THE EFFECT OF VARIATIONS SPEED OF THE CONDENSER FAN WITH CONTROL FREQUENCY INVERTER ON THE ICE SLUSH MACHINE APPLICATION

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ABSTRACT

The condenser is one of the main components in the ice slush machine system that functions to removed heat from the system to the environment. In this system, the condenser is equipped with a fan whose rotation speed is modified using an inverter that aims to determine the system performance and condenser capacity at each fan rotation variation of the ice slush machine. There are 3 variations of frequency settings in this system 50 Hz, 40 Hz, and 30 Hz, with equivalent velocity air 3.6, 2.9, and 1.9 m/s respectively. In this study, the performance of the ice slush machine with various condenser fan speed settings was studied including, how long the product temperature is reached, condenser capacity, actual COP, efficiency, and electrical power. The test results show that the fastest product temperature is reached when using a fan speed setting of 1397 rpm, which is 145 minutes with a condenser capacity of 42.36 kW. The highest actual COP is obtained from the fan speed set at 1397 rpm of 2.58 with an efficiency of 57.5% and electrical power consumption of 269.64 W. The fan speed setting at 1090 rpm has a condenser capacity of 33.78 kW, COP_{actual} of 2.46 with an efficiency of 56.2%, and electric power consumption of 272.09 W. The fan speed setting at 711 rpm has a condenser capacity of 21.73 kW, an actual CO of 2.15 with an efficiency of 49.2%, and electric power consumption of 312.71 W.

***Keywords**: Ice slush machine, inverter, efficiency, condenser, fan rotation*

1. INTRODUCTION

Currently, issues and impacts on the environment are of great concern related to global warming and the effects of the depletion ozone layer (Muliawan, 2022). Referring to the above problem, saving technology is needed as part of energy conservation. According to the Department of Energy USA (DOE, 2015); the electric power consumption for air conditioning commonly called HVAC has around 30-50% of the total electrical energy consumption of a building as well as applications in small-scale (domestic) refrigeration systems such as refrigerators (refrigerators) which require no small consumption (Henry Nasution, 2014). Technology for saving electrical energy is developing from time to time. Several control devices and equipment devices can be used as a saving technology, including inverters, Variable Speed Drives (VSD) (Nasution, et.al, 2014).

Ice slush machine is a cooling machine used to make cold drinks with a soft texture such as porridge to keep the product cold longer (Muliawan, 2020). There are 4 main components in this system, namely the evaporator, compressor, condenser, and expansion device (Widiyatmoko, 2018). The condenser in the refrigeration system is a device that functions to remove heat from the system to the surrounding environment. Where in the air conditioning system, the condenser is equipped with a fan to circulate air as a heat-taking fluid from the condenser.

The condenser is an important component of this system which functions as a heat exchanger. A good condenser can improve system work performance, so adding a fan to the condenser is usually done to make the heat release process faster and increase the performance of the ice slush machine, and make the ice slush machine cool quickly (Susilawati, 2017). Modification of the condenser fan by increasing the fan rotation will increase the mass flow rate of air through the condenser and also means that it will increase the capacity or heat load of the condenser, namely the amount of heat released to the environment from the cooling system (Sumeru & Sutandi, 2007).

Currently developing technologies that function to save electricity, including inverters.

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Inverter technology can provide convenience in operating a condenser fan by adjusting the frequency rotation.
Inverter technology is used to make it easier for a condenser fan to run the system by adjusting the frequency. The higher the frequency setting, the faster the fan rotation is generated. On the other hand, the smaller the frequency setting, the lower the fan rotation produced (Wellid, 2019).

The study aim is to show and find for the optimal rotation of the condenser fan as a form of energy saving. Knowing the effect of the condenser fan rotation on the performance of the ice slush machine system. The condenser's capacity at each variation of the rational speed of the condenser fan.

2. MATERIALS AND METHODS

This research method is carried out related to the place, time, method of measurement and data collection, materials and equipment used.

The ice slush machine system in this study uses an inverter as a frequency regulator for the electric power source on the condenser fan so that the frequency becomes 30 Hz, 40 Hz, and 50 Hz. The research methodology flow chart is shown in Figure 1.

