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Enhancement of vapour compression refrigeration system (VCR) performance using greenhouse gas mixtures

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Abstract:
In India, energy sector has received top priority in all the five-year plans so far. The industrial revolution increased the utilization of the new technological products in our daily life, which has led to the consumption of more energy. The gap between supply and demand of electrical energy is increasing every year. The proven reserves of fossil fuel in India are not very large. In addition, the global warming and ozone depletion are the two major environmental problems faced by the world today. The growing national and international concern towards reduction of global warming and emphasis on energy saving has leads to the study of this work. Green House gas is one of the major reasons for Global Warming. One of the Green House gases is Hydrofluoric carbon, which is used in refrigeration and air- conditioning. In India, about 80% of the domestic refrigerators working under simple vapour compression system use R134a as the refrigerant.
Main aim of this project is to investigate the performance and analysis of alternate refrigerants (hydrocarbon (HC) refrigerants, hydro fluoro carbon (HFC) refrigerants).The alternate refrigerants will be selected in the combination of Propane (R290) and Iso-butane (R600a). Propane and Butane will be used in the ratio (R290/R600 by weight %), Propane and Iso-butane (R290/R600a by weight 50/50%) were used. The details of experimental facility for testing the VCR with different refrigerants has been discussed. The refrigeration system variables considered for the investigation are evaporating temperature, condensing temperature of the refrigerant. For these studies, an experimental set-up has been built up. The working ranges of all the selected parameters are fixed by conducting trial runs. The effect of the different refrigerants on the performance of vapor compression refrigeration system has also be estimated with same operational parameters. For consider composition or weight (135gm) blended mixture (R290+R600a) was given good performance, less power consumption high cooling rate and less GWP compared to R134a.

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I. INTRODUCTION:

Many experimental investigations are happening on the replacement ofrefrigerants that has negative impact on environment. The most common refrigerantsbeing used is R-134a, R-410A, R-404A has a huge Global warming potential (GWP) and negligible Ozone depletion. potential(ODP) according to the recent research; thatGWP also has to be replaced as it contribute to global warming the other refrigerantssuch as R-12, R-22 are banned because of the harm it causes in depleting the Ozonelayer. The investigation is being made on replacement of these refrigerants with theHydrocarbons and Hydro Fluorocarbon'smixtures, which has less impact on Globalwarming and negligible Ozone depletion. The research papers dealing with thisinvestigation has been studied.

Ching-Song Jwo, Chen-Ching Ting, Wei-Ru Wang, Efficiency Analysis OfHome Refrigerators By Replacing Hydrocarbon Refrigerants, in this experiment theyconsidered 440 liters home refrigerator for test facility, which officially works with150g R-134a refrigerant. In this test R-134a refrigerant is replaced by varied masshydrocarbon refrigerant, which was mixed with R-290 and R-600a with each 50%component ratio. The result shows the Refrigerating Effect was improved by usinghydrocarbon refrigerants. Even there was a reduction in energy consumption andapplied mass of refrigerant is reduced by 40% **[1]**.

A.S. Dalkilic, S. Wongwises, A Performance Comparison Of Vapour-Compression Refrigeration System Using Various Alternative Refrigerants, atheoretical performance study on Vapor compression refrigeration system withrefrigerant mixtures based on HFC134a, HFC152a, HFC32,HC290,HC1270,HC600and HC600a was done for various ratios and the results were compared with CFC12,CFC22 and HFC134a as a possible alternate replacements. Theoretical results showsthat all of the alternate refrigerants investigated in this analysis have a slightly lowercoefficient of performance than CFC12, CFC22 and HFC134a for the condensationtemperature of 50ºC and evaporating temperature ranging between -30ºC and 10ºC.HFC290/HC600a (40/60 weight %) instead of CFC12 and HC290/HC1270 (20/80 by weight%) instead of CFC22 are used as replacement refrigerant among the alternatives in this paper as a result of analysis **[2]**.

