Experimental Analysis of the Performance of Vapor Compression Refrigeration System using R134a, R290 and R404a with Several Diameters of Capillary Tube

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Abstract— The main objective of this work is to enhance the performance of the domestic refrigerator .To attain this analysis is carried using the combination three different refrigerants (R134a, R290 and R404a) & three different inner diameters (0.3mm, 0.45mm, 0.50mm) of capillary tube. Comparing the performance parameters of the refrigeration system with different refrigerants & different capillary tube by keeping ambient temperature and compressor discharge constant for all the combinations, it is found that the COP of the system is better for the capillary diameter of 0.30mm for all three refrigerants R134a, R290 and R404a. As we increases the diameter of capillary tube the cop tends to decrease. Whereas, refrigeration effect value did not follow any regular trend. Highest cop value for refrigerant R134a is recorded for 0.30mm diameter of capillary tube which is 3.94. For R290 it is recorded as 3.19, for capillary diameter of 0.30mm. The same size of capillary (i.e. 0.30mm) gives optimum value of cop for R404a, which is 1.46.

Key words: Vapor Compression Refrigeration, Coefficient of Performance, Refrigeration Effect

I. INTRODUCTION

Refrigeration may be defined as the process to attain and keep an enclosed space at a temperature below than its surrounding temperature. This is done by continuous removal of heat from the enclosed space where as the temperature is lower than that of the surrounding temperature. Refrigerator is a cooling appliance encompassing a thermally insulated compartment and a refrigeration system is a system to churn out cooling effect in the insulated compartment. Meanwhile, refrigeration is put into words as a process of removing heat from a space or substance and carries that heat to another space or substance. Refrigerators are hugely used to store foods which decay at room temperatures; spoilage from bacterial growth and other processes is much slower in refrigerator that has low temperatures. In refrigeration process, the fluid working job as the heat absorber or cooling agent is called refrigerant. The refrigerant absorbs the heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure. As the heat is removed from the refrigerated space, area become cooler. The process of refrigeration occurs in a system which encompasses of a compressor, condenser, capillary tube and an evaporator. Most of the domestic refrigerators today are functioning based on the vapour compression refrigeration (VCR) system. It is somewhat relates to Reverse Rankine cycle. The vapour compression refrigeration system consists of four main components which are compressor, condenser, expansion device, and evaporator.

Compressor is used to compress the low pressure and low temperature of refrigerant from the evaporator to high pressure and high temperature. After the compression process the refrigerant entered into condenser. In the condenser, the condensation process occurs where heat is rejection to the surroundings. The refrigerant can be condensed by increasing the refrigerant's pressure and temperature above the atmospheric temperature. After the condensation process, the condensed refrigerant will flow into the expansion device, where the temperature and pressure of refrigerant will be dropped lower than the surrounding temperature. When the pressure drops, the refrigerant vapor will expand. For example, capillary tube. It is simply a long hollow tube of drawn copper with an internal diameter ranging from 3.3×10^{-4} to 2.5×10^{-3} m.

II. LITERATURE REVIEW

P. K. Bansal, A. S. Rupasinghe, (1996) [1]. This paper presents an empirical model that has been developed to size adiabatic and non-adiabatic capillary tubes for small vapor compression refrigeration systems, in household refrigerators and freezers. The model is based on the assumption that the length of a capillary tube dependents on five primary variables, namely the inner diameter of capillary tube, the mass flow rate of the refrigerant in the capillary tube, the pressure difference between high side and low side, the refrigerant sub-cooling at capillary inlet and the relative roughness of the capillary tube material.

T. Raghavendra, H. Ranganna, G. Maruthi Prasad Tadav, 2015 [8]. In this work, it is attempted to optimize Length/Diameter ratio of capillary tube for domestic refrigerator of capacity with R-134a as refrigerant and hermetic sealed compressor of capacity 0.14H.P. It is found that other than existing Length/Diameter ratio of capillary tube gave a better performance.

Li Yang, Wen Wang, 2008, [7]. In this work, a generalized correlation for predicting the refrigerant mass flow rate through the adiabatic capillary tube is developed. The collected database about capillary tubes covers the inner diameter from 0.5 mm to 2 mm, the tube length from 0.5 m to 5 m, the condensing temperature from 20^0C to 60^0C, the subcooling from 0^0C to 20^0C, and the quality from 0 to 0.3 at the inlet. Assessments for the correlation are made with some experimental data for R12, R22, R134a, R290, R407C, R410A, and R404A obtained from the open literature and some existing correlations based on the experimental database also. This correlation yields an average deviation of -0.83% and a standard deviation of 9.02% from the database.

S. G. Kim, M. S. Kim, S. T. Ro (2001) [4]. Several capillary tubes with different inner diameter and length were selected as test sections. Mass flow rate through the capillary tube was measured for various condensing temperatures and several degrees of subcooling at the inlet of each capillary tube. Mass flow rates of R410A and R407C were compared with those of R22 for the same test conditions. The results for

straight capillary tubes were also compared with those of coiled capillary tubes. The mass flow rate of R407C is greater by 4.0%, and those of R410A is greater by 23% as an average, than that of R22.