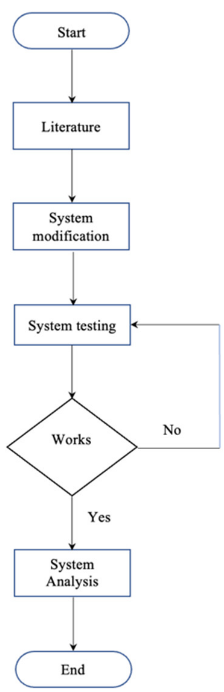

Figure 1. Flow Chart of method

This research was carried out with the following steps:

1. Literature Study
   Searching for literacy as the author's study or collecting theoretical basis that can be used as a support for writing this study report. Literature for the theoretical basis can be obtained from books in the library, journals from existing research, and explanations from supervisors (Dossat, 1961; Stoecker, 1996) (M. J. Moran dan H. N. Shapiro, n.d.).
2. Discussion Method
   Conducting questions and answers and discussions with supervisors, lecturers, and friends so that more knowledge is obtained for writing materials.
3. Modify the ice slush machine system
   Modify the expansion valve and condenser fan, so that the ice slush machine system in this study uses a capillary tube as an expansion device and an inverter as a condenser fan rotation speed regulator.
4. Testing the system as a whole and retrieving data from the system
   Perform testing on the system that has been made to find out whether the system has worked well and collected data from the system for analysis. Then do troubleshoot the obstacles that occur.
5. Making Report Analysis
   Making reports from the results of research and analysis.

In carrying out this experimental study, uses an ice slush machine using a Cola beverage product. The primary refrigerant used is R-134a (Muliawan et al., 2021) and the secondary refrigerant is a mixture of 30.5% ethylene glycol with 69.5% water and the frequency variations are 50 Hz, 40 Hz, and 30 Hz condenser fans.

In carrying out this experimental study, the author uses an ice slush machine with a vapor compression system and uses the brine cooling method. The Piping Diagram of ice slush machine used can be seen in the following picture Fig 2.

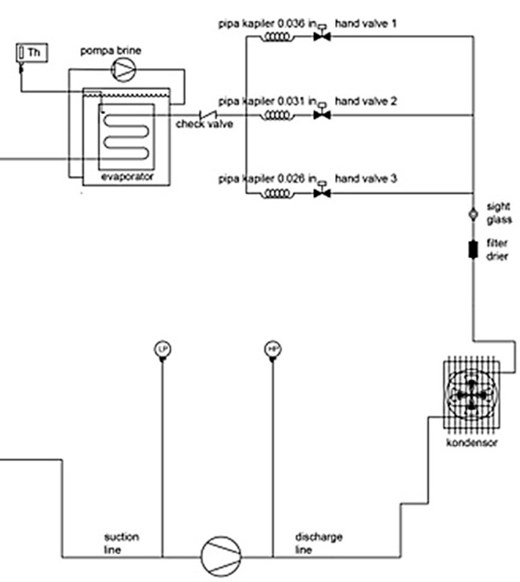

Figure 2. Piping Diagram of Ice Slush Machine System

The following are the equipment and specifications used in this study.

The specifications for the ice slush machine used before testing the performance of the system performance are as follows.

- Compressor : Vasco LT91 PK
- Condenser : Air cooled type (for specification fan is included) in condensing unit.
- Expansion device: Capillary tube with a length of 1.5 m and a diameter of 0.036 in
- Primary refrigerant : R134a
- Secondary refrigerant: Ethylene glycol

Equipment as follows :

- Pressure Gauge : Royal High Pressure Gauge (0-500 psi) and Royal
- Low Pressure Gauge (0-350 psi)
- Thermostat : Elite STC-200 range -40℃ - 70℃
- Inverter : TECO FM-50
- Ammeter: FORT FT-45 range 0-20 A
- Voltmeter: FORT FT-45 range 0-500V

The Method of calculation and analysis of the research as follows :

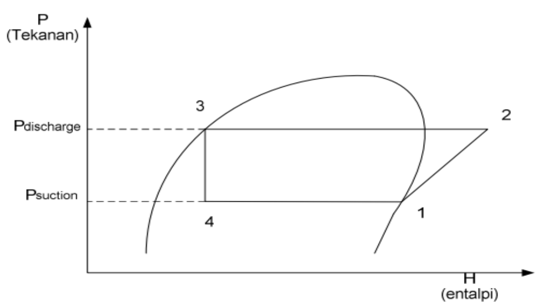

Figure 3. Ph Diagram system

- (Power of compression/compressor)

$$W = \dot{m} \, x \, \Delta h$$
$$= \dot{m} \, x \, (h_2 - h_1)$$
$$q_w = h_2 - h_1 \quad (1)$$

