

OPTIMIZATION OF CAPILLARY PIPE DIAMETER FOR THE PERFORMANCE OF A 100-LITER CAPACITY ICE PLANT AS A MEANS OF PRESERVING FISH

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ABSTRAK

Pipa kapiler merupakan salah satu alat ekspansi pada siklus refrigerasi kompresi uap (SKU), fungsinya untuk menurunkan tekanan refrigerant dari tekanan tinggi ke tekanan rendah. Ukuran dari pipa kapiler baik panjang ataupun diameternya sangat berpengaruh terhadap tekanan sistem pendingin. Penentuan ukuran pipa kapiler haruslah tepat sehingga kinerja sistem sesuai dengan yang diinginkan. Tujuan penelitian ini untuk mendapatkan diameter pipa kapiler yang optimal guna meningkatkan performa sistem pendingin pada pabrik es kapasitas 100 liter menggunakan outdoor unit AC 1 PK sebagai condensing unit, dimana sistem ini dirancang untuk mendukung proses pembekuan air (es) sebagai sarana pengawetan ikan secara sederhana dan efisien. Variabel utama yang dianalisis adalah diameter pipa kapiler (0,028 inch, 0,031 inch, dan 0,040 inch), dengan parameter evaluasi meliputi kerja dari unit pembekuan yang mencakup dampak refrigerasi (qc), kerja kompresor (wk), kalor yang dilepas kondensor (qk), dan koefisien performansi (COP). diameter pipa kapiler yang digunakan 0,028 inch menghasilkan dampak refrigerasi (qc) sebesar 345.35 kJ/kg; kerja kompresi (wk) sebesar 78,26 kJ/kg dan nilai coefficient of performance (COP) sebesar 3,41. Untuk pipa kapiler dengan diameter 0,031 inch menghasilkan dampak refrigerasi (qc) sebesar 344.37 kJ/kg; kerja kompresi (wk) sebesar 79.95 kJ/kg dan nilai coefficient of performance COP sebesar 3,31. Sedangkan untuk pipa kapiler dengan ukuran 0.040 mm menghasilkan dampak refrigerasi (qc) sebesar 343.46 kJ/kg; kerja kompresi (wk) sebesar 80,26 kJ/kg dan nilai coefficient of performance COP sebesar 3,29. Ukuran diameter terbaik yang menghasilkan coefficient of performance (COP) tertinggi pada unit pembuatan es dengan nilai sebesar 3,41 yaitu ada pada ukuran diameter pipa kapiler 0,028 inch.

Kata kunci: Optimalisasi; diameter pipa kapiler; condensing unit; COP

ABSTRACT

The capillary tube is an expansion device in the vapor compression refrigeration cycle (VCRC) that functions to reduce refrigerant pressure from high to low levels. The tube's diameter and length significantly affect the pressure and performance of the refrigeration system. Therefore, selecting the appropriate capillary tube size is essential to achieve optimal system operation. This study aims to determine the optimal capillary tube diameter to improve the performance of a 100 liter ice maker unit utilizing a 1 PK air conditioner outdoor unit as the condensing unit. The system is designed to support an efficient and simple ice freezing process for fish preservation. The main variable analyzed is the capillary tube diameter (0.028 inch, 0.031 inch, and 0.040 inch). Evaluation parameters include refrigeration effect (Qc), compressor work (Wk), condenser heat rejection (Qk), and coefficient of performance (COP). The results indicate that a 0.028-inch capillary tube yields a refrigeration effect of 345.35 kJ/kg, compressor work of 78.26 kJ/kg, and a COP of 3.41. The 0.031-inch and 0.040-inch diameters result in COP values of 3.31 and 3.29, respectively. Therefore, the 0.028-inch capillary tube provides the highest performance and is considered the most suitable for the 100 liter ice maker system.

Keywords: Optimization; capillary tube; diameter; condensing unit; coefficient of performance (COP)

INTRODUCTION

Maluku Province is known as an archipelago whose area consists mostly of waters and makes it one of the largest fish producers in Indonesia (1). However, the abundance of these catches presents its own challenges for fishermen, especially related to the need for ice to maintain the freshness of fish (2). Ice is indispensable for

preserving the fish caught so that it remains fresh, durable, and does not rot before it reaches the consumer (3). The availability of ice in many coastal areas of Maluku is still limited, this is due to the lack of factories needed to produce ice, so fishermen often have to use home-made ice that is of inadequate quality. This condition causes the quality of fish to decline and the selling price to be low.

