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ANALYSIS OF VAPOR COMPRESSION REFRIGERATION SYSTEM WITH DIFFERENT CONFIGURATIONS OF CAPILLARY TUBES USING R134A AS REFRIGERANT

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ABSTRACT

A capillary tube is widely used as throttling device in small sized refrigeration and air-conditioning applications having capacity less than 3 TR. This research paper provides a set of capillary tube performance data in a vapor compression refrigeration system using R-134a as working fluid. Several capillary tubes with different length and inner diameter were selected as test sections. Mass flow rate and Pressure drop through capillary tube was measured for several inlet temperatures of each capillary tube. The sub cooling and superheating temperatures are maintained constant throughout the experimentation. Experimental conditions for the condensing temperatures were selected from 38 to 54º C in the interval of 2º C. The effect of above given parameters on the Pressure difference, Power input, Evaporating capacity and Coefficient of performance for R-134a through the helically coiled capillary tube has been analyzed.

KEYWORDS: Expansion device, Capillary tube, Refrigerant pressure drop, R-134a, Compressor calorimeter test rig.

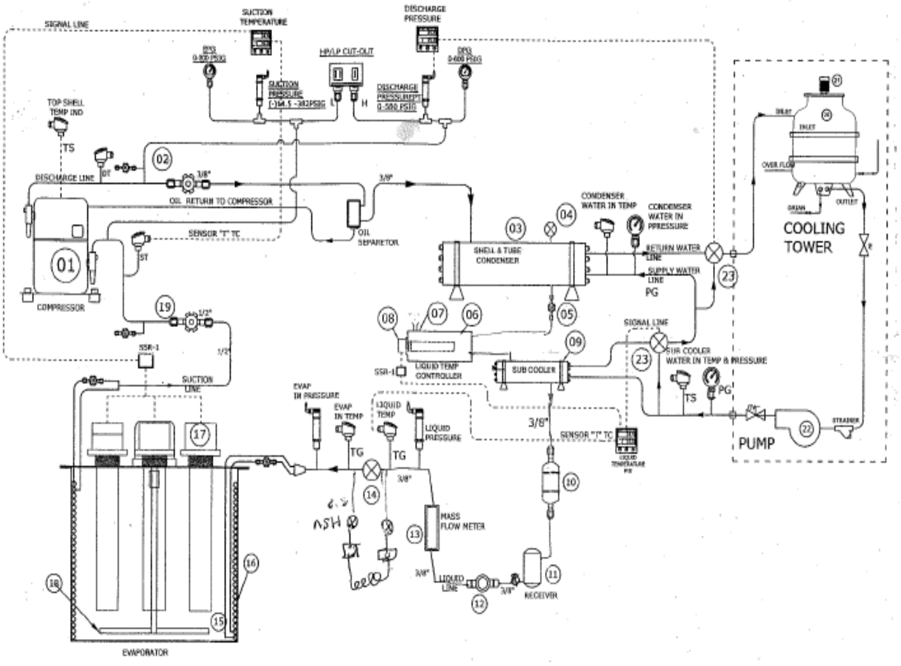
INTRODUCTION

Due to environmental problems like depletion of the ozone layer and global warming, CFC (chlorofluorocarbon) have been banned in developed countries since 1996 & from January 1st 2010 production and use of CFC's is prohibited completely all over the worlds. HCFC (hydro chlorofluorocarbon) refrigerants will also be phased out by 2020 & 2030 in developed and developing countries, respectively. As a result, Eco-friendly HFC (hydro fluorocarbon), like R-134a has emerged as alternative of R-12. Because of that in this experimental study, R-134a is used as working fluids.

The capillary tube as a throttling device is simple, reliable, and inexpensive. It is widely used in the small-size vapor compression refrigeration appliances such as window air conditioning and household refrigerators. It works as an automatic flow rate regulator of the refrigerant through refrigeration system, when varying load conditions and varying condensing and evaporating temperatures are to be encountered. The capillary tube is used where the cooling load is almost constant and the cooling capacity is less than 3 TR. Capillary tube is a long narrow hollow copper tube with an internal diameter ranging from 0.5 to 2.0 mm**.** The refrigeration systems work on vapor compression cycle comprising of evaporator, compressor, condenser, and expansion device. A capillary tube as an expansion device allows hermetically sealed compressor to start in an unloaded condition by allowing the pressures between the condenser and evaporator to equalize during the off cycle, thus, reduces the required starting torque of the compressor. Hence, a low starting torque motor can be used to run the compressor with the vapor compression systems. Also, the small and critical refrigerant charge required by the refrigeration system using capillary tube results in cost reduction of the refrigerant as well as no need for a receiver tank in the system. Thus, all the facts contribute towards substantial savings in the built–up cost of the refrigeration system.