III. EXPERIMENTAL SETUP

Experimental setup is the type of domestic refrigerator fabricated as per the experimental requirements. Its components are compressor, air-cooled condenser, evaporative coil and capillary tube as expansion device. To read the values of temperature and pressure at different points we have used temperature sensors and have installed pressure indicators. To measure the voltage and current provided to the compressor voltmeter and ammeter are also connected.

Three different refrigerants are filled into the system one by one with different capillary tube diameter. The refrigerants used are R134a, R290 and R404a and the capillary tube is helical coiled, with diameters 0.30mm 0.45mm and 0.50mm. One by one we replace the capillary tubes.

A. Components of the System

- Compressor-1/4 Hp Capacity Emerson Make 230 Volt Ac.
- Condenser-Air Cooled Condenser
- Pressure Gauges-

1) For Suction = -30 -0-150Psi
2) For Discharge = 0-500Psi

- Energy meter- 1 phase, 230 volt AC.
- Temperature indicator- digital temperature indicator. PT-100 sensors.
- Voltmeter- 0-300volt.
- Ammeter- 0-5amp.
- Evaporator tank.
- Capillary as expansion device.

Fig. 1: Actual Diagram of Experimental Setup

B. Refrigerant Properties

The chemical name of R-134a is Tetrafluoroethane and that of R290 is Propane. The refrigerant R404a is a mixture of three refrigerants R125, R143a & R134a with compositions 44%, 52% and 4% respectively.

S.NO.	BP	$T_{CR}(^0C)$	P_{CR}(Psi)	ODP	GWP
R134a	-26	101.1	4060	0	1200
R290	-42.09	96.70	4248	0	20
R404a	-46.45	72.07	3731.5	0	3300

Table 1: Refrigerant Properties [3]

IV. EXPERIMENTAL PROCEDURE

We made experimental setup and changed the diameter of capillary tube also changing the different refrigerants and analyze which refrigerant is suitable for a specific diameter of the capillary tube for achieving better COP.

We use following different type of refrigerant

- R134a
- R290
- R404a

We use following different type of capillary diameter

- 0.30mm
- 0.45mm
- 0.50mm

Length of capillary tube is constant for all the test conditions which is 5ft.

- Studied the key variables, like, COP, power of compressor, enthalpy of each points and mass flow rate of refrigerant. Many measured variables are also noted namely, the refrigerant temperature and pressure of each inlet & outlet of compressor ($T1$ & $T2$), outlet condenser $T3$, inlet & outlet evaporator $T4$ & $T1$ and evaporator cabinet.
- Also it measured high & low pressure of vapor compression cycle and electrical voltage & current consumed by compressor. The ambient temperature is 32^0C.
- Analyzing the results obtained to optimize the performance of the VCR system for different capillary diameters (0.3mm, 0.5mm, 0.6mm) and different refrigerants(R-134a, R-290 & R-404a).

V. RESULT AND DISCUSSION

Results for the different refrigerant with different size of capillary tube is noted and then the calculations are done by using appropriate formula to find the value of COP, RE, W_{comp} etc.

A. Refrigeration Effect

Firstly, the refrigeration effect is calculated for the different refrigerants with different diameters of capillary tube and the graphs are drawn (fig 2, 3 and fig 4). It is found that for R134a the RE value is best for capillary tube diameter of 0.50mm which is 2.55kW. For R290 RE value is best for 0.50mm which is 1.86kW and for R404a it is best for 0.30mm which is 0.62kW. RE value does not follow any regular trend for different diameter size of capillary tube.

B. COP

The COP values for each refrigerant with three different diameters of capillary tube are calculated and graphs are drawn (fig 5, 6 and fig 7). It is found that for all the three

refrigerants i.e. R134a, R290 and R404a, COP is highest for capillary tube inner diameter of 0.30mm. These highest COP values for R134a, R290 and R404a are 3.94, 3.19 and 1.76 respectively.

