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Research Article

Optimization of capillary tube in air conditioning system

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Abstract

The objectives of this research were to evaluate the optimization of a capillary tube in a split-type air conditioning system and to determine the coefficient of performance (COP) of the system. The optimization was determined by mathematical calculation to evaluate COP of a split-type air conditioning system within 5 different sizes of capillary tube. Following this, the experimental equipment was designed and constructed to verify the COP data obtained from the calculation. The results found that from the theoretical analysis and experiment, the COP was changing in a direction contrary to the diameter of the capillary tube. When the capillary tube diameter is smaller, COP values tend to be higher.

Keywords: Optimization, Capillary tube, COP

Introduction

Air conditioning and refrigeration systems play an important role in industry, infrastructure and households. The industrial sector includes the food industry, textiles, chemicals, printing, transport and others. Infrastructure includes banks, restaurants, schools, hotels and recreational facilities. Therefore, installation, repair and maintenance of equipment to function properly are important for the operations associated with those activities. At present reducing pressure valves used in air conditioning and refrigeration systems can be classified into two types: expansion valves and capillary tubes. The capillary tube is made from copper pipe, with a diameter around 0.5 mm to 5 mm and length around 0.5 m to 5 m. Its use depends on power and load capacity of the system. The capillary tube is often used with small cooling load or small changing load systems, such as refrigerators, water coolers and small air conditioners [1].

Problems from the blockage in the capillary tube results in lower injection of refrigerant into the evaporator, so there will be less cooling. Typically this problem can be solved by changing a new capillary tube. However, this also results in refrigerant being released from the system, which makes for higher cost and time wastage. Furthermore, the size of the replacement capillary tube must be the same and some sizes are difficult to source, which makes the maintenance cost even higher.

Taking into consideration these problems, the objective of this research is to determine the appropriate size of a new capillary tube that can replace the old blocked one and to construct an experimental equipment system with different capillary tubes to measure the real values. The resulting values will show which size of capillary tube can be used instead of the old one. This will be more convenient for maintenance and will save costs when fixing air conditioning and refrigeration systems.

Objective

- To evaluate the optimization of the capillary tube in a split-type air conditioning system.
- To determine the coefficient of performance (COP) of split-type air conditioning systems.

Mathematical Solution for Capillary Tube

Theoretically, the appropriate size of capillary tube can be calculated from the refrigerant effect, coefficient of performance (COP) and others. The system is assumed to work as an isentropic process and there are five different sizes of capillary tubes in this calculation.

To undertake simulation with any value it is necessary to use the results from the previous test in the real work environment. The compressor information, PCS 859217, is from the compressor manufacturer and has been adjusted into the theoretical calculation to determine the value of the variables depending on the different size of capillary tubes by evaluating COP at the various states of capillary tubes in the isentropic process.

Mathematical model

Mathematical model of capacity, input and flow rate can be expressed as [2] and [3]

$$\text{Capacity} = a_1 + a_2.\text{Tevap} + a_3.\text{Tevap}^2 + a_4.\text{Tcond} + a_5.\text{Tcond}^2 + a_6.\text{Tevap}.\text{Tcond} + a_7.\text{Tevap}^2.\text{Tcond} + a_8.\text{Tevap} . \text{Tcond}^2 + a_9.\text{Tevap}^2 . \text{Tcond}^2 \quad (1)$$

$$\text{Input} = b_1 + b_2.\text{Tevap} + b_3.\text{Tevap}^2 + b_4.\text{Tcond} + b_5.\text{Tcond}^2 + b_6.\text{Tevap}.\text{Tcond} + b_7.\text{Tevap}^2.\text{Tcond} + b_8.\text{Tevap} . \text{Tcond}^2 + b_9.\text{Tevap}^2 . \text{Tcond}^2 \quad (2)$$

$$\text{Flow rate} = c_1 + c_2.\text{Tevap} + c_3.\text{Tevap}^2 + c_4.\text{Tcond} + c_5.\text{Tcond}^2 + c_6.\text{Tevap}.\text{Tcond} + c_7.\text{Tevap}^2.\text{Tcond} + c_8.\text{Tevap} . \text{Tcond}^2 + c_9.\text{Tevap}^2 . \text{Tcond}^2 \quad (3)$$

Where C= capacity (x1000 :kcal/h)
Input= energy input (kW)
Flow rate = mass flow rate (kg/h)
a_i= constant i= 1,2,3…9
b_i= constant i= 1,2,3…9
c_i= constant i= 1,2,3…9
Tevap= Temperature at evaporator (^{o}C)
Tcond= Temperature at condenser (^{o}C)

Information regarding the specifications of the compressor, PCS 859217, is shown in Tables 1 to 3.

