Evaluation of supplementary / retrofit refrigerants for domestic refrigerators charged with HFC134a.

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Abstract - Conversion of R134a systems to environment friendly ones will be a major thrust area for refrigeration sector in the present time. As and when an existing refrigerator of R134a has to be recharged it is suggested to retrofit the system with new/natural and alternative refrigerants. Presently, hydrocarbon mixtures and pure hydrocarbons are available in market to replace R134a, but the optimum ratio and mass fraction to be used for better and safe performance of the system is given by only few researchers. This investigation focuses on mixture ratio of pure hydrocarbon R290 and R600a used in 200 liter domestic refrigeration system by certain changes in size of capillary. The performance of the HCM mixture R600a/R290 (60/40 by wt. %) was compared with those of HFC and HFC / HC mixtures at capillary length of 10 and 11 feet. It was observed that the COP of 125g R600a/R290 mixture was higher by 53.1% and 93.26% than that of 250g R134a at -5 ^{0}C and 5 ^{0}C evaporative temperatures, respectively. The pressure ratio was the maximum for the refrigerant R134a, at the capillary length of 10 feet and was in minimum for HCM R600a/R290.

Back pressure was in the range of 15 psi to 30 psi (commercial back pressure) by using HCM of 125g R600a/R290 in the VCR system, which is suitable for deep freezing purposes.

Keywords - HFC134a, Mass ratio of HCM, Domestic Refrigerator, R600a, R290.

1 Introduction

For the past half century, CFCs have been used extensively in the refrigeration sector. (CFCs) and hydrochlorofluorocarbons (HCFCs) became the most dominant types of refrigerants due to their properties of non- corrosiveness, non-flammability, non-toxicity and non-irritability[1-2]. The problems occurred, when in 1974, Molina and Rowland, reported and published their ozone depletion hypothesis in which they claimed that the chlorine element catalytically destroyed the ozone layer in the stratosphere [3]. In addition it was also found that these refrigerants were significant greenhouse gases. Air conditioning and refrigeration applications at domestic, industrial and commercial levels are becoming an essential part of present day living. Hydroflourocarbons (HFCs) and Hydrochloroflourocabons (HCFCs) have been used in refrigerators and air conditioners as a working refrigerant. Hydroflourocarbons (HFCs) can be short and mid-term replacements, but may not be permanent due to their high global warming potential (GWP) [4]. The need to find a long term solution calls for the use of natural refrigerants. The refrigerator and air- conditioning industries have started to address the future challenges. Within limited time the HCFCs including R-22 will also have to be substituted. Montreal protocol (MP) on substances that deplete ozone layer was established to phase-out the production and consumption of ozone depleting substances[5]. The Kyoto protocol (KP) in 1997 has decided to put HFCs together with other five gases such as CO_2, N_2O, CH_4, PFCs and SF_6 in one basket of controlled substances [6]. Several criteria must be considered while selecting alternative refrigerants. Since the process of search started, many computer programs have been developed worldwide. The experimental work carried out in this area is also extensive. Many drop-in tests are being carried out to check the performance of replacement refrigerant in existing machines, designed for CFCs, HFCs and HCFCs. Y. S. Lee et al.[7] did an experiment and tested Iso-butane in domestic refrigerator. The compressor input power varies from 230 and 300 W, while the refrigerant charged was about 150 g. It was found that the COP lie between 0.8 - 3.5 in freezing application. This study focused only on the performance of a VCR system with R600a as the alternative refrigerants. B. Tashtoush et al. [8] conducted an experiment with the aim to analyze hydrocarbons (R600/R290/R134a) at various quantities in R12 domestic refrigerator. The results shows that Butane/Propane/R134a mixtures provide excellent performance parameters, such as COP of refrigerators, compression power, volumetric efficiency, condenser duty, compressor discharge pressure and temperature, relative to a 210 g charge of R12.

