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Experimental Investigation of Vapor Compression Refrigeration system with low GWP Refrigerants

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ABSTRACT:- Time is insufficient for everyone in this express world. In the meantime, we have to concentrate on our environment for the betterment of humans and other species in the world. Ozone depletion and global warming are main disturbances for the good environmental condition. These disturbances are mainly occurring due to refrigerants which are having high GWP and ODP values. Hence, we need to find a substitute for present refrigerant in terms of low GWP and zero ODP values. In this paper, we summarized the results of researchers to find out a new refrigerant. Finally, after analyzing those results we found that the following refrigerant R290/R600a having zero ODP and very low GWP will give better COP, high cooling capacity and low energy consumption.

Keywords: *Refrigerant, ODP, GWP, COP, Energy Consumption.*

I. INTRODUCTION

In the modern world, home appliances are very much essential to make over the changes in the climatic condition. Hence, refrigerator and air conditioner are essential home appliances. But when the technology and science improves, environmental impacts are also improving proportionally. Global warming is the main issue that affects the climatic conditions and species in the world [1]. One of the main reasons of increasing global warming and ozone depletion is using refrigerant as the working medium in the refrigerator and the air conditioning systems which are having high values of ODP and GWP. Those refrigerants may tend to leak into the environment during recharging or mishandling of refrigerant. Due to leakage it affects the ozone layer and causes ozone depletion and increases the global warming. Hence, R22, R12 are phased out and alternative is found as R134a for the refrigeration system because it has similar efficiency as of R12. But the GWP of R134a refrigerant is very much high. Now refrigerator, air conditioning manufacturers are in the urge to find out a new substitute for R134a. In searching of new substitute some of them were focused on natural refrigerants like NH_3, and HC, CFC, HCFC, HFC and HFO refrigerants.

Some developed countries had already banned using refrigerants which are having high GWP [14]. Some of the developing countries are trying to phase out those refrigerants before 2030. When trying to find a new refrigerant it should be compatible with the existing system to reduce the retrofit expenses. While analyzing and selecting new refrigerants their basic properties which are related to environment, thermodynamic properties and physical properties should be considered [3].

Hydrocarbons are highly flammable but are having very low GWP. Researchers are analyzing refrigerant mixture consisting of HC, HFCs and HFOs to reduce the amount of hydrocarbons in the working fluid. To improve the performance of the system HC type compressors are used which are especially designed for hydrocarbon refrigerants.

Another type of refrigerant commonly used is hydro fluorocarbon (HFC) which are having zero ODP and high GWP [5]. But which give high performance in the system hence it is blended with some other refrigerants. Main drawback of HFC is its oil miscibility property, hence different types of compressors cannot be used with HFCs. To overcome this problem, HFCs are blended with HC refrigerants.

II. EXPERIMENTAL APPARATUS

An experimental setup of vapor compression refrigeration system was built up to investigate the performance of R134a, R600a and R290/R600a mixture. Fig. 1 shows the schematic diagram of the experimental setup. It consists of a refrigerator cabin, a hermetically sealed reciprocating compressor, air cooled condenser, a capillary strainer, two capillary tubes of different lengths with valves, an evaporator and a sight glass. To optimize the capillary tube length, two capillary tubes of 1.3mm and 0.91mm diameter with two different lengths (2.13m and 3.5 m) were provided. All the capillary tubes of the refrigerator were attached with the suction line to improve the performance. To estimate the actual COP and refrigeration capacity of the domestic refrigerator, the evaporator similar to one used in refrigerator was kept in a calorimeter filled with water as secondary refrigerant. The calorimeter was fitted with an electric heater connected with a dimmer stat to maintain constant temperature.

The calorimeter was insulated to reduce the ambient heat infiltration. A manually operated stirrer was provided in the calorimeter to maintain uniform temperature inside. Another two ball valves were fixed at the capillary tube inlet for choosing different capillary tube length. The refrigerator was instrumented with four compound pressure gauges at the inlet and outlet of the every component for measuring the suction and discharge pressures. Five calibrated RTD (Pt100) temperature sensors were placed inside the freezer, refrigerator cabin, compressor outlet, condenser outlet, capillary inlet, evaporator inlet and outlet, accumulator outlet, inside the calorimeter, entry and outlet of the evaporator fitted in calorimeter and suction of the compressor.

