Analytical Investigation on the Performance of Eco-friendly Refrigerant Mixture in Vapour Compression Refrigeration System

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Abstract

The present refrigeration and cooling businesses are moving towards chlorine and fluorine-free working liquids, as chlorine is one of the significant causative specialists for ozone layer consumption and fluorine is responsible for an Earth-wide temperature rise. R12, for the most part, acknowledged and more appropriate refrigerant for vapour compression refrigeration framework was eliminated by 1996 in developed nations and must be eliminated by 2010 in developing nations because of its high ozone exhaustion potential and a dangerous atmospheric warming potential. R134a has been proposed as option of R12 in vapour compression refrigeration frameworks. Hydrofluorocarbons (HFCs) are more secure to ozone layer however it has high an Earth-wide temperature rise potential. Thus, the creation and utilization of R134a will be ended sooner rather than later. A huge number of refrigeration frameworks, heat pumps and climate control systems all around the world working with R12 and R134a must be retrofitted reasonably in case of the above phase out. This has inspired me to examine the exhibition of vapour compression refrigeration framework with a portion of the accessible climate amicable liquids as substitutes for R12 and R134a. Hydrocarbon refrigerants like propane, butane, isobutane, or different hydrocarbons are proposed as elective refrigerants to R12 and R134a because they have zero ODP and low GWP. They can't be utilized as immediate substitutes. Yet, on the off chance that a few hydrocarbons are blended, the combination, known as non-azeotropic refrigerant combinations (NARMS) can have properties like those of R12 and R134a.

Keywords: Hydrofluorocarbon refrigerant, Alternative refrigerants, Hydrocarbon refrigerants, Propane, Isobutane

Nomenclature

CFC	chlorofluorocarbon
COP	coefficient of performance
GWP	global warming potential
h_1, h_2, h_3, h_4	enthalpies at different state 1, 2, 3 and 4
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
ODP	ozone depletion potential
RE	refrigerating effect
W_c	compressor work

1. Introduction

The utilization of refrigerator is normal and wide being used from all over world. Because of their amazing thermodynamic properties R12 and R134a were generally utilized as refrigerants for fridges.

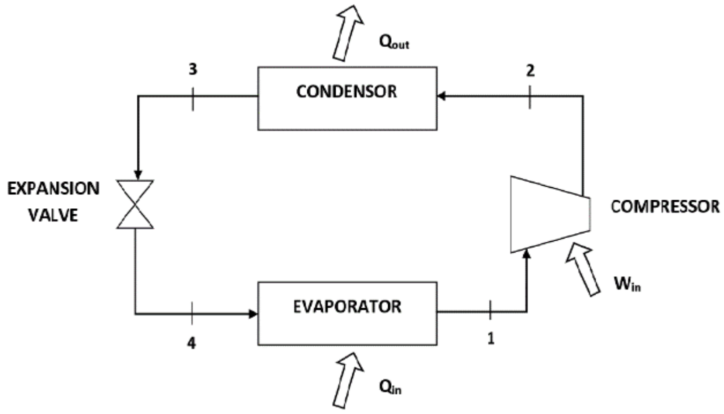

Figure 1 Schematic representation of simple VCR System

R12 because of its high Ozone Depleting Potential (ODP) was eliminated by 2010 as per the Montreal Protocol, additionally the utilization of R134a must be diminished because of its high Global Warming Potential (GWP). The ozone depletion potential (ODP) and a dangerous atmospheric warming potential (Global Warming Potential) have become the main criteria in the advancement of new refrigerants apart from the refrigerant CFCs because of their consumption of ozone layer and an unnatural weather change.

Montreal convention is identified with ODP, in 1987 Montreal convention set up the prerequisites that started the overall elimination of CFCs. Manufacturing of CFCs was eliminated by the Montreal Protocol in developed nations in 1996 and in developing nations in 2010. In 1992 Montreal convention set up the prerequisites that started the world – wide elimination of HCFCs. Complete manufacturing of HCFCs will be eliminated in 2030. Kyoto convention is identified with GWP, Kyoto convention targets eliminating of substances that will rise worldwide temperature. R134a is utilized in domestic fridges and other vapour pressure frameworks as it was identified as a substitution to R12.

Hydrocarbon refrigerants are harmless to the ecosystem, non-poisonous, not dangerous to ozone layer, lower GWP and substitute for chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFCs) and hydro fluorocarbons (HFCs).

Table 1 shows the value of global warming potential and ozone depletion potential for various refrigerants.

Table 1 ODP and GWP values of different refrigerants

Refrigerants		ODP	GWP(Time horizon of 100 years)
CFCs	R11 R12	1 1	4000 8500
HCFCs	R22	0.055	1700
HFCs	R134a R404a R410a	0 0 0	1300 3800 2000
Natural refrigerants	R717 (NH_3) R290 R600a	0 0 0	<1 3 3

1.2 Ecofriendly refrigerants

Hydrocarbon refrigerants have low poisonousness, high miscibility with mineral oil, and great material similarity. They additionally have great ecological properties with zero ODP and very low GWP. The significant downside with HCs is their combustibility. Be that as it may, it is very conceivable to utilize HCs securely in refrigeration and cooling frameworks. In many coolers, a hermetic compressor is utilized and the entire framework is subsequently totally sealed. Likewise, refrigerant charge is reduced due to hydrocarbon's higher specific volume of fluid when contrasted with conventional refrigerants.