To meet the ice needs in coastal areas of Maluku that experience limited ice supply, one innovative solution is to utilize an air conditioning (AC) unit as a condensing unit combined with an evaporator in a cooling box. This approach offers compact construction and easy availability of components on the market. To increase the effectiveness of cooling and speed up the ice freezing process, this system uses a circulated brine solution as a cooling medium. The use of brine (4) allows for more efficient heat absorption, thereby accelerating the formation of ice. To convert the function of air cooling into ice formation, modifications are needed to the refrigeration system, especially to the capillary pipes that function as expansion tools. Capillary pipes regulate the flow of refrigerant from the high-pressure side (condenser) to the low-pressure side (evaporator) according to the required load. The size of capillary pipes, both in length and diameter, greatly affects the pressure and performance of the cooling system.

Variations in capillary pipe length affect the compression work in small-scale ice-making units that use outdoor AC 2 PK. The results of the study showed that the longer the capillary pipe, the compression work increased linearly with a compression working value of 43,320 kJ/kg for a pipe length of 0.75 m, 49,880 kJ/kg for 1.0 m, and 57,530 kJ/kg for 1.25 m. This suggests that adjusting the length of the capillary pipe can optimize the performance of the ice-making system (5).

Several studies also examined the influence of capillary pipe diameter, including the effect of diameter on the performance of coolboxes with R-134a refrigerant type with diameter variations of 0.028 inches, 0.031 inches, 0.036 inches. From the results obtained, capillary pipes with a diameter of 0.031 inches and a length of 1.81 meters produced a greater efficiency value compared to other variations with a COP actual value of 2.66, COP Carnot 3.18, and system efficiency of 83.64% (6). Another supporting research is by varying the length of the capillary pipe of 1.5 m, 3 m and 4.5 m, with the diameter used being 0.054 and 0.70 inches. The results were that a capillary pipe with a length of 4.5 m and a diameter of 0.054 inches produced a COP of 5.6, and a pipe length of 1.5 m with a diameter of 0.70 inches produced a COP value of 6.8 (7).

Based on previous research, the focus of this study is on the analysis of the effect of capillary pipe diameter variations on the performance of small-scale ice factory cooling systems that use condensation units from AC 1 PK R-32. The use of air conditioner R-32 in this study is based on its availability in the market, having a

better cooling capacity, GWP of 675 thus reducing the contribution to global warming, high latent heat so that more heat can be absorbed (8)(9)(10). The main objective is to determine the optimal capillary pipe diameter to improve the efficiency of ice freezing, which is essential for fishermen in the coastal region of Maluku in maintaining the freshness of their catch. The results of this research are expected to contribute to the development of cost-effective and applicative refrigeration technology, as well as support the sustainability of the local fisheries industry.

RESEARCH METHODS

This research was conducted at the Refrigeration and Air Conditioning Laboratory, Faculty of Engineering, Pattimura University. The variables in this study include: Free variables in the form of diameters, namely 0.028 inches, 0.031 inches, and 0.040 inches. The variables tied to this study are the work of the freezing unit which includes the refrigeration impact (qc), compressor work (wk), condenser released heat (qk), and performance coefficient (COP).

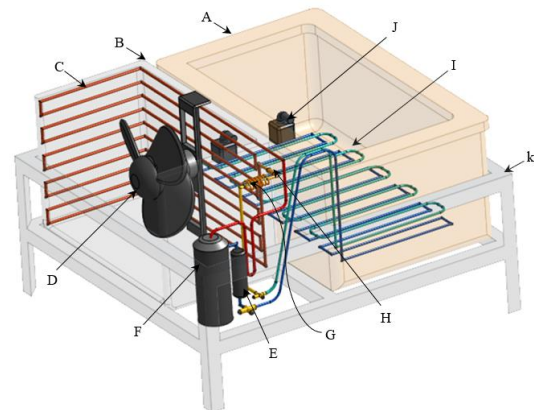


Figure 1. Research scheme

Image Caption

A = Coolbox	E = Akumulator
B = Outdoor AC	F = Compressor
C = Condensor	G = Pipe capillaries
D = Fan	H = Filter Dryer
I = Evaporator	J = Dip pump
K = Chassis	