A 2 kW air heater was placed inside the chamber to maintain the higher temperatures. The air heater was connected to a dimmer stat to maintain a constant temperature. The energy consumption of the refrigerator was measured under no load condition using a digital energy meter and instantaneous compressor power consumption was measured by a digital Wattmeter.

III. EXPERIMENTAL PROCEDURE

As per manufacturer's recommendation, 110 g of R134a was charged in the refrigerator for conducting baseline tests. During experimentation with R134a, 1.3mm diameter and 2.13m capillary tube length was used.

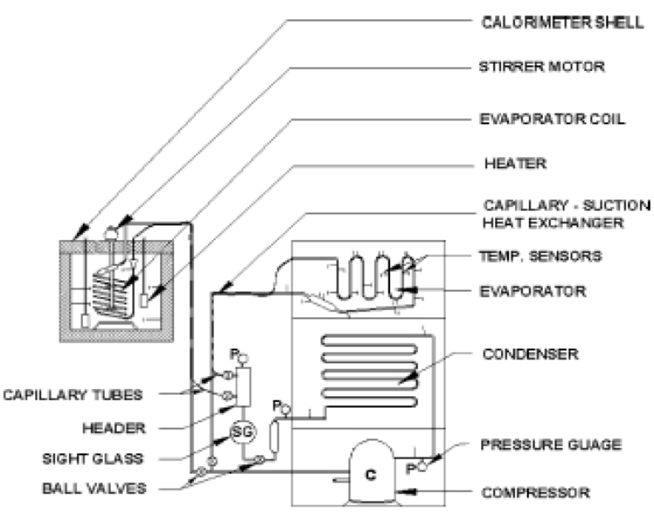

Fig. 1. Schematic diagram of experimental setup.

The continuous running tests were carried out by connecting the evaporator inside the calorimeter with the system. The actual refrigeration capacity and COP of the refrigerator were calculated as per the procedure. The energy consumption of the compressor and heater were measured by separate energy meters. All the experimental observations were made after attaining the steady state conditions. After completing the base line reference test with R134a, the refrigerant was recovered from the system. Before experimenting with different refrigerants, the length of the capillary tube was optimized for maximum COP. During capillary tube optimization, the refrigerator was charged with optimum refrigerant charge and ambient temperature was 28 °C. Then, the refrigerator was charged with various refrigerants and these tests were repeated. Temperatures at different locations were recorded every ten minutes intervals. Pressure at compressor suction and discharge was measured every twenty minutes intervals. The instantaneous power consumption of the refrigerator during continuous running tests was measured after attaining the steady state condition. The measured values were used to study the performance characteristics of the refrigerator.

IV. EXPERIMENTAL ANALYSIS

A. Refrigerating effect

Refrigerating effect produced from the system per unit time period should be measured by using the difference in enthalpy values at the inlet and outlet of the evaporator with mass flow rate of refrigerant.

$$RE_{theo} = h_1 - h_4$$

$$RE_{act} = \frac{(5 \text{ x } 3600)}{(1200 \text{ x } t_h)}$$

B. Work input

The vapor refrigerant at low pressure p_1 and temperature T_1 is compressed isentropic ally to dry saturated vapor as shown by the vertical line 1-2 on T-s diagram and by the curve 1-2 on the p-h diagram. The pressure and temperature rises from p1 to p2 and T1 to T2 respectively. The work input during isentropic compression per kg of refrigerant is given by

$$W_{theo} = h_2 - h_1$$

$$W_{act} = \frac{(5 \text{ x } 3600)}{(1200 \text{ x } t_c)}$$

C. Coefficient of performance

The coefficient of performance is the ratio of heat extracted in the evaporator to the work input to the compressor. Mathematically,

$$COP_{theo} = \frac{\text{Refrigerating effect}}{\text{work input}}$$

$$COP_{act} = \frac{RE_{act}}{W_{act}}$$

D. Optimum capillary length

The incremental length of capillary tube for the first step, ΔL_1 is,

$$\Delta L_1 = \frac{\Delta P - G\Delta V}{2x_1\left(\frac{G}{2D}\right)[fv]_{mean}}$$

E. Energy destruction

A system delivers the maximum possible work as it undergoes a reversible process from the specified initial state to the state of its environment, that is, the dead state. This represents the useful work potential of the system at the specified state and is called energy.