2 Literature Survey

E. Halimic et al. [9] had experimented and studied to compare the operating performance of three alternative refrigerants R401a, R290 and R134a with R12 for vapor compression refrigeration cycle on the basis of refrigeration capacity and COP. Hence when seen in terms of green house impact, COP and cooling effect R290 gained the best performance than other. S. Joseph Shekhar et al. [10] had performed experimental analysis on a 165 liter, CFC-12 based domestic refrigerator retrofitted with eco-friendly refrigerant mixture of HFC134a / HC290 / HC600a without changing the mineral oil. The system had been running successfully for more than 12 months, thus it was observed that the new mixture was compatible with mineral oil. The improvement in theoretical analysis of COP and actual COP were found out from 3 to 12% and 3 to 8%, respectively. Somchai Wongwises et al. [11] had analyzed by conducting a study on a refrigerator designed to work with HFC-134a with a gross capacity of 239 liter. The refrigerant mixtures have been classified in three groups:

i. Mixture of three hydrocarbons: It contains of the three pure hydrocarbons (propane/isobutene/butane) mixture in the ratio of 75/25/5, 100/0/0 and 50/40/10.
ii. Mixture of two hydrocarbons: It consisted of two pure hydrocarbons propane / butane and propane / iso-butane in the ratio of 60/40.
iii. Mixture of two hydrocarbons : This is the mixture of propane / butane or propane/ Iso-butane in the ratio of 40/30 and rest of HFC-134a are in mixtured in appropriate ratio.

In this way, groups of hydrocarbon mixtures were experimented and the best alternative of HFC 134a in each group was selected. Hence it can be shown that the propane/butane (60/40 by wt. %) was the most appropriate alternative refrigerant to R134a. M. Fatouh et al. [12] had used LPG i.e. mixture of 60% propane and 40% commercial butane for drop-in replacement of HFC134a, in a single evaporator domestic refrigerator with a volume of 10 ft^3. Highest actual COP, lowest on-time ratio and lowered electric consumption were achieved in LPG refrigerator than that of R134a by 7.6%, 14.3% and 10.8%, respectively. Hence, it can be concluded that the proposed LPG shown to be an appropriate and long-term alternative refrigerant to replace R134a in the existing refrigerator. M. Fatouh et al. [13] found the possibilities of using hydrocarbon mixtures as a alternative refrigerant to replace R134a in a domestic refrigerators through, a simulation analysis. The results found that the pure propane couldn't be used as a drop-in replacement for R134a in domestic refrigerators because of its high operating pressures and lower COP. Commercial butane obtained many desirable characteristics but required compressor change. The reported results confirmed that the propane / Iso-butane/butane mixture with 60% propane was the best drop in replacement for R134a in domestic refrigerators under normal, tropical and subtropical operating conditions. K.Senthil Kumar et al. [14] experimentally tested HC mixture (30%R290 & 70%R123) and computationally replacing R12 in this work, to overcome the above said problem, in a refrigerant mixture R290 has been identified as suitable for combination with R123. It is observed that the difference of pressure and temperature characteristics disappears as the R290 mass fraction is increased from 10% to 30% with R123 and the curve almost matches the R12 curve, which symbolized that mixture 7/3 can exhibits similar properties and could be used as a substitute for CFC-12. M. Mohanraj et al. [15] studied that domestic refrigerator uses HFC134a as refrigerant, due to its excellent thermodynamics and thermal-physical properties. But, HFC134a has high global warming potential (GWP) of 1300. This paper presents experimental results of an energy-efficient hydrocarbons (HC) mixture consisting of 45% HC290 and 55% HC600a as a drop-in substitute for HFC134a as various mass charges of 40 g, 50 g, 70 g and 90 g in domestic refrigerators. The experiments were done in a165 liter domestic refrigerator using HFC134a with synthetic oil as lubricant. The performance characteristics such as COP, energy consumption, pull-down time and discharge temperature of HC mixture were measured and compared with those of HFC134a. During the experimentation the ambient temperature was maintained at 30± 2^{o}C. The results practically showed that the 70 g mixture as barrier of COP, lower power consumption, lower pull-down time and lower discharging temperature than HFC134a. The miscibility of synthetic oil with HC refrigerant mixture was also found to be good. K. Mani et al. [16] done an experiment and analyzed that the performance study on a VCR system with the new refrigerant mixture R290/R600a as a drop-in replacement was with CFC-12 and HFC134a.