II. METHODOLOGY:

Refrigerants with good thermo physical properties and which satisfy the new environmental restrictions must be made available to replace those phased out. Furthermore, the concept of employing a multicomponent refrigerant introduces a desirable degree of freedom in developing substitute refrigerants, since a mixture exhibits a critical locus, depending on composition, ranging between the critical points of its components.

2.1 Problem Statement

The performance of a vapour compression refrigeration system depends mainly on the properties of the working fluid being used. In the context of ozone depletion and global warming, the effort is now focused on the identification of working fluids that exhibit best chemical, thermodynamic and transport properties with a ecofriendly nature. A number of studies have been reported in the literature on replacements for CFC12 fluids in a vapour compression refrigeration system. But very few studies exist on the replacement of HFC134a. Non-azeotropic refrigerant mixtures (NARMS) have attained importance as replacements for CFC12 and HFC134a because a single substitute cannot replace CFC12 and HFC134a. Based on both the ozone layer depletion and global warming point of view, new refrigerant mixtures is identified and selected as substitute for HFC134a.

2.2 Objective

This research focuses on investigations on environmental friendly refrigerant mixtures as substitutes for CFC12 and HFC134a in a vapour compression refrigeration system. The objectives of the present research work are:

1. To identify environmental-friendly non-azeotropic refrigerant mixtures (NARMS) as drop in substitute for CFC12 and HFC134a.
2. To study theoretically the performance of a vapour compression refrigeration system with environment-friendly refrigerant mixtures and their performance comparison with CFC12 and HFC134a for ideal conditions.
3. To investigate the performance of the selected alternative refrigerant mixtures experimentally and their performance comparison with that of CFC12 and HFC134a.
4. To develop regression models using design of experiments to study the performance parameters such as refrigeration capacity, compressor power and coefficient of performance of all the selected refrigerant mixtures and their performance comparison with that of CFC12 and HFC134a.

2.3 Approach

The present project work has been undertaken to investigate the performance of the selected alternative refrigerants mixture in a vapour compression refrigeration system. The refrigeration system variables considered for this investigation are evaporating temperature, condensing temperature and compressor power consumption. For these studies an experimental set-up has been built. The working ranges of all the selected parameters are fixed by conducting trial runs. This has been carried out by varying one of the factors and by keeping the rest of them at constant values.

2.4 Screening and selection process

A new method of selection and optimization of refrigerant mixture choice has been developed aiming at finding new candidates, non-flammable or moderately flammable and non toxic. This method allows, starting from a certain number of pure refrigerants, the calculation of all the possible mixtures (up to 4 pure components), and allows the organization of the various mixtures obtained in groups according to the selection criteria.

At the initial stage of an investigation, one needs to survey available refrigerant substitutes and current work efforts. Up-to-date information is necessary for coordinating the activities. Currently, investigators consider ordinary refrigerants in new applications and alternative compounds as substitutes. Such refrigerant candidates include ordinary refrigerants, possibly as mixtures, in non-design applications.

The challenge of selecting and using novel refrigerants often becomes a compromise between conflicting but desirable properties. The overall selection must comply with and account for industry standard operating temperatures, pressures and equipment limits, materials of construction for compressor parts, heat exchangers, elastomers in seals, and lubrication oils. Table 3.1 gives the overall procedure adopted for investigation of alternatives.

Table 2.1: Procedure for Investigation

Phase of investigation	Approach
Screening and selection process	a) Survey available refrigerant substitutes b) Select candidate alternative refrigerants c) calculate thermo physical properties of candidate compounds d) Analyze compatibility of candidate refrigerants with equipment e) Use theoretical study or simulation programs to predict capacity and system performance with new refrigerants
Experimental evaluation	f) Design and fabricate a system for testingpurposes g) Measure thermodynamic and transportproperties h) Determine safety characteristics i) Evaluate and predict performances j) Report results of comparison

III. EXPERIMENTAL INVESTIGATION:

Figure 3.1 shows a photographic view of vapour compression refrigeration test rig made with 30liter capacity for testing water. The evaporator was a steel container with a insulating material surrounding it. Filter-drier is installed before the capillary tube to absorb the moisture which may exist in the refrigerant circuit. As the refrigerant is condensed in the condenser, it flows through the high-side filter- drier into a capillary tube.