Irreversibility's such as friction, mixing, chemical reactions, and heat transfer through a finite temperature difference, unrestrained expansion, non-quasi equilibrium compression or expansion always generate entropy, and anything that generates entropy always destroys energy. The energy destroyed is proportional to the entropy generated. Energy destruction occurred in compressor is

$$\dot{E}_{x,dest,1-2} = \dot{m}T_0(S_2 - S_1)$$

Energy destruction occurred in condenser is

$$\dot{E}_{x,dest,2-3} = \dot{m}[h_2 - h_3 - T_0(S_2 - S_3)] - \dot{Q}_H\left(1 - \frac{T_0}{T_H}\right)$$

Energy destruction occurred in Capillary tube is

$$\dot{E}_{x,dest,3-4} = \dot{m}T_0(S_4 - S_3)$$

Energy destruction occurred in Evaporator is

$$\dot{E}_{x,dest,4-1} = \dot{m}[h_4 - h_1 - T_0(S_4 - S_1)] - \left[-\dot{Q}_L\left(1 - \frac{T_0}{T_L}\right)\right]$$

The total energy destruction in the cycle can be determined be adding energy destruction in each component

$$\dot{E}_{x,dest,total} = \dot{E}_{x,dest,1-2} + \dot{E}_{x,dest,2-3} + \dot{E}_{x,dest,3-4} + \dot{E}_{x,dest,4-1}$$

The second law efficiency (or exergy efficiency) of the cycle can be determined by

$$\eta_{II} = \frac{\dot{E}_{X,QL}}{\dot{W}}$$

$$\eta_{II} = \frac{\left[-\dot{Q}_L\left(1 - \frac{T_0}{T_L}\right)\right]}{\dot{W}}$$

V. RESULT AND DISCUSSION

Investigations have been carried out for different refrigerants with old and new capillary tubes and their performance have been compared graphically. Parameters that are compared are refrigerating effect, work input to the refrigerator, COP and second law efficiency.

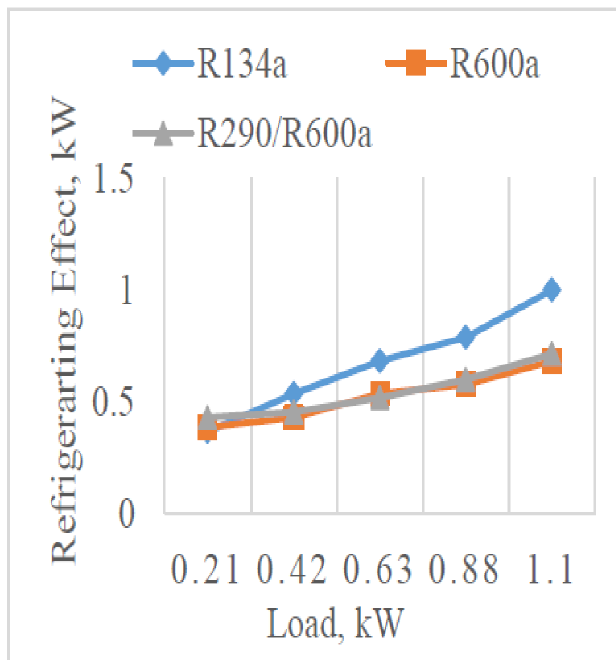

Fig. 2. Refrigerating Effect of Different Refrigerants with Old Capillary Tube.

Cooling capacity of the refrigerator will vary for different refrigerants as shown in Fig. 2 hence, comparison of cooling capacity with other refrigerants result in consideration of suitable refrigerant. High cooling capacity refrigerants like R1234ze(E), R290/R600a mixture and HC refrigerants can be considered.

