Experimental study of Hydrocarbon Refrigerant Mixture R290/R600a as an alternative to Refrigerant R134a used in a Domestic Refrigerator

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ABSTRACT

In the present work, an experimental study has been done with hydrocarbon refrigerant mixture consist of R290/600a in the ratio of 50:50 by weight as an alternative to R134a in a domestic refrigerator of capacity 220 litre. Also an attempt is made to improve the system performance with the use of liquid line suction line heat exchanger (LSHX). Continuous running test were performed under ambient temperature of 29°c with constant evaporator temperature of -25°c and condenser temperature of 42°c. The refrigerant mass charge of hydrocarbon mixture R290/R600a used for the same system was approximately 50% of that of R134a system. Without use of LSHX R290/R600a has more refrigeration effect than R134a by about 35.29% and with the use of LSHX R290/R600a has more refrigeration effect than R134a by about 12.5%. Less compressor work done for R290/R600a than R134a by about 9.12% without use of LSHX and with the use of LSHX there is also less compressor work done for R290/R600a than R134a by about 14.68%. R290/R600a has more COP than R134a by about 46.92% without use of LSHX and with the use of LSHX there is also an increment in COP of R290/R600a than R134a by about 31.91%. The discharge temperature of compressor for R290/R600a is less than R134a by about 8K without use of LSHX and with the use of LSHX is less for R290/R600a than R134a by about 5K.

Keywords: Coefficient of performance, Compressor discharge temperature, Compressor work done, Liquid line suction line heat exchanger, Refrigeration effect.

I.INTRODUCTION

Refrigerants are undergone through radical development due to the environmental issues like ozone depletion and climate change concerns. The selection of suitable refrigerant for various applications is now very crucial which satisfies the factors like, chemical properties, physical properties, transfer properties of substance and the most important is the substance ozone depletion potential (ODP) and global warming potential (GWP). For this reason the production and eventually the use of most popular refrigerants such as HFC 134a (R134a) will be terminated in the near future.

Refrigerants are generally classified as: chlorofluorocarbons (CFC), Hydrochlorofluorocarbons (HCFC), Hydrofluorocarbon (HFC) and Hydrocarbons (HC). The first three are known as halocarbon refrigerants because their substances contain one or more halogens. Studies have shown that, CFC greatly contributes to the depletion of ozone layer depletion of the ozone layer poses a serious threat to human survival. The molecules of CFC are composed of chlorine, fluorine and carbon. They are very stable and do not break up easily when released into the atmosphere. HCFC are largely destroyed in the lower layer of the atmosphere known as troposphere. Consequently, they have lower ODP and GWP values compared to CFC. HFC content only hydrogen, fluorine and carbon atoms. Different from CFC and HCFC they contain no chlorine atoms, therefore cause no ozone depletion and have low to zero toxicity levels. Nonetheless, HFC have really very high GWP levels. Hence, before the discovery of GWP phenomenon, HFC were recommended as alternative refrigerants to replace CFC in refrigeration and air conditioning systems [1]. M.Mohanraj et al. [2] experimented with hydrocarbon refrigerant mixture composed of R290/R600a in the ratio of 45.2:54.8 by weight as an alternative to R134a in 200 litre single evaporator domestic refrigerators. Discharge temperature for HCM was found to be lower than that of a R134a, that are about 11.5K to 18.7K, 8.5K to 13.4K and 5.5K to 8.7K respectively. For HCM 50, HCM 60 and HCM 70 due to its lower specific heat ratio. The discharge temperature of R134a, HCM50, HCM 60 and HCM 70 gets increased by about 33K with increase in ambient temperature from 24°C to 43°C. For power Consumption it is observed that HCM 50 and HCM 60 were found to be lower than that of R134a by about 2.77% to 3.19% and 0.92% to 1.06% respectively. But HCM 70 showed about 0.91% to 1.05% higher power consumption than that of R134a for ambient temperature between 24°C to 42°C. For COP of R134a and HCM it is found that COP of HCM60 and HCM 70 were higher than that of R134a by about 3.25% to 3.6% and 1.2% to 1.66% respectively for ambient temperature between 24°C and 42°C. The COP of HCM 50 was lower than that of R134a by about 2.4% to 2.59% due to lower refrigeration capacity. COP of refrigerator decreases with increase in ambient temperature from 24°C to 42°C due to increase in power consumption.

