60	25.2	0.10	Starting to freeze
6	9000	29.2	10	-11.5	293.2	0.73	24.9	0.15	Partially frozen
7	10800	29.7	10	-11.5	300.6	0.90	24.90	0.21	Partially frozen
8	12600	30.2	10	-10.5	303.8	1.06	25.08	0.28	Partially

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									frozen
9	14400	30.3	10	-11.3	302.9	1.21	24.69	0.40	Partially frozen
10	16200	30.4	10	-13.4	300.5	1.35	24.98	0.50	Partially frozen
11	18000	30.6	10	-13.6	297.6	1.49	24.75	0.60	Completely frozen

Tabel 3. Hasil penelitian pada percobaan hari pertama dengan massa larutan garam 14 kg.

No.	Time (s)	T_{ling} (°C)	Freshwater mass freezed (kg)	T_{so}, Solution tempera ture (°C)	Comp ressor power Pc (W)	kWh	Pump power Pp (W)	Total kWh	Freshwater condition
1	0	26.2	10	25.5	0.0	0.0	0.00	0.00	Soft
2	1800	27.0	10	12.6	296.6	0.15	26.82	0.01	Soft
3	3600	27.7	10	6.4	298.7	0.30	25.00	0.02	Soft
4	5400	28.3	10	-2.5	299.3	0.45	24.77	0.05	Soft
5	7200	28.7	10	-10.9	300.0	0.60	24.51	0.08	Soft
6	9000	29.2	10	-12.0	299.0	0.75	24.57	0.13	Starting to freeze
7	10800	29.3	10	-12.9	298.2	0.90	24.28	0.21	Partially frozen
8	12600	29.5	10	-12.8	298.8	1.05	24.49	0.28	Partially frozen
9	14400	29.7	10	-13.3	301.9	1.21	24.80	0.36	Partially frozen
10	16200	29.8	10	-13.3	301.4	1.36	24.81	0.45	Partially frozen
11	18000	30.1	10	-13.6	303.5	1.52	24.83	0.55	Partially frozen
12	19800	29.9	10	-13.9	302.0	1.66	25.03	0.66	Partially frozen
13	21600	30.0	10	-14.4	301.6	1.81	25.19	0.78	Completely frozen

The relationship between the mass of the solution and the freezing time can be drawn based on tables 1 to 3 for 3 different mass of solution. Figure 4 shows the drop in freshwater temperature to freezing for three mass solutions. The lowest temperature that can be achieved by each solution period ranges from -12°C to -14°C. Why is the temperature of the solution lower for large mass of solution? One of the causes of this phenomenon is because the more mass of the solution, the greater the distance between the evaporator pipe pipe and the fresh water in the plastic wrap that you want to freeze. Freshwater that is frozen floats, so between the fresh water and the evaporator pipe there is a gap in the thickness of the mass of the solution. Therefore, to make the temperature of fresh water the same as the freezing condition, a lower evaporator and solution temperature is needed for large solution masses. In addition, large mass of solution takes longer to reach the same cold temperature. This is in accordance with equation (4) if the ocean mass increases, it takes a long time to reach a certain temperature and also requires greater energy. However, all the mass of the solution is sucked in heat with the same evaporator capacity. If the power of the evaporator is different, of course it will be different. The drastic drop in temperature occurs from zero seconds to about 500 seconds. This is because the temperature difference between the solution and the evaporator wall is still large. The longer the temperature difference is, the lower it gets, so the temperature drop begins to slope. The freezing time is faster compared to using a common ice machine. Making common ice takes a long time, but using an outdoor air conditioner machine can be faster as explained by Nugroho, et al (2016), Akhyar (2022), Pramudantoro and Sunanto (2023). However, Lubis' research (2017) takes

2 hours and Akhyar (2022) takes 120 minutes while Pramudantoro and Sunanto (2023) take 4 hours. However, their research uses an average of 1 PK of outdoor power so that the time to freeze ice is faster.