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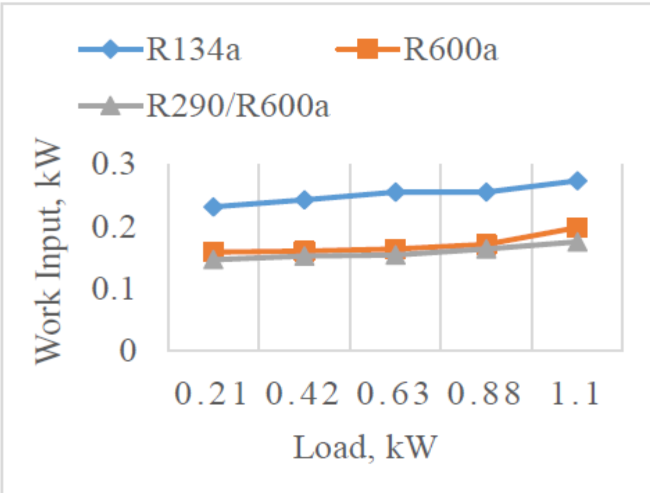

Fig.3. Work Input to Different Refrigerants with Old Capillary Tube

Energy consumption of the system using different refrigerants is illustrated in Fig.3. It shows that R12, R32, R424A are the refrigerants consuming more energy when compared to R134a.

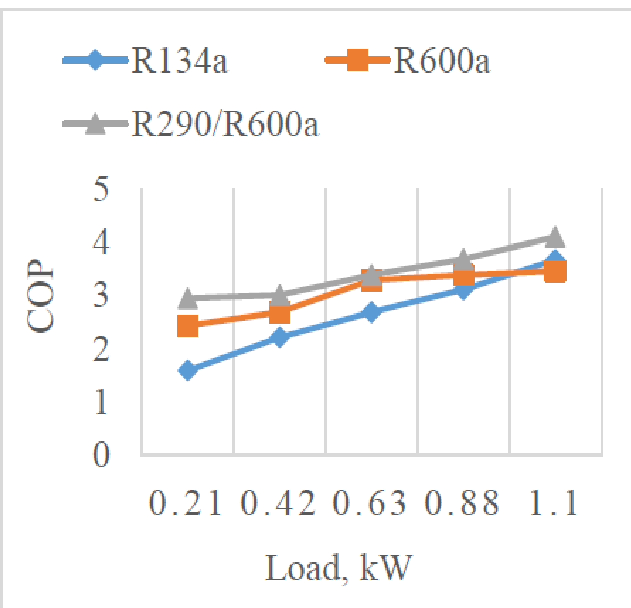

Fig. 4. Performance of Different Refrigerants with Old Capillary Tube

COP of different refrigerants are compared in Fig.4 and it shows that R22, R417A, R422A, R422D, R424A have better COP. But, there is a limitation based on ODP and GWP. On the basis of ODP and GWP R290, R600a, R1234yf, R1234ze(Z), R125 and R152a can be considered as better substitute for R134a.

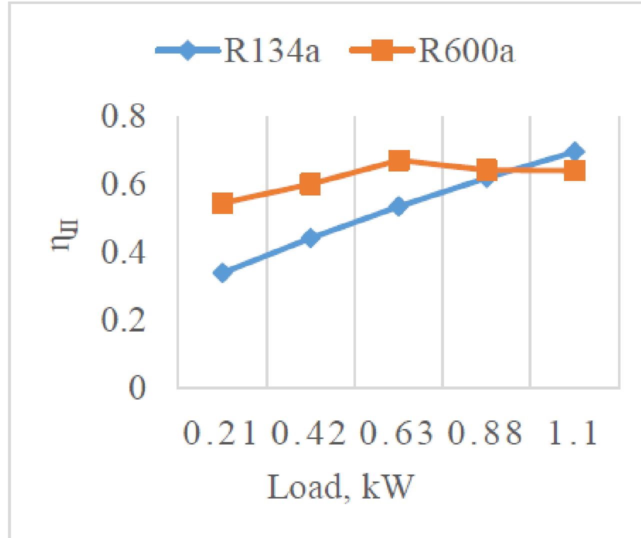

Fig.5. η_{II} of Different Refrigerants with Old Capillary Tube

Second law efficiency for two refrigerants are shown in fig. 10.5. Second law efficiency of refrigerant R134a gradually increases from the lowest load condition to highest load condition as well as it also having highest value at highest load when compared with R600a. At lowest load condition R600a has highest second law efficiency than R134a but at higher load, hydrocarbon refrigerant slightly moves downwards from its way.