Table 1. Capacity x 1000(kcal/h) at different temperature of evaporator and condenser.

Condenser Temperature(^{o}C)	**Evaporator Temperature** (^{o}c)		
	0	5	10
40	3.6	4.35	5.25
50	3.25	3.8	4.7
60	2.8	3.4	4.15

Table 2. **Input (kW) at different temperature of evaporator and condenser.**

Condenser Temperature(^{o}C)	**Evaporator Temperature** (^{o}c)		
	0	5	10
40	1.25	1.26	1.27
50	1.50	1.52	1.55
60	1.75	1.80	1.86

Table 3. Mass flow rate (kg/h) at different temperature of evaporator and condenser.

Condenser Temperature(^{o}C)	**Evaporator Temperature** (^{o}c)		
	0	5	10
40	87.50	103.05	122.21
50	84.72	100	118.05
60	81.94	95.83	113.88

To find the constant values: Substitution a_1, a_2, a_3, …a_9 and values from Table 1 into equation (1) the 9 equations and 9 unknowns are given by:

$$a_1+40\,a_4+1{,}600\,a_5=3.6 \tag{4}$$

$$a_1+50\,a_4+2{,}500\,a_5=3.6 \tag{5}$$

$$a_1+60\,a_4+3{,}600\,a_5=2.8 \tag{6}$$

$$a_1+5a_2+25a_3+40a_4+1{,}600a_5+200a_6+1{,}000a_7+8{,}000a_8+40{,}000a_9=4.35 \tag{7}$$

$$a_1+5a_2+25a_3+50a_4+2{,}500a_5+250a_6+1{,}250a_7+12{,}500a_8+62{,}500a_9=3.8 \tag{8}$$

$$a_1+5a_2+25a_3+60a_4+3{,}600a_5+300a_6+1{,}500a_7+18{,}000a_8+90{,}000a_9=3.4 \tag{9}$$

$$a_1+10a_2+100a_3+40a_4+1{,}600a_5+400a_6+4{,}000a_7+16{,}000a_8+160{,}000a_9=5.25 \tag{10}$$

$$a_1+ 10a_2+100a_3+50a_4+2{,}500a_5+ 500a_6+5{,}000a_7+25{,}000a_8+250{,}000a_9=4.7 \quad (11)$$

$$a_1+ 10a_2+100a_3+60a_4+3{,}600a_5+ 600a_6+6{,}000a_7+36{,}000a_8+360{,}000a_9=4.15 \quad (12)$$

To solve equation (4)-(12) the constant values are given as follows:

$a_1=4$

$a_2=1.275$

$a_3=-0.093$

$a_4=0.01$

$a_5=-5\text{x}10^{-4}$

$a_6=-0.0465$

$a_7=4\text{x}10^{-3}$

$a_8=4.5\text{x}10^{-4}$

$a_9 =-4\text{x}10^{-5}$

Substitution of a_1, a_2, a_3,… a_9 into equation (1) capacity can be written as:

$$\text{Capacity} =4+1.275\text{Tevap}-0.093\text{Tevap}^2+0.01\text{Tcond} - 5\text{x}10^4\text{Tcond}^2 0.0465\text{Tevap}.\ \text{Tcond}+4\text{x}10^3\text{Tevap}^2.\text{Tcond}+ 4.5\text{x}10^{-4}\text{Tevap}.\ \text{Tcond}^2 -4\text{x}10^{-5}.\text{Tevap}^2.\ \text{Tcond}^2 \quad (13)$$

The accuracy of equation (13) can be checked by the temperature values from Table 1. The results are the same as in Table 1, so the equation is correct. In a similar way, substitution of values from Table 2 into equation (2) and values from Table 3 into equation (3):

$b_1=0.25$

$b_2=0.0176$

$b_3=0$

$b_4=0.025$

$b_5=0$

$b_6=-8.9\text{x}10^{-4}$

$b_7=0$

$b_8=1.3\text{x}10^{-5}$

$b_9 =0$

$$\text{Input}=0.25+0.0176\text{Tevap}+0.025\text{Tcond} -8.9\text{x}10^4\ \text{Tevap}.\text{Tcond} +1.3\text{x}10^{-5}\text{Tevap}\ .\ \text{Tcond}^2 \quad (14)$$