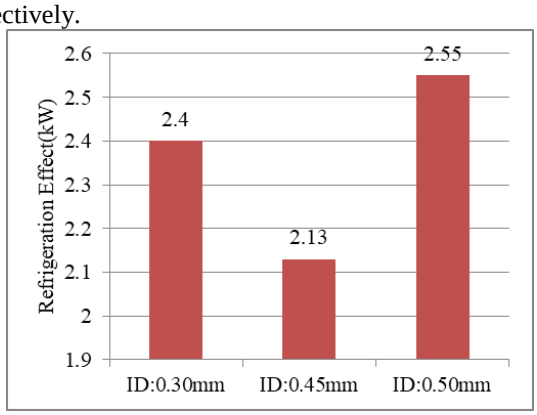

Fig. 2: Refrigeration effect vs Capillary tube diameter for R134a

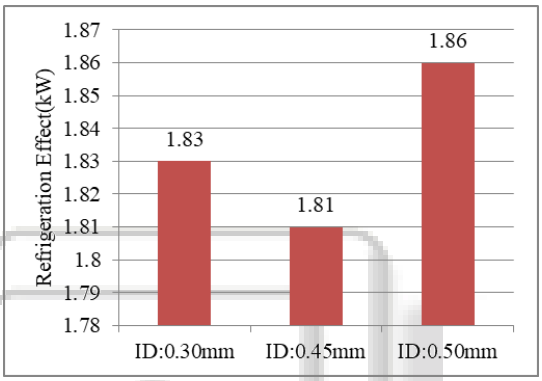

Fig. 3: Refrigeration effect vs Capillary tube diameter for R290

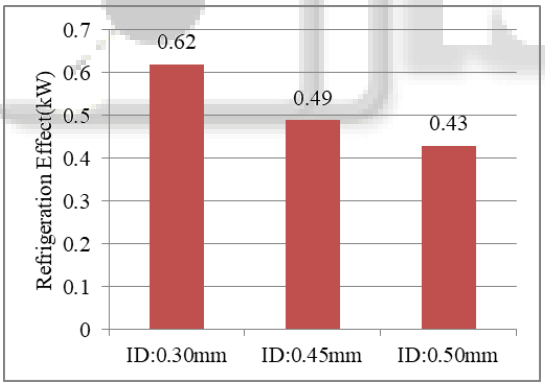

Fig. 4: Refrigeration effect vs Capillary tube diameter for R404a

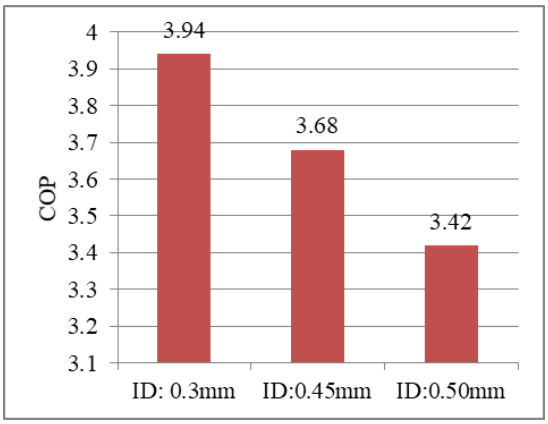

Fig. 5: COP vs Capillary tube Diameter for R134a

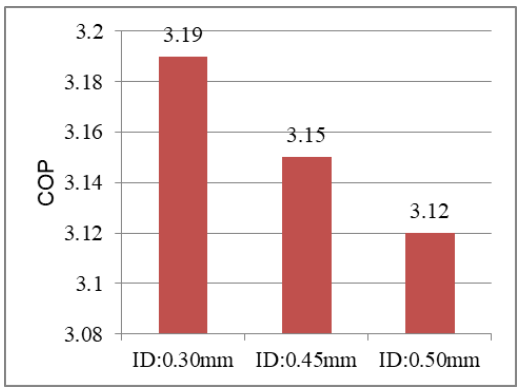

Fig. 6: COP vs Capillary tube Diameter for R290

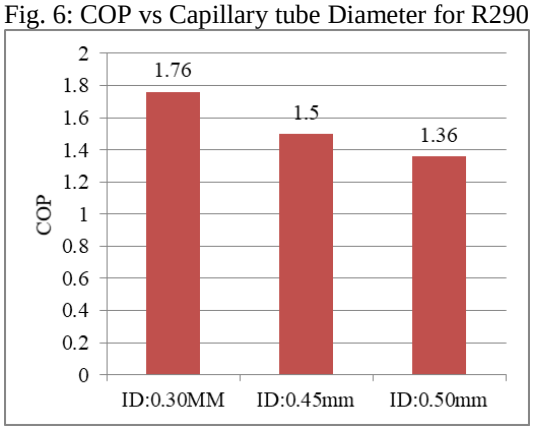

Fig. 7: COP vs Capillary tube Diameter for R404a

VI. CONCLUSIONS

The conclusion for the current research is as following

- It is found that, RE is highest for R134a for capillary tube inner diameter of 0.50mm, which is 2.55kW. And for the same refrigerant COP is highest for 0.30mm, which is 3.94. If power consumed is considered, we prefer capillary tube of inner diameter 0.30mm for R134a.
- The COP is highest for R290 for 0.30mm capillary, which is 3.19. Hence, 0.30mm inner diameter is preferred for R290.
- For R404a, the value of COP is highest for 0.30mm diameter of capillary tube, which is 1.46.
- The COP value for all the refrigerants tends to decrease with increasing inner diameter of capillary tube.
- From the above results it is found that 0.30mm inner diameter of capillary tube gives optimum performance for all the three refrigerants. Hence, 0.30mm inner diameter is preferred for the selected refrigerants (R134A, R-290 and R-404A) for optimum performance of the VCR cycle.

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