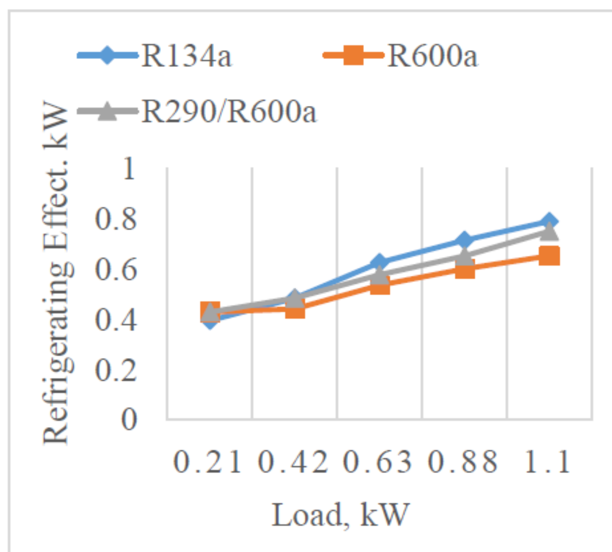

Fig.6. Refrigerating Effect of Different Refrigerants with New Capillary Tube.

Evaporator temperature is the main criteria which provide good refrigerating effect. Combination of low evaporative temperature and low power consumption refrigerants can give better refrigerating effect. Evaporator temperature achieved by different refrigerants is summarized in Fig.6. HFO refrigerants and HC refrigerants will give lower evaporator temperature when compared with others.

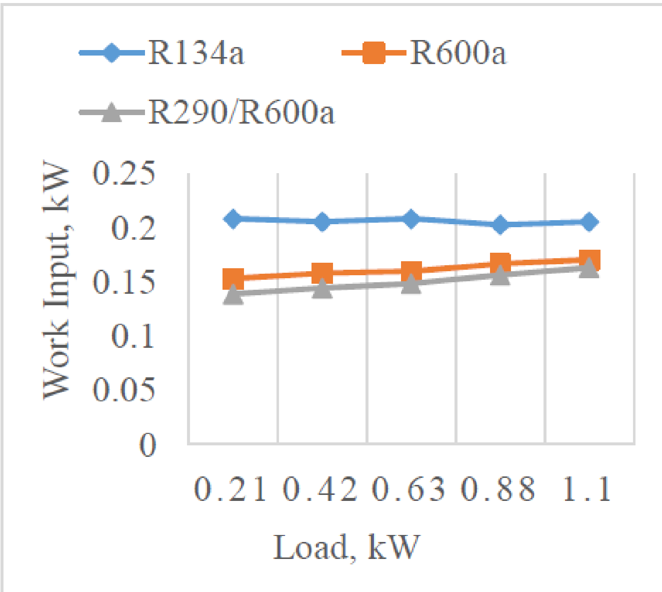

Fig.7. Work Input to Different Refrigerants with New Capillary Tube

Discharge temperature of the refrigerant from the compressor varies the work of the compressor. It is an important parameter to be considered. Fig.7. illustrates the discharge temperature of the refrigerants. R1234yf, R152a, HC refrigerants and their mixture will give low discharge temperature. While using those refrigerants life of the compressor will be extended.

