Performance Evaluation of a Refrigerator through Varied Design Parameters

Chende Praveen[1], K Vijaya Kumar Reddy[2], Gugulothu Ravi[3]
[1]*Department of Mechanical engineering, Jawaharlal Nehru Technological University Hyderabad, Telangana,*
[2]*Department of Mechanical engineering, Jawaharlal Nehru Technological University Hyderabad, Telangana,*
[3]*Department of Mechanical engineering, Jawaharlal Nehru Technological University Hyderabad, Telangana.*

Abstract: **Farmers rely on cost-effective refrigeration technologies, which are crucial for preserving crops and preventing spoilage. This study aims to enhance refrigerator efficiency by modifying an adiabatic capillary tube. Experiments were conducted using different capillary tube diameters—0.031", 0.036", and 0.040"—with R134a and R600a refrigerants. The results showed that the 0.031" diameter tube achieved faster cooling due to a quicker pressure drop. Optimal performance was observed with a 40 mm coil diameter, outperforming both 60 mm and elliptical coils. Increasing the tube diameter from 0.031" to 0.040" led to an 8% increase in the coefficient of performance (COP) due to reduced pressure and compressor workload. The combination of a 0.040" diameter tube with a 40 mm coil diameter yielded the highest COP. With a 40% reduction in mass charge, R600a demonstrated a 46% improvement in refrigeration efficiency over R134a, attributed to its superior heat absorption and lower operating pressures, making it more effective for cooling.**

Keywords: Refrigeration, Capillary tube, Refrigerants, Coefficient of Performance (COP)

I. INTRODUCTION

Refrigeration is the process of extracting heat from a low-temperature medium and transferring it to a higher temperature media. Cooling and maintaining temperatures below the surrounding air temperature is the main purpose of refrigeration, and is frequently used to preserve food and other consumables [1]. With the use of this technology, consumable goods may be transported and stored safely, increasing their shelf life and ensuring food security [2].. Air conditioning, refrigeration, and maintaining optimal temperatures for different manufacturing procedures are all critical components of industrial processes. It uses Vapor Refrigeration cycle which is most effective and efficient cycle

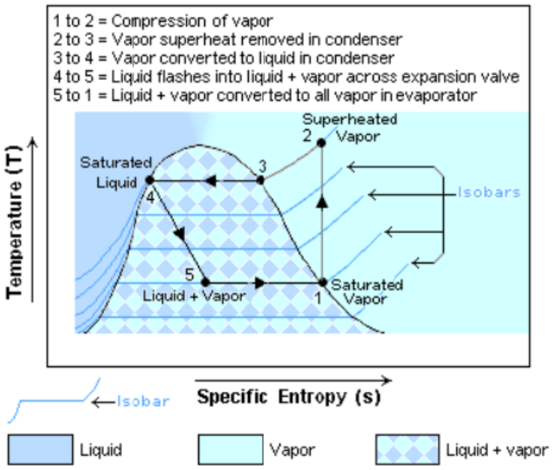

Fig.1: Basic Refrigeration with VCR cycle [1]

Vapor Compression Refrigeration Cycle
A refrigeration system comprises several key components: the compressor, condenser, expansion valve or capillary tube, and evaporator, these components as shown in fig. 1.1 work on Vapor Compression Refrigeration cycle which comprises of 4 following processes [1]
1.Isentropic compression
2.Isobaric heat rejection
3.Isenthalpic expansion and
4.Isobaric heat extraction
Isenthalpic expansion will give the desired cooling effect which is the function of expansion device like capillary tube
A Capillary tube is a straightforward, fixed-length tube with a narrow internal diameter as illustrated in Figure 2. It acts as expansion device by inducing a pressure drop due to its restrictive design. When the high-pressure liquid refrigerant from the condenser enters the capillary tube, it undergoes a pressure reduction as it moves through the narrow passage. This pressure drop causes the refrigerant to expand and cool quickly before it reaches the evaporator.