Where :

q_w = The amount of work compression (kJ/kg)

h_1 = Enter Enthalpy of refrigerant (kJ/kg)

h_2 = Leaving Enthalpy of refrigerant (kJ/kg)

$\dot{m}$ = Refrigerant flow rate (kg/s)

- Capacity of the condenser

$$Q_{air} = v \, x \, A \quad (2)$$

Where :

Q_{Air} = air flow through the condenser (m³/s)

v = Velocity air through the condenser (m/s)

A = Area of the condenser (m²)

$$\dot{m} = \rho \, x \, Q_{air} \quad (3)$$

Where:

ṁ = Mass flow rate of air of the condenser (kg/s)

ρ = Density of air (kg/m³)

Then the equation :

$$Qk = \dot{m} \, x \, \Delta h \quad (4)$$

or

$$Qk = \dot{m} \, x \, C_p \, x \, \Delta T \quad (5)$$

Where :

q_{udara} = The rate of air heat transfer in the condenser (kW)

ṁ = Mass flow rate of air of the condenser (kg/s)

Δh = changes of enthalpy (kJ/kg)

C_p = Specific heat of air (kJ/kgºC)

ΔT = The air temperature difference (ºC)

Table 1. Measurement data

No		Frequency			Unit
		50 Hz	40 Hz	30 Hz	
1	Condenser fan rotation speed	1397	1090	711	rpm
2	Condenser fan airflow speed	3,6	2,9	1,9	m/s
3	Condenser length	24	24	24	cm
4	Condenser width	21	21	21	cm

- (System efficiency)

The equation of system efficiency :

$$\text{Refrigeration efficiency} = \frac{COPa}{COPc} \quad (5)$$

$$COP_c = \frac{Te}{Tk - Te} \quad (6)$$

Where:

COP_c = *Coefficient of performance Carnot*

Te = Evaporation Temp (K)

Tk = Condensing Temp (K)

$$COP_a = \frac{\text{Effect of refrigeration}}{\text{Compression of work}} = \frac{qe}{qw} = \frac{h1 - h4}{h2 - h1} \quad (7)$$

Where :

COP_a = *Coefficient of performance Actual*

Q_e = Heat absorbed in the evaporator (kJ/kg)

q_w = The amount of compression work (Kj/kg)

3. RESULTS AND DISCUSSION

3.1 Research Results

3.1.1 Analysis of Frequency Variation on Fan Rotation Speed

In this experiment, the fan rotational speed is regulated using an inverter by adjusting the frequency of the fan power supply at 30 Hz, 40 Hz, and 50 Hz. The magnitude of the rotational speed resulting from the frequency setting is given in Figure 4 Based on that the graph, it can be seen that the system with a frequency of 50 Hz has the highest rotational speed of 1397 rpm, followed by a system with a frequency of 40 Hz, which is 1090 rpm, and a frequency of 30 Hz, which is 711 rpm. This shows that the greater the frequency setting of the given fan power source, the greater the rotational speed of the fan produced by the condenser fan. The speed of fan is influenced to drive because the linear function from the frequency rpm. If rotation of frequency increased so the speed fan is high.

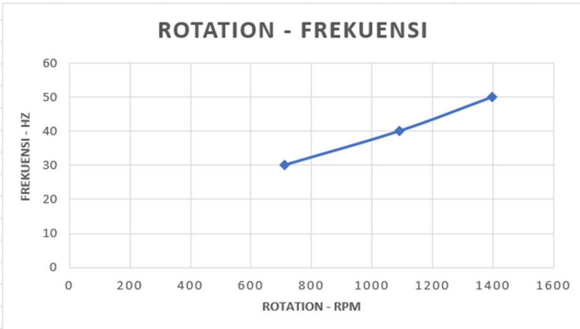

Figure 4. Graph of Condenser Fan Rotational Speed Results From Frequency Settings 50 Hz, 40 Hz, 30 Hz.