Calculation of the Working Amount of the Refrigeration Unit

1) Refrigeration Impact

The refrigeration impact is calculated as the difference between enthalpy at point 1 and point 4, namely:

$$q_c = (h_1 - h_4) \quad (1)$$

Where:

= Refrigeration impact, kJ.kg
 h_1 = Enthalpy at point 1, kJ/kg.
 h_4 = Enthalpy at point 4, kJ/kg.

2) Refrigerant Mass Flow Rate

The mass flow rate of refrigerant is calculated by the equation:

$$\dot{m} = \frac{\dot{Q}_c}{q_c} \quad (2)$$

Where:

$\dot{m}$ = Refrigerant mass flow rate, kg/s.
 $\dot{Q}_c$ = Evaporator absorbed heat or cooling load, kW
 q_c = Impact of refrigeration, kJ.kg

3) Compressive Power

$$W_K = \dot{m}(h_2 - h_1) \quad (3)$$

Where:

$\dot{m}$ = Refrigerant mass flow rate, kg/s.
 h_2 = Enthalpy at the state level 2, kJ/kg.
 h_1 = Enthalpy at the state level 1, kJ/kg.

4) Heat released by the Condenser

The heat released by the condenser is calculated by the equation:

$$\dot{Q}_H = \dot{m}(h_2 - h_3) \quad (4)$$

Or it can also be calculated by equation:

$$\dot{Q}_H = W_K + \dot{Q}_c \quad (5)$$

Where:

$\dot{m}$ = Refrigerant mass flow rate, kg/s.
 h_2 = Enthalpy at the state level 2, kJ/kg.
 h_3 = Enthalpy at the state level 3, kJ/kg.

5) Performance Coefficient (COP)

$$COP = \dot{Q}_c / W_K \quad (6)$$

Where:

$\dot{Q}_c$ = Cooling load, W
 W_K = Compressive power, W

RESULTS AND DISCUSSION

The results of the measurement and calculation of the effect of variations in capillary pipe diameter on the condition and working variables of the coolbox cooling unit with a capacity of 1 PK used are shown in Table.1. The working conditions of the steam compression cycle for the three treatment variations in capillary pipe diameter were obtained according to the results of the average measurement of the amount of condensation pressure ($p_2=p_3$) and evaporation pressure ($p_4=p_1$) as well as final evaporation/initial compression temperature (T1),

final compression/initial condensation temperature (T2) and final condensation temperature (T3).

Table 1. The results of the measurement and calculation of the effect of variations in capillary pipe diameter on the working conditions and variables of the refrigeration unit

Variabel kerja mesin pendingin	Diameter pipa kapiler			satuan
	0.028"	0.031"	0.040"	
Tekanan kondensasi, $p_2=p_3$	330.17	340.64	352.14	Psia
Tekanan evaporasi, $p_4=p_1$	66.05	79.87	84.94	Psia
Penurunan tekanan ekspansi, $\Delta P = (P_1-P_4)$	264.12	260.77	267.20	Psia
Rasio Kompresi, $Cr = p_2/p_1$	0.2501	0.3063	0.3179	
Temperatur evaporasi, T_{evap}	-16.9010	-11.6100	-9.8515	°C
Temperatur awal kompresi, T_1	-5.30	-5.70	-6.20	°C
$\Delta TSH = (T_{evap} - T_1)$	-11.6010	-5.9100	-3.6515	°C
Temperatur akhir kompresi, T_2	101.30	100.20	99.60	°C
Temperatur kondensasi, T_{kond}	36.551	37.810	39.160	°C
Temperatur akhir kondensasi, T_3	30.45	29.81	29.37	°C
$\Delta TSC = (T_{kond} - T_3)$	6.101	8.000	9.790	°C
Entalpi akhir evaporasi/awal kompresi, h_1	523.11	519.13	517.20	kJ/Kg
Entalpi akhir kompresi, h_2	601.37	599.08	597.26	kJ/Kg
Entalpi akhir evaporasi/awal kompresi $h_1 = h_4$	256.02	254.71	253.80	kJ/Kg
Entropi awal kompresi, $s_1=s_2$	2.2647	2.2225	2.2066	kJ/(Kg·°C)
h_{1s}	595.50	581.68	577.58	
Entropi akhir kompresi, s_2	2.2805	2.2700	2.2606	kJ/(Kg·°C)
Produksi entropi, Δs	0.0158	0.0475	0.0540	kJ/(Kg·°C)
Dampak refrigerasi, $q_c = (h_1-h_4)$	267.09	264.42	263.4	kJ/Kg
Kalor spesifik yang dilepas kondensor, $q_k = (h_2-h_3)$	345.35	344.37	343.46	kJ/Kg
Kerja kompresi spesifik, $w_k = h_2-h_1$	78.26	79.95	80.06	kJ/Kg
Coefficient of Performance, $COP = q_c/w_k$	3.4129	3.3073	3.2900	

