EXPERIMENTAL ANALYSIS OF ALTERNATIVE REFRIGERANT AS REPLACEMENT OF HFC134A

Deepak Paliwal[1], S.P.S.Rajput[2]

[1,2] Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal, (India)

ABSTRACT

An experimental performance study on VCR system with 100g R600a/R290 refrigerant mixture and 100g R600a (pure isobutene) as drop in replacement of R134a was conducted . continuation running tests were performed under different length of capillary for R600a/R290 & R600a. The result showed that the hydrocarbon mixture (R600a/R290) had highest COP at L=10 feet length capillary by17.35% -23.5% for 5^{0}C to -5^{0}C evaporating temperature. Pull down time also lesser for R600a/R290 mixture than R600a pure isobutene. Refrigeration effect of R290/R600a (60/40 by wt%) mixture was higher in the range 20% -26.76% than R600a for L=10 feet length capillary. In this system capillary of L_1=10 feet, L_2=11 feet, L_3=12 feet length were tested and the results are best for L=10 feet length. The overall performance has proved that the100g R600a/R290 (60/40 by wt%) with 10feet length capillary could be the best long term alternative refrigerant to phase out R134a.

Keywords: Domestic refrigerator; Alternative Refrigerant; R600a/R290; R600a; Capillary

I. INTRODUCTION

Air conditioning application at domestic, commercial and industrial level are becoming an integral part of present day living. The demand and supply of air conditioning system is increasing day by day with the changing lifestyle. The accelerated technical development and economic growth of most countries during the last century has resulted in recognition of the fact that man-made products contributing to human comfort have side effects threatening our health as a result to harming the environment: ozone depletion and global warming. These concerns are the biggest driving force for recent technical innovations in the field of refrigeration and air conditioning.

Chlorofluorocarbons (CFCs) and Hydrochloroflourocabons (HCFCs) have been used in refrigeration and air conditioning as working refrigerants as well as blowing agents in foam. CFCs an HCFs are now being regulated because of ozone depletion. Hydroflourocarons (HFCs) can be short and mid-term replacements , but may not be permanent due to their high GWP [Hwang 1998]. The need to find a long term solution calls for the use of natural refrigerants. The refrigerator and car air conditioning industry have already begun to address the challenges. Within limited tie, the HCFCs including R-22 also will have to be substituted.

Montreal protocol (MP) on substances that deplete ozone layer was established to phase-out the consumption and production of ozone Depleting substances. The Kyoto protocol (KP) at the 3rd conference of Parties on the frame work convention of the global Climate Change in Kyoto 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.

Alternative refrigerant to CFC-12, (HFC-152a, HFC-134a, MP66/39, HC-290/600a etc.) HFC-134a is non-flammable and has zero ozone depletion potential. Hydrocarbon refrigerants are flammable. They have zero ozone depletion potential and a greenhouse warming potential approaching zero. Many researchers have reported performance evaluation of hydrocarbon mixtures by both experimental and simulation methods. Domanski et al., indicate that even though final verification in refrigerant screening is possible with laboratory testing only, theoretical models help in predicting the suitability of the refrigerants for specific applications. Weng et al. report on theoretical methods for performance evaluation of different organic substances includes hydrocarbons. Jung et al. investigated 15 pure and 21 refrigerant mixtures using cycle simulation based on successive substitutions and Newton Raphson interactive methods. Mathur et al., based on a predictive model, recommend 50/50 mixture of propane and iso-butane in refrigeration systems for better heat transfer characteristics and thermodynamic properties. The assessment of alternative refrigerants is a difficult task. 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 is also extensive. Many drop-in tests are being carried out to check the performance of replacement refrigerant in existing machines, designed for CFCs and HCFCs.

II. LITERATURE REVIEW

The use of hydrocarbons in domestic refrigerators and freezers; by many researchers goes back to the 1990s [1-4]. Refrigerators are identified as major energy consuming domestic appliance in house hold environment , many researchers have reported that hydrocarbon mixed refrigerants is found to be an energy efficient and environmental friendly alternative option in domestic refrigerators[3].