3.1.2 Analysis of the influence of fan rotational speed on discharge pressure

Based on the graph in Figure 5, it can be seen that the highest discharge pressure value is 12.4 Bar_{abs} at a fan rotational speed of 711 rpm, followed by a fan rotational speed of 1090 rpm with a discharge pressure value of 11.6 bar abs and a fan rotational speed of 1397 rpm with a discharge pressure value. 11.2 bar_{abs}.

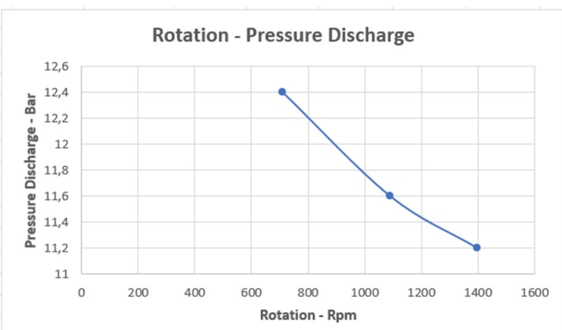

Figure 5. Graph of the Effect of Condenser Fan Rotating Speed on Discharge Pressure

The reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) increases the discharge pressure. This of course will increase the compression ratio of the compressor used by the ice slush machine. As a result, the compression work that must be done by the compressor increases, because the compressor has to work harder to increase the refrigerant pressure.

3.1.3 Analysis of the effect of fan rotational speed on the condenser outlet temperature

Figure 5 shows a graph of the effect of fan rotational speed on the resulting discharge pressure.

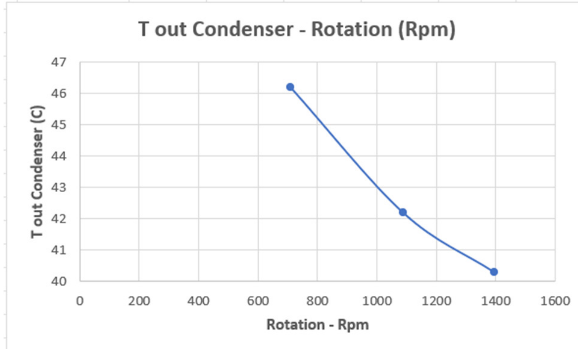

Figure 6. Graph of the Effect of Condenser Fan Rotating Speed on Condenser Output Temperature

Based on the graph in Figure 6, it can be seen that the highest condenser output temperature value is 46.2 ^{0}C at a fan rotation speed of 711 rpm, followed by a fan rotational speed of 1090 rpm with a condenser output temperature value of 42.2 ^{0}C and a fan rotational speed of 1397 rpm with a value of 42.2 ^{0}C. condenser outlet temperature 40.3 ^{0}C.
From figure 6, it can be seen that the reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) causes an increase in the condenser output temperature. This is an indication that at a low fan rotation speed, the airflow in the condenser is also low, resulting in a high increase in air temperature.
The mainly factor is because from speed of fan is influenced to drive because the linear function from the frequency rpm. If rotation of frequency increased so the speed fan is high.

3.1.4 Analysis of the effect of fan rotational speed on system power consumption

Figure 7 below shows a graph of the effect of fan rotational speed on the resulting system power consumption.

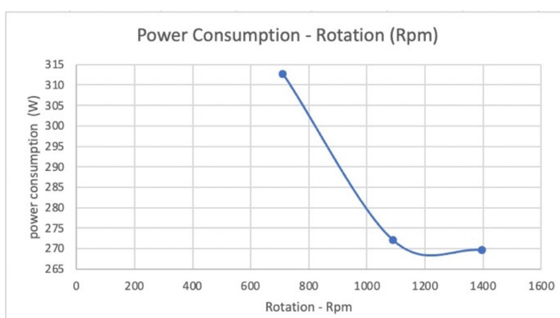

Figure 7. Graph of the Effect of Condenser Fan Rotation Speed on System Power Consumption

Based on the graph in Figure 7 it can be seen that the highest system power consumption value is 312.71 W at a fan rotational speed of 711 rpm, followed by a fan rotational speed of 1090 rpm with a system power consumption value of 272.09 W and a fan rotational speed of 1397 rpm with a value of system power consumption 269.64 W.
From this figure, it can be seen that the reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) causes an increase in system power consumption. This is because the compression ratio of the compressor used by the ice slush machine increases. As a result, the compression work that must be done by the compressor increases, because the compressor has to work harder to increase the refrigerant pressure.