Experimental results showed that the refrigerant effect of R290/R600a (68/32 by wt. %) mixture was higher than that of R12 in the range of 19.9% to 50.1% at the lower evaporating temperature and in the range of 21.2 to 28.5% at the higher evaporating temperatures, respectively. COP of R290/R600a mixture increased from 3.9% to 25.1% at lower evaporating temperatures than that of R12 and COP of R290/R600a mixture increased from 11.8% to 17.6% at higher evaporating temperatures to than that of R12. The refrigerant R134a showed slightly lower coefficient of performance than R12. The R290/R600a (68/32 by wt. %) mixture can be considered as a drop-in replacement refrigerant for CFC-12 and HFC134a refrigerants.

3 Experimental Setup

An experimental set-up for vapor compression refrigeration system was built up to investigate the performance of 250g R134a, 200g mixture of R134a/R600a/R290 (82.5/10/7.5 by wt.%) and 125g mixture of R600a/R290 (60/40 by wt %) refrigerants. Fig 3.1 shows actual view of the experimental set-up. The test object was a 200 liter domestic refrigerator (with deep freezing capacity) that was originally designed for R134a and mass of refrigerant was 150 g. When the baseline tests were conducted with calorimeter, 250g R134a was used due to increased size of evaporator tube inside calorimeter and multi capillary arrangement for capillary optimization. Hermetically sealed reciprocating compressor of 200 liter refrigerator recommended for R134a refrigerant (with deep freezing capacity) was used in the experiment. Pressure, temperature and a wattmeter was attached with the compressor to find out of the values at suction and discharge side. The size of condenser 10x10 square inches for single pass copper tubing having size 1/4 inches, with thin aluminum sheets crosswise for improvement of heat dissipation. Capillary tubes of size 10 feet (3m),11 feet (3.35m) and 12 feet (3.5 m) length and diameter 0.036 inches were alternatively used as expansion device in the system. Experiment was conducted only for capillary tubes of size 10 and 11 feet length to assesses and optimize the capillary for above mentioned VCR system. A calorimeter connected in the loop designed for measuring refrigerating effects of the system. It consisted of a cooling coil of 5/16 inches diameter and 25 feet length, temperature measuring device, a stirrer rotted by motor, a electric heater and a watt meter to measure R.E.

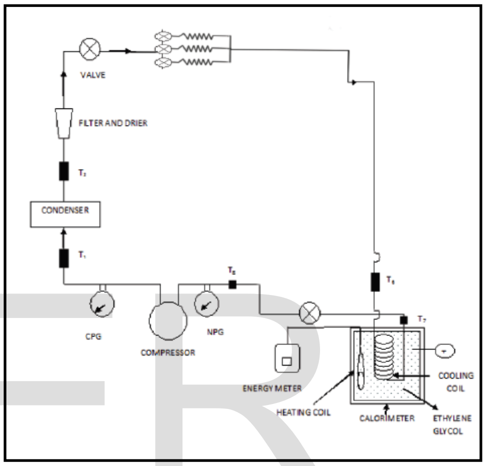

Figure 3.1: Line diagram of the experimental set-up with multi capillary arrangement.

4 Experimental procedure

Initially, the system was evacuated by using vacuum pump up to the negative pressure -20 psi to eliminate impurities, moisture and other foreign materials present inside the system, which might affect the accuracy of the experimental set-up. Then the refrigerator was charged with the help of electronic weight m/c and charging valves. After appropriate mass charging the system was started with the help of electric switches and regulator. When the system reached steady state condition (calorimeter temperature was maintained for 10 minutes at measured value temperature with the help of dimmerstat) watt meter readings for compressor and calorimeter were measured.