Hammed and Alsaad (1999)[5] studied the performance of 320 L R12 based domestic refrigerator using R290:R600:R600a (50:38.3:11.7 by weight) as an alternative. It has been reported that the COP of refrigerator using this mixture is 3.7 with an evaporator temperature of -16 0C and condensing temperature of 27 0C (compared to R12, which has a COP of 3.6). Jung et al. (2000b)[6] examined R290/R600a as an alternative in 299 and 465 Liter R12 domestic refrigerators. A thermodynamic analysis indicated that the R290/R600a in composition range 0.2-0.6 mass fraction of HC290 yields an increase in COP up to 2.3% as compared to R12. Power consumption and pull-down test indicate that the energy efficiency was improved by 3-4% with slightly higher capacity than that of R12.

Tashtoush et al. (2002)[7] tested with (R600/R290/R134a) at various quantities in R12 domestic refrigerator. It has been reported that it is possible to use HC/HFC mixture as an alternative to R12 in a domestic refrigerator without changing the mineral oil (lubricant). The hydrocarbon mixture (R290/ R600/R134a) in the mass ratio of 25:25:30 and the charge amount of 80g had performance characteristics very close to that of R12. The discharge temperature of the mixture was found to be lower than that of R12. For a wide range of evaporator capacity. The volumetric efficiency of the compressor is slightly higher and mass flow rate of the mixture was found to be 40% lower. Akash and Said (2003)[8] studied the performance of the R12 retrofitted system with LPG (30% R290, 55% R600 and 15% R600a by weight) as an alternative at various charge amounts (50 g, 80 g and 100 g) for R12 in 240 L domestic refrigerator. The results reported that 80 g of LPG mixture showed best performance and higher cooling capacities compared to that of R12.

Bilal and Salem [9] recommended that a mixture of 60% R290 and 40% R600 (or R600a) was the best substitute for R134a in all environmental conditions. He et al. (2005)[11] studied theoretically and experimentally with HFC mixture composed of Rl52a and R125 at different weight percentage (80:20, 85:15 and 90:10) as R12 alternative in a domestic refrigerator. It has been reported that the discharge temperature of the mixture was found to be slightly higher than that of R12. The energy consumption of the domestic refrigerator with optimum proportion 85:15 by weight percentage at 97 g is 1.156 kW h per day with 2.8-3.2% higher COP than that of

R12. The mixed refrigerant R152a/R125 seems to be the long-term alternative to replace R12 as a new generation refrigerant of domestic refrigerators, due to its better environmentally acceptable properties and its favorable refrigeration performance. Wongwises and Chimres (2005) [12] investigated with HC mixtures composed of R290 and R600 at different mass ratio in a 240 L capacity domestic refrigerator by replacing the R134a. They have reported that R290/R600 mixture (in the ratio of 60:40, by mass fraction is the most appropriate alternative to R134a due to its excellent thermodynamic and environmental properties. The refrigerator working with above HC mixture requires less energy consumption per day compared to R134a due to its high latent heat. In spite of the flammability of hydrocarbons, many companies especially in Europe and Asia use hydrocarbons as refrigerants without any hazard for consumers [13]. Using propane and butane mixture (LPG) achieves lower freezer and refrigerator temperatures than using R134a. When hydrocarbon and R134a are compared form the energy consumption viewpoint, mass flow rate and refrigerant mass are lower for hydrocarbons [14]. The results of using R290, R600 and R600a hydrocarbons in a domestic refrigerator [15] showed that R290 could not be used as an alternative refrigerant due to its high operating pressure in comparison with R134a. Although R600 and R600a represent many desirable characteristics such as operating pressure, mass flow rate and discharge temperature, although the compressor should be changed.