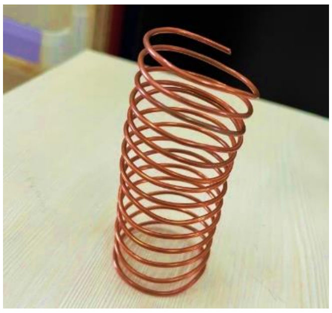

Fig. 2: Capillary tube

Factors to Consider while choosing

a) Capillary tube diameter: it is a most sensitive parameter [3] in capillary tube. They are typically possesses an internal diameter of 0.5 to 2.0 mm. A smaller tube diameter can have more chilling effect but they have less refrigeration effect overall while a larger diameter may have more mass flow rate but they cannot give higher evaporator temperature but can have more refrigeration effect compared to smaller tube diameter capillary tubes.

b) Tube Length: The length of the capillary tube also plays significant role because it directly affects the pressure drop across the tube. The length of the tube can affect the performance [4], greater pressure drops tend to be the result of longer tubes, which can have an impact on system performance and refrigerant flow. The length of capillary tube ranges from 0.5 to 5 m.

c) Tube material: Capillary tubes are often made of copper, which has excellent heat conductivity and corrosion resistance. The inner tube walls' smoothness and surface finish may also have an effect on the flow characteristics. Stainless steel and aluminium are also used as tube material depending upon application.

d) Refrigerant type: The capillary tube selection should be compatible with the specific refrigerant used in the system, as the performance of the tube is impacted by the thermophysical characteristics of the various refrigerants like CO_2 has 2.5 times more surface roughness than R600a refrigerant [6]. Refrigerant can impact the length **Error! Reference source not found.** as CO_2 requires 18% more length for helical compared to spiral capillary tube.

II. EXPERIMENT AND METHODOLOGY

Experimental setup

A single door domestic refrigerator (LG) with a capacity of 185L cooling space and R134a as refrigerant medium has been used for the experiment as shown in Fig.3. Firstly, all the experiment related to R134a refrigerant of mass 70grams with varying the capillary tube dimensions by keeping the length 3.048m (10feets) as constant throughout the experiment. 3 Capillary tube diameters of 0.031", 0.036" and 0.040" were taken with change in coil diameters of 60mm and 40mm along with change in shape from circular to elliptical shape of 40x55. The same experiment done for R600a refrigerant with 40grams mass for performance comparison.

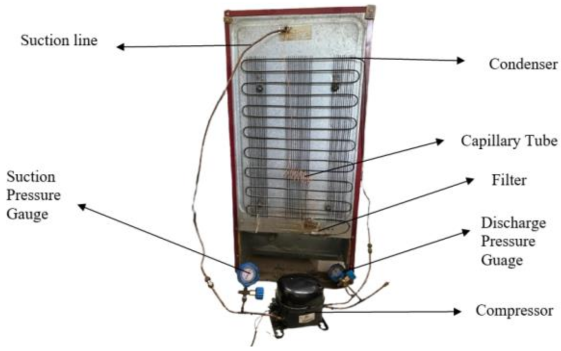

Fig. 3: Experimental setup

Table 1: Compressors specifications

Experimental Procedure

For R134a

•The experiment is being conducted by attaching the R134a compressor by brazing technique. All the required instruments are connected to the equipment before starting the experiment and made sure all instruments are working properly.

•Refrigerant are charged into the compressor while it is running and measure with the help of weighing machine and pressure gauge (Approx. 12PSI for R143a).

•Before performing the experiment, the steady state is achieved every time, sensors are kept at their respective positions and recorded the initial values including pressure gauge reading and environmental conditions have been neglected like humidity, air velocity due to they may not influence much on the performance unlike air-condition system.

•The Experiment is conducted for NO LOAD condition i.e. the fridge door is kept close all time until the required temperature attained. All temperature and pressure readings are taken at for every 5minutes and also time has been recorded for every 1°C change in fridge temperature using digital temperature sensors.

For R600a

•After all experiment on R134a vacuuming is done in order to remove trapped gas inside the components.

•Same experiment procedure has been followed for the R600a compressor except the mass of the refrigerant charged is 40 grams and pressure are 2PSI.

•For change in capillary tube the refrigerant charged freshly after doing vacuuming.

Formulae used

The following formulas have been used for the calculating performance of the refrigerator

COP= (Refrigeration Effect)/ (Compressor work)

Refrigeration Effect= h_1-h_4 (1)

h_4= Enthalpy at evaporator inlet in kJ/kg

h_1= Enthalpy at evaporator outlet in kJ/kg

Compressor Work= h_2-h_1 (2)

h_1= Enthalpy at compressor inlet kJ/kg

h_2= Enthalpy at compressor outlet kJ/kg

III. RESULTS AND DISCUSSION

Pull Down Time (PDT): The time taken to reach certain temperature in minutes is recorded as PDT, for every 5°C change in temperature till 0°C and after that until -3°C temperature considered as 1°C change.