Richardson and Butterworth [3] investigated the performance of hydrocarbon refrigerants in vapour compression refrigeration system. He compared the coefficient of performance between R12 and hydrocarbon refrigerants mixture R290/R600a with different compositions like R290/R600a 56:44 and R290/R600a 43:57 for various evaporator temperature -40°C, -30°C, -20°C, -10°C, 0°C, 10°C, and 20°C. For this 56:44 mixture has a COP greater than that of R12 throughout the range of temperatures investigated while 43:57 mixtures only achieves a better COP at temperature above about -10°C. K Mani et al. [4] studied vapour compression refrigeration system with new R290/600a refrigerant mixture and compared with CFC12 and HFC 134a. The refrigerant mixture R290/R600a 68/32 had the highest refrigerating capacity than R12 and R134a. The refrigerating capacity of R290/R600a 68/32 mixture was 19.9 % to 50.1 % higher than R12 and 28.6 % to 87.2 % higher than R134a for the lower evaporating temperature below - 5°C. The energy consumed by the system with R290/R600a 68/32 mixture was higher by 6.8 % to 17.4 % than R12 and 8.9 % to 20 % higher than R134a for all operating conditions. Further the coefficient of performance of R290/R600a 68/32 mixture was 3.9 % to 25.1 % higher than r12 at the lower evaporating temperature below - 8°C. The refrigerant R290/R600a showed 11.8 % to 17.6 % higher than R12 at higher evaporating temperature above -8°C. Joaquin et al. [5] experimented for the influence of an internal heat exchanger on the performance of vapour compression system using R1234yf as drop in replacement for R134a. The result obtained for cooling capacity due to the internal heat exchanger adoption using R134a and R1234yf that the cooling capacity increases with the internal heat exchanger adoption being this increase between 0 % to 5 % for R134a and 2 % to 9 % for R1234yf. Due to the internal heat exchanger adoption there is an increase in the discharge compressor about 4K to 11k for both refrigerants increasing with compression ratio. However maximum value of discharge temperature in system with internal heat exchanger working with R1234yf is 355K and 369K in case of R134a. With internal heat exchanger introduction being this increased between 0 % to 6 % for R134a and 2 % to 10 % for R1234yf.

Prayudi roswati nurhasenah [6] studied the effect of subcooling on vapour compression refrigeration system with cooling load variation. Refrigerant R134a and R600a are used. He used the variations that of subcooling by operating the valves. It was found the evaporator temperature with refrigerant R134a with simple cycle between 11.7°C to 13.4°C and with subcooling ranges between 9.5°C to 11.5°C if valve is half open and 8.5°C to 10.5°C. If valve is full open also for refrigerant R600a the evaporation temperature without subcooling ranges 6.8°C to 8.9°C and with subcooling ranges 5.1°C to 6.5°C. If valve is half open and 2.9°C to 4.9°C if valve is full open greater the cooling load increases subcooling and greater decrease in temperature. The compressor work without subcooling with R134a as a refrigerant is 35. 57 kj/kg, with subcooling increase to 36.71 kj/kg if valve is half open and 37.58 kj/kg if valve is full open. Also with refrigerant R600a without subcooling compressor work is 55.79 kj/kg with subcooling increased to 56 kj/kg if valve is half open and 57.77 kj/kg if valve is full open. Further the effect on coefficient of performance the percentage increase in COP with R134a is 2.10 % if valve is half open and 2.83 % if the valve is full open. Also the percentage increase in COP with R600a is 3.59% if valve is half open and 3.49 % if valve is full open. R. Cabello et al. [7] Presented experimental comparison between R152a and R134a working in a refrigeration facility. At the same working conditions R152a yields lower compressor power consumption than R134a. This reduction in power consumption is assessed in a range between 5.52 % and 16.03 %. Further compared a discharge temperature of a R152a and R134a. it was found that R152a has always a discharge temperature higher than R134a. The maximum difference registered between R152a and R134a was 4.49 K. At the same working conditions the cooling capacity using R134a is higher than using R152a especially at high evaporating temperature. Furthermore the use of a R152a instead of R134a improves the COP of the refrigeration facility whatever the evaporating level. Prayudi et al. [8] studied the effect of the effectiveness of liquid suction heat exchanger to performance of cold storage with refrigerant R22, R404A and R290/R600a. In this liquid suction subcooling method is typically used to improve the refrigeration effect of vapour compression refrigeration system. The use of mixture refrigerant R290/R600a results in an increased in refrigeration capacity greater than using refrigerant R22 and R404A.Thus from the perspective of increase in refrigeration capacity can be said that of liquid suction heat exchangers subcooling and use of mixture refrigerant R290/R600A has better performance than using refrigerant R22 and R404A. Also the effect on work of compressor with liquid suction heat exchanger subcooling the average working compressor for R22, R404A and R290/R600a respectively by 47.596 Kj/kg, 40.15 Kj/kg and 84.205 Kj/kg. The liquid suction heat exchanger subcooling leads to increase in compressor work. Now effect of liquid suction heat exchangers subcooling on COP for R22, R404A and mixture of R290/R600a respectively is 2.63, 3.18 and 3.38. Thus from the perspective of increase in COP the use of liquid suction heat exchangers subcooling and use of mixed refrigerant R290/R600a has better performance than using refrigerant R22, R404A on vapour compression refrigeration system.