After the CFCs and HCFCs were considered unsuitable as working liquids in refrigeration, cooling, and heat pump applications, there has been a renaissance for carbon dioxide innovation moreover. CO_2 is one of only a handful of exceptional normal refrigerants, which is neither combustible nor harmful. It is modest, broadly accessible, and doesn't influence the worldwide climate as numerous different refrigerants. CO_2 has a GWP worth of 1. Carbon dioxide is a brilliant alternative refrigerant among the normal refrigerants, particularly in applications where the harmfulness and combustibility of ammonia and hydrocarbons might be an issue.

In this research work, the performance of vapour compression refrigeration system with the following refrigerants have been investigated theoretically as a retrofit for R12 and R134a.

1. R290/R600a (55/45 by wt.%)
2. R290/R600a (62/38 by wt.%)
3. R290/R600a (70/30 by wt.%)

2. Literature review

Since this examination has been centred around retrofitting of existing R12 and R134a frameworks with elective refrigerants, an itemized writing study identified with the exhibition of HFCs, HCs and their combinations in refrigeration, heat pump and cooling frameworks has been made.

Jabaraj and Mohanlal [1] presumed that the R-407C/HC blend could be an ozone amicable, energy productive, safe and financially reasonable option in contrast to R-22 for window cooling frameworks. The way that POE oil can be apportioned with by utilizing R-407C/HC blend in the spot of R-407C is a huge finding in this work. It is accepted that this blend could be a comfort to the air conditioning area that is tested with the states of Montreal Protocol to eliminate R-22.

Senthilkumar et al [2] directed a performance test on R123/R290 (70/30) refrigerant combination to track down an option in contrast to R12. At all evaporator conditions considered, the COP and overall performance of the blend was observed to be more than that of R12. It was likewise seen that the temperature and pressure ratio variety of the blend was like that of R12, thus no changes in the R12 framework were required.

Mani and Selladurai [3] performed experiments using a vapour compression refrigeration system with the new R290/R600a refrigerant mixture as a substitute refrigerant for R12 and R134a. 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 performance coefficient (COP) is improved by 3.9-25.1% compared to that of R12 at lower evaporating temperatures and by 11.8–17.6% at higher evaporating temperatures. The refrigerant R134a had a slightly lower coefficient of performance (COP) than R12.

Srinivas et al [4] investigated five different combinations of R134a/R290/R600a and concluded that the ternary combination of (25%R134a/37.5%R290/37.5%R600a) is by all accounts a suitable long-haul elective for R134a from the perspective of eco-friendly refrigerant combination with zero ODP, low GWP and high energy effective, requiring negligible changes in the current coolers.

Lalitha Saravanan and Mohan Lal [5] proposed low GWP HC290 refrigerant that utilized as an option in contrast to HCFC22 with shrewd improvement in case of eliminate on existing forced air systems, just as for new frameworks. In existing frameworks, minimization of refrigerant charge can be accomplished by part level changes. Consequently, HC290 is a superior substitute for changing over existing HCFC22 forced air system and can be productively utilized in new frameworks additionally with least charge amount.

Lovelin Jerald and Senthil Kumaran [6] carried out the work to dissect and think about the different thermo actual properties of drop in refrigerants: R134a (HFC), R404a (HFC mixture) and R600a (HC) with R12 (CFC) refrigerants with various tube bore around of 0.30-inch, 0.30 inch (twofold), 0.036-inch, 0.044 inch and 0.50 inch for a length of 10 m.

SP Arunkumar and Koshy Mathews [7] seen that the hydrocarbon mixtures of R290/R600, R290/R600a and LPG is found be a suitable option in contrast to R134a in a vapour compression refrigeration framework. During the exergy investigation, it was tracked down that the condenser and evaporator temperatures effectively affect COP and the exergy proficiency of the framework.

A Baskaran and Koshy Mathews [8] investigated the alternative chosen refrigerants R152a and an azeotropic combination of R152a/R600a which appears to be a fitting long-haul elective for R134a from the perspective of eco-friendly refrigerant combination with zero ODP, low GWP and high energy proficient, requiring negligible changes in the current fridges. Test examinations were done on a domestic fridge with the above selected elective refrigerants and the benchmark tests were directed with R134a. The performance boundaries like draw down time, energy utilization of the compressor, refrigeration impact, COP, compressor discharge temperature and so on, were examined and contrasted with the base refrigerant.