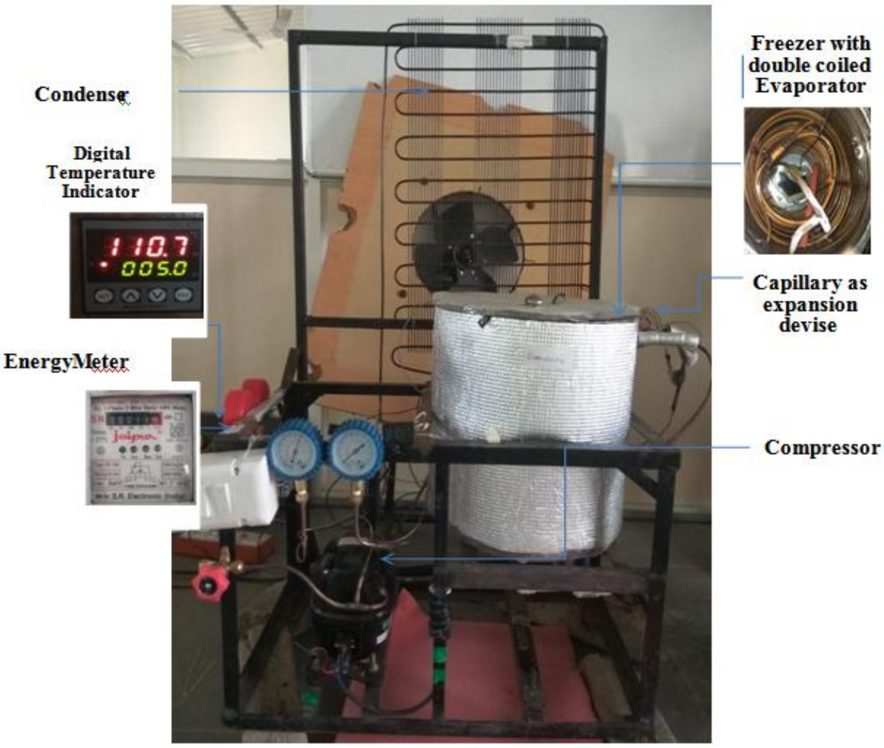


Fig. 3.1 Photographic view of experimental setup

Table 3.1 theoretical Performance comparison of selected alternative refrigerants with the base refrigerants with same operating conditions

Sl.No	Refrigerant mixture	Refrigeration Effect (kJ/kg)	Specific Work (kJ/kg)	COP
1	R134a	137.28	41.42	3.315
2	HC (50%R290/50%R600a)	266.7	97	2.74
3	R152a	229.76	66.24	3.469
4	R170	327.35	92.92	3.523
5	R32	238.21	75.83	3.141
6	R290	258.66	79.4	3.258
7	R600a	247.59	72.37	3.421
8	R1270	265.03	81.85	3.238

3.1 Preparation of refrigerant mixture:

The following are the steps that have been followed by the researcher for preparing ternary mixture

- Initially cylinders were cleaned and flushed with R134a twice.
- Evacuate the cylinder by vacuum pump up to 0.1mbar.
- Cylinders were kept at a low temperature bath while filling to avoid cross contamination and quick transfer of refrigerant.
- Initially cylinders were filled with required quantity of HC, as HC has a lower vapour pressure than R134a.
- Later the required quantity of R134a is filled in to the cylinder.
- Each cylinder was properly labeled to indicate the name and quantity of filled refrigerant mixture

a) vacuum process

b) charging of the refrigerant

c) weighing scale **d) charging kit and low temperature bath**

Fig. 3.2 Photographic views of the preparation of the ternary mixture

Table 3.2 Technical specifications of domestic refrigerator test unit

Storage Volume	30L
Current rating	1.1 max
Voltage	220-240V
Frequency	50Hz
Refrigerant type	R134a & Blend(R600a+R290)
Defrost System	Auto defrost
Refrigerant charged	0.140 kg
Capillary tube length	1.5m
Capillary tube inner diameter	0.002
Cooling capacity	240 W