The existing domestic refrigerator system working with the refrigerant R134a is experimentally tested with the use of hydrocarbon refrigerant mixture R290/R600a (50:50). Behind all this the motivation related to environmental friendliness, energy conservation, safety and economy, etc. The use of environmentally unfriendly refrigerants is still dominant in many domestic and commercial refrigeration systems and becomes a reason for increment in global warming. One of the factors for this increased use of such refrigerants is associated with costs attached to the replacements of existing systems. It may be expensive to buy a new unit using non- CFC refrigerant to replace the existing refrigeration package, in which case to find the alternative refrigerant for the existing system may be the cost effective option. In the present work, an experimental study has been done with hydrocarbon refrigerant mixture consist of R290/600a in the ratio of 50:50 by weight as an alternative to R134a in a domestic refrigerator of capacity 220 litre. Also an attempt is made to improve the system performance with the use of liquid line suction line heat exchanger (LSHX). The experimental comparison for the system performance between R290/R600a and R134a were performed under ambient temperature of 29°c with constant evaporator temperature of -25°c and condenser temperature of 42°c.

II. EXPERIMENTAL SETUP

Test rig shown in figure 1 mainly consists of four major components they are compressor, condenser, expansion device and evaporator as in basic vapour compression refrigeration system. The refrigeration system used for experimentation was of 220 litre capacity originally designed for the refrigerant R134a.. We brought components individually other than four major components of vapour compression system and assembled as a domestic refrigerator test rig. Along with the major components this system consist of counter flow heat exchanger i.e. LSHX, rotameter 1 and rotameter 2 as a fluid flow measurement devices i.e. for the measurement of mass flow rate of vapour refrigerant and for liquid refrigerant respectively, temperature sensors for the measurement of temperatures at six different locations, pressure gauges for the measurement of compressor suction and discharge pressure. And energy meter for the measurement of compressor power consumption. In this, two different systems one is simple vapour compression refrigeration system and other one is LSHX vapour compression refrigeration system. And these two different systems is control with the help of five valves. These five valves are placed at five different positions in order to regulate the flow of refrigerants for the completion of system. These valves are in red colour. The names of valves are V1, V2, V3, V4, and V5, the actual positions of these five valves are shown in figure 1. Initially the refrigerant R134a is used and then the mixture of hydrocarbon R290/R600a in the ratio of 50:50 by weight is used as refrigerant. Compressor used is of a single cylinder hermetic reciprocating compressor design and manufactured by LG. It is original designed for only R134a, such type of compressor using in almost every domestic refrigerator system. There is no compressor design for the hydrocarbon refrigerant mixture of R290/R600a in the ratio 50:50 by weight, So that experiments were done in this compressor. This is mainly for finding the alternative to the currently using refrigerants R134a which is used as a working fuel in domestic refrigerator. Condenser used is of wire and tube type and it has serpentine shape. This condenser rejected the heat to the air by natural Convection. Next one is evaporator of coil and shell type is used. It is a box type of heat exchanger which is made up of aluminium. Capillary tube is used as expansion device.