$c_1=98.608$

$c_2=-1.8031$

$c_3=0.58292$

$c_4=-0.2777$

$c_5=0$

$c_6=0.202671$

$c_7=-0.0216506$

$c_8=-2.2211\text{x}10^{-3}$

$c_9 =2.2206\text{x}10^{-4}$

$$\text{Flow rate}=98.608-1.8031.\text{Tevap}+0.58292.\text{Tevap}^2-0.2777.\text{Tcond}+0.202671.\text{Tevap}.\text{Tcond}-0.0216506.\ \text{Tevap}^2.\text{Tcond}-2.2211\text{x}10^{-3}\text{Tevap}.\text{Tcond}^2+ 2.2206\text{x}10^{-4}\text{Tevap}^2.\text{Tcond}^2 \quad (15)$$

The next step was to find the size of capillary tubes, including diameter and length, that are available in the market and can be used in the experiment to evaluate the various parameters.

The important factor is to know the size of diameter and length of the old capillary tube before starting to calculate the size of a new capillary tube. The size of a new capillary tube can be calculated from:

$$\text{New length} = \text{Factor} \times \text{ the old length} \quad (16)$$

Table 4. Length factor for capillary tube calculation [4].

Part No.	**TC-55**	**TC-59**	**TC-64**	**TC-70**	**TC-75**
Tube Inner Diameter	0.055	0.059	0.064	0.070	0.075
Factor	0.5	0.69	1	1.5	2.07

Table 5. Dimensions of 5 different capillary tubes used for calculation and experiment.

No.	**Diameter** (Inch)	**Length** (inch)	**Diameter** (mm)	**Length** (m)
1	0.075	66.24	1.905	1.6824
2	0.07	48	1.778	1.2192
3	0.064	32	1.6256	0.8128
4	0.059	22.08	1.4986	0.5608
5	0.055	16	1.397	0.4064

From equation (15), mass flow rate of refrigerant R-22 can be evaluated as shown in Tables 6 and 7.

Table 6. Mass Flow rate (kg/h) of R-22 at different temperature of evaporator and condenser.

Condenser Temperature (^{o}C)	**Mass flow rate(kg/h) Evaporator Temperature** (^{o}C)		
	0	5	10
40	87.50	103.05	122.22
45	86.11	101.67	120.14
50	84.72	100.00	118.05
55	83.33	98.06	115.97
60	81.95	95.83	113.89

Table 7. Mass Flow rate (g/s) of R-22 at different temperature of evaporator and condenser.

Condenser Temperature (°C)	**Mass flow rate(g/s) Evaporator Temperature** (°C)		
	0	5	10
40	24.31	28.63	33.95
45	23.92	28.24	33.37
50	23.53	27.78	32.79
55	23.15	27.24	32.21
60	22.76	26.62	31.64

The next step is to find the Coefficient of Performance (COP) of the system. Assuming the system works as an isentropic process [5, 6].

Refrigerant properties in various conditions when passing through a capillary tube can be evaluated from [7]:

$$\dot{m} = C_1 D^{C_2} L^{C_3} T^{C_4} 10^{C_5 \times DSC} \tag{17}$$

Where $\dot{m}$= Flow rate R-22 (g/s)

D= Diameter (mm)

L= Length(m)

T= Condenser Temperature (°C)

DSC= Subcool Temperature(°C)

C_1= constant = 0.249029

C_2= constant = 2.543633

C_3= constant = -0.42753

C_4= constant = 0.746108

C_5= constant = 0.013922

Equation (17) is then rearranged to find the sub-cooled temperature:

$$DSC = \frac{1}{C_5}\log_{10}\frac{\overset{o}{m}}{C_1 D^{C_2} L^{C_3} T^{C_4}} \tag{18}$$

Substituting the values from Tables 4 and 6 into equation (18), the sub-cooled temperature can be shown as in Table 8.

Table 8. Sub-cooled temperature of each capillary tube at different temperature of evaporator and condenser.

Condenser Temperature (°C)	Evaporator Temperature (°C)	Sub-cooled Temperature (°C)				
		Tube1	Tube2	Tube3	Tube4	Tube5
40	0	12.848	14.027	15.730	17.236	18.511
	5	17.951	19.129	20.832	22.338	23.613
	10	23.267	24.446	26.149	27.655	28.930
45	0	9.602	10.781	12.484	13.990	15.265
	5	14.781	15.960	17.663	19.169	20.446
	10	19.988	21.167	22.870	24.376	25.651
50	0	6.637	7.816	9.519	11.025	12.300
	5	11.817	12.996	14.699	16.205	17.480
	10	16.989	18.168	18.871	21.377	22.652
55	0	3.911	5.090	6.793	8.299	9.574
	5	8.986	10.165	11.868	13.374	14.649
	10	14.214	15.393	17.096	18.602	19.877
60	0	1.356	2.535	4.238	5.744	7.019
	5	6.243	7.422	9.125	10.630	11.906
	10	11.636	12.811	14.514	16.020	17.295

The inlet temperature of refrigerant entering the capillary tube can be calculated from:

Inlet temperature of refrigerant entering capillary tube (°C) = Condenser temp. – sub-cooled temp. (19)

The results from equation (19) can be expressed as in Table 9.

