International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-05, Issue-04, July 2019

Experimental evaluation of the liquid suction heat exchanger influence on a vapour compression plant energy efficiency working with R134a and Hydrocarbon

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Abstract - Heat transfer devices are provided in vapour compression refrigeration systems to exchange energy between the cool gaseous refrigerant leaving the evaporator and warm liquid refrigerant exiting the condenser. Liquid-suction heat exchangers are commonly installed in refrigeration systems with the intent of ensuring proper system operation and increasing system performance. Environment unfriendly refrigerants used in vapor compression refrigeration system are responsible for the depletion of ozone layer and global warming. The utilization of hydrocarbons offers great substitution for the current halogenated refrigerants as far as environmental concern. In this paper, an audit of the past examinations did with liquid suction heat exchanger and hydrocarbons as option refrigerants in vapor compression refrigeration system. A study has been made to cover the possibilities and issues identified with the utilization of hydrocarbons as alternative refrigerants and use of liquid suction heat exchanger. Hydrocarbon characteristics, combustible properties, safety considerations, refrigerant properties and environmental impacts are likewise introduced. Results demonstrated that The use of liquid suction heat exchanger have both positive and negative influences on the plant overall energy efficiency, depending on the working fluid and the operating conditions. However despite exceedingly flammable characteristics, hydrocarbons can offer appropriate options to the halogenated refrigerants from the stance of environment impact, energy efficiency and COP.

Keywords: COP, Global warming, Halogenated refrigerants, Hydrocarbons, Liquid suction heat exchanger, Ozone layer

I. INTRODUCTION

For proper system operation and increasing system performance liquid-suction heat exchangers are commonly installed in refrigeration systems. The main performance implications of a liquid suction heat exchanger adoption are both positive and negative [1]. The main advantages of the liquid-suction heat exchanger cycle are: subcooling liquid refrigerant to ensure liquid phase entrance to the expansion device, increasing refrigerating effect at the evaporator, minimizing the risk of liquid refrigerant presence at the compressor inlet;

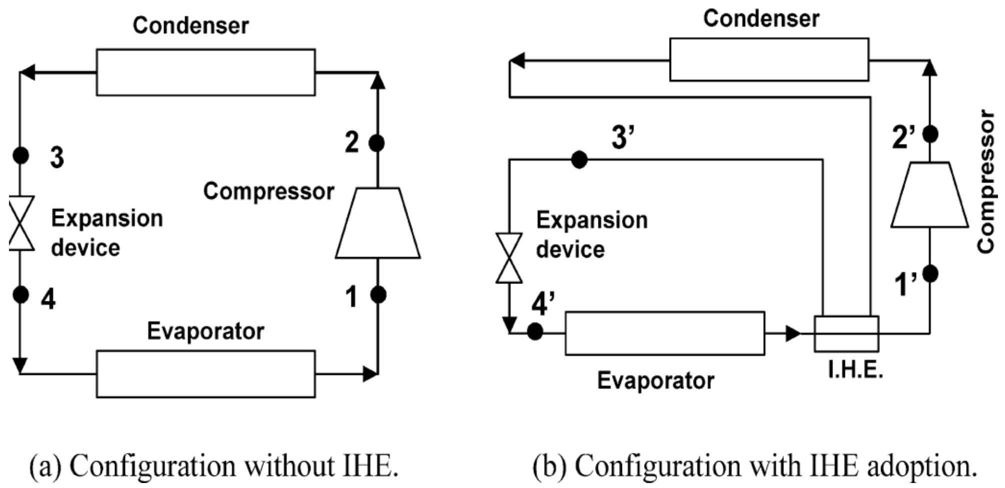

Figure 1: vapor compression refrigeration system with and without a liquid-suction heat exchanger. [3]

Specifically, ASHRAE (1998) [2] states that liquid-suction heat exchangers are effective in:

 DOI : 10.35291/2454-9150.2019.0315

ISSN : 2454-9150 Vol-05, Issue-04, July 2019

1) Increasing the system performance
2) Subcooling liquid refrigerant to prevent flash gas formation at inlets to expansion devices
3) Fully evaporating any residual liquid that may remain in the liquid-suction prior to reaching the compressor.