Elumalai and Vijayan [9] experimented on a window air conditioning system with the five chosen refrigerant blends and the effect of the new combinations were examined. The helpful exhibition boundaries, for example, coefficient of performance, compressor power, refrigeration effect, mass stream rate, compressor discharge temperature and pressure ratio and so forth, were examined and compared with the base refrigerant R22. The structure assigned as Mix 3 has given better execution among the five chose elective blends.

Karthikeyan et al [10] investigated and concluded that the VCR automobile air conditioning framework working with hydrocarbon refrigerant R600a (Isobutane [2-methylpropane]) as working liquid in the consolidating pressure around 7 bar, furthermore, COP going from 2.08 to 2.5 could be the best option for all the working states of the framework examined.

The literature review introduced gives a thought regarding the different optional refrigerants accessible to retrofit the conventional frameworks with its own benefits and disadvantages. In the subsequent segments the point by point writing study given gives the approaches to track down a new eco-friendly elective refrigerant blend to be utilized in a vapour compression refrigeration framework to work on the performance.

3. Selection of refrigerant mixture

Among the different properties of the refrigerants, it has been found from the review that the vapour pressure, fluid density, latent heat and fluid viscosity are the significant boundaries to anticipate the performance of elective refrigerants. In this way the above properties of the combinations alongside R12 and R134a were acquired from REFPROP software (NIST).

3.1 Vapour pressure

The saturated vapour pressure for mixtures of propane and isobutane concentration equal to 70% and 30% by weight proportion respectively is very close to the refrigerant R12 and R134a and saturated vapour pressure of other two mixture combinations are also close to both refrigerants R12 and R134a as shown in Figure 2.

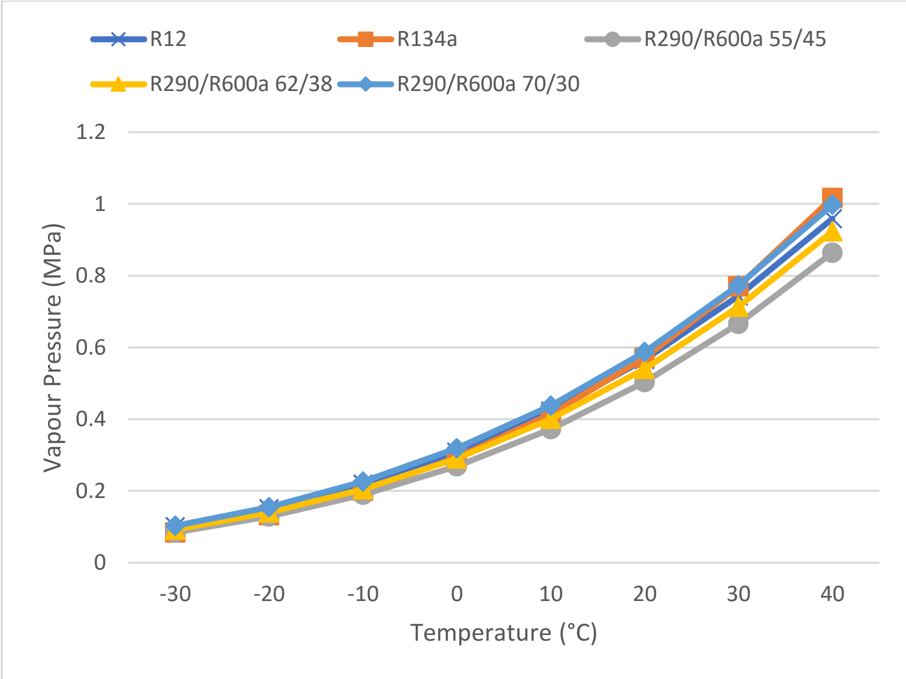

Figure 2 Variation of Vapour Pressure with Saturation Temperature

3.2 Liquid Density

The variety of liquid density with saturation temperature for the selected new hydrocarbon mixture combinations, R12 and R134a is plotted in Figure 3. It was tracked down that all three combinations have lesser density than R12 and R134a and with the increment in HC mixture in the refrigerant blend the density reduces. Consequently, the charge amount will be lesser for HC refrigerant combinations. It was seen that among the taken refrigerant blends, the liquid density of all three propane/isobutane mixture combinations was observed to be least and close to each other, which was lower than that of R12 and R134a.