Table 9. Inlet temperature of refrigerant entering capillary tube.

Condenser Temperature (°C)	Evaporator Temperature (°C)	Inlet temperature of refrigerant entering capillary tube (°C)				
		Tube1	Tube2	Tube3	Tube4	Tube5
40	0	27.151	25.972	24.269	22.763	21.488
	5	22.049	20.870	19.167	17.661	16.386
	10	16.732	15.553	13.850	12.344	11.069
45	0	35.397	34.218	32.515	31.009	29.734
	5	30.218	29.039	27.336	25.830	24.554
	10	25.011	23.832	22.129	20.623	19.348
50	0	43.362	42.183	40.480	38.974	37.699
	5	38.182	37.003	35.300	33.795	32.52
	10	33.010	31.831	31.128	28.622	27.347
55	0	51.088	49.909	48.206	46.700	45.425
	5	46.013	44.834	43.131	41.625	40.350
	10	40.785	39.606	37.903	36.397	35.122
60	0	58.643	57.464	55.761	54.256	52.98
	5	53.756	52.577	50.874	49.369	48.094
	10	48.363	47.188	45.485	43.979	42.704

Results and Discussion

Analysis of the results from the theoretical calculation of COP

Inlet temperature of refrigerant entering capillary tube from Table 8 is used to analyze COP by assuming the isentropic process. The results can be expressed as in Table10.

Table 10. COP of each capillary tube at different temperature of evaporator and condenser.

Condenser Temperature (^{o}C)	Evaporator Temperature (^{o}C)	COP				
		Tube1	Tube2	Tube3	Tube4	Tube5
40	0	6.087	6.124	6.199	6.266	6.322
	5	7.552	7.613	7.701	7.779	7.844
	10	10.081	10.158	10.269	10.366	10.449
45	0	5.125	5.174	5.244	5.305	5.357
	5	6.296	6.352	6.469	6.502	6.562
	10	7.746	7.810	7.903	7.984	8.053
50	0	4.362	4.407	4.473	4.531	4.579
	5	5.316	5.367	5.441	5.506	5.561
	10	6.464	6.522	6.557	6.724	6.782
55	0	3.737	3.780	3.843	3.898	3.944
	5	4.527	4.576	4.646	4.707	4.758
	10	5.463	5.517	5.595	5.663	5.720
60	0	3.449	3.495	3.560	3.618	3.666
	5	4.201	4.251	4.324	4.387	4.441
	10	5.108	5.164	5.244	5.315	5.374

From Table 10 it is found that the capillary Tube No.5 has the maximum COP. The smaller diameter and shorter length of Tube No.5 causes the mass flow rate of refrigerant to be high, so the cooling capacity of the evaporator is high. In other words, the refrigerant effect of small tube size will be higher than the large tube size.

Analysis of the experimental results for COP

Table 11. Experimental results in average view.

Measurement position	Symbol	Unit	Capillary tube				
			Tube 1	Tube 2	Tube 3	Tube 4	Tube 5
Compressor pressure	P_1	bar	4.14	4.21	4.07	4.13	4.14
	P_2	bar	16.90	16.55	16.14	16.36	16.21
Cap tube pressure	P_3	bar	16.55	15.86	16.07	16.22	16.21
	P_4	bar	5.48	6.26	6.17	5.94	5.56
Compressor temperature	T_1	°C	1.00	1.00	0.40	1.00	1.00
	T_2	°C	44.50	43.80	43.00	43.40	43.00
Cap tube temperature	T_3	°C	44.00	42.40	42.00	43.50	43.80
	T_4	°C	8.30	12.20	11.80	11.00	9.00
Condenser temperature	T_5	°C	31.10	32.40	30.60	31.40	30.80
Evaporator temperature	T_6	°C	8.20	8.20	9.80	9.40	8.80
Ambient temperature	T_7	°C	17.00	16.60	17.00	17.00	16.60
	T_8	°C	30.00	29.00	29.00	29.00	29.00
Mass flow rate	$\dot{m}$	g / s	13.70	16.60	15.80	15.80	14.70
COP.	COP.	-	4.37	4.35	4.37	4.33	4.42

NB. In the experiment, COP is calculated from saturated pressure by using the saturated properties of the refrigerant.