Effect of Capillary Pipe Diameter Variation on Refrigeration Unit Working Conditions

The effect of variations in capillary pipe diameter on the working conditions of the steam compression cycle refrigeration unit that is studied, as a whole can be traced according to the change in the thermodynamic properties of refrigerant R-32 used at state level 1 (end of evaporation / beginning of compression), state level 2 (end of compression / beginning of condensation), state level 3 (end of condensation / beginning of expansion) and state level 4 (end of expansion / beginning of evaporation).

Various changes in thermodynamic properties at the state level expressed as process statements on the enthalpy pressure diagram (p-h) scheme, for experiments with variations in capillary pipe diameter were studied.

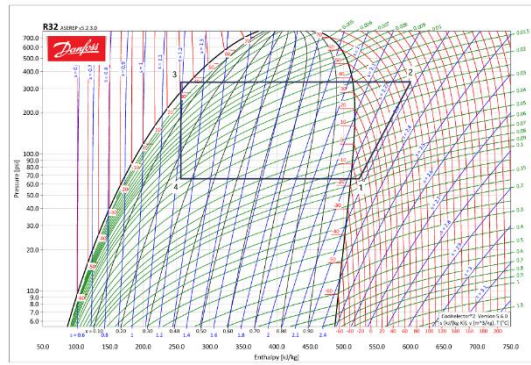


Figure 2. Diagram Schematic p-h Diameter 0.028"

Figure 2 obtained pressure data ($P_1=P_4$) = 4.55 bar and ($P_2=P_3$) = 30.57 bar, temperature $T_1 = -5.3^\circ\text{C}$, $T_2 = 101.3^\circ\text{C}$, $T_3 = 30.45^\circ\text{C}$, $T_{\text{kond}} = 36.55^\circ\text{C}$ and $T_{\text{evap}} = -16.9^\circ\text{C}$ from the data, the enthalpy values $h_1 = 523.11$ kJ/kg, $h_2 = 601$ kJ/kg and $h_3 = 256.02$ kJ/kg were obtained so that the q_k values = 345.35 kJ/kg, $q_c = 267.09$ kJ/kg and $w_k = 78.26$ kJ/kg were obtained.

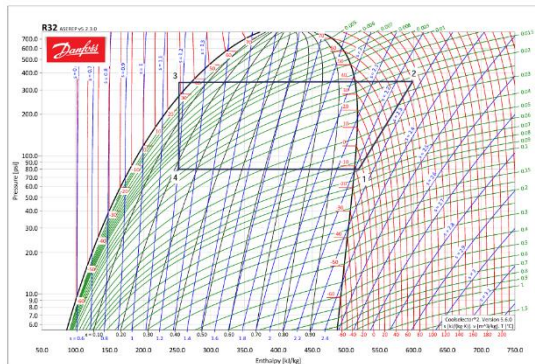


Figure 3. Schematic Diagram p-h Diameter 0.031"

Figure 3, pressure data ($P_1=P_4$) = 5.50 bar and ($P_2=P_3$) = 23.48 bar, with temperature $T_1 = -5.7^\circ\text{C}$, $T_2 = 100.2^\circ\text{C}$, $T_3 = 29.81^\circ\text{C}$, $T_{\text{kond}} = 37.81^\circ\text{C}$ and $T_{\text{evap}} = -11.6^\circ\text{C}$ from the data, enthalpy values $h_1 = 519.13$ kJ/kg, $h_2 = 599.08$ kJ/kg and $h_3 = 254.71$ kJ/kg were obtained so that q_k values = 344.37 kJ/kg, $q_c = 264.42$ kJ/kg and $w_k = 79.95$ kJ/kg were obtained.