The possible disadvantages can be: increasing compressor discharge temperature, decreasing the refrigerant mass flow rate delivered by the compressor, increasing suction specific volume at the compressor entrance.

In today's scenario, environmental related issues are most concerned topic all over the world. Many of the refrigerants may cause environmental related problems. The first major concern is depletion of ozone layer and the second one is global warming. Therefore, refrigerants are developed by considering two major environmental concerns of zero ozone depletion potential and zero global warming potential. Global warming issues developed due to greenhouse gases emission and halocarbons are responsible for ozone depleting and greenhouse gas. Halocarbons are the compounds consisting carbon and one of the halogen atom, such as fluorine, chlorine, iodine, and bromine. Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) having excellent thermodynamic and chemical properties, thus commonly used as working fluids. CFCs and HCFCs contain chlorine which is responsible for the depletion of ozone layer. Whereas HFCs don't contains chlorine or bromine so it doesn't effects ozone layer but it contains fluorine, which is a greenhouse gas. Therefore HFCs are responsible for the global warming potential. For remarkable wellbeing properties of Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), it was used widely as refrigerants in cooling and refrigeration systems from 1930s.

Due to protocol signed in 1987, refrigerants having high ozone potential (CFCs) are banned. HCFCs (halogenated hydrocarbon compounds) are also not environmental friendly refrigerants therefore they are also phased out. After the year 2010 no equipment would be made which works on utilizing HCFCs refrigerants and after the year 2030 production of HCFCs also phased out. Chlorine atoms are responsible for the depletion of ozone layer and some of the halogenated molecule groups are free from chlorine atoms are also existed. New refrigerants are developed by considering the criteria of having low ozone depleting potential (ODP) and global warming potential (GWP). The hydro fluorocarbon (HFC) refrigerants with zero ozone depletion potential have been recommended as alternatives of CFCs and HCFCs due to their contribution to ozone layer depletion and global warming. But it has high global warming potential; therefore it is also phased out after Kyoto protocol. [11-26]

II. LIQUID SUCTION HEAT EXCHANGER

The influence of adopting an HE on the coefficient of performance (COP) have been studied by Aprea et al. [10], assuming adiabatic device and negligible pressure drops, obtaining that:

$$\mathbf{COP' - COP} = \frac{(h1 - h4) + (h1' - h1)}{h2' - h1'} - \frac{(h1 - h4)}{(h2 - h1)} > \mathbf{0}$$

Where '' indicates the case when the liquid-suction heat exchanger is working.

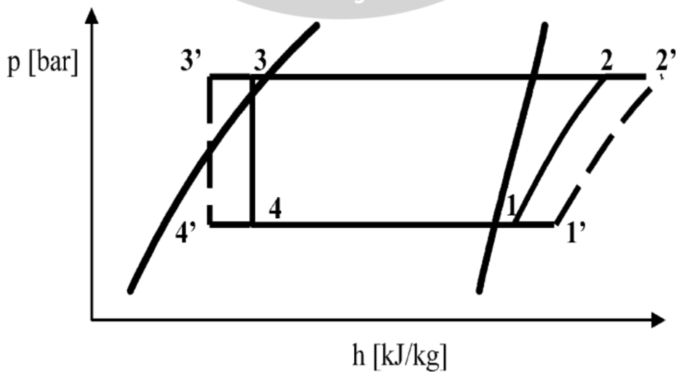

Fig. 2

Assuming the same isentropic compression work in both cases, that can be approximated by

$$\mathbf{W_s = (n\, p_{suc}\, v_{suc})\, (r^{(n-1)/n} - 1)/ (n - 1)}$$

The adoption of a liquid-suction heat exchanger is advantageous when the inequality is accomplished.

$$\mathbf{(h1' - h1) > (h1 - h4)\ [(T1' - 1)/ T1]}$$

DOI : 10.35291/2454-9150.2019.0315

- **Heat Exchanger Effectiveness**

The ability of a liquid-suction heat exchanger to transfer energy from the warm liquid to the cool vapour at steady-state conditions is dependent on the size and configuration of the heat transfer device. The liquid-suction heat exchanger performance, expressed in terms of effectiveness, is a parameter in the analysis. The effectiveness of the liquid-suction heat exchanger is defined as equation [76]:

$$\varepsilon = \frac{T2-T1}{T3-T1} = (T_{vapor,\,out} - T_{vapor,\,in}) / (T_{liquid,\,in} - T_{vapor,\,in})$$