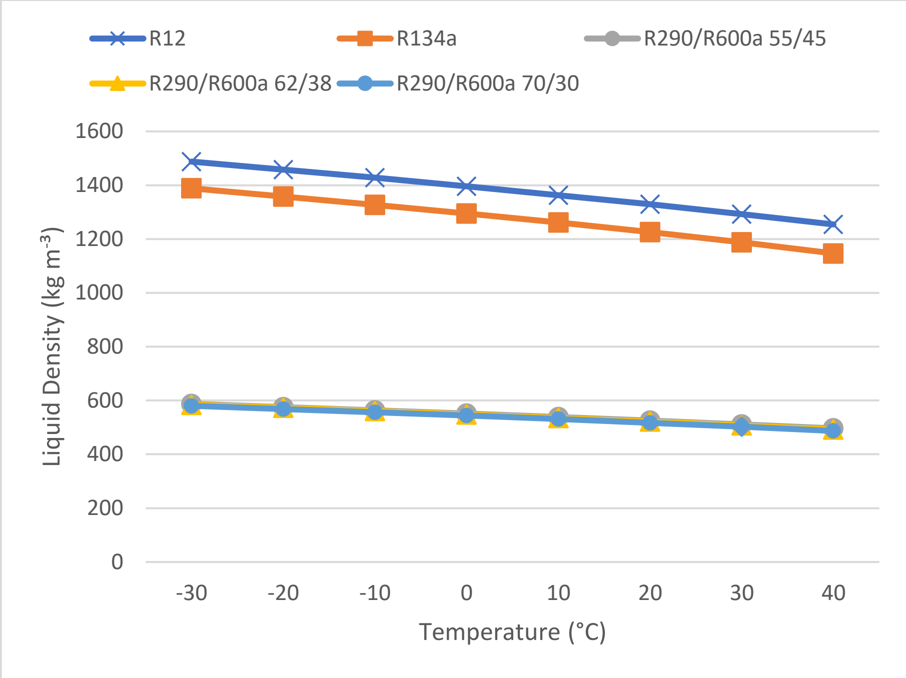

Figure 3 Variation of Liquid Density with Saturation Temperature

3.3 Vapour Density

The work of compression generally increases with the increment in the vapour density. Since the framework considered is vapour compression refrigeration framework, it is important to examine the vapour density of refrigerants utilized in this work. Below Figure 4 shows the variety of vapour density of the refrigerants regarding saturation temperature. As it is seen that all three chosen hydrocarbon blends have lower vapour density than that of R12 and R134a. And propane and isobutane mixture of concentration equals to 55% and 45% respectively is lowest among all the selected refrigerants

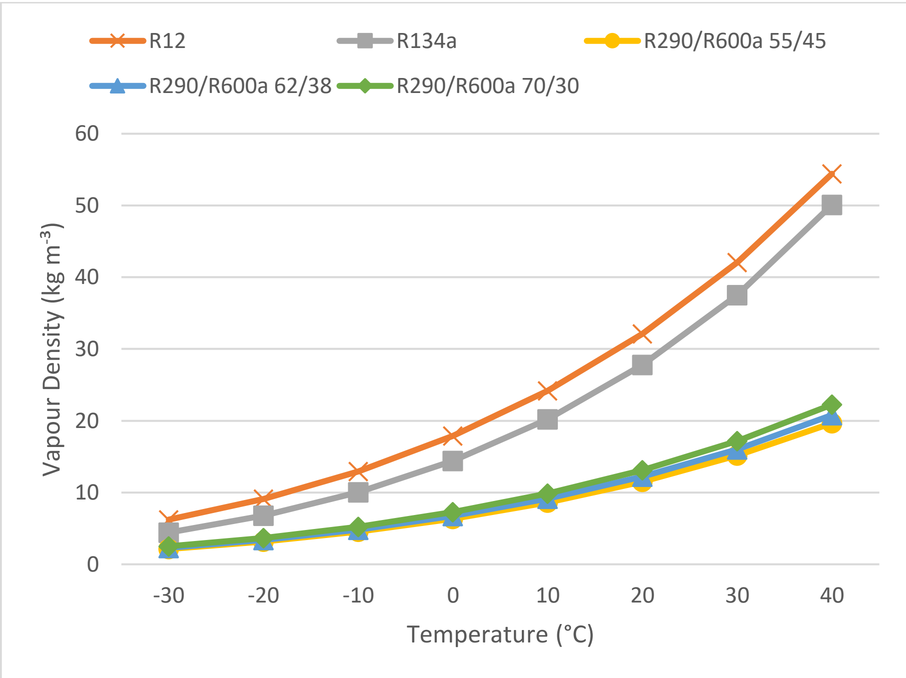

Figure 4 Variation of Vapour Density with Saturation Temperature

3.4 Latent Heat of Vapourization

The latent heat of evaporation plays a significant part in choosing the refrigeration capacity. The variation of latent heat of the R12, R134a and three hydrocarbon mixture combinations is represented in the Figure 5. It is seen that the latent heat of all three chosen hydrocarbon mixture combinations was higher than that of R12 and R134a. The refrigerant R12 has the most minimum latent heat and R290/R600a combination whose concentration equals to 70/30% by weight proportion has the maximum latent heat at various saturation temperatures. Accordingly, there is chances to have higher refrigeration capacity of the chosen refrigerant combinations than that of R12 and R134a.