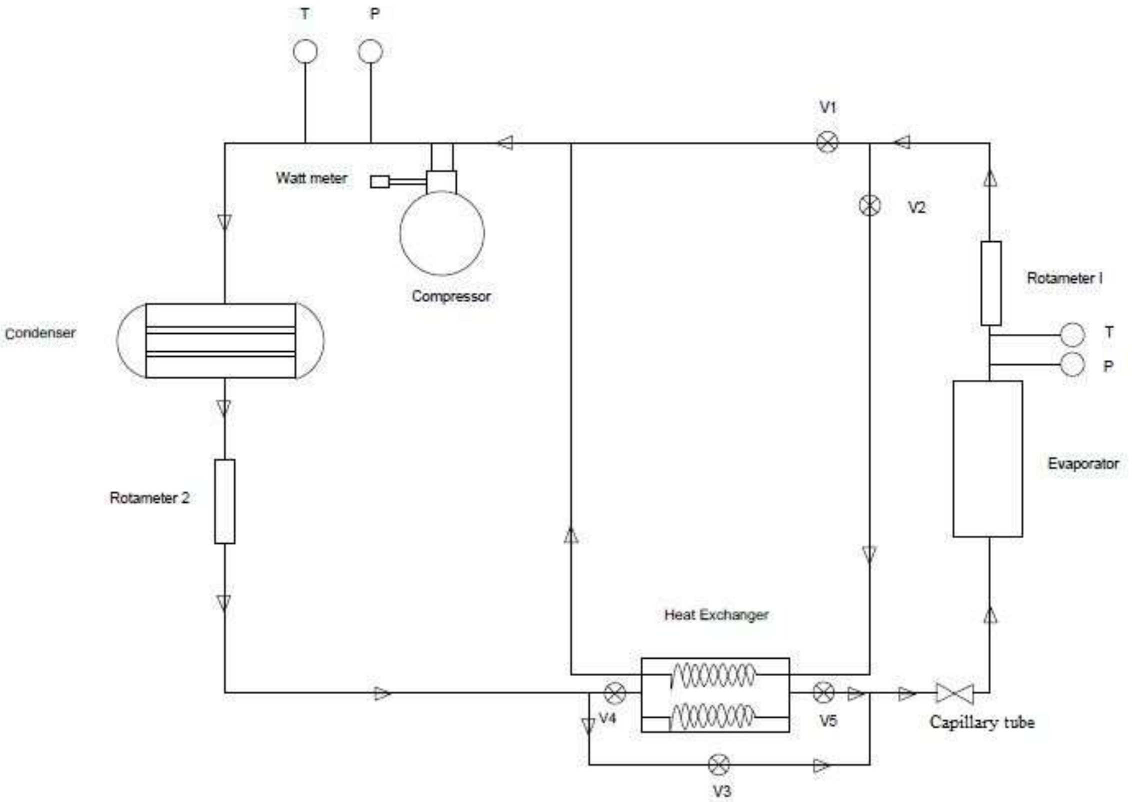

Fig. 1 Schematic diagram of domestic refrigerator experimental setup.

III.EXPERIMENTAL PROCEDURE

Initially the system was flushed with nitrogen gas to eliminate moisture, foreign materials and other impurities which are available inside the system, which may affect the accuracy of the experimental results with this whole components of test rig was evacuated using vacuum pump, once system is evacuated then suction line of compressor is attached with the valve of refrigerant cylinder. As per the manufacturer's recommendation 190 gram of mass charge of R134a was charged in the refrigerator system for conducting the baseline test. From figure 1 there are five valves are provided in order to regulate the system, this regulation will help to convert the simple vapour compression refrigeration system in to the LSHX vapour compression refrigeration system. Among the five valves V2, V4 and V5 was closed and V1 and V2 was open to form simple vapour compression refrigeration cycle. During experimentation with R134a 3 metre capillary tube length was used. The running test was carried out by connecting the evaporator inside the refrigerator with the system. All the experimental observations were made after attaining the steady state condition for 3 hours. Test were carried out at 29°C ambient temperature with the constant compressor suction pressure of 15 psi and compressor discharge pressure of 155 psi which is kept constant throughout the experimentation. Temperature at different locations were recorded in every 10 minutes of interval also the pressure at compressor suction and discharge was measured in every 10 minutes of interval which was observed as a constant as per manufacturers recommendation. The energy consumption of compressor was measured by separate energy metre after the attainment of steady state condition. In order to reduce the experimental uncertainties, experiment was repeated for three times and average values were considered. After the completion of the baseline reference test with R134a as a refrigerant in simple vapour compression refrigeration cycle then turned off the refrigerator switch and operated the walls V1 and V3 in closed position which was initially open for simple cycle. After then open the valves V2, V4 and V5 simultaneously, with this the baseline system gets converted into liquid suction heat exchanger vapour compression cycle. After operating the valves, allowed the compressor to completely cool up to the surrounding temperature. After this switched on the system and the same procedure was followed for the liquid suction heat exchanger vapour compression refrigeration system running with refrigerant R134a similar with simple vapour compression refrigeration system. The running test was carried out at 29°C ambient temperature and also with the constant compressor suction pressure and compressor discharge pressure. After recording of the experimental data of simple vapour compression refrigeration system and liquid suction heat exchanger vapour compression system recover the refrigerant R134a from the refrigeration system. Before starting of the experimentation with hydrocarbon mixture refrigerant turn the refrigerator for vacuuming with the help of vacuum pump up to the zero mm of Hg. as it is calibrated on suction side of low pressure gauge. Once the system is evacuated then the suction line of compressor is attached with the valve of refrigerant cylinder using pressure gauge. The suction side pressure of a domestic refrigerator is kept generally at 15 psi and in order to maintain the same pressure of 15 psi in the system so we charged the hydrocarbon mixture refrigerant up to the suction pressure of 15 psi and measured the charge amount of hydrocarbon mixture refrigerant with the help of electronic balance having an accuracy of ± 0.01 gram. Then system was charged with 92 gram of hydrocarbon mixture refrigerant and the running test was repeated for HCM R290/R600a (50:50) same as the simple vapour compression refrigeration system of R134a. Similarly with same charge amount of hydrocarbon mixture refrigerant, running test was repeated for HCM R290/R600a (50:50) same as liquid suction heat exchanger vapour compression refrigeration system of refrigerant R134a. After this the experimental data were recorded for the same system.