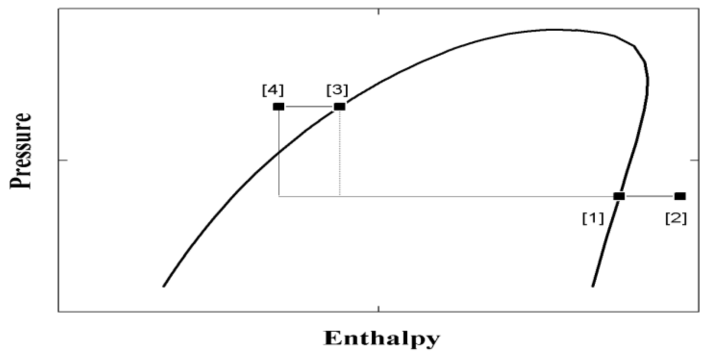

Fig. 3

Klein et al. [5] have studied about Heat transfer devices, which provided in many refrigeration systems to exchange energy between the cool gaseous refrigerant leaving the evaporator and warm liquid refrigerant exiting the condenser. By neglecting the reduction in refrigerant mass flow rate, he would conclude that liquid-suction heat exchangers lead to performance improvements for any refrigerant. Under closer evaluation, liquid-suction heat exchangers increase the temperature and reduce the pressure of the refrigerant entering the compressor causing a decrease in the refrigerant density and compressor volumetric efficiency. From his analysis, he can be concluded that liquid-suction heat exchangers are most useful at high temperature lifts and for refrigerants having a relatively small value of $\Delta h_{vap}/(c_{p,L}T_c)$.

Domanski et al. [6] have evaluated the performance analysis of vapour compression refrigeration system when liquid suction heat exchanger is installed in it. His evaluation is based on theoretical concept about parameters of cycle and properties of refrigerant. He concluded that liquid suction heat exchanger is advantageous or not depends upon the cycle parameters and refrigerant properties.

Muller [7] wanted to increase system performance by using internal heat exchanger in vapour compression refrigeration system. He stated that the internal heat exchanger can be viably connected in the refrigerant cycle utilizing zeotropic refrigerant blends. He concluded that R22 and R407C showed better energy efficiency when used with refrigerant mixture however at low evaporating temperature R22 showed no improvement of energy efficiency. He found that evaporator works more efficient when there is no superheating of refrigerant.

Navarro et al. [3] have investigated about the impact of internal heat exchanger on vapour compression refrigeration system. In his paper he used two refrigerants R134a and R1234yf and compares their performance with and without use of internal heat exchanger in vapour compression refrigeration system under different scope of operating conditions. He found that cooling capacity and COP are reduced in 6 - 13% when using R1234yf instead of R134a. However the use of an internal heat exchanger would lessen the decline in the cooling limit and COP somewhere in the range of 2 and 6%.