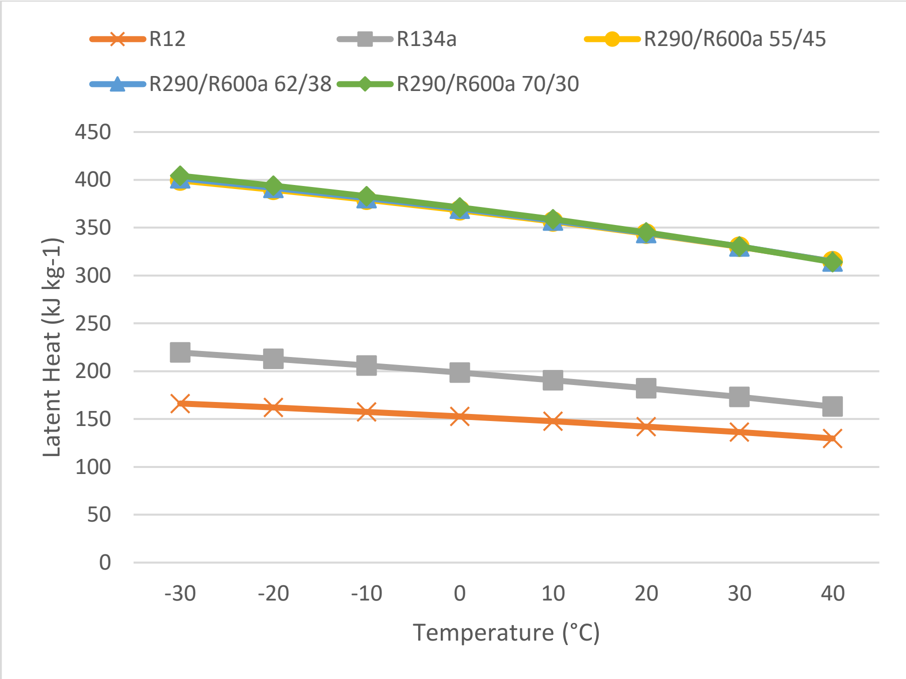

Figure 5 Variation of Latent Heat with Saturation Temperature

3.5 Fluid Viscosity

The fluid viscosities (liquid and vapour) of the refrigerants utilized in this examination were determined and plotted in graphs. Below Figures show that both the viscosities of the chosen refrigerant combinations are lower than that of R12 and R134a.

From the Figure 6 we see the liquid viscosity of all three hydrocarbon refrigerant combinations is close to each other, in which the propane/isobutane mixture whose concentration equals to 70/30 % is lowest among others.

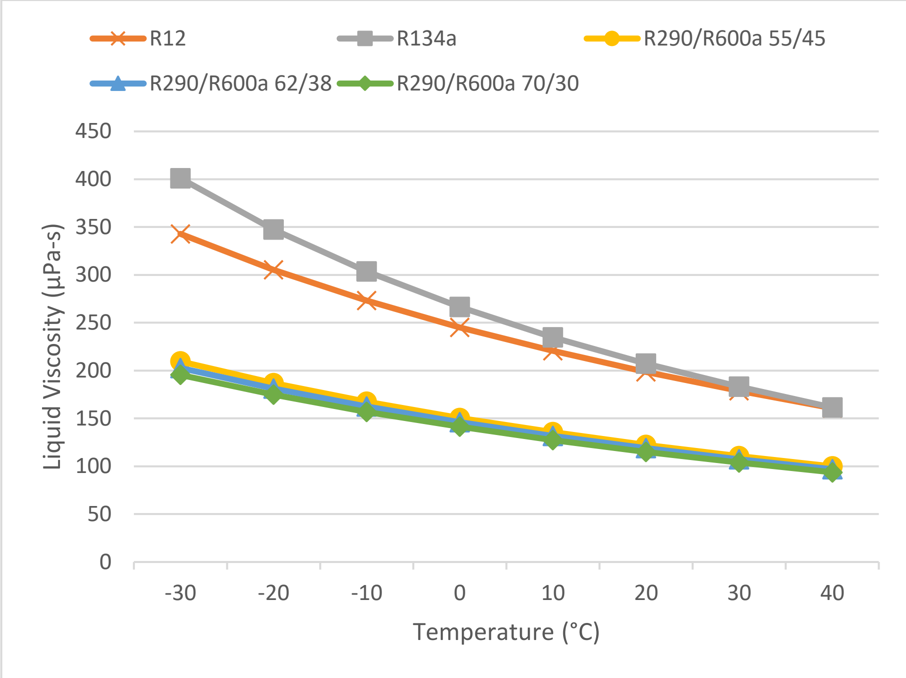

Figure 6 Variation of Liquid Viscosity with Saturation Temperature

From the Figure 7, it is concluded that the vapour viscosity of all three chosen hydrocarbon refrigerant combinations is approximately same or very close to each other and lowest among the other two refrigerants R12 and R134a. Thus, better thermodynamic transport properties could be predicted with the HC refrigerant combinations.