In the past, capillary tube performance using R-12 and R-22 were extensively studied by many researchers; Bostland and Jordan [2], Cooper et al.[3], Koizumi and Yokoyama [4], Chen et al. [5], Li et al. [6].Recently, a capillary tube performance for R-134a has been studied by many researchers including Chun-Lu Zhang [7], Kim et al.[8], Khan et al. [9] and Motta et.al.[10] .Also, The experimental studies on straight coiled capillary tubes are mostly available in open literatures but helically coiled capillary with all practical operating conditions are not sufficiently covered. Therefore, to strengthen the earlier study, the experimental investigation has been undertaken to study the flow of R-134a through helically coiled capillary tube

The main objective of this study is to provide a set of capillary tube performance data in a vapor compression refrigeration system using R-134a as working refrigerant. While achieving this objective, the experimental apparatus using capillary tubes is devised. Several capillary tubes with different length and inner diameter were selected as test sections. Mass flow rate and Pressure drop through capillary tube was measured for several inlet temperatures of each capillary tube. The variation of inner diameter, tube length and operating conditions of inlet pressure/temperature are the main parameters of this study.



S NO	DESCRIPTION	QTY
1	COMPRESSOR	1
2	DISCHARGE HAND SHUFT VALVE 3/8"	1
3	WATER COOLED CONDENSER	1
4	PRESSURE RELIF VALVE	1
5	HAND SHUFT VALVE	1
6	HEATER BANK COIL 3/8" x 10'	1
7	LIQUID TEMP CONTROL HEATER BANK TANK	1
8	WATER HEATER	1
9	SUBCOOLER CONDENSER	1
10	DRIER	1
11	RECIVER	1
12	SIGHT GLASS	1
13	FLOWMETER	3
14	EXPANSION VALVE	1
15	EVAPORATOR COIL	1
16	SEALED TANK	1
17	GLYCOL HEATER	1
18	STERROR	1
19	SUCTION HAND SHUT-UP VALVE	1
20	COOLING TOWER	1
21	COOLING TOWER MOTOR	1
22	COOLING TOWER PUMP	1
23	ELECTRONIC PROPORTIONAL CONTROL WATER VALVES	2

	DESCRIPTION	QTY
	TEMP. SENSOR	7
	GAUGE	4
⊗	HAND SHUFT VALVE	3
	PID	3
TIC	TIC	1
⋈	BALL VALVE	2
⋈	GLOBE VALVE	2
	STRAINER	2

Fig. 1 Schematic diagram of Experimental setup

EXPERIMENTS

EXPERIMENTAL SET-UP AND PROCEDURE

The schematic diagram of experimental set-up is shown in Fig. 1. The test-section was a copper capillary tube, in which the refrigerant expands from high pressure side to low pressure side. The helically coiled tube test-section in the experimental set-up was put in horizontal position. Suitable isolation valves are installed for easy replacement of test pieces. The low pressure refrigerant coming out from capillary tube entered the evaporator consisting of a copper coil submerged in a glycol tank. An electric heater was fitted in the evaporator tank to provide a heat load to the evaporator. The heating load was varied through a Solid state rely and PID controller. An agitator was also fitted in the tank to maintain the uniform bulk temperature of glycol. The refrigerant vapors emerging from the evaporator were sent to suction port of compressor after assurance of achieving desired suction superheat of refrigerant. The hermetically sealed compressor was run by means of single phase electrical supply. The high pressure superheated vapors emerging from the compressor entered the oil separator. The oil free vapors from separator were condensed in the water cooled condenser. The desired condensing pressure/temperature was achieved by varying mass flow rate through condenser by using three way proportionate control valve and PID controller. The cooling tower was used to reject heat in to the atmospheric. The provision of on-off of cooling tower fan was made to control the cooling tower water temperature. To vary the degree of sub-cooling, a pre-heater followed the sub-cooler was installed. In the pre-heater, liquid refrigerant heating was done by electrical heater and controlled by Solid state relay and PID controller. The high pressure saturated liquid from the pre-heater was made to flow through sub-cooler to control the degree of sub-cool. The same arrangement like condenser cooling water circuit was made to achieve desired sub-cooling. However the cooling water first flow through sub-cooler and then flow through condenser. The sub-cooled liquid refrigerant collected in a receiver to ensure a continuous supply of refrigerant to the capillary tube.