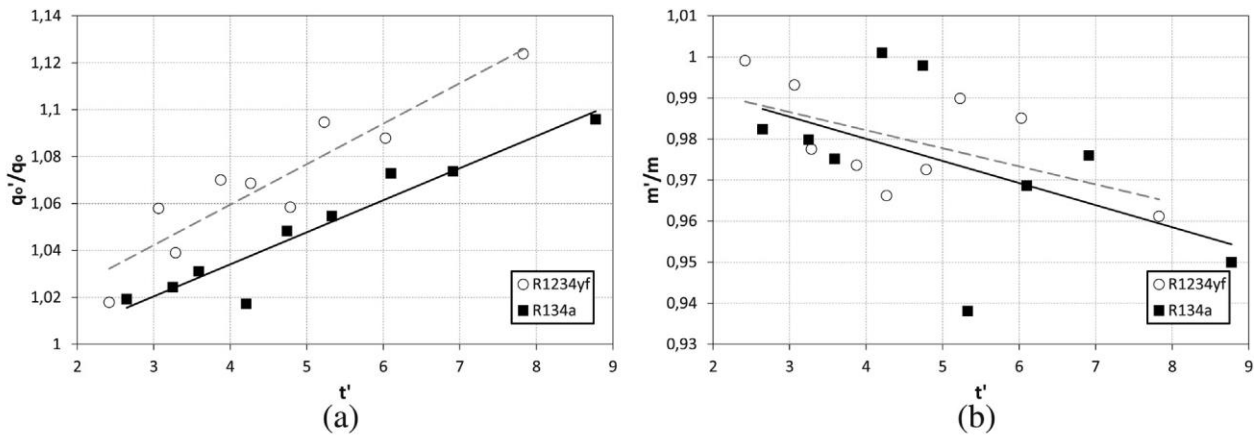

Fig. 4: Relative variations caused by the IHX adoption in: (a) refrigerating effect, and (b) refrigerant mass flow rate.

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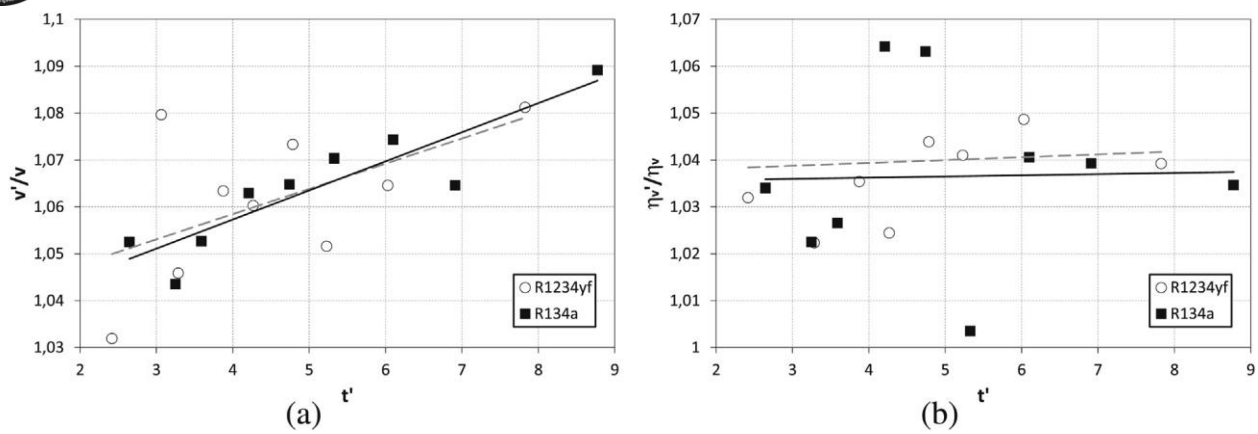

Fig. 5: Relative variations caused by the IHX adoption in: (a) suction specific volume, and (b) compressor volumetric efficiency.

J. Esbrı et al. [4] have used internal heat exchanger and compared the energy efficiency of vapour compression refrigeration system by taking three different refrigerants R22, R134a and R407C. His objective is accomplished by transferring energy to the cool gaseous refrigerant leaving the evaporator from hot fluid refrigerant leaving the condenser. In his thesis the test outcome acquired from a refrigeration system with and without the use of liquid suction heat exchanger, utilizing R22, R134a and R407C as refrigerants keeping same the condensing and evaporating temperatures inclusive of the subcooling and superheating degrees at leaving of condenser and evaporator. He found that the use of internal heat exchanger increments the performance of the system at low compression ratios except for R134a.