3.1.5 Analysis of the influence of fan rotational speed on condenser capacity

Analysis of the influence of fan rotational speed on condenser capacity. Figure 8 shows a graph of the effect of fan rotational speed on the resulting condenser capacity.

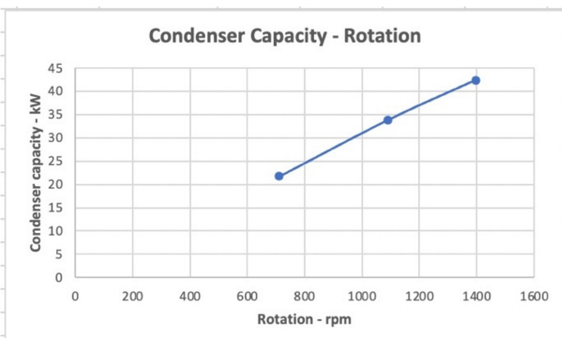

Figure 8. Condenser capacity - Rotation

Based on the graph in figure 8 it can be seen that the highest condenser capacity value is 42.36 kW at a fan rotation speed of 1397 rpm, followed by a fan rotation speed of 1090 rpm with a condenser capacity value of 33.78 kW and a fan rotational speed of 711 rpm with a condenser capacity value of 21.73 kW. From figure 8, it can be seen that the reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) causes a decrease in the condenser capacity. This is because, at the reduced rotational speed of the condenser fan, there is a decrease in the airflow velocity of the condenser fan, airflow rate, and air mass flow rate, at the same condenser cross-sectional area and air density.

3.1.6 Analysis of Product Temperature vs Time

Figure 9 below shows a graph of the comparison of product temperature against time using variations in the speed of the 50 Hz, 40 Hz, and 30 Hz condenser fan.

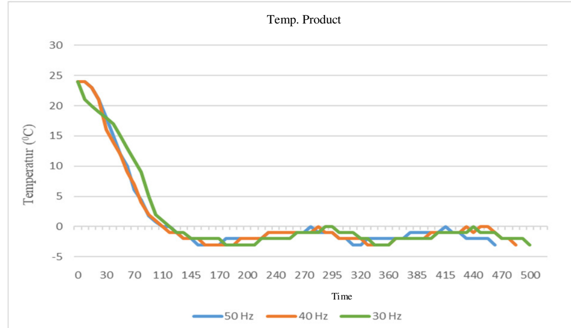

Figure 9. Graph of Product Temperature - Time

The product used is 3.6 liters of carbonized beverage drink with a design temperature of -3℃. Systems using the 50 Hz frequency variation take 145 minutes to cool the product. While the system that uses a 40 Hz frequency variation takes 150 minutes to cool the product. Then a system that uses a frequency variation of 30 Hz takes 170 minutes to cool the product.
From this figure 9, it can be seen that the reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) causes less heat to be dissipated in the condenser so that the capacity of the condenser becomes smaller which results in a longer time required to cool the product.

3.1.7 Analysis of electric current against time

Figure 10 shows a graph of the ratio of current to time using variations in the speed of the 50 Hz, 40 Hz, and 30 Hz condenser fan

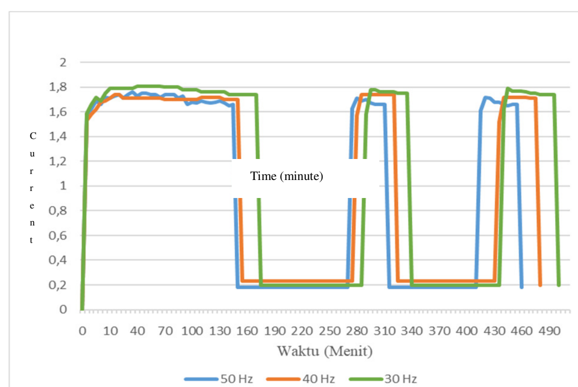

Figure 10. Graph of Electric Current - Time

In Figure 10 the electric current when the system operates using a frequency variation of 50 Hz tends to be constant at around 1.7 A until the system is cut off. When the system is cut off, there is a significant decrease in electric current to 0.18 A. When the system is cut in, the electric current becomes 1.7 A, then drops to 1.6 A when the system is stable. While the electric current when the system operates using a frequency variation of 40 Hz tends to be constant at around 1.7 A until the system is cut off.