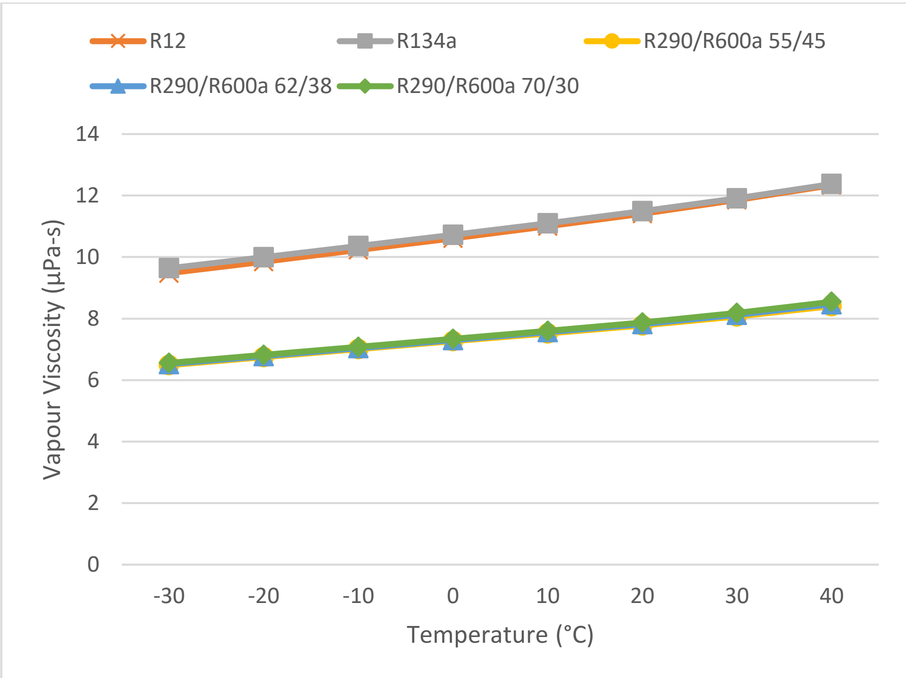

Figure 7 Variation of Vapour Viscosity with Saturation Temperature

4. Theoretical analysis

It is also assumed that steady state and uniform flow conditions exist throughout the elements of this simple vapour compression refrigeration cycle and changes in kinetic and potential energies and heat loss from the compressor are neglected.

Therefore, compressor work W_c can be written as,

$$W_c = h_1 - h_2$$

where h_1 and h_2 are the enthalpies of refrigerant at the compressor inlet and exit respectively. During the throttling process in the expansion valve, it is assumed that there is no heat transfer to the environment, which results in

$$h_3 = h_4$$

The refrigerating effect of the cycle calculated from the rate of enthalpy change in the evaporator

$$RE = (h_1 - h_4)$$

Where RE is the refrigerating effect of the refrigeration cycle.

The COP of the theoretical refrigeration cycle is then calculated by

$$COP = \frac{RE}{W_c}$$

The parameters such as pressure ratio, refrigerating effect, compressor work and coefficient of performance of the alternative hydrocarbon refrigerant blends of propane and isobutane were calculated and compared with the refrigerants R12 and R134a.

4.1 Pressure ratio

Figure 8 shows the variation of Pressure Ratio (PR) with evaporating temperature for a condensing temperature (T_c) of 35°C. The pressure ratio of R134a is 5.3% to 21.6% higher than that of R12. The Pressure Ratio values of the three hydrocarbon (HC) mixture combinations of different proportions are approximately 2.87% to 10.35% and 7.76% to 26.31% lower than that of R12 and R134a respectively. R290/R600a mixture concentration equal to 70/30% has the lowest Pressure Ratio values. At the rating conditions, the descending order of pressure ratios for the refrigerants is R134a, R12, R290/R600a (55/45%, 62/38%, 70/30%).