Table.1. Properties chart for the refrigerants under study

Refrigerants	**R-134a**
Environmental Classification	HFC
Chemical Formula	CH_2FCF_3
Molecular Weight	102.03
Boiling Point At 1 Atm.(^{0}C)	-26.06
Critical Temperature (^{0}C)	101.08
Critical Density (kg/m^3)	515.3
Liquid Density (kg/m^3)	1220.60
Vapor Density (kg/m^3)	5.25
Heat of Vaporization	217.01
Specific Heat of Liquid (J/kg-^{0}C)	1505.99
Specific Heat Vapor (J/kg-^{0}C)	831.91
Global Warming Potential (CO_2 = 1.0)	1674
Lubricant oil used	Polyol Ester (POE)

The unwanted solid particles and moisture in refrigerant were removed through a filter-drier. A hand operated expansion valve was also provided in parallel to the capillary tube. A centrifugal pump was used to circulate cooling water through the sub-cooler and condenser. The mass flow rate of high pressure liquid refrigerant was measured by magnetic mass flow meter having an accuracy of ±0.25% of indicated value. A sight glass was also provided to visualize the state of refrigerant entering into the capillary tube. A number of hand shutoff valves were provided in between the major components of the experimental set-up. Therefore, in case of leakage or any repair, the damaged component was retrieved with ease. The temperature at different locations of the set-up and the test section was measured by means of T-type thermocouples with an accuracy of ±0.2. The pressure of the refrigerant was measured by pressure transducers having an accuracy of ±0.25% FS (2000 kPa).

Capillary tubes with three inner diameters, 1.52 mm, 1.63 mm and 1.78 mm, were selected for this study. The capillary tube diameters were measured with the help of tool maker's microscope having an accuracy of 0.01 mm The pressure at capillary tube inlet was adjusted from 963 kPa to 1492 kPa. The degree of sub-cooling and degree of superheating was maintained constant throughout the experimentation to 3ºC and 5ºC respectively. All the test data were collected under steady state conditions. At the start up, the system typically takes about 1 h to reach the steady state and thereafter, it takes only 15 min for any subsequent setting.

EXPERIMENTAL CONDITIONS

The refrigerants used in this study were R-134a. Table.1. shows the properties of R134a.Several capillary tubes with different length and inner diameter were selected as test sections. Various test sections are named as C1, C2, C3, C4, C5. In this study, the condensing pressure i.e. pressure at the capillary tube inlet was adjusted to the saturation pressure corresponding to the condensing temperatures from 38 to 54º C in the interval of 2º C.

Table 2: Shows The Specification Of Capillary Tubes.

Capillary Sample	Configuration (Diameter * Length)
C1	1.625*1599 mm
C2	1,52*1499 mm
C3	1.78*1499 mm
C4	1.625*1499 mm
C5	1.625*1399 mm

The sub cooling and superheating temperatures are maintained constant throughout the experimentation. In this study, tests were carried out for the capillary tubes that were coiled with constant coiled diameter every time. Table.2. shows the specification of capillary tubes.

EXPERIMENTAL RESULTS AND DISCUSSIONS

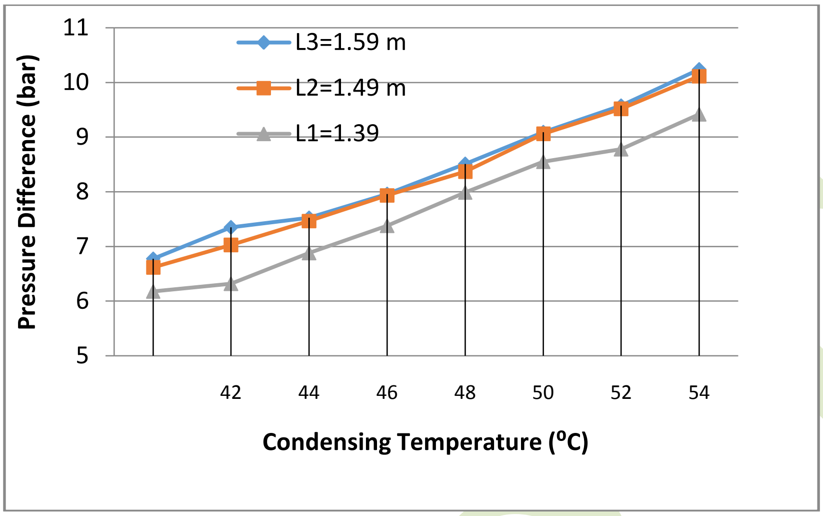


Figure 2: Variation of Pressure difference Vs condensing temperature for capillary tube samples of constant diameter 1.625 mm but of different lengths L1=1.39 m, L2=1.49m, L3=1.59m.