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When the system is cut off, there is a significant decrease in electric current to 0.23 A. When the system is cut in, the electric current increases to 1.74 A and is constant when the system is stable. Then the electric current when the system operates using a frequency variation of 30 Hz tends to be constant at around 1.74 A until the system is cut off. When the system is cut off, there is a significant decrease in electric current to 0.2 A. When the system is cut in, the electric current increases to 1.78 A and then drops to 1.75 when the system is stable.

All frequency variations experience a decrease in current from the system at the first to last cut-in (unstable) due to an unstable source voltage, where the source voltage has a relationship with the current value. The difference in electric current between the frequency variations of 50 Hz, 40 Hz, and 30 Hz is present when the system operates. This is caused by the reduced rotational speed of the condenser fan from its normal speed (frequency 50 Hz) which causes the compressor work to increase when the system operates so that the resulting current is greater.

3.1.8 Analysis of Efficiency

- Frequency 50 Hz or equivalent fan speed 3,6 m/s

Table 2. Measurement data

No.	Measuring Point	Value	Unit
1	*Pressure Discharge*	11,2	$Bar_{absolute}$
2	*Pressure Suction*	1,70	$Bar_{absolute}$
3	Temperature *Discharge*	71,6	℃
4	Temperature *Suction*	-3,8	℃
5	Tout Condenser	40,9	℃

From table 2 and then plot to software coolpack.

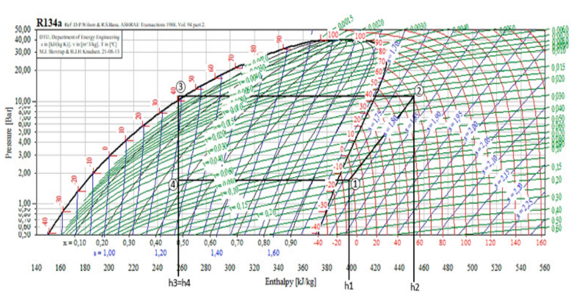

Figure 11. Ph Diagram R-134a (50Hz)

From the plot diagram P-h and get :

h1 = 397,7 kJ/kg

h2 = 452,1 kJ/kg

h3 = h4 = 257,5 kJ/kg

Te = -14,14℃ = -14,14 + 273,15 = 259,01 K

Tc = 43,66℃ = 43,66 + 273,15 = 316,81 K

With the enthalpy value that has been obtained, the actual CO value can be determined using equation (7)

$$COPa = \frac{397{,}7 - 257{,}5}{452{,}1 - 397{,}7}$$

$$COPa = 2{,}58$$

Then it can be seen the COPcarnot value using equation (6)

$$COPc = \frac{259{,}01}{316{,}81 - 259{,}01}$$

$$COPc = 4{,}48$$

After getting the COPa and COPc values, the system efficiency value can be determined by using equation (5)

$$\eta = \frac{2{,}58}{4{,}48}\ x\ 100$$

$$\eta = 0{,}5749\ x\ 100 = 57{,}49\%$$

- Frequency 40 Hz or equivalent fan speed 2,9 m/s

Table 3. Measurement data

No.	Measuring Point	Value	Unit
1	*Pressure Discharge*	11,6	$Bar_{absolute}$
2	*Pressure Suction*	1,69	$Bar_{absolute}$
3	Temperature *Discharge*	72,2	℃
4	Temperature *Suction*	-5,37	℃
5	Tout Condenser	42,2	℃

From table 3 and then we could plot to software coolpack. We get the diagram Ph as follows :

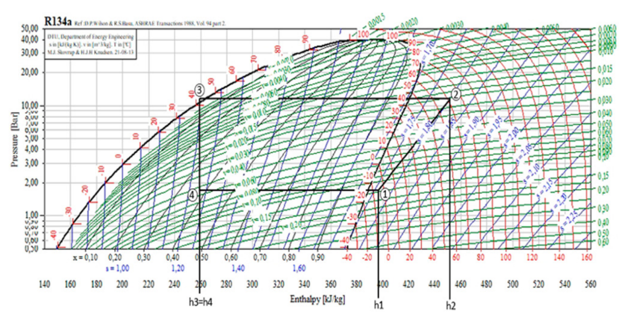

Figure 12. Ph Diagram R-134a (40Hz)