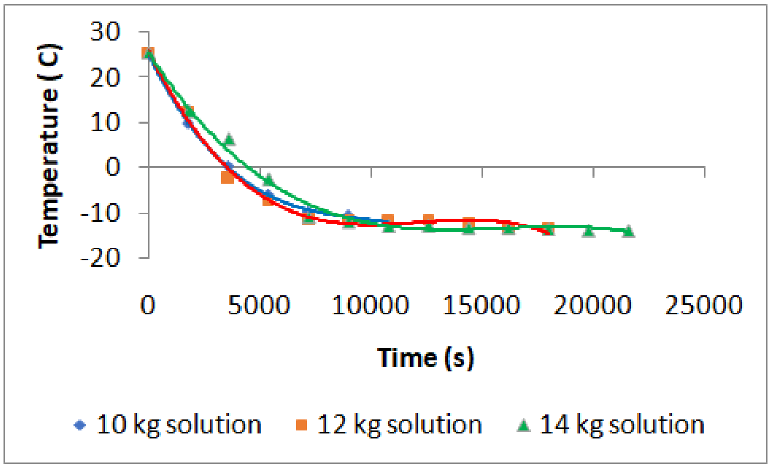

Figure 4. Relationship of temperature versus time for three solution masses

Then to find out the heat transfer from the solution into the evaporator equation (6) and from the above data obtained the total heat transfer as shown in figure 5. The censible heat transfer is lower compared to the latent heat transfer. This is because sensible heat transfer for the same mass is highly dependent on temperature differences. If the temperature difference is high, then the sensible heat transfer is also high. In addition, sensible heat transfer in closed and isolated rooms will decrease with increasing time until there is temperature equilibrium and there is no more heat transfer.

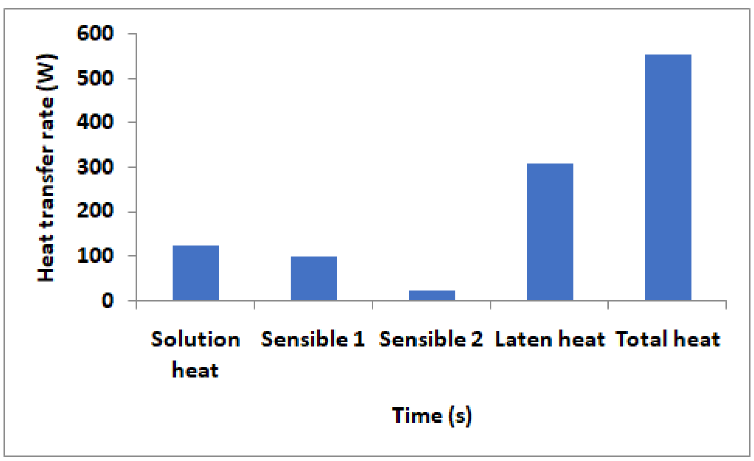

Figure 5. Heat transfer rat for 10 kg solution and 10 kg freshwater.

The latent heat transfer is greater depending only on mass. The larger the mass, the greater the heat transfer. Its total heat transfer is the sum of the sensible heat transfer of water and solution and latent heat transfer. The total heat transfer for a 10 kg solution mass is 555.3 W. Now we look at the variation in the 12 kg solution mass, whether it requires more power or even a little. Figure 6 shows the heat transfer from fresh water and solution to the evaporator. The trend is the same, i.e. the latent heat transfer is greater than the sensible heat transfer.

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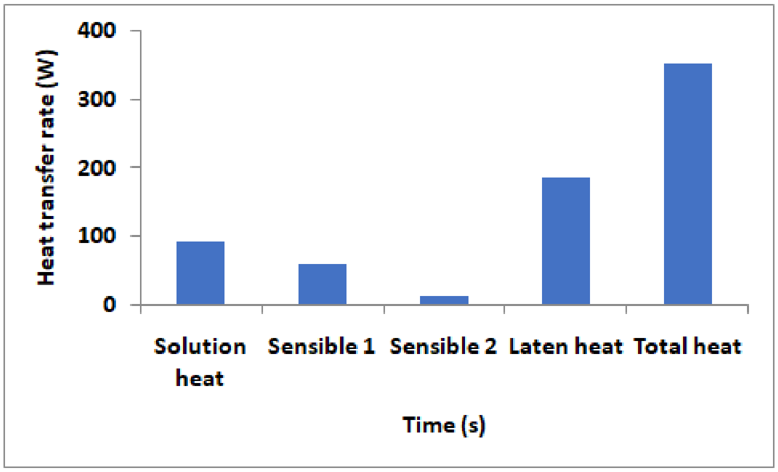

Figure 5. Heat transfer rate for 12 kg solution and 10 kg freshwater.