To change the capillary (length) shut valves were used. Temperatures were recorded in ^{0}C by 9 thermocouples, which were placed at all major equipments, after every 10 minute interval. Pressure at suction and discharge of the compressor were also measured by two pressure gauges, after every 10 minute interval. In pull down test system was cooled up to desired temperature from atmospheric temperature. R. E. at particular evaporating temperature was found by maintaining calorimeter, at that temperature with the help of heating device and at the same time watt meters reading was also recorded. In this process, wattmeter attached with calorimeter gave R. E. and wattmeter attached with compressor gave power consumption. This process was repeated for every capillary size and refrigerants were tested at all measured evaporating temperature.

5 RESULT AND DISCUSSION

The experimental results obtained from the performance analysis of 250g R134a(HFC), 200g mixture of R134a/R600a/R290 (82.5/10/7.5 by wt.%, HFC/HC) and 125g mixture of R600/R290 (60/40 by wt%, HC) refrigerants have been discussed with respect to the parameters such as pull down test, refrigerating effect, compressor energy consumption, COP, temperatures and pressure ratio (P_1/P_2) for capillary of 10 feet and 11 feet lengths, to optimize the refrigerant for the system.

5.1 Pull down characteristics

The temperature of ethylene glycol (10 liter) was reduced from 20 ºC in 60 minutes (continuous running test) for different lengths of capillary and refrigerants. The lowest temperature obtained in calorimeter was -7.5 ºC for 200 g R134a/R600a/R290 (82.5%/10%/7.5% by wt.%) at capillary length of 11 feet. Second lowest temperature in calorimeter was measured to be -5.4 ºC for 125 g R600a/R290 mixture (60/40 by wt. %) at capillary length of 11 feet. It was observed that the cooling effect of 200 g mixture R134a/R600a/R290 was maximum as compared to other tested refrigerants, at 11 feet capillary length. It is due to the fact that the cooling rate increases with the increase of mass flow rate of refrigerant. The increase in propane mass fraction, refrigerant mass flow rate increases M. Fatouh et al.[16,38]. Also with the increase in capillary length (with sufficient mass), inlet temperature of the evaporator decreases that also increases cooling rate of the system. The nature of the graphs is similar as reported by Chao-Chieh Yu et al. [18].

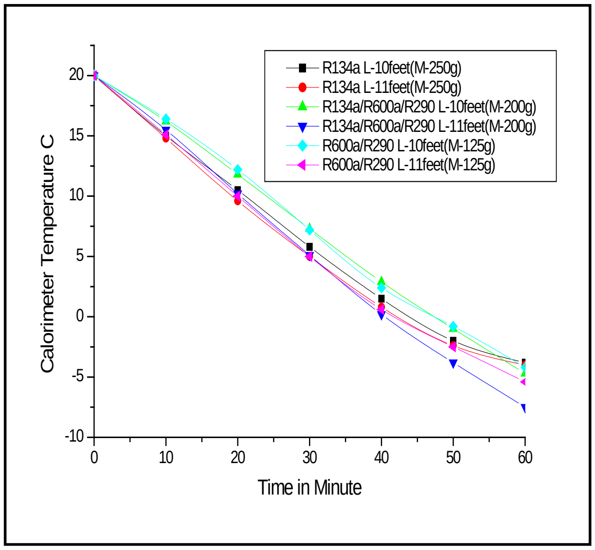

Figure 5.1 : Variations of calorimeter temperature with respect to time in minute.