From the plot diagram P-h and get :

h1 = 396,3 kJ/kg

h2 = 452,1 kJ/kg

h3 = h4 = 259,5 kJ/kg

Te = -14,29℃ = -14,29 + 273,15 = 258,86 K

Tc = 45,01℃ = 45,01 + 273,15 = 318,16 K

With the enthalpy value that has been obtained, the actual CO value can be determined using equation (7)

$$COPa = \frac{396,3 - 259,5}{452,1 - 396,3}$$
$$COPa = 2,46$$

Then it can be seen the COP_{carnot} value using equation (6)

$$COPc = \frac{258,86}{318,16 - 258,86}$$
$$COPc = 4,37$$

After getting the COPa and COPc values, the system efficiency value can be determined by using equation (5)

$$\eta = \frac{2,46}{4,37}\ x\ 100$$
$$\eta = 0,5624\ x\ 100 = 56,24\%$$

- *Frequency 30 Hz or equivalent fan speed 1,9 m/s*

Table 4. Measurement Data

No.	Measuring Point	Value	Unit
1	*Pressure Discharge*	12,47	$Bar_{absolute}$
2	*Pressure Suction*	1,85	$Bar_{absolute}$
3	Temperature *Discharge*	76	℃
4	Temperature *Suction*	-6,57	℃
5	Tout Condenser	46,4	℃

From table 4 and then we could plot to software coolpack. We get the diagram Ph as follows :

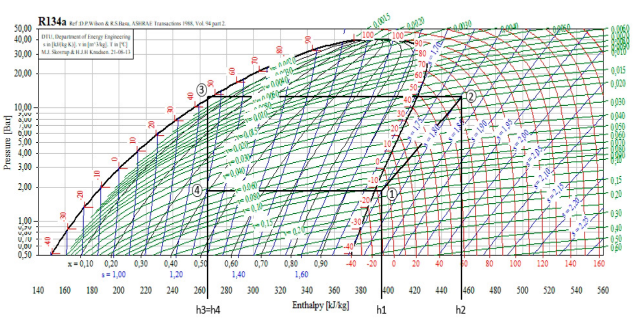

Figure 13. Ph Diagram R-134a (30 Hz)

From the plot diagram P-h and get :
h1 = 394,8 kJ/kg
h2 = 455 kJ/kg
h3 = h4 = 265,9 kJ/kg
Te = -12,05℃ = -12,05 + 273,15 = 261,1 K
Tc = 47,82℃ = 47,82 + 273,15 = 320,97 K

With the enthalpy value that has been obtained, the actual CO value can be determined using equation (7)

$$COPa = \frac{394,8\ - 265,9}{455 - 394,8}$$
$$COPa = 2,15$$

Then it can be seen the COP_{carnot} value using equation (6)

$$COPc = \frac{261,1}{320,97 - 261,1}$$
$$COPc = 4,36$$

After getting the COPa and COPc values, the system efficiency value can be determined by using equation (5)

$$\eta = \frac{2,15}{4,36}\ x\ 100$$
$$\eta = 0,4921\ x\ 100 = 49,21\%$$

3.1.9 Analysis Efficiency with respect to time

The results of the measurement data used to calculate the efficiency value in this ice slush machine system use system data before experiencing the first cut-off of the three frequency variations. Figure 14. shows a graph of the system efficiency value between each variation of the frequency of 50 Hz, 40 Hz, and 30 Hz.

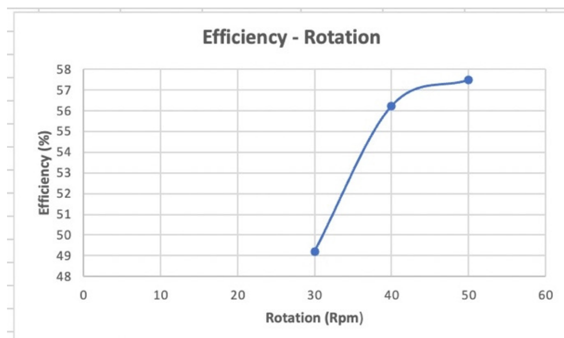

Figure 14. Graph of system efficiency Value against frequency variations

From the graph in figure 14, It can be seen that the efficiency values in the Three frequency variations have different values. The system with a frequency of 50 Hz has the highest system efficiency value of 57,49 %, followed By a frequency of 40 Hz which is 56,24 %, and a frequency of 30 Hz which is 49,18 %. From this figure, It can be seen that the reduced rotational speed of the condenser fan From its normal speed (50 Hz Frequency), causes the efficiency of the system performance to get worse.