From figure 2 it is clear that pressure difference increases as the condensing temperature increases. Also, for a given condensing temperature pressure difference increases as the length of capillary tube increases.

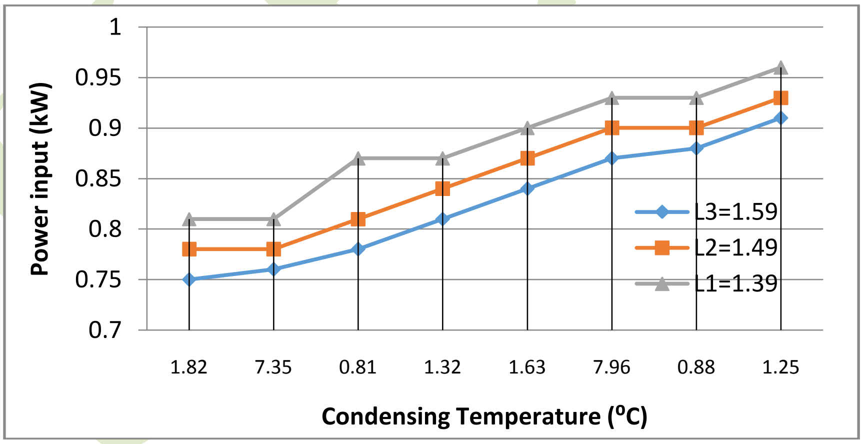


Figure 3: Variation of Power input Vs condensing temperature for capillary tube samples of constant diameter 1.625 mm but of different lengths L1=1.39 m, L2=1.49m, L3=1.59m.

From figure 3 it is clear that power input increases as the condensing temperature increases. Also for a given condensing temperature power input decreases as the length of capillary tube increases.

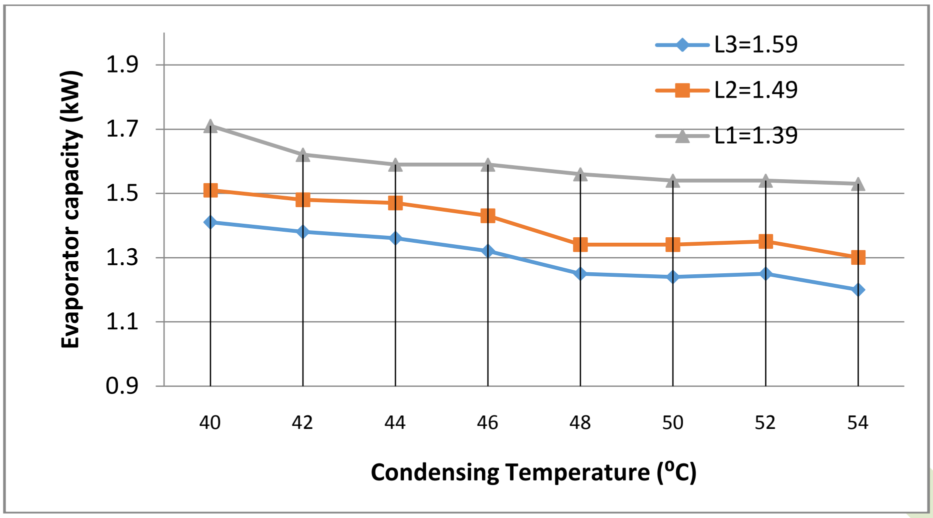


Figure 4: Variation of Evaporating capacity Vs condensing temperature for capillary tube samples of constant diameter 1.625 mm but of different lengths L1=1.39 m, L2=1.49m, L3=1.59m.

From figure 4 it is clear that Evaporating capacity decreases as the condensing temperature increases. Also, for a given condensing temperature evaporating capacity decreases as the length of capillary tube increases.