Table 3.3 Measured quantities with their range and accuracy

Quantity	Range	Accuracy
Temperature	-0.1°C to 35°C	+0.1°C
Power consumption	0 to 1000W	1W
Voltage	0 to 240V	0.1V
Current	0 to 10A	0.1A
Pressure	0 to 21bars	+0.7bars

IV. RESULTS AND DISCUSSION:

Experiments are carried out on a specially modified vapour compression refrigeration test rig. The vapour compression refrigeration test rig used in this test setup is tested with R134a and hydrocarbons propane/isobutane zeotropic blend of 50/50%. Initially transient test is carried out to test the time taken to attend the steady temperature.

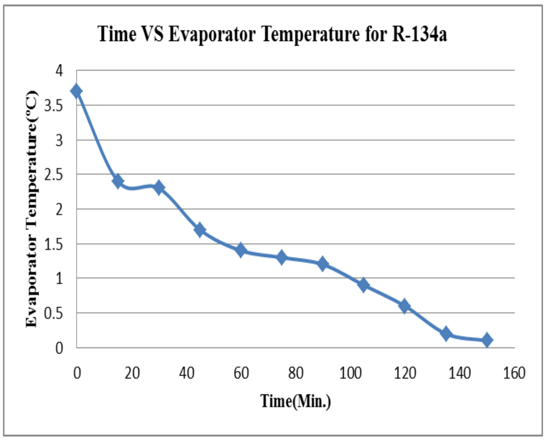
The procedure for performing the test is given below:

i. Optimization of refrigerant charges for R290 and R600a for retrofitting. ii. Energy consumption Test. v. Performance Test.

From numerical, theoretical analysis 50gms of R600a and 50gms of R290 gives the more refrigeration effect and it consumes less power compare to remaining proportions (25%+75%,75%+25%) and the global warming potential and TEWI given less compare to remaining proportions.

Firstly the vapour compression test is carried out with R-134a and the parameters which are evaporator temperature, coefficiencient of performance, power consumption, refrigerating effects are obtained. Later the same test is performed by the alternate blended mixture that is R290/R600a with (50/50% weight proportion) and tested the following parameters were investigated and compared with the R-134a.

The test is done at various refrigerants and refrigerants mixture. Fig. 4.1& Fig. 4.2 shows the Evaporator temperature drop for R-134a refrigerant and blend (50%/50% R290/R600a) mixture refrigerant. The lowest Evaporator temperature is achieved as 0.1ºC with 135g charge for R134a at variation of cooling capacity and 0.05 ºC with 135g of (50%/50% R290/R600a) blend. It is observed that as time increases the cooling capacity increases and reaches 200 W at 0.05ºC with hydrocarbon blend and 0.1ºC for R-134a.



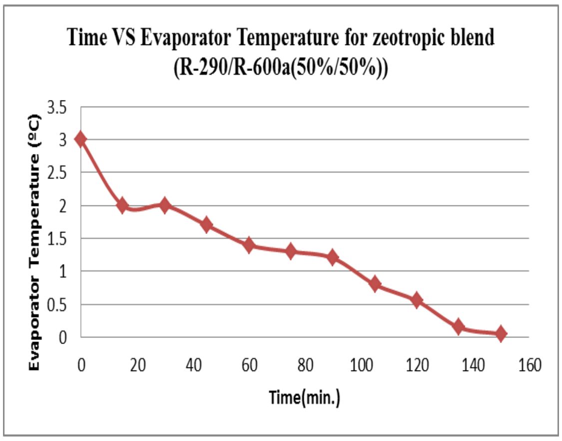


Fig. 4.1 Variation of Evaporator temperature respect to time for R-134a. Fig. 4.2 Variation of Evaporator temperature with respect to time for blend (50%/50% R290/R600a).