Experiments conducted on pure butane [16] in a domestic refrigerator designed for R134a at 25 0C and 280C ambient temperatures showed that their energy consumption are the same and the inlet temperature of the evaporator for hydrocarbons are lower than that of R134a. Therefore, it is better to use hydrocarbon for low temperature applications. The weight of R134a used was 140 g, while the weight of the required hydrocarbon was 70 g. Also, the results showed that using pure butane as refrigerant is possible without any change in the refrigerator components. Mani and Selladurai [17] performed experiments using a vapor compression refrigeration system with the new R290/R600a refrigerant mixture as a substitute refrigerant for R12 and HFC134a. According to the results of their experiments, the refrigerant R290/R600a had a refrigerating capacity 19.9% to 50.1% higher than that of R12 and 28.6% to 87.2% than that of R134a. The R290/R600a blend's coefficient performance (COP) is improved by 3.9-25.1% compare to that of R12 at lower evaporating temperature and by 11.8-17.6% at higher evaporating temperatures.

The refrigerant R134a had a slightly lower COP than R12. An experimental investigation was conducted by Mohanraj et al . [18] using a hydrocarbon mixture consisting of propane and butane with a ratio of 45.2:54.8 by weight as a replacement for R134a in a domestic refrigerator. The results showed that this hydrocarbon mixture leads to a reduction in the compressor energy consumption, pull down time,1 and on time ratio2 by 11.1%, 11.6% and 13.2%. respectively. Moreover, the mixture of hydrocarbons was offered as the best substitute for R134a. The results showed that for a domestic refrigerator with 110 g R134a, the optimum weight of the hydrocarbon mixtures was 60g. Another investigation was carried out with a mixture of propane and iso-butane with a ratio of 50:50 by weight in a domestic refrigerator [19] which worked with 150 g of R134a. The results showed that this hydrocarbon mixture reduced the energy consumption by -4.4% and the weight of the refrigerant used was reduced by 40% compared to that of R134a. Mohanraj et al. [20] have reviewed the developments of new refrigerant mixtures for vapor compression based refrigeration systems. They stated that hydrocarbon refrigerants are identified as long-term alternatives to phase out the existing halogenated refrigerants in the vapor compression based systems. Recently, M. Rasti et al.(2013) [21] investigated energy efficient domestic refrigerator by using R436A (mixture of 46% iso-butane and 54% propane) and R600a as alternative refrigerants to R134a.

III. EXPERIMENTAL SETUP

The schematic diagram to a R134a based domestic refrigerator (experimental setup) in which 250gram 134a is used for desired refrigeration application is as shown in fig. 1. It Consisted of a hermetically sealed reciprocating compressor, a force convection 10inches×10inches size condenser, three capillary of different length (L_1=10 feet, L_2 = 11 feet, L_3=12 feet) with handset values, a calorimeter for refrigerating effect calculation. It consist 5/16inches diameter copper tubes of 20 feet length evaporator with in 10 liter ethylene glycol as secondary refrigerant. The calorimeter was fitted with an electric heater (connected with wattmeter) to calculate R.E. (heat gain by heater will be equal to heat removed by evaporator coil) and to regulate heater wattage a dimmer stat is used to maintain temperature.