From Table 11 it is found that the capillary Tube No.5 has the maximum COP (4.42). COP of the smaller sized capillary tube will be higher than the larger one because the mass flow rate of the smaller size is too high when compared with each other. These experimental results correspond with the results from the calculation in Table 9, or at least they indicate the same trend.

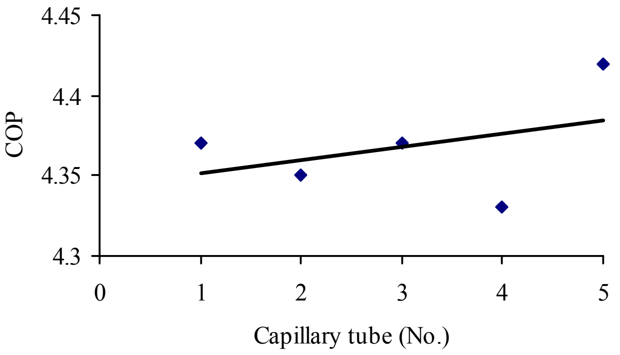

Figure 1. COP of experimental results in average view compared with capillary tube number.

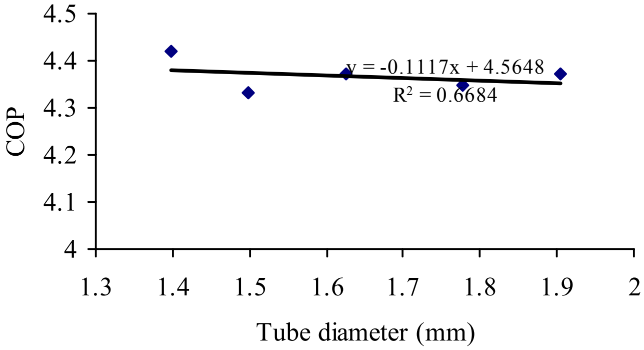

Figure 2. COP of experimental results in average view compared with capillary tube diameter.

From Figures 1 and 2 it is apparent that when the capillary tube diameter is smaller, the value of COP is higher. Furthermore, the capillary Tube No.5, with a diameter of 0.055 inches or 0.1397 mm, has the maximum COP. The size of this capillary tube is small in diameter and short in length, so mass flow rate of refrigerant will be high. Therefore, COP of the air conditioning system is high.

Conclusions

The diameter and the length of capillary tube have a direct relationship. If the diameter is smaller, the length is shorter. If the diameter is larger, the length is longer. All of these factors enable the exit pressure from the capillary tube to be reduced corresponding with the cooling requirements. COP of system will be constant or changed in the required interval.

Refrigerant effect (Qin) changes in the opposite direction with diameter of capillary tube. When the diameter of capillary tube decreases, refrigerant effect increases.

Compressor work (Win) will be constant or unchanged when compared with the capillary tube diameter. When the diameter of capillary tube decreases, compressor work is constant or nearly constant.

Coefficient of performance (COP) changes direction in contrast to capillary tube diameter. When the diameter of capillary tube decreases, COP tends to be higher.

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References

1. Poolkrajang, A. (2004). **Refrigeration and Air Conditioning**. Promote Vocational Center, Bangkok, Thailand (in Thai).

2. Stocker, W.F. and Jones J.W. (1982), **Refrigeration & Air Conditioning.** McGraw-Hill Book Company, Singapore.

3. Jakobson, A., Rasmussen, B.D., Skovrup, M.J. and S.E.Andersen, S.E. (2001). **CoolPack: a collection of simulation tools for refrigeration Tutorial Version 1.46**. Department of Energy Engineering, Technical University of Denmark (DTU).

4. Kulthorn Kirby Foundry Co.,Ltd. (n.d.). **Refrigeration & Air Conditioning Manual.** Bangkok, Thailand.

5. ASHRAE (1998). **1998 ASHRAE HANDBOOK REFRIGERATION SI EDITION**. Atlanta, USA.

6. ASHRAE (2001). **2001 ASHRAE HANDBOOK FUNDAMENTALS SI EDITION**. Atlanta, USA.

7. Jung, D., Park, C. and Park B. (1999). **Capillary tube selection for HCFC22 alternatives**, Department of Mechanical Engineering, Inha University, Inchon, Korea.