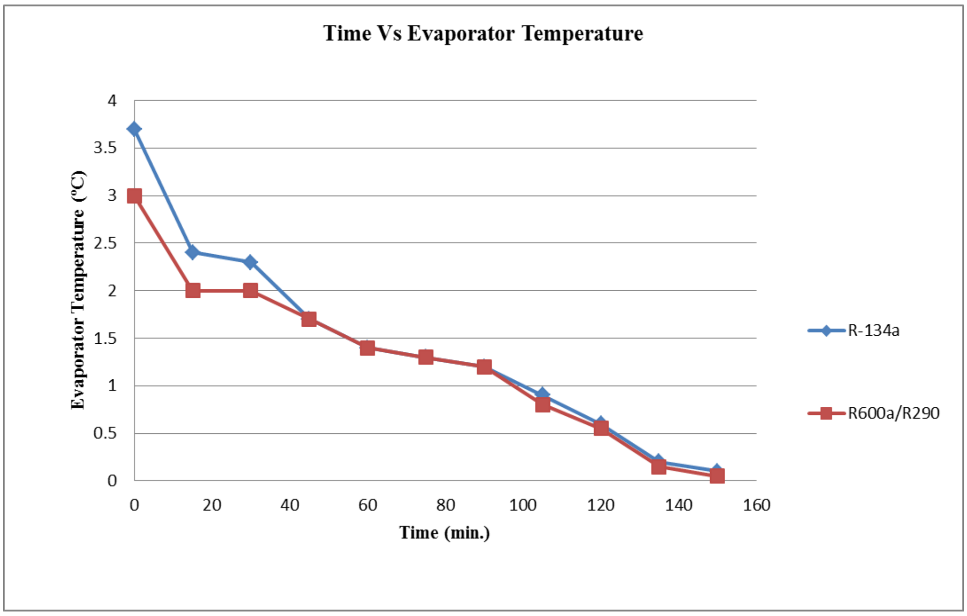
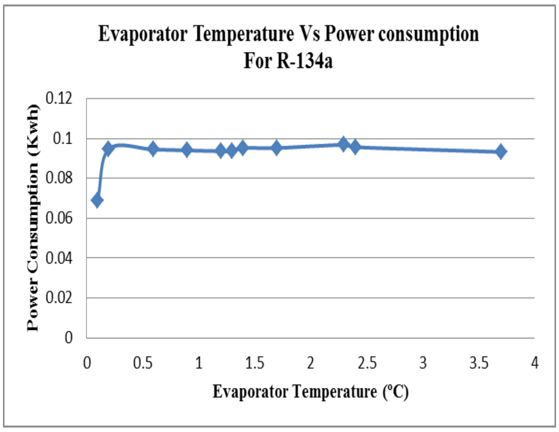


Fig. 4.3 Variation of Evaporator Temperature of Vapour compression refrigeration system with respect tot time.

Above figure shows the falling of evaporator temperature of R134a and blended mixture

Fig. 4.4, Fig. 4.5 and Fig.4.6 show the variation of power consumption blend of R600a/R290 and 134a. The power consumption with R134a is higher due to larger amount of charge, almost 0.25 times in comparison with hydrocarbon blend. Maximum power consumption is noted as 0.10 kWh for R134a and 0.07 kWh for HC blend and, almost 30% higher with R134a.



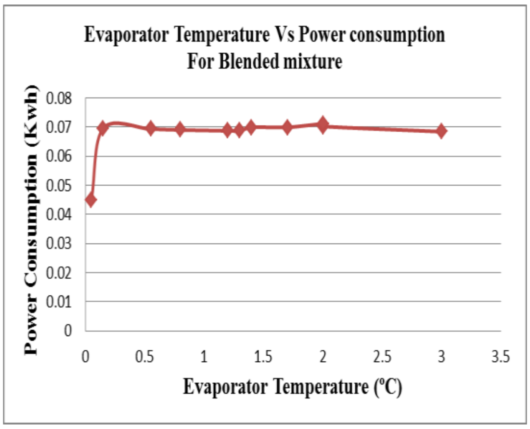


Fig. 4.4 Variations of power consumption for Blended mixture.

Fig. 4.5 Variations of power consumption for R134a.