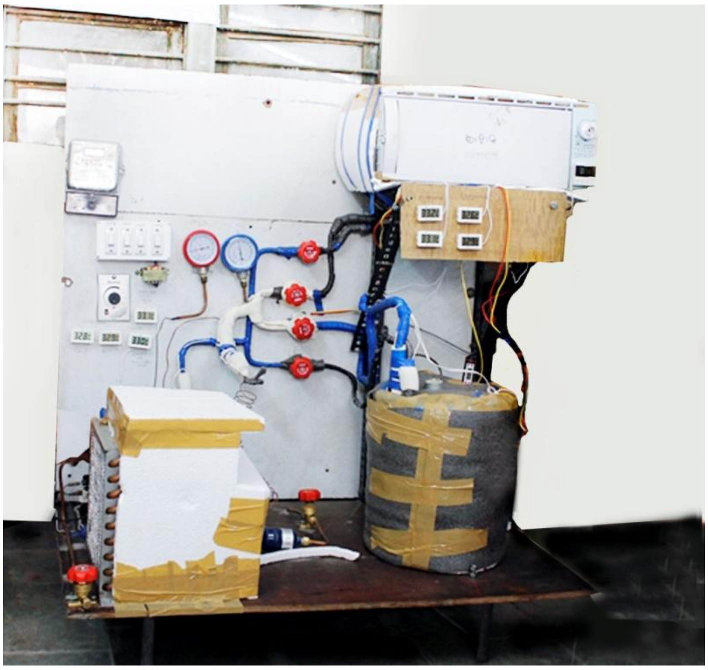

Fig. 1 Experimental Setup of VCR System

The calorimeter was insulated to reduce the ambient heat infiltration. A motor operated stirrer was provided in the calorimeter to maintain uniform temperature inside the refrigerator was instrumented with two compound pressure gauge with an accuracy to one psi at the suction and discharge of the compressor for measuring pressures. With all these 9 thermocouples of rang - 50^0C to 80^0C with $\pm$ $1.^0$C accuracy fitted at inlet and outlet of all equipments. A separate wattmeter is used to measure energy consumption of compressor. A supply energy meter also used to calculate energy consumption in KWhr.

IV. EXPERIMENTAL PROCEDURE

Initially the system was evacuated by vacuum pump up to -30psi pressure. After that hydrocarbon refrigerant mass 100 g R600a (Iso-butane pure) and R600a/ R290 (60/40 by wt%) mixture used alternatively in the system. First we charged R600a Iso-butane of 100 g mass in the system and calculate refrigerating effect, compressor work and COP for different length (L_1=10 feet, L_2=11feet, L_3=12 feet) and 0.036 inches diameter of capillary. Pull down test on load carried out by connecting calorimeter in refrigerator as per procedure followed by M. Mohanraj et al [18]. Pull down carried from 21^0C temp. of calorimeter for 120 min. The actual refrigeration capacity and COP of the system were calculated as per the procedure followed by Sekhar and Lal [10]. The heater load was adjusted by a dimmer stat to maintain a temperature (-5, -2.5, 0, 2.5,5^{0}C) inside the calorimeter. The energy consumption of the compressor and heater were measured by separate energy meters. After completing the test on different size of capillary similar process apply for 100g mixture of R600a/R290 (60/40 by wt.%) was charged with the help of charging unit & weight measuring device. Weight measurement done with ± 0.01gram accuracy . Temperature, pressure and watt meter reading were recorded after every ten minutes intervals. The measured values were used to study the performance characteristics of the system.

V. RESULT AND DISCUSSION

The experimental results obtained from the performance analysis of pure 100 g of R600a (iso-butane) and 100 g mixture of R 600/R 290 (60/40 by wt%) are discussed with respect to the parameters such as refrigeration effect, compressor energy consumption, COP, Pull down test, different point temp. and pressure ratio (P_1/P_2).

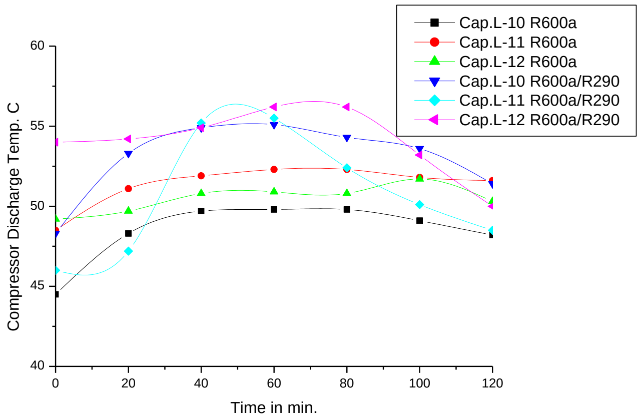

Fig. 2 Pull down time vs. compressor discharge temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10,11&12 feet length & dia. 0.036 inches(continuous running test).

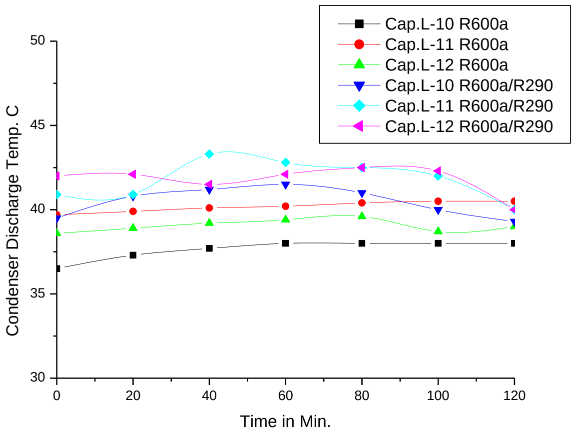

Fig. 3 Pull down time vs. condenser discharge temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10,11&12 feet length & dia. 0.036 inches(continuous running test).