5.2 Refrigerating effect

Figure 5.2 shows the effect of evaporating temperature on R. E. for the three refrigerants 250 g R134, 200 g R134a/R600a/R290 (82.5/10/7.5by wt.%), and 125 g R600a/R290(60/40 by wt.%) and two capillaries of length 10 feet and 11 feet. It was seen that the over entire range of evaporating temperature, the R.E. was in general maximum for the mixture R134a/R600a/R290, at 10 feet length because of its higher mass flow rate. Mixture R134a/R600a/R290 provided R. E. higher by 60% and 45.5% than that of the refrigerants R134a and R600a/R290, respectively at -5 ºC evaporating temperatures for capillary length of 10 feet. Over complete range of investigated evaporating temperatures, the refrigerating effect was measured to be minimum for R134a at 250 g for the capillary length of 10 feet. The R. E. increases with the increase in length for the R134a, whereas it decreases with the increase in length for the HCM, since mass flow rate decreases as the length of the capillary increases. The nature of the graphs is similar as reported by M. Mohanraj et al. [17].

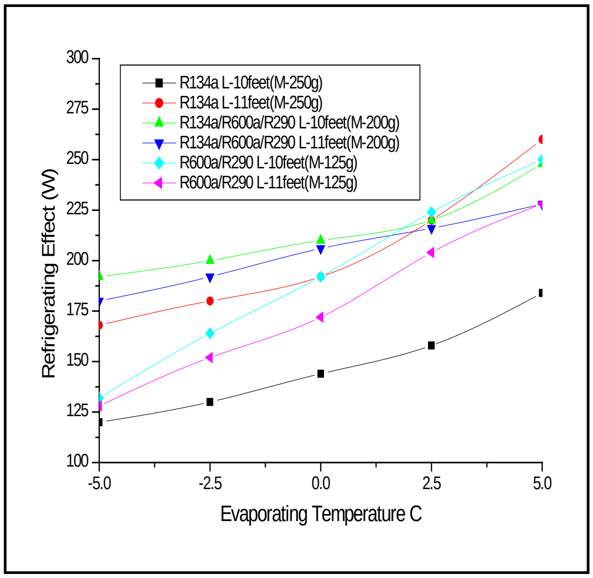

Figure 5.2: Variations of refrigerating effect with respect to the evaporating temperatures.

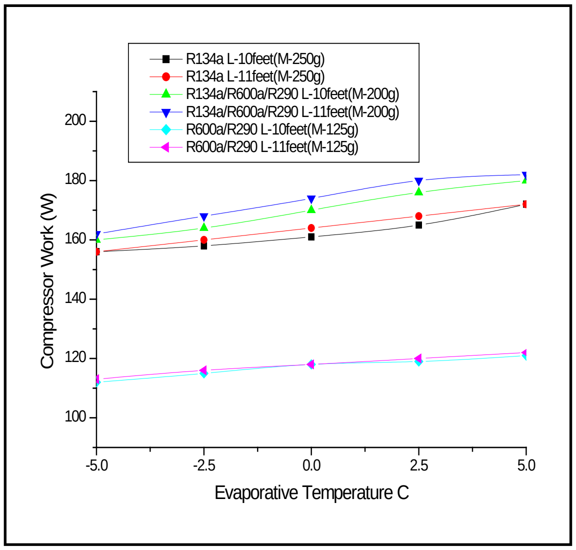

Figure 5.3 : Variations of energy consumption with respect to the evaporating temperature.

5.3 Compressor energy consumption

Figure 5.3 shows the effect of evaporating temperature on power consumption for the three refrigerants 250 g R134, 200 g R134a/R600a/R290 (82.5/10/7.5by wt.%), and 125 g R600a/R290 (60/40 by wt.%) at the capillaries length of 10 feet and 11 feet. It was seen that the energy consumption increases with the increase in the evaporating temperature. It was also observed that the over entire range of evaporating temperature, the power consumption was maximum for the mixture R134a/R600a/R290 at capillary length of 11 feet, and minimum for the mixture R600a/R290 at capillary length of 10 feet. Energy consumption was lowest for 125 g HCM R600a/R290 refrigerant due to its lowest mass flow rate. Refrigerant R134a/ R600a/R290 consumed higher energy than that of R134a by 3.8% and 5.8%, at -5 ºC and 5 ºC evaporating temperatures, respectively at capillary length of 11 feet. Energy consumption for 125 g R600a/R290 was lower than that of 250 g R134a by 39.2% and 42.1%, at -5 ºC and 5 ºC evaporating temperatures, respectively for the capillary length of 10 feet. The nature of the graphs is similar as reported by M. Mohanraj et al. [17].