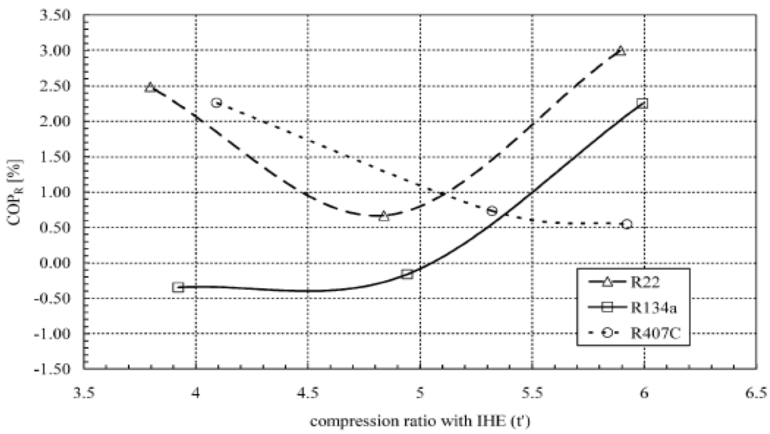

Fig. 6 - Relative variations of the refrigerating capacity due to IHE adoption

Zhang et al. [8] have studied about the performance of the Transcritical Carbon Dioxide Refrigeration Cycle working with internal heat exchanger. He analyzed it theoretically regarding first and second laws of efficiency. He found that the specific cooling capacity and compression work increases due to internal heat exchanger addition in the carbon dioxide refrigeration cycle with an expander however the optimum heat rejection pressure and the expander output power decreases.

Sencan et al. [9] has examined about subcooling and superheating effects of alternative refrigerants for vapour compression refrigeration system. He performed analysis by considering three refrigerants: R134a, R407c and R410a and the impact of subcooling and superheating on the three refrigerants taken is resolved. It is discovered that both condenser and evaporator temperatures have powerful influence on the coefficient of performance (COP) and irreversibility of the system. Additionally subcooling and superheating applications influence the system execution. From his experiment he found that R134a has the most effectiveness rate while R410a, which is another refrigerant has the least effectiveness rate and impact is the same for R134a and 407c, and distinctive for 410a.

Aprea et al. [10] has examined the paradigm for anticipating the benefits of using a suction/liquid heat exchanger in refrigerating system. He also compared the system performance with and without the use of liquid suction heat exchanger. He discovered that a disentangled decision basis could be utilized if a few suppositions are made; these present blunders which have been confirmed to be fewer than 5%. The basis has been emphatically checked for a few working fluids, for example, CFCs, HCFCs and substitutes.

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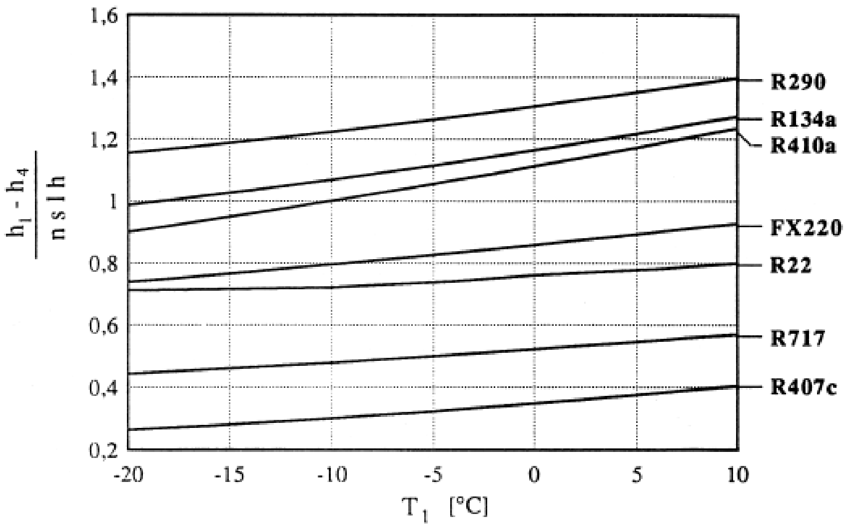

Fig. 7: Chart for evaluating the possible thermodynamic advantage of adopting a suction/liquid heat exchanger. Refrigerant R22 and its substitutes.

III. REFRIGERANTS HISTORY

Refrigerants are the medium in vapor compression system through which heat is carried. Different refrigerants were used after the invention of vapor compression refrigeration cycle by Parkin in the 1830s (such as carbon dioxide (CO_2), ammonia (NH_3), water (H_2O), carbon tetrachloride (CCl4), hydro carbons (HCs), etc.). At that time safety precautions was priority for all and environment related problems were not much of concern. Refrigerants used at that time were flammable, as well as toxic. Accidental cases due to refrigerants were increased. Thus after 1930s, CFCs refrigerants were used as working fluid in vapor compression cycle before the establishment of Montreal Protocol. CFCs refrigerants are having excellent thermodynamic and chemical properties, thus it was commonly used as working fluids. But CFCs were phased out due to their high ozone depleting potential. HCFCs were used as an alternative due to relatively less harmful than CFCs. HCFCs also restricted due to ozone depleting potential.