5.1 Pull Down Characteristics

In this we reduces the temp. of ethylene glycol (10 liter) from 21^{0}C in 120 min. (continuous running test) and it was observed that for different length of capillary and refrigerant, lowest temp. in calorimeter was -8.1^{0}C for R 600$_a$/ R 290 mixture (60/40 by wt%) and length of capillary is 10 feet. Similarly second lowest temp. --7.5^{0}C in calorimeter for R600a at 10 feet length capillary. It observed that cooling effect of mixture R600a/R290 was good as compound to R600a and the capillary length L=10 feet is suitable for the system. Fig. 4 show the variation of calorimeter temp. with respect to time and fig. 2&3 shows the variation of compressor and condenser discharge temp. with respect to time in min.

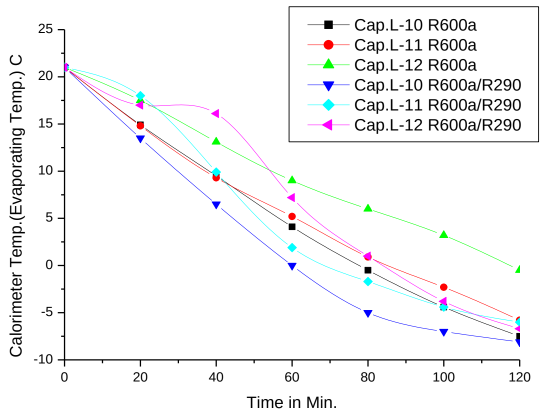

Fig. 4 Pull down time vs. calorimeter temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10,11&12 feet length & dia. 0.036 inches(continuous running test).

5.2 Refrigerating Effect

Fig 5 shows the variations of refrigerating effect with respect to evaporating temp. It was observed that the refrigerant mixture R600a/R290 (60/40 by wt %) had higher refrigerating effect than R600a pure isobutene. It is also observed that lower length capillary for mass 100g gives better result than other. Mixture R600a/ 290 give 26.76% higher RE than R600a at -5^{0}C evaporating temp 10 feet length capillary, for 5^{0}C temperature the rise in RE is 20%. It was observed from result that RE of mix. R600a/290 is higher for all length of capillary than R600a.

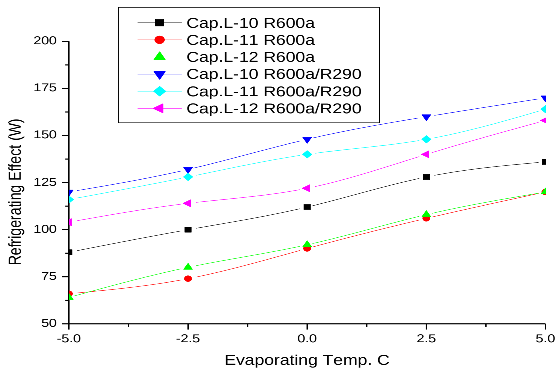

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Fig. 5 Variation of refrigerating effect with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10,11&12 feet length & dia. 0.036 inches.

5.3 Compressor Energy Consumption

Fig.6 showed that the energy consumed by compressor increase with increase in evaporating temperature. Energy consumption is lower for R600a capillary of 11 & 12 feet length and consumption of energy is higher for mix. R600a/R290 capillary of 11 & 12 feet length. Mixture R600a/R290 was consumed higher energy by 4% to 6% than R600a for L=10 feet capillary. Energy consumption for R600a/R290 was higher than R600a by 10% - 21% for 11 feet length capillary , and higher by 16% to 18% for 12 feet length capillary.