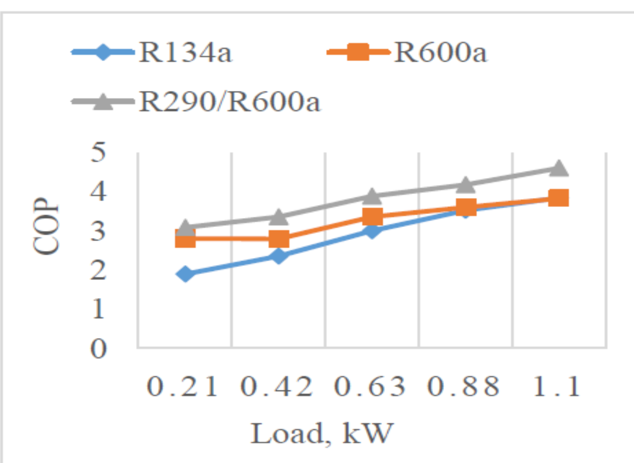

Fig.8. Performance of Different Refrigerants with New Capillary Tube

Graphical representation of refrigerants exhibits that R290/R600a refrigerant mixture gave better performance than other two refrigerants. In fig. 8. R600a provides higher COP than R134a even at minimum load and it attains same COP like R134a at the maximum load. R290/600a exhibits highest COP for all loads comparing to other refrigerants.

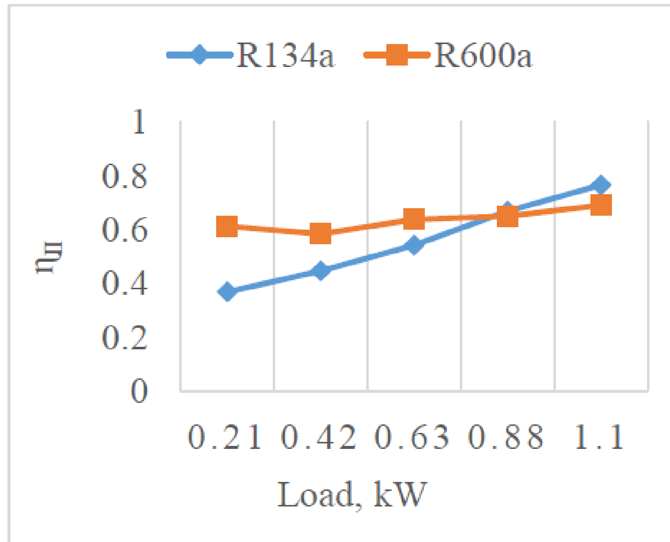

Fig.9. ɳII of Different Refrigerants with New Capillary Tube

R600a, hydrocarbon refrigerant is having highest second law efficiency at minimum load as shown in fig. . R134a is having highest second law efficiency at maximum load. Second law efficiency of R600a maintains nearly constant value even for different loads.

VI. CONCLUSION

After comparing coefficient of performance, pressure ratio, ODP and GWP of various refrigerants RE170 was found suitable alternative refrigerant for R134a. To achieve lower energy consumption it is advised to use HC compressor for hydrocarbon refrigerant instead of HFC compressor.

The R290/R600a mixture is preferred as drop-in replacement refrigerant for R12 and R134a.

Due to high flammability and explosive property of hydrocarbon refrigerants, these are not often used as refrigerants. Most of the researchers suggested that the hydro fluorocarbon refrigerants are the best alternative for CFC and HCFC refrigerants due to their similar performance.

When compared with existing refrigerants, HFC refrigerants are energy efficient and also offering significant benefits. Replacing existing refrigerant R22 with HCFCs needs to be retrofitted for better performance. Lubricating oils, expansion valve and other components need to be replaced with better and optimum accessories. Due to their high GWP, hydro fluorocarbons need to be phased out within 2030 as per the regulation of Kyoto protocol.

In the investigation of HFC and HFO refrigerants, R-1234yf has similar cooling capacity and energy consumption of R134a. But R-1234ze gives only better energy consumption. Because of the lower cooling capacity of R-1234ze, compressor run time increases. So it is very much essential to retrofit an R1234ze system for better performance similar to R134a due to lower cooling capacity.

From the summarization of lower GWP refrigerants with lower power consumption, low volumetric efficiency and high COP, R1234yf can be preferred as good alternative to R134a in domestic refrigeration applications.

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