HFCs are free from chlorine, hence started using by many countries. HFCs are having zero ozone depleting potential but global warming comes into picture and Kyoto protocol is established for banned of refrigerants which contains greenhouse gases. [11-31]

A. CFCs

Its molecule contains chlorine, fluorine and carbon. It has high ODP and GWP. It is non flammable. Example - R11, R12, R115 etc.

B. HCFCs

Its molecule contains hydrogen, chlorine, fluorine and carbon. It has medium ODP and GWP. It is non flammable. Example - R22, R141b, R124 etc.

C. HFCs

Its molecule contains hydrogen, fluorine and carbon. It has zero ODP and medium GWP. It is non flammable. Example - R407C, R32, R134a etc.

D. Hydrocarbons

This is primarily propane (R290), butane (R600) and isobutene (R600a). It has zero ODP and GWP. It is highly flammable.

IV. HALOGENATED REFRIGERANTS

Halocarbons are the compounds consisting carbon and one of the halogen atom, such as fluorine, chlorine, iodine, and bromine. Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are halogenated refrigerants. These refrigerants are causes for environmental related issues, such as depletion of ozone layer and global warming. [19-21]

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A. Performance of halogenated refrigerants

Halogenated refrigerants are having excellent thermodynamic and chemical properties. Thus performance coefficient obtained by these refrigerants is higher. These refrigerants are non flammable and non toxic. Due to this feature, less safety precautions are needed. Many researchers have examined about the halogenated refrigerants. Arzu Sencan, A.S. Dalkilic, Ahmet Selim and R. Cabello [33-35] were concluded in their investigation that halogenated refrigerants showed better performance. **A.S. Dalkilic** **[43]** has compared CFC12, CFC22 and HFC134a with different blends of HFC134a, HFC152a, HFC32, HC290, HC1270, HC600 and HC600a in different proportions in vapour-compression refrigeration system. They found that hypothetical results demonstrated that the majority of the blend refrigerants examined in the investigation have a marginally lower coefficient of performance (COP) than CFC12, CFC22, and HFC134a at the condensing temperature of 50 °C also, evaporation temperatures extending between −30 °C and 10 °C. **Selim et al.** **[44]** has compared different type of refrigerants for vapour compression refrigeration system in his paper. . In his experiment he used HCFC-22, CFC-502 and compared their options, for example HFC-134a, HFC-32, HFC-152a, HFC-404A, HFC-407C, HFC-507, HFC-410A for Single-stage vapour compression system and contrasted with an actual vapour compression cycle, single stage process with internal heat exchanger, and a two-stage process with economizer. He concluded that R152a and R134a are observed to be the most reasonable alternative refrigerants in between researched refrigerants. **Arora et al.** **[45]** have presented exergy analysis of a Vapour Compression Refrigeration system using R-22, R-407C and R-410A as refrigerants. They compared refrigerants R-22, R-407C and R-410A with respect of performance coefficient (COP), exergy destruction and exergetic effectiveness. They were taken evaporator temperature in the limit of −38°C to 7°C and condenser temperature in the limit of 40°C to 60°C. They demonstrated from their outcomes that COP and exergetic effectiveness for R-22 are higher in contrast with R-407C and R-410A. **Menlik et al.** **[46]** has examined exergy of vapour compression refrigeration system and compared the coefficient of performance working with R22 and its substitutes R407C and R410A. His investigations have been performed for various evaporators having scope of -40°C to 0°C with 5°C interims, condenser having scope of 40°C to 55°C with 5°C interims. After his analysis he concluded that COP and exergetic efficiency of R22 is superior to that of its substitutes at diverse condenser temperatures somewhere in the range of 40°C and 55°C. The best replacement for R22 is R407C on account of its higher COP with respect of R410A. **Reddy et al.** **[47]** have used refrigerants R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A to determine COP and exergetic analysis in vapour compression refrigeration system. Amid the examination, it was discovered that the condenser and evaporator temperatures strongly affect COP furthermore, exergetic efficiency of the refrigeration system. In this investigation, it was discovered that R-134a has the most effective performance in all regard though R407C refrigerant has inferior performance. **Rocca et al.** **[48]** have compared the refrigerant R22 with three HFC fluids R417A, R422A and R422D on the basis of performance in vapour compression refrigeration system. He has done a few number of tests considering R22 (context fluid) and the elective fluids (R417A, R422A and R422D). He found that R22 was enthusiastically more proficient and effective than alternative refrigerants. **Mukul** **[49]** has used the refrigerants R-134a and Hydrocarbon for performance determination of vapour compression refrigeration system. In between refrigerants R-134a and Hydrocarbon, he found that R-134a gives better performance and exergy efficiency in vapour compression refrigeration system. **Khan et al.** **[50]** has used R12, R22, R134a for energy and exergy analysis of vapour compression refrigeration system. At condenser temperature of 40°C and evaporator temperatures scopes from -10°C to -40°C he found that R12 gives us better COP and exergetic efficiency with respect of R22 and R134a whereas R134a have higher energy destruction ratio with respect of R22 and R12. **Bisht et al.** **[51]** has studied about the vapour compression refrigeration system utilizing R-22, R407C and R410A refrigerants and compared their performance. He found that R22 gives highest and R407c gives lest COP. R410a has highest RCI whereas R22 has lowest (at evaporator temperature of 0°C). R22 has higher value of exergetic efficiency with respect of R410A and R407C whereas R407C has lowest value of exergetic efficiency of all three refrigerants. **Bolaji et al.** **[52]** has compared three ozone friendly HFC refrigerants R32, R134a and R152a in vapour compression refrigeration system. He found that R32 is worst and R152a is the best among these three refrigerants according to their performance coefficient. He concluded that the COP of R152a gained was relatively higher than R134a and R32 by 2.5% and 14.7%. However due to zero ODP and very less GWP of R152a, he suggested that we can replace R134a by R152a effectively.