5.4 Coefficient of performance (COP)

Figure 5.4 shows the effect of evaporating temperature on COP for the refrigerant 250 g R134, 200 g R134a/R600a/R290 (82.5/10/7.5by wt.%), and 125 g R600a/R290 (60/40 by wt.%) at capillary lengths of 10 feet and 11 feet. It was observed that the COP was maximum for the refrigerant R600a/R290 (60/40 by wt.%) at capillary length of 10 feet and minimum for R134a at capillary length of 10 feet. It was due to the minimum work consumed by compressor for refrigerant 125 g R600a/R290 (60/40 by wt.%) than others refrigerant. It was also observed that the COP of R600a/R290 (60/40 by wt.%) was higher than that of R134a by 53.1% and 93.26% at -5 ºC and 5 ºC evaporative temperatures, respectively and for the capillary length of 10 feet. It was observed from the graphs that the COP of R134/R600a/R290 was higher than that of R134a by 56% and 29% at -5ºC and 5 ºC evaporating temperatures, respectively and for the capillary length of 10 feet. At lowest evaporating temperature R134a/R600a/R290 gave 2% higher value of COP than that of R600a/R290 (60/40 by wt.%) due to its higher mass flow rate, which improves R. E. The results obtained are in good agreement with the results of K. Mani et al.[16].

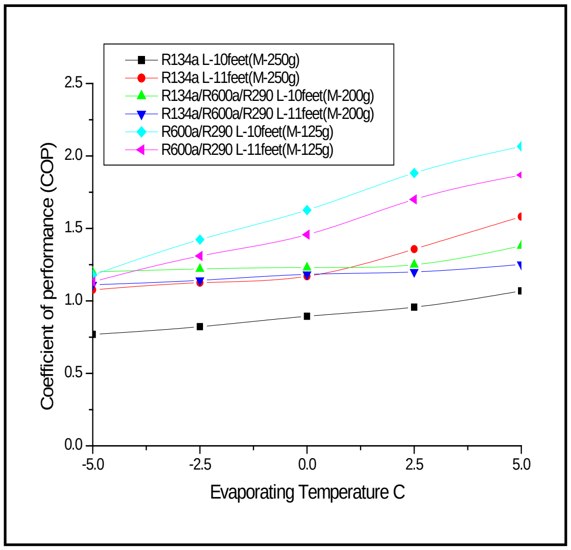

Figure 5.4 : Variations of coefficient of performance with respect to the evaporating temperature.

5.5 Pressure ratio (P_1/P_2)

The pressure ratio was the maximum for the refrigerant R134a at the capillary length of 10 feet and was in general minimum for HCM R600a/R290 at the capillary length of 10 feet. The minimum pressure ratio of R600a/R290 is because of its lowest mass and better volumetric efficiency.

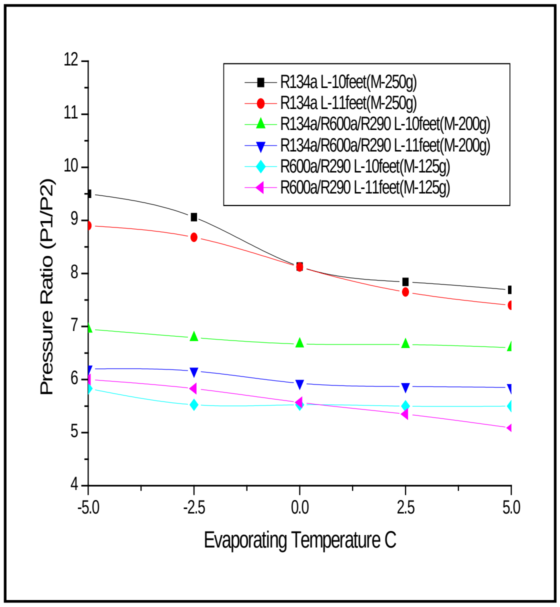

Figure 5.5 : Variations of compressor pressure ratio P_1/P_2 (Discharge /Suction)with respect to the evaporating temperature.