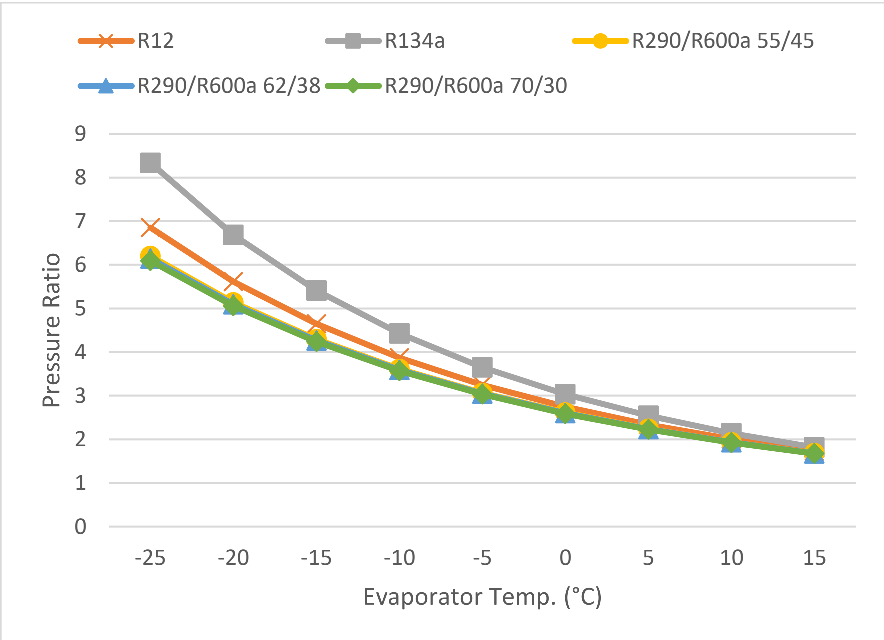

Figure 8 Variation of Pressure Ratio with Evaporator Temperature

4.2 Refrigerating Effect

Figure 9 shows the variation of Refrigerating Effect (RE) with evaporating temperature for $T_c = 35°C$. From the Figure 9 it is observed that all three hydrocarbon (HC) mixture combinations of different proportions have higher RE than that of R12 and R134a. This is due to the higher enthalpy values of the saturated vapour of HC blends with higher evaporating temperatures. R134a has 25.41% to 26.24% higher RE than that of R12. Among three hydrocarbon blends the refrigerant mixture R290/R600a (70/30%) has 141.8% to 145% and 92.8% to 94% higher RE than that of R12 and R134a respectively.

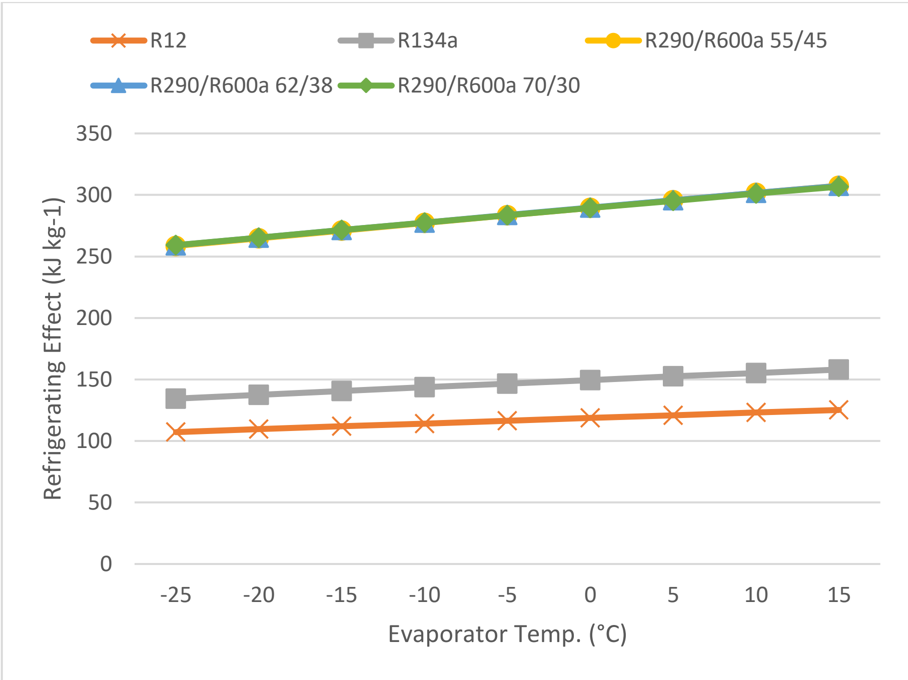

Figure 9 Variation of Refrigerating Effect with Evaporator Temperature

4.3 Compressor work

Figure 10 shows the Compressor Work (W_c) with evaporating temperature for $T_c = 35°C$. The Compressor Work of all the refrigerants increases with decreasing evaporator temperature. This behaviour is due to the constant entropy lines in the superheated region on P-H diagram. All the alternative hydrocarbon refrigerant mixture combinations require 135.18% to 136.56% and 82.11% to 85.95% higher Compressor Work than that of R12 and R134a. The refrigerant R12 requires the lowest Compressor Work. R134a requires 27.21% to 29.14% higher Compressor Work than that of R12. The descending order of refrigerants for Compressor Work is R290/R600a (70/30%, 62/38%, 55/45%), R134a, and R12.