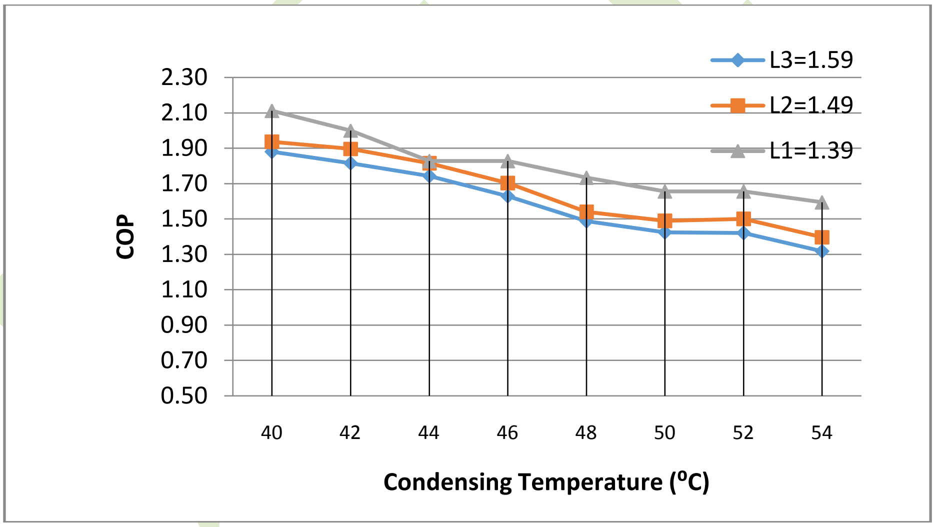


Figure 5: Variation of COP Vs condensing temperature for capillary tube samples of constant diameter 1.625 mm but of different lengths L1=1.39 m, L2=1.49m, L3=1.59m.

From figure 5 it is clear that COP decreases as the condensing temperature increases. Also, for a given condensing temperature power COP decreases as the length of capillary tube increases.

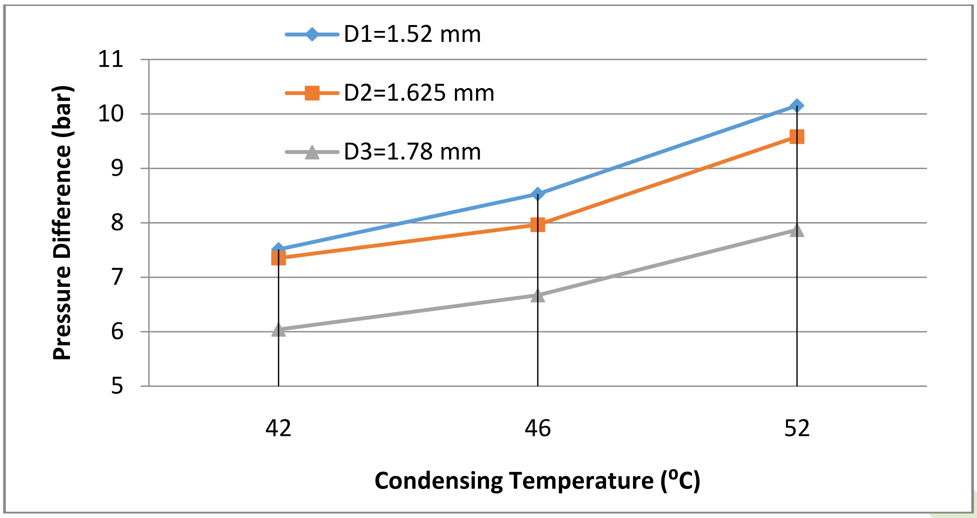


Figure 6: Variation of Pressure difference Vs condensing temperature for capillary tube samples of constant length 1.49 m but of different lengths D1=1.52 mm, D2=1.625 mm, D3=1.78 mm.

From figure 6 it is clear that pressure difference increases as the condensing temperature increases. Also, for a given condensing temperature pressure difference decreases as the diameter of capillary tube decreases.