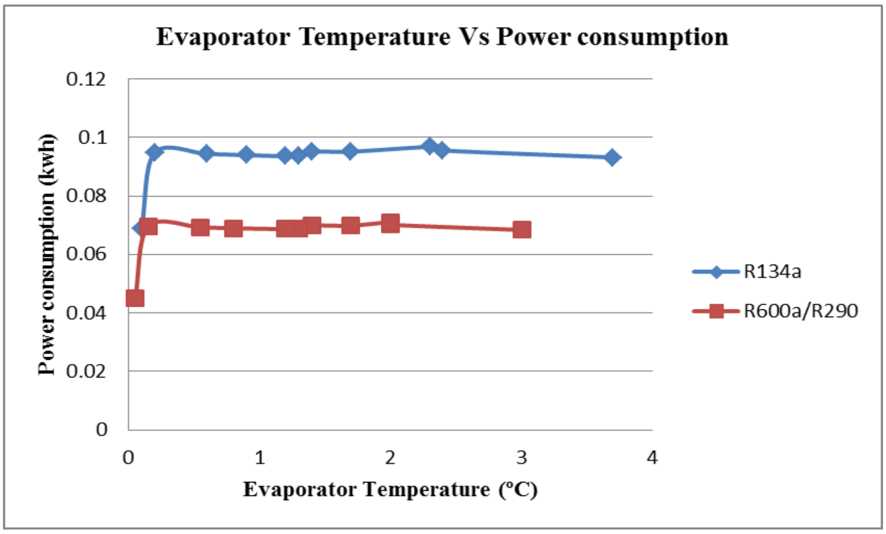


Fig. 4.6 Power consumption of compressor between R134a and Blended mixture

Fig. 4.5 represents the results using hydrocarbon refrigerant has better coefficient of performance than R-134a,. The curve of R-290/R-600a is moved down with value about 0.1

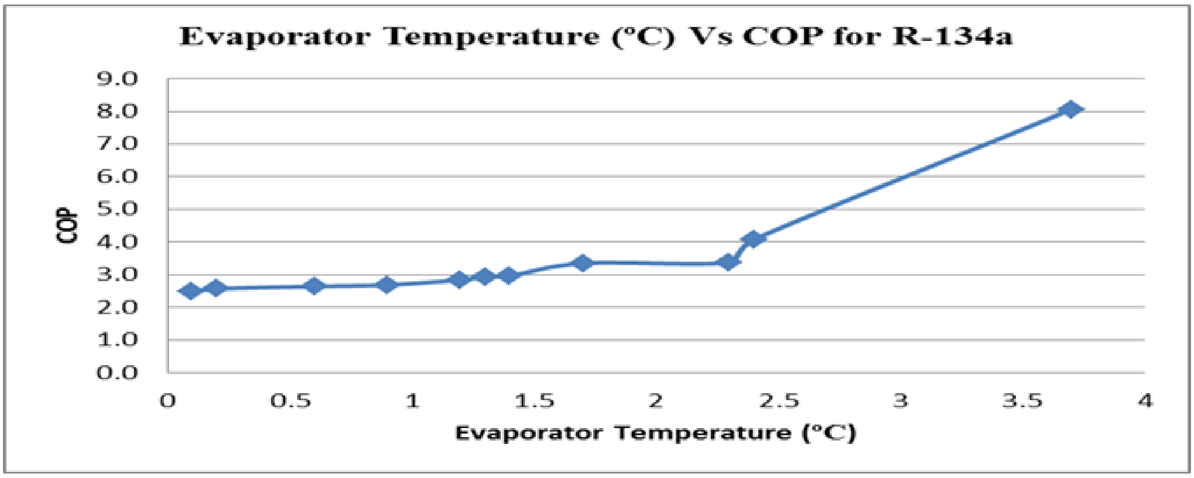


Fig. 4.7 Variations of coefficient of performance with respect to evaporator temperature for R134a