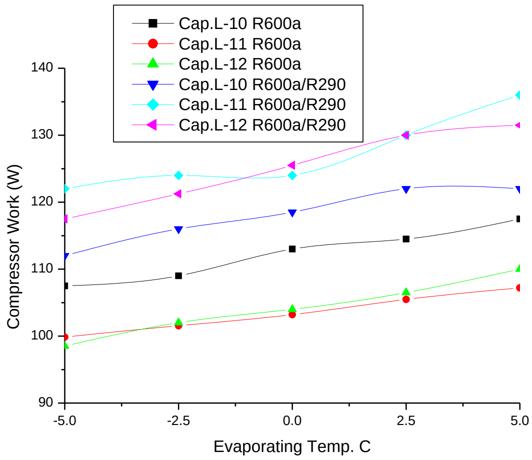

Fig.6 Variation of compressor work with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10,11&12 feet length & dia. 0.036 inches.

5.4 Coefficient of Performance (COP)

Fig. 7 shows the coefficient of performance of R600a and R600a/R290 (60/40 by wt%) mixture for different length of capillary with respect to evaporating temp. (-5, -2.5, 0, 2.5, 5^0C). It was observed that the COP of R600a/R290 (60/40 by wt%) was higher than R600a by 23.5% and 17.35% for -5^0C & 5^0C evaporating temp respectively at L=10 feet length capillary. It was observed from graphs that COP of R600a/R290 (60/40 by wt%) for capillary length L=10feet, higher than capillary length L=11 feet by 11.2% - 14.28% and higher than capillary length L=12 feet by 17.25%-22.4% at – 5^0C to + 5^0C evaporating temp.

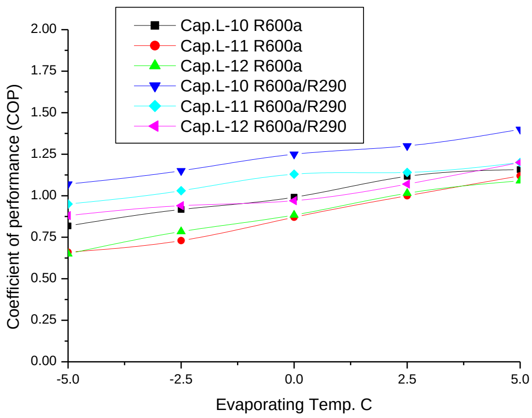

Fig. 7 Variation of COP with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10, 11 &12 feet length & dia. 0.036 inches.

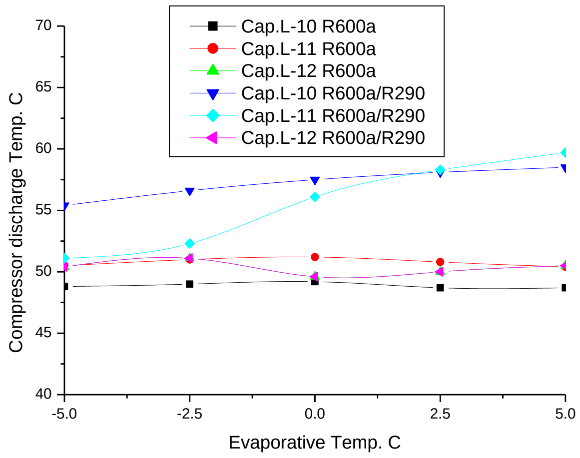

Fig. 8 Variation of compressor discharge with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10, 11 &12 feet length & dia. 0.036 inches.

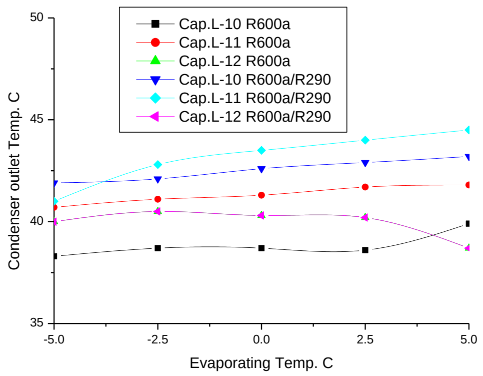

Fig. 9 Variation of condenser outlet temp. with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10, 11 &12 feet length & dia. 0.036 inches.