Pull Down Time (PDT-R134a

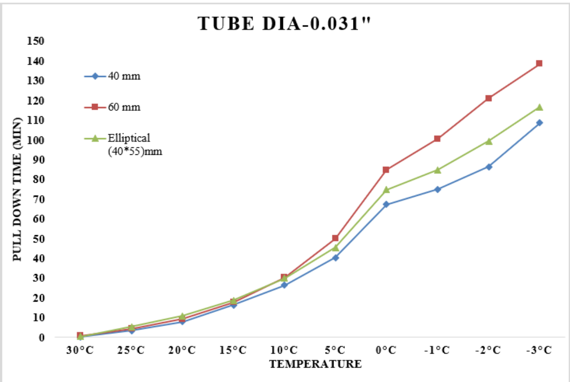

Fig. 4: PDT vs Temperature (R134a-0.031")

Capillary tube with 0.031" diameter has shown quick cooling compared to other diameters. As illustrated in Fig.4 the PDT for 0.031" tube diameter the PDT is very low compared to all geometry of others.

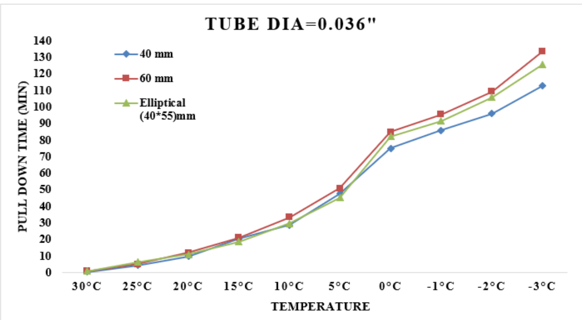

Fig. 5: PDT vs Temperature (R134a-0.036")

Fig.5 shows the PDT for 0.036" tube diameter with40mm coil diameter shown most effect on reaching temperature quickly compared to 60 mm coil diameter and elliptical shape. The change in geometry to elliptical 40x55 mm gave 5% more cooling effect than 60mm coil diameter.

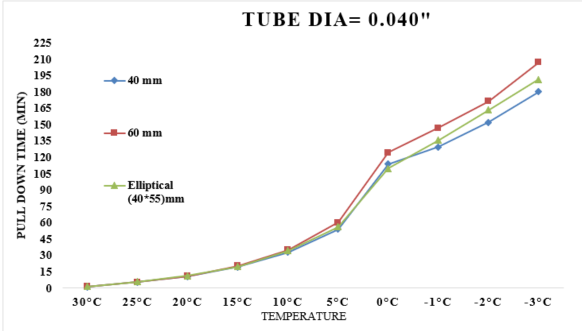

Fig. 6: PDT vs Time (R134a-0.040")

PDT for 0.040” tube diameter using R134a refrigerant which has low cooling impact on the system taking 35% more time to reach the set temperature compared with other geometry. Even for this diameter 40mm coil diameter shown good performance as illustrated in Fig. 6