IV.RESULTS AND DISCUSSION

This chapter presents the results of the experimental performance that was conducted on R134a and hydrocarbon refrigerant mixture for simple vapour compression refrigeration system and also with liquid suction vapour compression refrigeration system. The main purpose was to compared the experimentally a refrigeration system that is originally designed for pure R134a refrigerant with the hydrocarbon refrigerant mixture of R290/R600a 50:50 by weight under the same operating conditions of evaporation pressure, condensation pressure and the ambient temperature.

4.1. Refrigeration effect

In figure 2 the actual refrigeration effect of hydrocarbon refrigerant mixture is greater than about 35.28 % than R134a working in simple vapour compression refrigeration system. The refrigeration effect of hydrocarbon mixture refrigerant is greater than R134a, this shows that the heat absorbed in the evaporator is maximum when hydrocarbon refrigerant mixture is used as the working fluid in simple cycle.

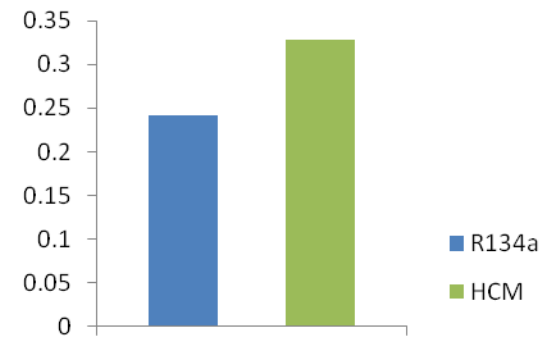

Fig. 2 Comparison of actual refrigration effect between R134a and HCM of simple vapor compression refrigeration system

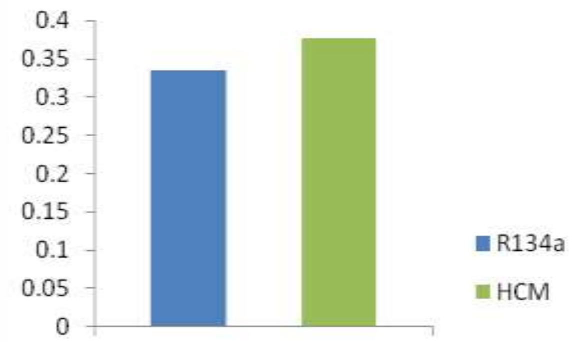

Fig. 3 Comparison of actual refrigration effect between R134a and HCM of LSHX vapor compression refrigeration system

Further the effect on the refrigeration effect when simple system was improved with liquid suction heat exchanger to form liquid suction heat exchanger vapour compression refrigeration system. Now figure 3 for liquid suction heat exchanger vapour compression refrigeration system the actual refrigeration effect for the hydrocarbon refrigerant mixture and R134a is directly calculated experimentally. And it was found that the actual refrigeration effect for hydrocarbon refrigerant mixture is larger about 12.5 % than R134a. From the above figure the actual refrigeration effect for hydrocarbon refrigerant mixture working in both the system of simple system and with the use of liquid suction heat exchanger system, it seems that the heat absorption in the evaporator for R290/R600a 50:50 is larger than the R134a. The refrigeration effect is desirable parameter for the refrigeration system.