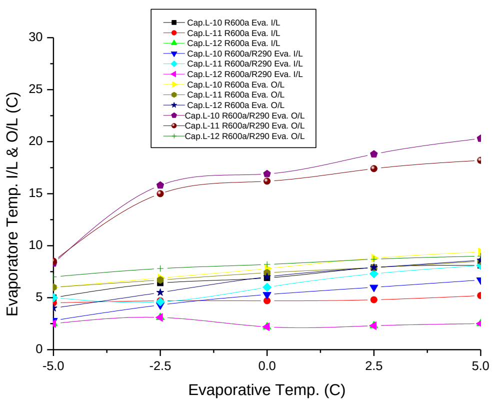

Fig. 10 Variation of evaporator I/L & O/L temp. with evaporating temp. (calorimeter temp.). of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10, 11 &12 feet length & dia. 0.036 inches.

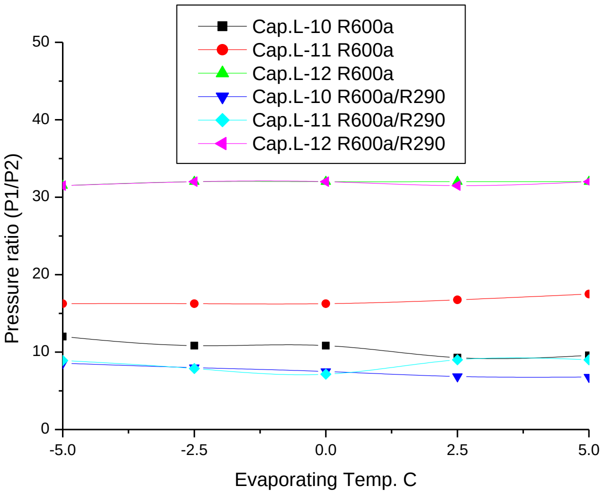

Fig. 11 Variation of compressor press. ratio (P1/P2) Discharge /Suction with evaporating temp. of refrigerant R600a and R600a/R290 (60/40 by wt.%) at 38 degree ambient temp. for capillary 10, 11 &12 feet length & dia. 0.036 inches.

VI. CONCLUSIONS

A performance analysis on R134a refrigerant based VCR system with HCM refrigerant (R600a/R290) mixture & R600a pure iso-butane was made the following conclusion.

- Refrigerating effect of R600a/R290 (60/40 by wt%) mixture was higher in the range 20%- 26.76% from higher evaporating temp. 5^0C to lower evaporating temp. – 5^0C than R600a at L=10 feet length capillary.
- Energy consumption of R600a/R290 (60/40 by wt%) mixture was higher in the range 4%-6% than R600a for L=10 feet length capillary
- With increase in capillary length energy consumption increases. For L=11 feet length capillary 10%-21% higher & for L=12 feet length capillary 16%-18% higher energy consumption in R600a/R290 mix. than R600a.
- COP of R290/R600a (60/40 by wt%) mixture was higher for all length of capillary than R600a (iso-butane).
- COP of R290/R600a (60/40 by wt%) mixture was higher than R600a at L=10 feet length capillary by 17.35% & 23.5% for 5^0C and -5^0C evaporating temp respectively.
- Pull down time of the R600a/R290 mixture was lesser than R600a for desired evaporating temperature.
- Pressure ratio is lesser for L=10 feet length capillary for both refrigerant than L=12 feet length capillary.
- The compressor discharge tamp is higher for R600a/R290 mixture than R600a. Hence the life of the compressor lesser for HCM.

Thus the results prove that the hydrocarbon mixture refrigerant R600a/R290 (60/40wt%) give best performance than 600a (iso-butane) in domestic refrigeration system and the mixture gives best result for replacement refrigerant in existing machines, designed for CFCs and HCFCs. Capillary L=10 feet give good result than other higher length of capillary.

REFERENCE

[1]. R.W. James, J.F. Missenden, The use of propane in domestic refrigerators, Rev. Int. Froid. 15 (2) (1992) 95-100.

[2]. E. Bodio. M. Chorowski, M., Wilczek, Working parameters of domestic refrigerator filled with propane-butane mixture. Rev. Int. Froid. 16(5) (1993) 353-356.