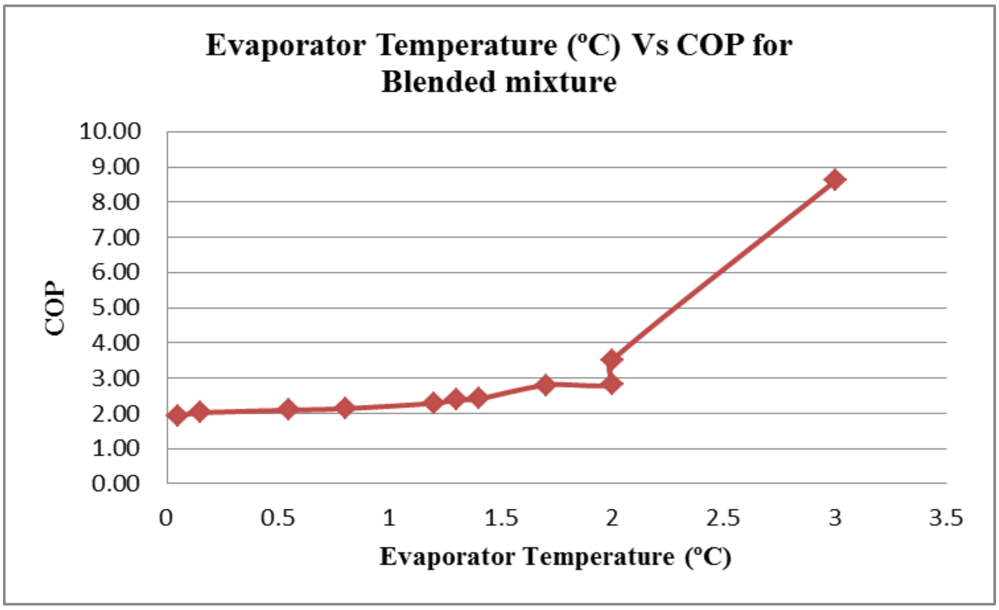


Fig. 4.8 Variations of coefficient of performance with respect to evaporator temperature for blended mixture.

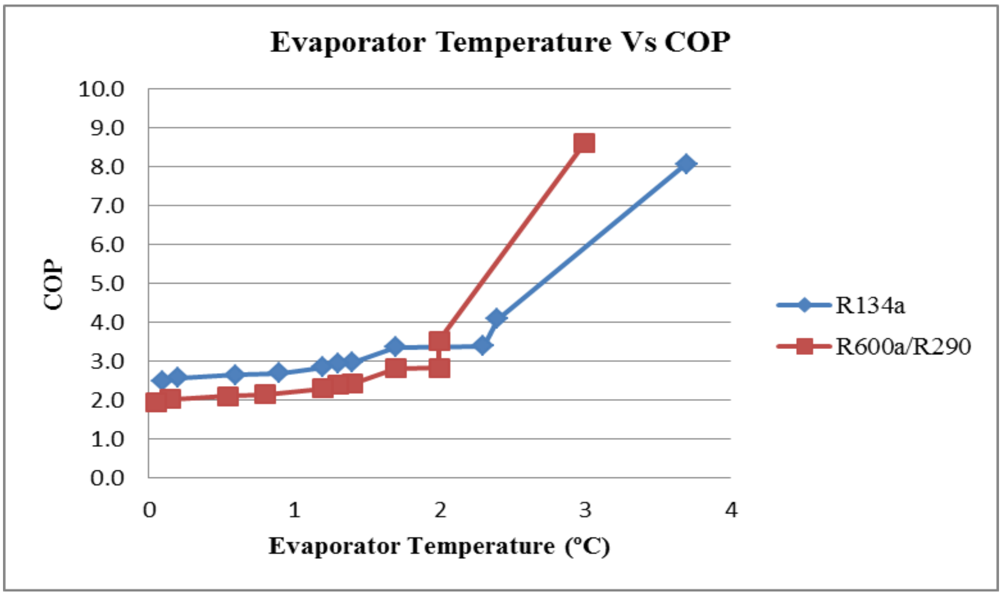


Fig4.9 Variations of COP of vapour compression system with respect to evaporator temperature

Another test for comparison of vapour compression refrigeration test condenser temperature change is shown in Fig. 5.6 represents that using blend has lesser condenser temperature than R-134a. To reach the same refrigeration effect it takes less condensation time.