5.6 Compressor Discharge Temperature

Compressor Discharge Temperature always be higher for small length capillary for same refrigerants but you can see in graphs the value of discharge temperature was quit low for HCM because lower mass of refrigerants as well as better cooling tendency of HCM than other tested refrigerants. This is also give advantage for consumption of lubricating oil also low for HCM.

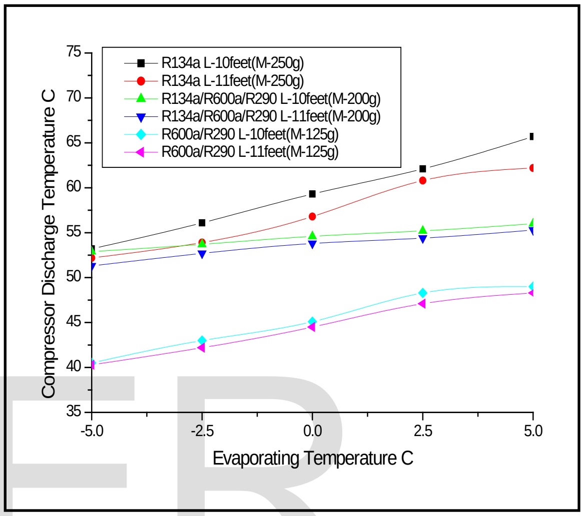

Figure 5.6: Variations of compressor discharge temperature with respect to the evaporating temperature.

6 CONCLUTION

The cooling effect of 200 g HFC and HC mixture of R134a/R600a/R290 at the 11 feet capillary length was the maximum as compared to that for other refrigerants. Over entire range of evaporating temperatures, the R. E was in maximum for the mixture R134a/R600a/R290 at 10 feet length because of its higher mass flow rate in the evaporator. Mixture R134a/R600a/R290 provided R. E. higher by 60% and 45.5%. than that of R134a and R600a/R290, respectively at -5 ºC evaporating temperature and for that capillary length was 10 feet. Energy consumption was the lowest for 125 g HCM R600a/R290 refrigerant due to its lowest mass flow rate. Energy consumption for 125 g R600a/R290 was lower than that of 250g R134a by 39.2% and 42.1%, at -5 ºC and 5 ºC evaporating temperatures, respectively for that capillary length was 10 feet. COP of HCM refrigerant R600a/R290 was higher than that of

R134a by 53.1% and 93.26%, at -5ºC and 5ºC evaporating temperatures, respectively for that capillary length was 10 feet. COP of R134a/R600a/R290 mixture was higher than that of R134a by 56% and 29%, at -5 ºC and 5 ºC evaporating temperatures, respectively for that capillary length was 10 feet. The pressure ratio was the maximum for the refrigerant R134a, at the capillary length of 10 feet and was in minimum for HCM R600a/R290.

Finally, different pure hydrocarbons fluids can be mixed in different mass ratio for future requirements of refrigeration and air conditioning industry.

7 FUTURE SCOPE

Hydrocarbons and its mixtures refrigerants are most promising alternatives as they are environment friendly. Hydrocarbon based refrigerator require safety precaution when they are used for domestic purposes, so further study is required to find out inflammable limits of HCM R600a/R290 (60/40 by wt. %). The GWP value of HFC and HC mixed refrigerant (at different mass ratio) is also one of the important parameter because if it's value of is with-in the permissible limit, then the HFC and HC mixed refrigerant are most promising alternative refrigerant to be retrofitted in the present VCR systems, because of its having HFC part in it which is non flammable.

Finally, different pure hydrocarbons fluids can be mixed in different mass ratio for future requirements of refrigeration and air conditioning industry.

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