Next is the result of heat transfer calculations for a solution mass of 14 kg and a mass of freshwater of 10 kg which can be seen in figure 6. The trend is still the same, which is always dominated by latent heat transfer. That's why heat exchangers are always recommended at latent heat transfer conditions.

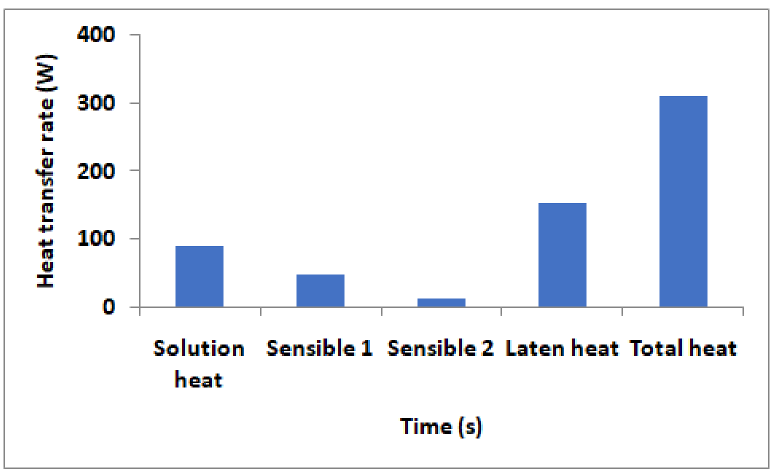

Figure 6. Heat transfer rate for 14 kg solution and 10 kg freshwater.

However, it is very difficult to assess the effect of the mass of the solution on heat transfer. Therefore, Figure 7 is presented as a comparison of the influence of the mass of the solution on the total heat transfer. It turns out that the heat transfer rate shows a downward trend with an increase in the mass of the solution. This can happen because the time used for the heat transfer process is longer than that of a small amount of mass. The mass flow rate depends on the time, if the time is long then the mass flow rate gets smaller while the heat transfer depends on the mass flow rate. Consequently the heat transfer decreases with the increase in the experiment time. The energy required by the compressor and water pump is also of course different, see figure 8.

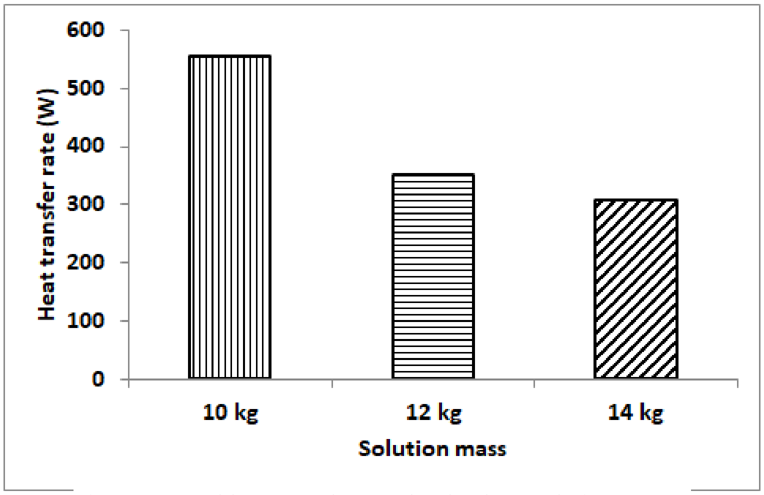

Figure 7. Total heat transfer rate for the three solution masses

To determine the efficiency of this ice machine, the EER is calculated using equation (7) and the result is shown in figure 8.