4.2. Compressor work done

As referring to the figure 4, the actual work done of compressor for hydrocarbon refrigerant mixture is less than R134a working in simple system and this is less than about 29.58 % than R134a. This actual work done of compressor for hydrocarbon refrigerant mixture and R134a working in simple system calculated experimentally. Also referring to figure 5 with the adoption of liquid suction heat exchanger it seems that actual compressor work done for hydrocarbon refrigerant mixture is smaller than R134a by about 14.68 %. This actual compressor work done value for hydrocarbon refrigerant mixture and for R134a with liquid suction heat exchanger system is calculated experimentally. In general lower the value of compressor work done less is the power consumption by the system.

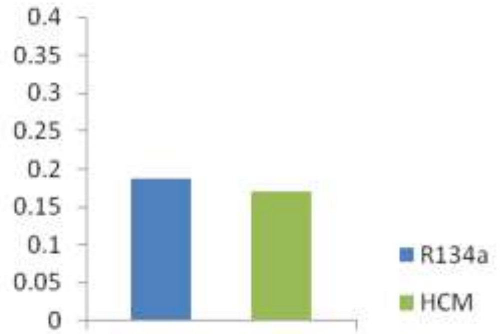

Fig. 4 Comparision of actual compressor work done between R134a and HCM for simple vapor compression refrigeration system

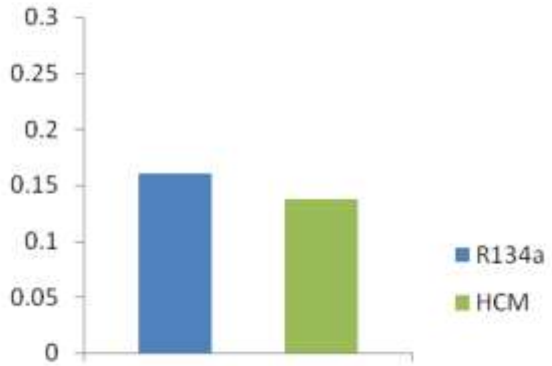

Fig. 5 Comparison of actual compressor work done between R134a and HCM of LSHX vapor compression refrigeration system

As seen from both the refrigeration system the theoretical compressor work done is greater for hydrocarbon refrigerant mixture than R134a in both refrigeration system i.e. simple system and with liquid suction heat exchanger system. In contrast to this the actual compressor work done for the hydrocarbon refrigerant mixture is smaller than the refrigerant R134a in simple cycle and with liquid suction heat exchanger cycle.

4.3. Coefficient of performance

As referring to the figure 6, the actual coefficient of performance for hydrocarbon refrigerant mixture is greater than R134a working in simple system by 46.92 %. This actual coefficient of performance for hydrocarbon refrigerant mixture and R134a working in simple system calculated experimentally.

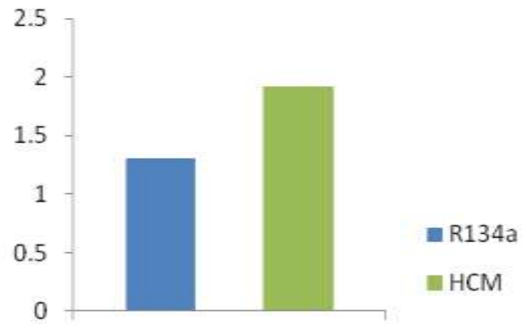

Fig. 6 Comparison of actual COP between R134a and HCM for simple vapor compression refrigeration system

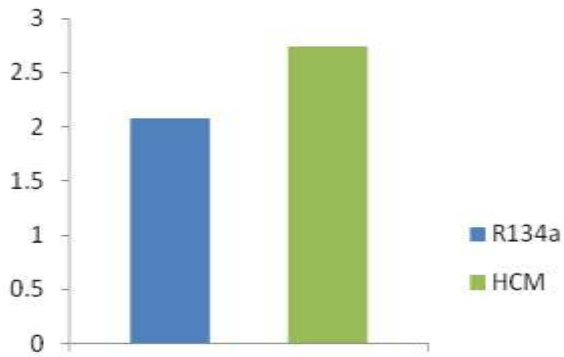

Fig. 7 Comparison of actual COP between R134a and HCM for LSHX vapor compression refrigeration system