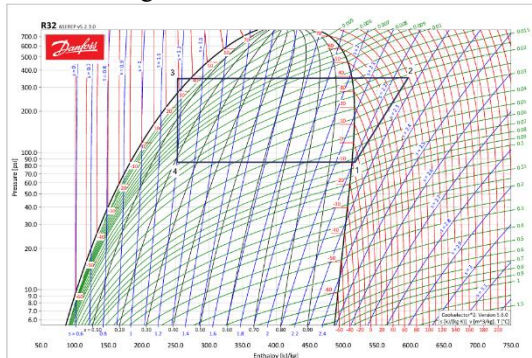


Figure 4. Diagram Diagram p-h Diameter 0.040"

Figure 4, pressure data ($P_1=P_4$) = 5.85 bar and ($P_2 = P_3$) = 24.27 bar, with temperature

$T_1 = -6.2^\circ\text{C}$, $T_2 = 100.2^\circ\text{C}$, $T_3 = 29.37^\circ\text{C}$, $T_{\text{kond}} = 39.16^\circ\text{C}$ and $T_{\text{evap}} = -9.8^\circ\text{C}$ from the data, the enthalpy value $h_1 = 517.20$ kJ/kg, $h_2 = 597.23$ kJ/kg and $h_3 = 253.80$ kJ/kg were obtained so that the q_k values = 343.46 kJ/kg, $q_c = 263.40$ kJ/kg and $w_k = 80.06$ kJ/kg were obtained.

Effect of Capillary Pipe Diameter on Evaporation Temperature, T_{evap}

From the test results, it is known that the diameter of the capillary pipe has an influence on the evaporation temperature. Where by changing the diameter of the capillary pipe, a different evaporation temperature is obtained as seen in figure 5. The graph above shows the evaporation temperature trendline, where the smaller the capillary pipe diameter has the lower the evaporation temperature, The best condenser exhaust heat value is at -16.90°C .

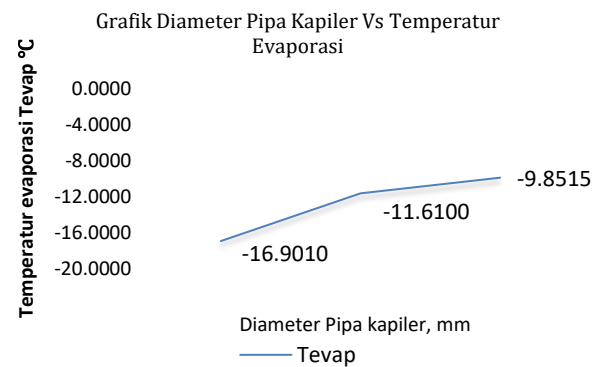


Figure 5. Graph of the effect of variation in capillary pipe diameter on the decrease in evaporation temperature.

Influence on Cycle Work Variables

According to the limitations of the problem, in this study, the cycle work variables reviewed are the impact of refrigeration (q_c), specific compression work (w_k) and Coefficient of Performance (COP). In Figure 6, the effect of capillary pipe diameter on the impact of refrigeration (q_c) is shown, where it can be seen that with the smaller the diameter of the capillary pipe, there is a decrease in the impact of refrigeration.