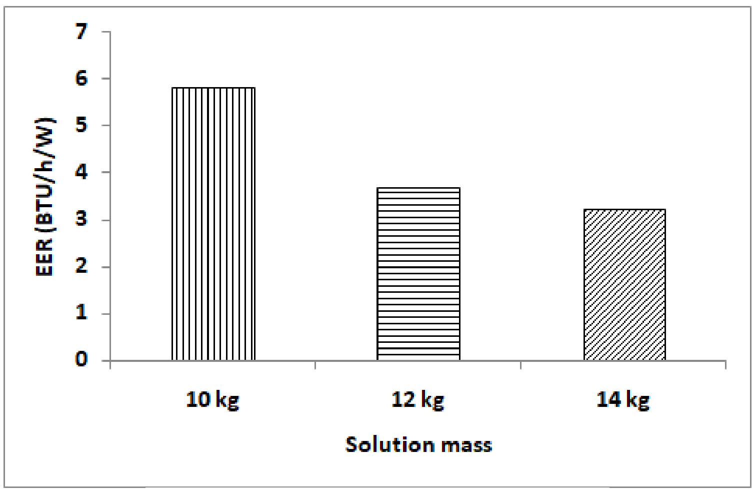

Figure 8. EER of the ice machine in this study

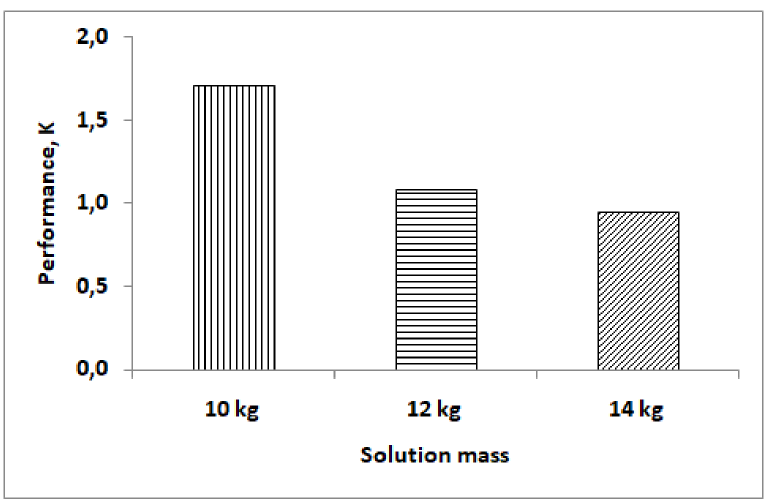

Figure 9. Effect of solution mass on K performance

Figure 8 indicates that the EER decreases as the mass of the solution increases. This is because the ability to cool or transfer heat from the solution to the walls of the evaporator decreases as the mass of the solution increases. However, this EER has never been presented in previous studies such as in the research of Nugroho, et al. (2016), Akhyar (2022), Pramudantoro and Sunanto (2023). Figure 9 shows the effect of the mass of the solution on the performance of the machine calculated based on equation (5). The trend is the same as in figures 7 and 8, which is decreasing with increasing mass of the solution. This is because along with the decrease in heat transfer to the increase in the mass of the solution and while the electrical power used is relatively low, the performance of K will decrease with the increase in the mass of the solution. Similar to EER, the performance of this ice making machine, abbreviated as K, has also never been included in a paper or research by Nugroho, et al. (2016), Akhyar (2022), Pramudantoro and Sunanto (2023). So these two parameters are new to similar studies and these two parameters show whether the machine works well on various mass of solutions.

4. CONCLUSION

Based on the results of research and analysis on the effect of solution mass on freezing time and heat transfer from solution and water to the evaporator wall, the following important things are obtained: (i) The fastest freezing process occurs at a solution mass of 10 kg with the time required to freeze 10 kg of fresh water is 3.5 hours. The largest heat transfer was obtained at a 10 kg solution mass, which was 554 W. EER and the highest K were also obtained for a solution mass of 10 kg. The higher the mass of the saline solution, the longer it will take to freeze 10 kg of water. The EER obtained is quite good and the engine is said to be efficient. This machine is suitable for further use and development.

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