B. Impact on environment

Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are halogenated refrigerants. Molecules of CFCs and HCFCs contain chlorine, which is harmful for ozone layer. CFCs, HFCs and HCFCs contain fluorine, which is a greenhouse gas. Hence halogenated refrigerants effect badly the environment. Ozone layer restricts the ultraviolet rays coming from the sun. Halogenated refrigerants are unsafe for the stratospheric ozone layer. In between ozone (O_3) and O_2, O_3 is unstable with respect to O_2. Chlorine radicals are responsible for removing of ozone and ozone changes to oxygen. Nearly 100000 ozone molecules are ruined by single chlorine atom. Ozone depletion potential is relative degradation on a scale using reference CFC-11, marked as ODP = 1.

 DOI : 10.35291/2454-9150.2019.0315

Global warming is due to greenhouse gases. Greenhouse gases entrap the heat and increasing the temperature of the earth. Accordingly, ODP and GWP have progressed toward becoming a standout amongst the most significant criteria in investigating new option refrigerants for the VCRSs. [14, 15, 19, 33-35]

TABLE 1 Environmental effect of different groups of refrigerants. [29]

Refrigerant group	Refrigerant example	ODP	GWP (100 year)	Atmospheric life time (years)	Flammability	Comments
CFCs	R11, R12, R115	0.6–1	4750–14,400	45–1700	Non-flammable	Very high ODP and GWP
HCFCs	R22, R141b, R124	0.02–0.11	400–1800	1–20	Non-flammable	Medium ODP and GWP
HFCs	R407C, R32, R134a	0	140–11,700	1–300	Non-flammable	Zero ODP and medium GWP
Natural refrigerants	R744, R717, HC (290, R600, R600a)	0	0	Few days	Flammable	Zero ODP and zero GWP

V. NEED FOR ALTERNATIVES OF HALOGENATED REFRIGERANTS

A. *Concern towards environment*

People are committed towards social, economic and environmental pillars of sustainable improvement are refrigeration. Refrigeration systems are main assets for all countries but it is important to minimize use of refrigerants which causes environmental issues. It is also necessary to reduce energy consumption of refrigerators and air conditioners. Ozone layer depletion and global warming are the two major concerns for environment due to the use of halogenated refrigerants. [11-19]

B. *Montreal Protocol and Kyoto protocol*

Because of depletion of ozone layer due to refrigerants, Montreal Protocol came in 1987, it was chosen to build up necessities that started the overall eliminate of CFCs. According to Montreal Protocol, CFCs production was ruled out from developed countries in 1st of January 1996 and from developing countries in 2010. HCFCs replace CFCs due its low ozone depletion potential. In 1992, it was chosen to build up necessities that started the overall eliminate of HCFCs. HCFCs will completely phased out from 2030 in developed countries by Montreal Protocol.