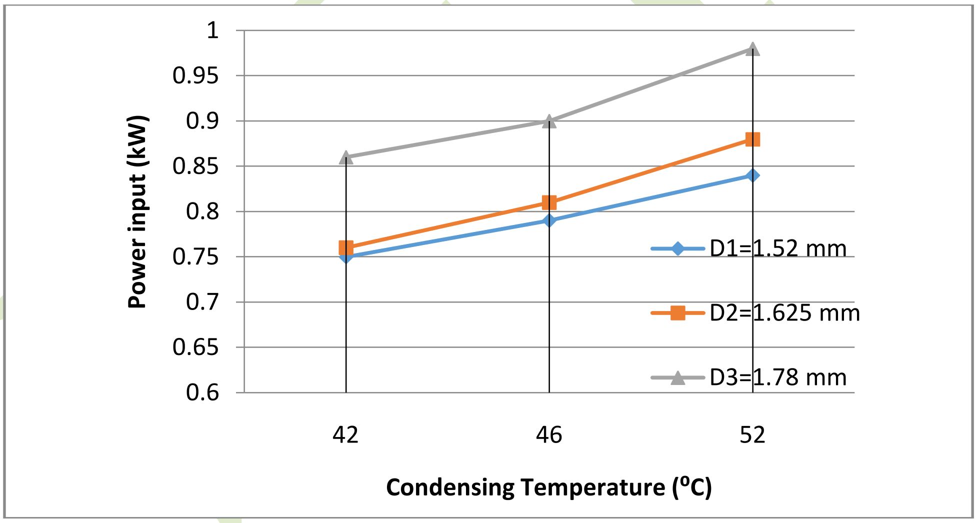


Figure 7: Variation of Power input Vs condensing temperature for capillary tube samples of constant length 1.49 m but of different lengths D1=1.52 mm, D2=1.625 mm, D3=1.78 m

From figure 7 it is clear that power input increases as the condensing temperature increases. Also, for a given condensing temperature power input decreases as the length of capillary tube decreases.

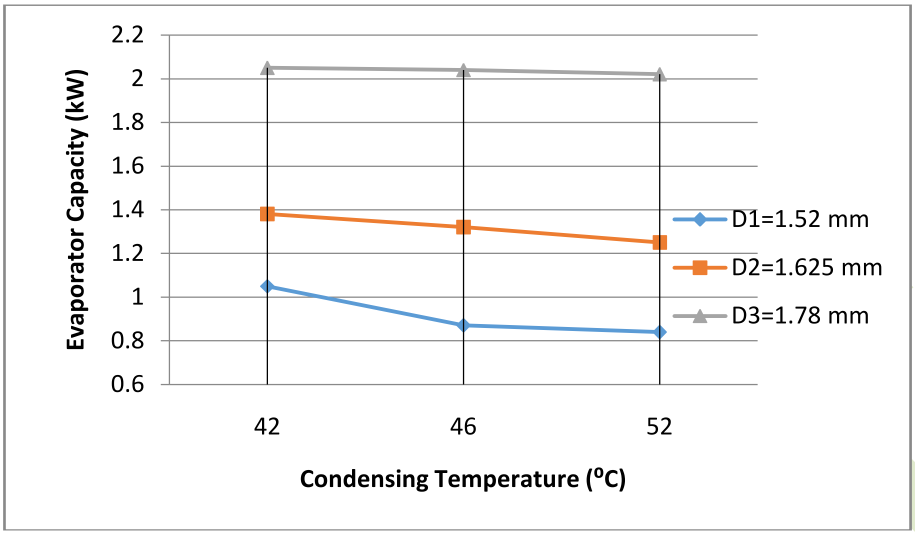


Figure 8: Variation of Evaporating capacity Vs condensing temperature for capillary tube samples of constant length 1.49 m but of different lengths D1=1.52 mm, D2=1.625 mm, D3=1.78 mm.

From figure 8 it is clear that Evaporating capacity decreases as the condensing temperature increases. Also, for a given condensing temperature Evaporating capacity decreases as the length of capillary tube decreases.

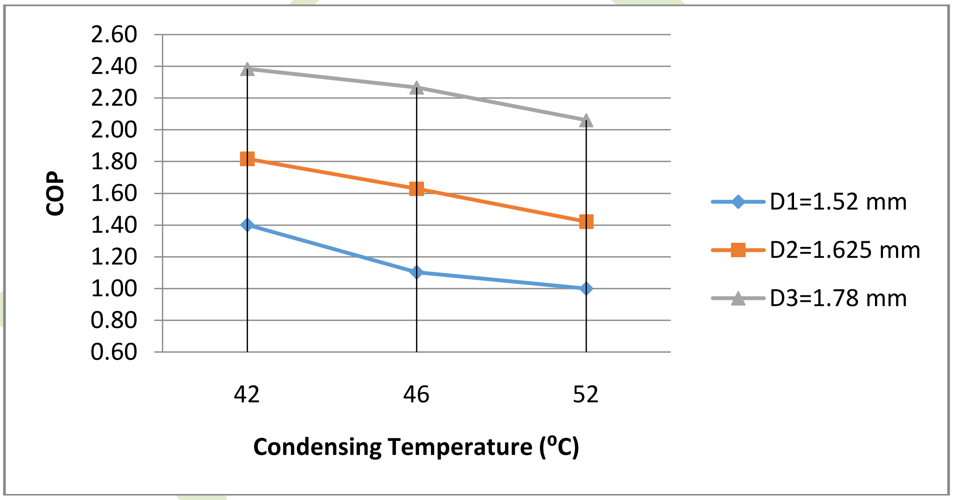


Figure 9: Variation of COP Vs condensing temperature for capillary tube samples of constant length 1.49 m but of different lengths D1=1.52 mm, D2=1.625 mm, D3=1.78 mm.