Also referring to figure 7 with the adoption of liquid suction heat exchanger it seems that actual coefficient of performance for hydrocarbon refrigerant mixture is greater than R134a by about 31.91 %. This actual coefficient of performance value for hydrocarbon refrigerant mixture and for R134a with liquid suction heat exchanger system is calculated experimentally. The coefficient of performance is a ratio of cooling provided to the work required. Higher COP equates to lower operating costs.

4.4. Compressor discharge temperature

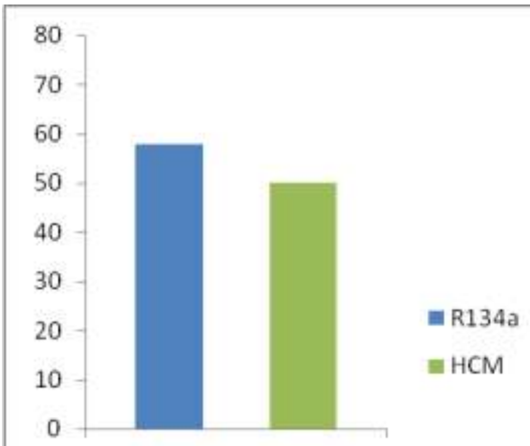

Fig. 8 Comparison of actual compressor discharge temprature between R134a and HCM of simple vapor compression refrigeration system

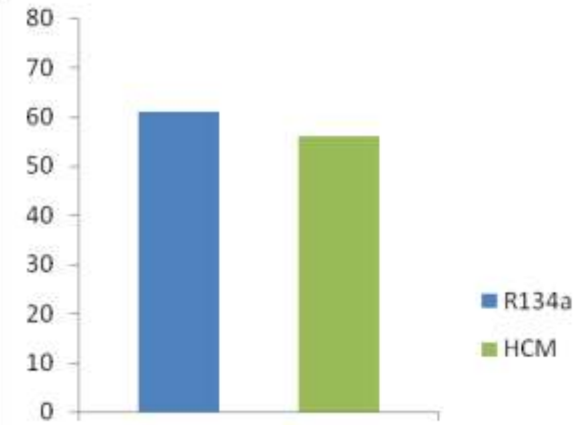

Fig. 9 Comparison of actual compressor discharge temperature between R134a and HCM for LSHX vapor compression refrigeration system

Figure 8 shows the actual compressor discharge temperature for HCM is less than the R134a by about 13.79 % working with simple system and it is obtained directly by measuring with the help of temperature sensors. Also from figure 9 with adoption of liquid line suction line heat exchanger the actual compressor discharge temperature for HCM and R134a is taken into consideration. It seems that temperature for HCM is smaller than the R134a by about 8.19 %. And it is directly measure with the use of temperature sensor.

With the adoption of liquid line suction line heat exchanger there is an increment in compressor discharge temperature for both refrigerants i.e. for R134a and HCM. When comparing with R134a the HCM have less compressor discharge temperature in both the cases like in simple system and with the liquid suction heat exchanger system.

V. CONCLUSION

Experimental performance of a domestic refrigerator of working fluid R134a is experimentally tested with hydrocarbon refrigerant mixture R290/R600a (50:50) by weight and the following conclusions are drawn. The mass charge of hydrocarbon refrigerant mixture of R290/R600a (50:50) requirement is significantly lower which is almost half of the refrigerant mass charge of R134a. The R290/R600a (50:50) mixture exhibits higher actual refrigeration effect than R134a at same condenser temperature and evaporator temperature. For R290/R600a (50:50) the actual work done of compressor is smaller than the R134a also the compressor discharge temperature for R290/R600a is less than the R134a. So the compressor running with R290/R600a has longer running life than running with R134a. The R290/R600a mixture exhibits higher COP value than R134a at same condenser and evaporator temperature. Also the use of liquid line suction line heat exchanger for both the refrigerants R134a and HCM is favourable i.e. there is a positive effect on refrigeration effect and finally on COP. The hydrocarbon refrigerant mixture R290/R600a (50:50) can act as an alternative for refrigerant R134a.

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