[3]. R Radermacher. K. Kim. Domestic refrigerators: recent developments, Int.J Refrig. 19 (1996) 61-69.

[4]. K. Man-Hoe, I. Byung-Han. Ch. Euy-Sung, The performance analysis of a hydrocarbon refrigerant R600a in a household refrigerator/freezer, KSME Int J. 12 (4) (1998) 753-760.

[5]. M.A. Alsaad. M.A. Hammad, The use of hydrocarbon mixtures as refrigerants in domestic refrigerators, Appl. Therm Eng. 19 (1999) 1181-1189.

[6]. Jung, D.S.Song,Y.Park 2000b.Testing of propene/isobutane mixture in domestic refrigerators. Int. J. of Ref. 23, 517-527.

[7]. Tashtoush, B., Tahat, M., Shudeifat, M.A.,2002. Experimental study of new refrigerants mixture to replace R12 in domestic refrigerators. Applied Thermal Engineering 22, 495-506.

[8]. B.A. Akash, S.A. Said, Assessment of LPG as a possible alternative to R-12 in domestic refrigerator, Energy Conversion Management 44(2003) 381-388.

[9]. A.A. Bilal, A.S. Salem, Assessment of LPG as a possible alternative to R-12 in domestic refrigerators, Energy Convers Manage 44 (2003) 381-388.

[10]. S.J.Sekhar, D.M.Lal, R134a/R600a/R290 a retrofit mixture for CFC12 systems, Int. J. Refrig. 28(2005)735-743.

[11]. He, M.-G., Li, T.C., Liu, Z.-G., Zhang, Y.,2005. Testing of the mixing refrigerant HFC152a/HFC125 in domestic refrigerator. App. Therm. Engg. 25,1169-1181.

[12]. S.Wongwises, N.Chimres, Experimental study of hydrocarbon mixtures to replace HFC134a in domestic refrigerators, Energy Conservation and Management 46(2005) 85-100.

[13]. M. Fatouh, M. kafafy, Experimental evaluation of a domestic refrigerator working with LPG, Appl. Therm. Eng. 26 (2006) 1593 -1603.

[14]. M. Fatouh, M Kafary, Assessment of propane/commercial butane mixtures as possible alternatives to R134a in domestic refrigerators, Energy Convers. Manage. 47 (2006) 2644-2658.

[15]. M.A. Sattar. R. Saidur, H.H. Misjuki, Pure butane as refrigerant in domestic refrigerator-freezer, in: GMSARN International Conference on Sustainable Development challenges and Opportunities for CMS, Thailand. December 12-14,2007.

[16]. M. Mohanraj. S. Jayaraj, C. Muraleedharan, Improved energy efficiency for HFC134a domestic refrigerator retrofitted with hydrocarbon mixture (HC290/ HC600) as drop-in substitute, Energy Sustain. Dev. 11 (4) (2007) 129-33.

[17]. K. Mani. V, Selladurai, Experimental analysis of a new refrigerant mixture as drop in replacement for CFC12 and HFC 134a Int. J. Therm. Sci. 47 (2008) 1490-1495.

[18]. M. Mohanraj, S. Jayaraj, C. Muraleedharan, P.Chandrasekar, Experimental investigation of R290/ R600a, mixture as an alternative to R134a in a domestic refrigerator, Int. J. Therm. Sci. 48 (2009) 1036-1042.

[19]. J. Ching-Song, T. Chen-Ching. W. Wei-Ru, Efficiency analysis of home refrigerators by replacing hydrocarbon refrigerants, Measurement 42 (2009) 697-701

[20]. M. Mohanraj. C. Muraleedharan, S Jayaraj, A review on recent developments in new refrigerant mixtures for vapor compression based refrigeration air conditioning and heat pump units Int. J Energy. Res 35 (8) (2011) 647-669 .

[21]. M. Rasti, S. Aghamiri ,M. Hatamipour, Energy efficiency enhancement of domestic refrigerator using R436A and R600a as alternative refrigerants to R134a, Int. J. of Thermal Sc. 74(2013) 86-94.