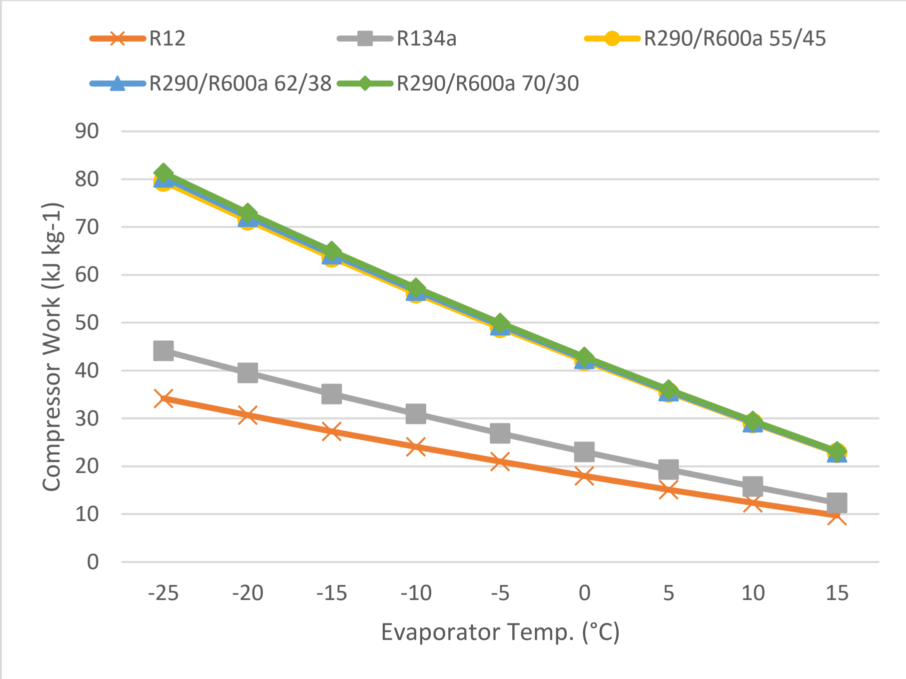

Figure 10 Variation of Compressor Work with Evaporator Temperature

4.4 Coefficient of performance

Figure 11 shows the Coefficient of Performance (COP) for R12, R134a and alternative refrigerants for various evaporating temperatures for $T_c = 35°C$. The COP of selected all three hydrocarbon refrigerant mixture combinations is approximately 2.76% to 3.77% and 4.57% to 5.82% higher than that of R12 and R134a for the range of temperatures considered in this study. R134a has COP values very close to that with R12. R290/R600a mixture concentration equals to 55/45% by weight proportion has the highest COP. The descending order of refrigerants for COP is R290/R600a (55/45%, 62/38%, 70/30%), R12 and R134a.

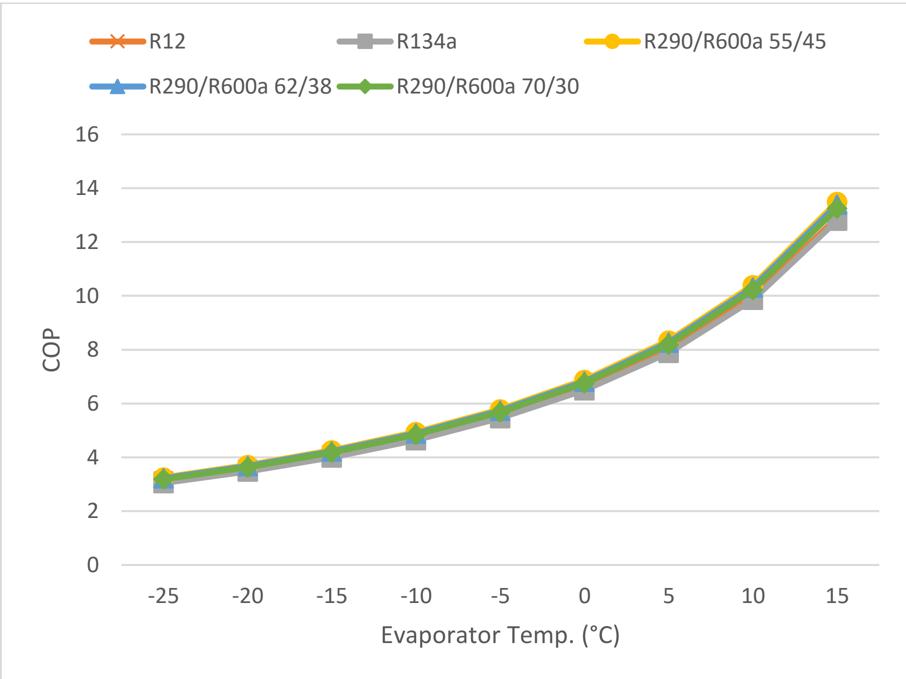

Figure 11 Variation of COP with Evaporator Temperature

5. Conclusion

The Following results were obtained from this survey paper

1) All three hydrocarbon combinations have vapour pressure close to or lower than that of R12 and R134a.
2) The charge amount of all three hydrocarbon refrigerant mixture combination in the vapour pressure refrigeration framework is less than that of R12 and R134a due to their lower fluid densities.
3) The latent heat of all three hydrocarbon refrigerant mixture combination is higher than that of R12 and R134a and in this way these hydrocarbon combinations will give higher refrigerating capacity.
4) The fluid viscosities of all three hydrocarbon refrigerant mixture combination is lower than that of R12 and R134a refrigerants.
5) The pressure ratio of all three hydrocarbon blends is lower than that of R12 and R134a.
6) The refrigerating effect of the chosen refrigerant combinations R290/R600a (55/45%, 62/38% and 70/30%) is higher than that of R12 and R134a.
7) The work of compression of all the chosen hydrocarbon refrigerant combinations is higher than that of R12 and R134a. The work of compression of all the refrigerants rises with the reducing evaporating temperature.
8) The coefficient of performance of all three hydrocarbon blends is higher than that of R12 and R134a because of higher refrigerating capacity.

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