Pull Down Time (PDT)-R600a

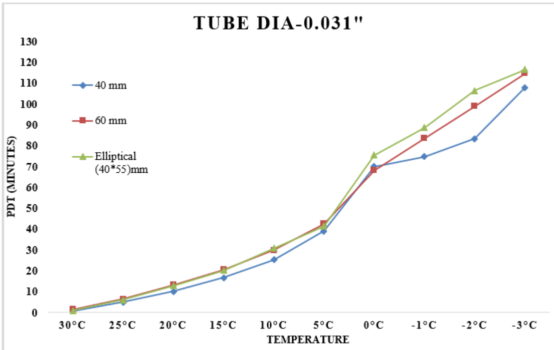

Fig. 7: PDT vs Temperature (0.031") R600a

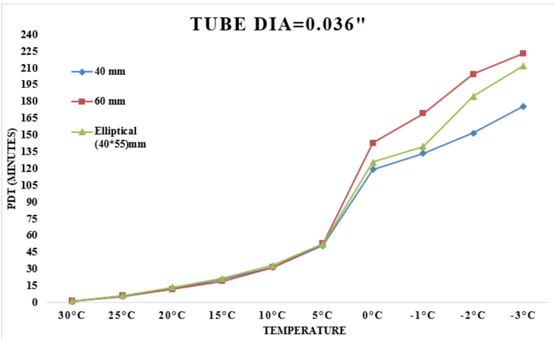

Fig. 8: PDT vs Temperature (0.036") R600a

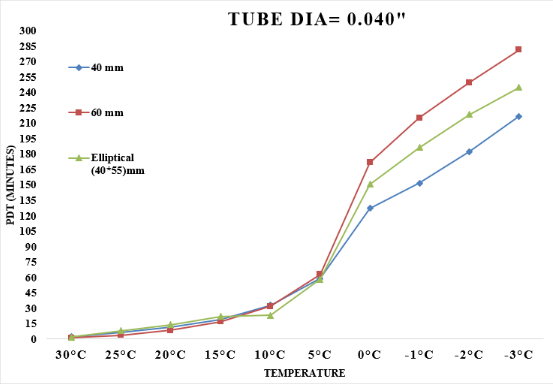

Fig. 9: PDT vs Temperature 0.040" (R600a)

PDT for R600a followed same pattern as R134a refrigerant as shown in Figures 7,8,9. As the diameter of the tube increasing, The PDT also increasing due to decreasing in flow restriction.

Coefficient of Performance (COP)

COP of the refrigerator is calculated using Equation (1) and (2), which consists of enthalpies of the refrigerants at different temperatures and phases. All the values taken from ASHRAE Hand book [5] Obtained values are tabulated in Table 2 for both refrigerants

Table 2

R134a										
Tube diameter/Temp		T_1	T_2	T_3	h_1	h_2	h_3	RE	W	COP
0.031"	60 mm	12.8	52.4	-18.0	405.1	452	176.2	228.9	46.9	4.9
	40 mm	15.2	50.9	-12.7	406.5	451	182	224.5	44.5	5.0
	55x40 mm	15.3	52.4	-12.6	406.4	452	176.2	230.2	45.6	5.0
0.036"	60 mm	12.8	52.4	-17.9	405.4	450	176.9	228.5	44.6	5.1
	40 mm	15.2	50.9	-12.7	407.2	448	183.1	224.1	40.8	5.5
	55x40 mm	15.3	52.4	-12.6	407.2	450	183.2	224	42.8	5.2
0.040"	60 mm	6.4	53.4	-16.7	402.3	455.0	178.2	224.1	52.7	4.3
	40 mm	6.0	53.5	-16.7	401.9	451.2	177.5	224.4	49.3	4.5
	55x40 mm	3.5	53.0	-7.2	401.0	454.0	190.1	210.9	53.0	4.0

R600a										
Tube diameter/Temp		T_1	T_2	T_3	h_1	h_2	h_3	RE	W	COP
0.031"	60 mm	1.4	65.2	-13.8	577.9	678.0	170.4	407.5	100.1	4.1
	40 mm	-2.8	67.7	-20.0	580.6	675.1	154.2	426.4	94.5	4.5
	55x40 mm	1.6	65.8	-12.2	578.2	679.0	172.4	405.8	100.8	4.0
0.036"	60 mm	-1.8	65.3	-13.7	578.3	668.5	170.6	407.7	90.2	4.5
	40 mm	3.5	64.8	-11.8	590.2	669.9	172.2	418.0	79.7	5.2
	55x40 mm	1.8	62.4	-11.4	587.4	665.0	181.4	406.0	77.6	5.2
0.040"	60 mm	-1.0	63.4	-13.7	572.2	671.0	173.6	398.6	98.8	4.0
	40 mm	-1.7	65.5	-14.9	583.1	670.7	165.9	417.2	87.6	4.8
	55x40 mm	-0.5	64.3	-12.7	573.6	667.0	171.8	401.8	93.4	4.3

Validation

The obtained values are validated with Mohammad Harun-Or-Rashid et al.[8] who conducted experiment on a refrigerator having volume 386.2 Liters with a capillary tube diameter of 0.064" (0.00163 m) and length of 1 m. They used both R134a and R600a refrigerant and compared the performance, from the literature evaporator vs temperature data has have been taken validate the experimental data. For both R134a and R600a refrigerants the graph pattern followed as shown in figures 10 and 11.