From figure 9 it is clear that COP decreases as the condensing temperature increases. Also, for a given condensing temperature COP decreases as the length of capillary tube decreases.

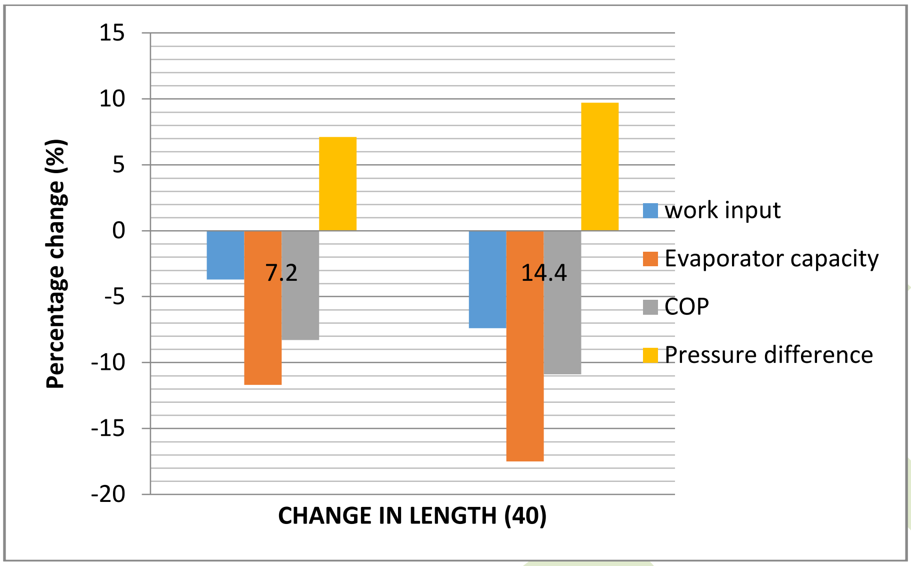


Figure 10: Variation of % change in length Vs % change in Power input, Evaporating capacity, COP and Pressure difference at constant Condensing temperature 42°C for three different configurations viz. C5, C4 and C1 i.e. of different lengths 1.39, 1.49 and 1.59 m respectively.

From figure it is clear that for length change from 1.39 to 1.49m i.e. for 7.2% variation in length, variation in Power input, Evaporator capacity and COP is -3.7%, -11.7% and -8.3% respectively while percentage change in pressure difference is 7.15%.Negative sign indicates with increase in length there is decrease in pressure drop. Again for length change from 1.49 to 1.59m i.e. for 14.2% variation in length, variation in Power input, Evaporator capacity and COP is -7.4%, -17.5% and -10.9% respectively while percentage change in pressure difference is 9.7%.

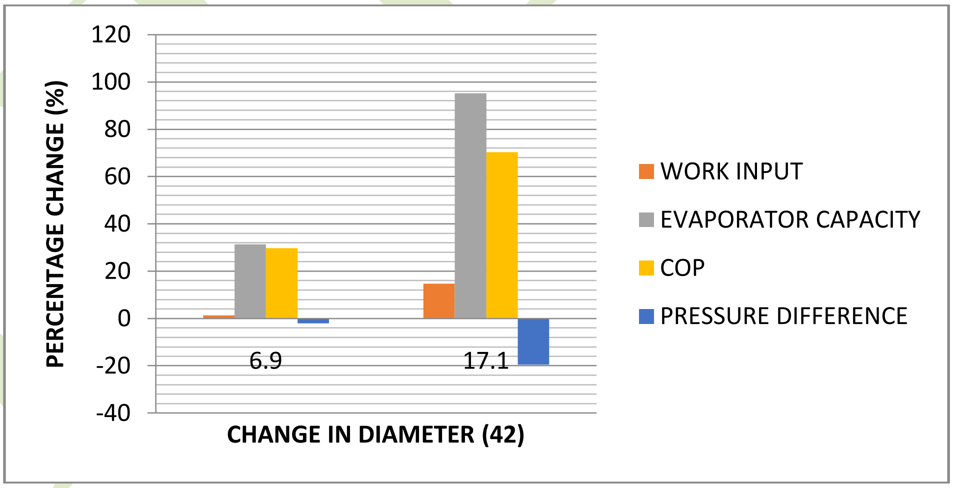


Figure 11: Variation of % change in Diameter Vs % change in Power input, Evaporating capacity, COP and Pressure difference at constant condensing temperature of 42°C for three different configurations viz. C2, C4 and C3 i.e. of different diameters 1.52, 1.625 and 1.78 mm respectively.