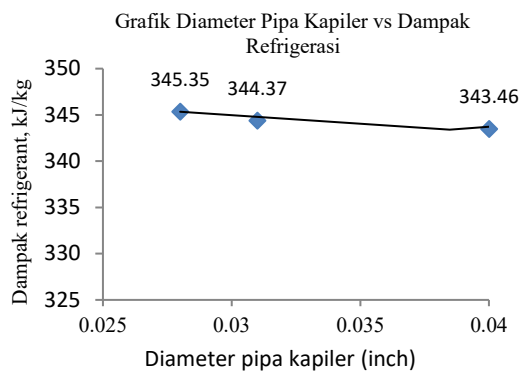


Figure 6. Graph of the Effect of Capillary Pipe Diameter on the Impact of Refrigeration, QC.

From the test results, it is known that the diameter of the capillary pipe has an influence on the work of the compressor. Where by changing the size of the capillary pipe diameter, different compressor work is obtained as seen in Figure 7.

The larger the diameter of the capillary pipe, the more the compressor work. This happens because the energy produced from the refrigerant flowing in the capillary pipe is related to the work of the compressor, if the diameter of the capillary pipe is getting larger it will affect the pressure and temperature of the refrigerant coming out of the compressor

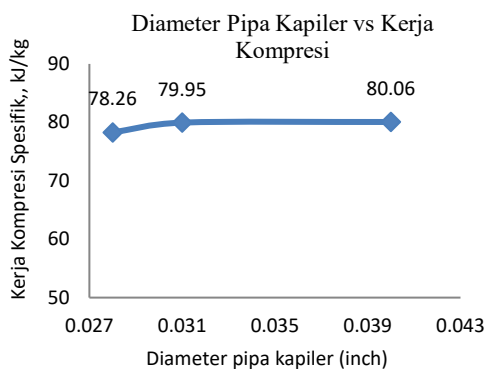


Figure 7. Graph of the Effect of Capillary Pipe Diameter on Compressor Work (WK)

If the pressure and temperature increase, it will increase the pressure and affect the work of the compressor. The best compressor work is found at the smallest value, which is 78.26 kJ/kg.

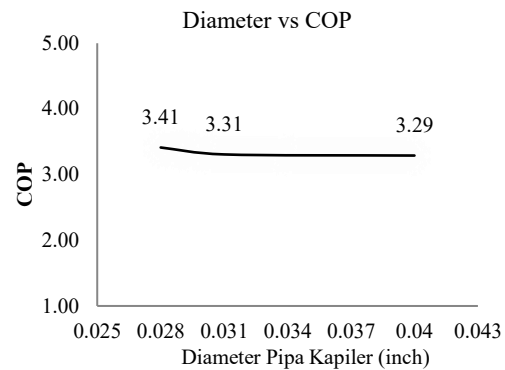


Figure 8. Graph Effect of Pipe diameter variation Capillaries Against Coefficient Of Performance, COP

In Figure 8, it shows the influence of capillary pipe diameter on the Coefficient of Performance (COP), where it can be seen that the larger the capillary pipe diameter decreases the Coefficient of Performance (COP), which is 1.8%. According to the COP formula, this decrease is due to an increase in the specific compression work as shown in Figure 6 and Figure 7 earlier

CONCLUSION

Variations in capillary pipe diameter have a real influence on the working conditions and performance of the cooling system of a 100-liter capacity ice factory with R-32 refrigerant, including:

1. The increase in capillary pipe diameters from 0.028, 0.031 and 0.040 inches causes: The condensation pressure ($p_2 = p_3$) increases from 330.17 Psia to 352.14 Psia, The evaporation pressure ($p_1 = p_4$) increases from 66.05 Psia to 84.94 Psia, the evaporation temperature rises from -16.90°C to -9.85°C , and the compression ratio increases from 0.2501 to 0.3179. The highest Coefficient of performance (COP) value was obtained at the capillary pipe diameter of 0.028 at 3.4129, followed by 0.031 inch at 3.3073, and the lowest at 0.040 inch at 3.29

2. The capillary pipe diameter of 0.028 inch provides the most optimal performance, as it produces a large enough expansion pressure difference to keep the refrigerant rate according to the needs of the evaporator, so that the refrigeration capacity is increased and the compressor work is more efficient. Thus, the optimization of the capillary pipe diameter of 0.028 inch is recommended for use in 100-liter capacity ice plant

systems, as it provides the best energy efficiency and the highest COP of 3.41, which signifies the system works most effectively in harnessing electrical energy to produce a cooling effect.

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