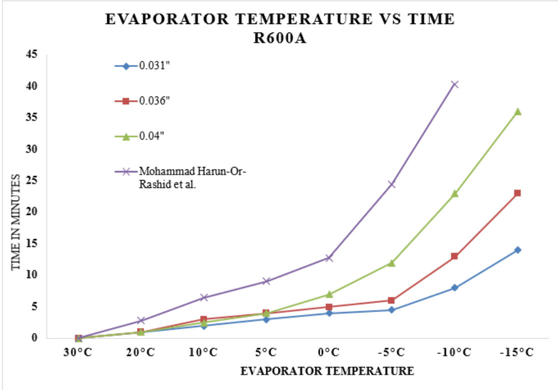

Fig. 10: Evaporator temperature vs time R134a

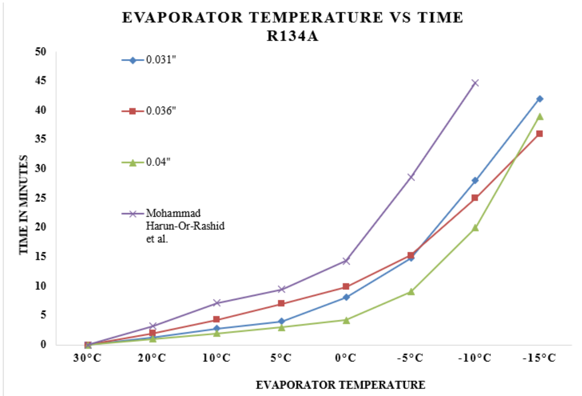

Fig. 11: Evaporator temperature vs time R134a

COP Validated with the available literature [9] P.thangavel et al. and obtained results are plotted on a graph which says as time goes COP will decreases as shown in fig.12.

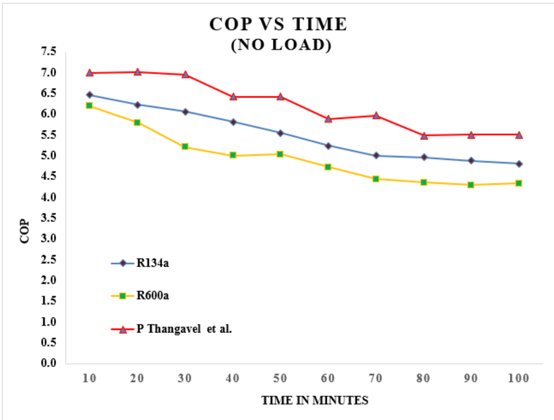

Fig. 12: COP vs Time

IV. CONCLUSIONS

A capillary tube with a 0.031" diameter reached the set temperature quicker because its smaller diameter restricts refrigerant flow more, accelerating expansion and pressure drop. This quick expansion enhances heat absorption, leading to faster cooling.

An increase in capillary tube diameter leads to a slower cooling process due to reduced flow restriction and lower pressure drop. Larger diameter tubes cause the refrigerant to expand more slowly. Thus, smaller diameter tubes facilitate quicker cooling.

A 40mm coil diameter showed better results than 60mm and elliptical coils, most likely due to an ideal balance of surface area for heat exchange and flow dynamics. Higher flow resistance or less effective heat transfer may result from larger or elliptical coils.

Change in PDT by changing the coil diameter from 60mm to 40mm are illustrated in table 6.1 for different tube diameters of both refrigerants.

The Optimum coil tube Dia for the 0.031", 0.036" & 0.040" capillary tubes are 40mm which gives faster cooling effect.

For refrigerant R600a, a variation of 50% in Pull Down Time (PDT) was noticed between 0.031" and 0.040" diameters, and a 20% between 0.040" and 0.036" diameters. Smaller diameter tubes (such as 0.031") accelerate the cooling process through creating a greater pressure drop. However, the deviation is caused by bigger tubes, such as 0.040", that exhibit a slower cooling rate and pressure drop.

Effect on COP

The COP (Coefficient of Performance) increases with the diameter of the capillary tube, attaining highest at 0.036" for both refrigerants. Smaller tube diameters result in higher pressure drops, inadequate heat transfer, and decreased mass flow rates, leading to lower COP and larger tube diameters results in lesser pressure drop, low throttling results in decreasing in COP

Optimum design for maximum COP is 0.036" and 40mm coil diameter for both refrigerants

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Abbreviations and units

COP- Coefficient Performance

PDT- Pull Down Time (minutes)

Tube diameter in inches

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