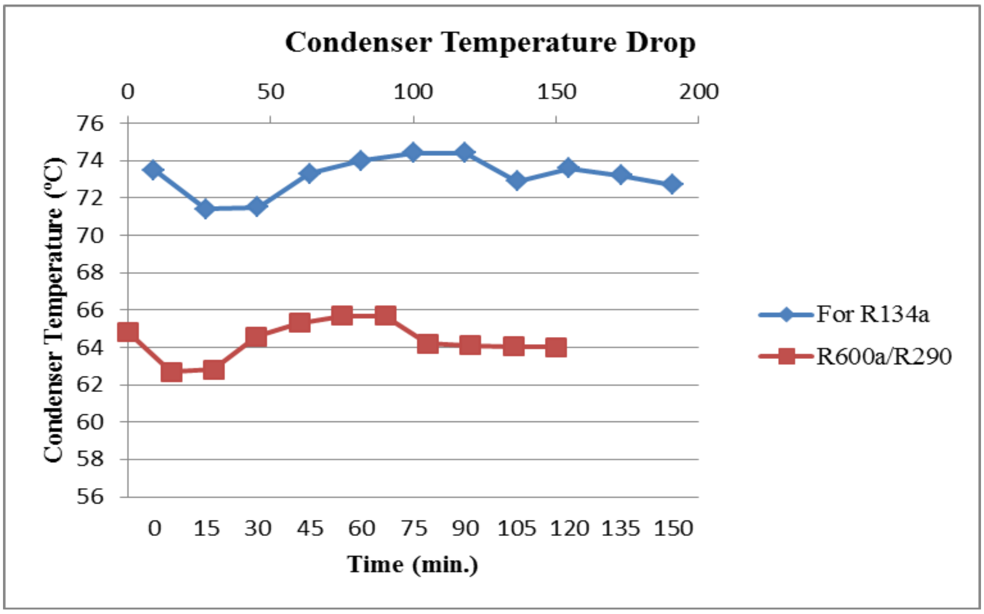


Fig. 4.10 Condenser temperature Drop for vapour compression refrigeration system by R134a and blended mixture

The GWP of blended mixture is 6 and total eaquallent warming impact is 0.05 for blended mixture, whereas for R134a GWP is 1300 to 1400 and TEWI is 1.5

V. CONCLUSIONS :

In the present work experimental investigation is carried out to investigate the performance of vapour compression refrigeration system of a modified vapour compression refrigeration system for water chiller of 30liters capacity, with R134a and blend mixture of isobutane(R290) and propane(R600a) as refrigerants by adopting different lengths of liquid line suction line heat exchanger for domestic refrigerator

1. R290/R600a (50/50%) zeotropic blend can act as drop in substitute
2. There is an optimum charge 134gms for R290/R600a (50/50%) zeotropic blend with choosing operating conditions.
3. The R290/R600a (50/50%) zeotropic blend exhibits higher COP value at all operating conditions, due to it require less power consumption for considered compressor
4. The cooling capacity of the system with blend is comparatively more than R134a, because of amount of heat extracted from the blend in easy compare to R134a
5. The temperature of condenser, during the condensation process for blended is less. It shows the it won't requires any external energy for condensation
6. The vapour compression refrigeration test using zeotropic blend as refrigerant, power required to run the compressor is less as compared with R134a.
7. The mass of refrigerant requirement is significantly lower by using R290/R600a (50/50%) zeotropic blend as refrigerant, almost 1/3 of the original charge of R134a.
8. It can be concluded that R290/R600a (50/50%) zeotropic blend can be a good option as a replacement of R134a.However, the flammability aspect of the hydrocarbons needs to be addressed.
9. The global warming potential for blended mixture is less compare with the R134a for considered proportion mixture.
10. Global worming potential of blended mixture is less compare to the R134a and we can said blended mixture won't effects the environ mental effects and blended mixture having less ozone depilation potential

Future scope:

Propane and isobutane have a flammable characteristics, if we reduces this characteristics in future, then it will be use full for any domestic and industrial applications.

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