From figure it is clear that for diameter change from 1.52 to 1.625 mm i.e. for 6.9 % variation in diameter, variation in Power input, Evaporator capacity and COP is 1.3%, 31.4% and 29% respectively while percentage change in pressure difference is -2.1%.Negative sign indicates with increase in diameter there is decrease in pressure drop

Again for length change from 1.49 to 1.59m i.e. for 14.2% variation in length, variation in Power input, Evaporator capacity and COP is 14.7%, 95.2% and 70.3% respectively while percentage change in pressure difference is -19.6%.

CONCLUSION

- Pressure difference is directly proportional to capillary length while, inversely proportional to inner diameter of capillary tube.
- With change in length of capillary tube, Power input, Evaporating capacity and COP decreases while Pressure difference increases.
- With change in diameter of capillary tube, Power input, Evaporating capacity and COP increases while Pressure difference decreases

REFERENCES

[1] S. G. Kim, M. S. Kim, S. T. Ro, "*Experimental investigation of the performance of R22, R407c and R410A in several capillary tubes for air-conditioners*". Int J Refrigeration 25(2002) 521-531.

[2] Mohd. Kaleem Khan, Ravi Kumar, Pradeep Sahoo, "An experimental study of the flow of R134a inside an adiabatic spirally coiled capillary tube".

[3] R.Cabello,J.Navarro-Esbr, "Department of Applied Thermodynamics, Camino de Vera, 14, Polytechnic University of Valencia, E.Torrella ,Department of Technology, Campus de Riu Sec, University Jaume I, E-12071 Castell_on, Spain, *"Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids"* ,Applied Energy 88 (2011) 2809–2815.

[4] Chang Nyeun Kim & Young Moo Park*,"Investigation on the selection of capillary tube for the Alternative Refrigerant R407c,"* International Journal of Air-conditioning and Refrigeration Volume 8,May,(2000), pp.40-49.

[5] M.A. Akintunde, *"The Effects of Friction Factors on Capillary Tube Length"* The Pacific Journal of Science and Technology,Volume 8, Number 2, November (2007), pp 273-281.

[6] C. Aprea,A. Greco,Dipartimento di IngegneriaMeccanica, Universit_a di Salerno, via Ponte Don Melillo,84084 Fisciano, Salerno, Italy,DETEC, Universit_adegliStudi di Napoli Federico II, P.leTecchio 80, 80125 Napoli, Italy, *"Performance evaluation of R22 and R407C in a vapour compression plant with reciprocating compressor" Applied Thermal Engineering 23 (2003) 215–227.*

[7] Chunlu Zhang, Guoliang Ding, *"Approximate analytic solutions of adiabatic capillary tube"*. Int J Refrigeration 27(2004) 17-24.

[8] M. Fatouh,Talaat A. Ibrahim,A. Mostafa, Department of Mechanical Power Engineering, Faculty of Engineering El-Mattaria (Helwan University), Masaken El-Helmia, Cairo 11718, Egypt,King Saud University, P.O. 70908, 11577 Riyadh, Saudi Arabia, *"Performance assessment of a direct expansion air conditioner working with R407C as an R22 alternative",* Applied Thermal Engineering 30 (2010) 127–133.

[9] S. M. Sami, Shawn Aucoin, "*Effect of magnetic field on the performance of new refrigerant mixtures,"* Int.J. Energy Res. 2003, 27, pp. 203–214.

[10] Melo, C., Ferreira, R. T. S., Neto, C. B., Goncalves, J. M., and Mezavila. M.M., 1999*, "An Experimental Analysis of Adiabatic Capillary Tubes," Appl. Therm. Eng., 19(6), pp. 669–684.*

[11] S. Devotta, National Environmental Engineering Research Institute, Nehru Marg, Nagpur 440 020, India, A.S. Padalkar, Process Development Division, National Chemical Laboratory, HomiBhabha Road, Pune 411 008, India, N.K. Sane, Department of Mechanical Engineering, Walchand College of Engineering, Sangli 416 415, India, *"Performance assessment of HCFC-22 window air conditioner retrofitted with R-407C".*