3.2 Comparison of Data Analysis

The following is a comparison of the results of the analysis of the 50 Hz, 40 Hz, and 30 Hz condenser fan speed variations in the Ice slush machine system, which can be seen in table 5.

Table 5. Comparison of experimental results

No	Parameter	Frequency variations		
		50 Hz	40 Hz	30 Hz
1	Fan Rotation Speed	1397 rpm	1090 rpm	711 rpm
2	Discharge Pressure	11,2 Bar_{abs}	11,6 Bar_{abs}	12,4 Bar_{abs}
3	Tout Condenser	40,3 ^{0}C	42,2 ^{0}C	46,2 ^{0}C
4	COP_a	2,58	2,46	2,15
5	COP_c	4,48	4,37	4,36
6	Efficiency	57,5%	56,2%	49,2%
7	Current	1,66 A	1,7 A	1,74 A
8	Chilling time product	145 (minute)	150 (minute)	170 (minute)
9	Energy consumption	2,13 kWh	2,26 kWh	2,76 kWh
10	Condenser Capacity	42,36 kW	33,78 kW	21,73 kW

The highest fan rotation speed is obtained from the 50 Hz frequency setting, which is 1397 rpm, this is due to the greater the frequency setting on the condenser fan used, the greater the rotational speed of the resulting fan.

The highest discharge pressure is obtained at a frequency setting of 30 Hz, which is 12.4 bar $_{abs}$, this is due to the smaller rotational speed of the condenser fan than its normal speed (frequency 50 Hz) resulting in greater compression work that must be done by the compressor because the compressor has to work harder to increase the refrigerant pressure.

The highest condenser output temperature is obtained at a frequency setting of 30 Hz, which is 46.2 ^{0}C, this is due to the smaller rotational speed of the condenser fan resulting in low airflow in the condenser, resulting in a high increase in air temperature. The largest actual COP value was obtained at the rotation speed of the condenser fan at 1397 rpm of 2.58. The frequency setting on the inverter that is good for this system is 50 Hz (normal speed) because the efficiency value is greater than other variations.

The greatest electric current is obtained from the rotational speed of the 711 rpm condenser fan of 1.74 A, this is due to the smaller the rotational speed of the condenser fan than its normal speed (frequency 50 Hz), the greater the electric current due to the increase in the compression ratio on the compressor so that the compressor works, the compressor is getting heavier. The fastest product chilling time is obtained from the rotation speed of the condenser fan at 1397 rpm, which is 145, the smaller the rotational speed of the condenser fan than its normal speed (frequency 50 Hz) results in a longer product cooling time.

The greatest energy consumption is obtained from the rotation speed of the condenser fan at 711 rpm, which is 2.76 kWh, this is due to the longer the chilling time of the product, the more electrical energy is used. The largest condenser capacity is obtained from the rotation speed of the condenser fan at 1397 rpm, which is 42.36 kW, this is because the greater the rotational speed of the condenser fan, the greater the heat release in the condenser.

4. CONCLUSION

Based on the experimental, the conclusions obtained in writing this research are the variations in the rotational speed of the condenser fan affect the performance of the system which includes compressor work, condenser capacity, COP_{aktual}, COP_{carnot}, and efficiency, the smaller the rotational speed of the condenser fan from its normal speed (frequency 50 Hz), the system performance will be worse decreased.

The value of the condenser capacity from the highest to the lowest frequency is 42.36 kW, 33.78 kW, and 21.73 kW, respectively. The smaller the rotational speed of the condenser fan than its normal speed (frequency 50 Hz) affected by the condenser releases more heat. The condenser is an important component of this system which functions as a heat exchanger. A good condenser can improve system work performance, so adding a fan to the condenser is usually done to make the heat release process faster and increase the performance of the ice slush machine, and make the ice slush machine cool quickly.

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