Kyoto protocol comes for eliminating of substances that will prompt global warming. HFCs (R134a) is most commonly used refrigerant in vapor compression refrigeration systems, which contains zero ozone depletion potential (ODP) but very high global warming potential (GWP). Therefore in near future, HFCs will be eliminated worldwide due to Kyoto protocol.

To satisfy worldwide natural issues adequately, these refrigerants must be supplanted by other refrigerants with zero ozone depletion potential and global warming potential. These halogenated refrigerants can be supplanted by the utilization of natural refrigerants, for example, hydrocarbons (HCs) which have zero ODP and GWP. These HCs are naturally occurring, cheap, and can cover almost every current refrigeration application. [11, 14, 41, 42, 29-31]

VI. HYDROCARBONS AS ALTERNATIVE REFRIGERANT

Hydrocarbon refrigerants are natural refrigerants mainly consists of carbon and hydrogen. Hydrocarbon refrigerants are best choice due to its zero ozone depleting potential and very low global warming potential. Hydrocarbons (HCs) are the class of natural occurring substances that include propane, pentane and butane in which isobutene (R-600a, C_4H_{10}) and propane (R-290, C_3H_8) are used frequently in refrigerators and in small commercial appliances respectively. Hydrocarbon refrigerants have a very low environmental impact in comparison with CFCs, HCFCs and HFCs therefore they are environmentally good alternative for CFCs, HCFCs and HFCs. Hydrocarbons are good alternative for many reasons – They have low discharge temperature compare to HFCs, HCFCs and CFCs. Thus compressor life increases. It gives good performance coefficient. They have good heat transfer, solubility and critical point properties. No problems occur to use hydrocarbons with copper.

Hydrocarbons were used as refrigerants in between 1867 to 1930s. But many accidental problems were occurred during this period. Thus, the flammability of hydrocarbon is a topic of concern to use as an alternative. Care is expected to guarantee that combustibility does not present safety issues: There should not be any leakage in the system, working with hydrocarbon.

 DOI : 10.35291/2454-9150.2019.0315

ISSN : 2454-9150 Vol-05, Issue-04, July 2019

Hydrocarbons should be handled safely. Charging area and equipments are chosen carefully. [35-73]

Table. 2: Flame limits and ignitions data for a few flammable refrigerants. [74]

Refrigerant	LFL %(vol.)	UFL %(vol.)	Ignition temp(°C)	Ignition energy, (J)
Propane, (R290)	2.1	9.5	466	0.00025
Iso-butane (R600a)	1.3	8.5	455	0.00025
Cyclopropane (RC270)	2.4	10.4	495	0.00017
Dimethyl ether (DME)	3.4	17	235	
R152a	3.9	16.9		0.22
Ammonia (R717)	15.5	27.0	651	0.68

Many researchers have studied about hydrocarbon refrigerants and their comparative analysis. **Choudhari et al**. [53] has investigated the performance of natural refrigerant R290 to know the possibilities for the substitution of R22. The performance in done on vapor compression cycle with evaporator temperature in range of -25°C to 10°C and condenser temperature of 45°C. He found that R290 has slightly more coefficient of performance than R22. Discharge temperature, volumetric refrigerating capacity and required mass flow of refrigerant is also found larger in R22.

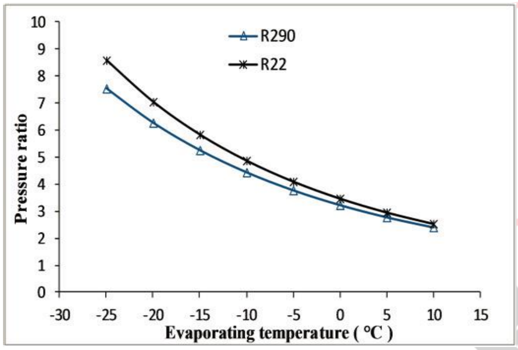


Fig A. Variation in pressure ratio

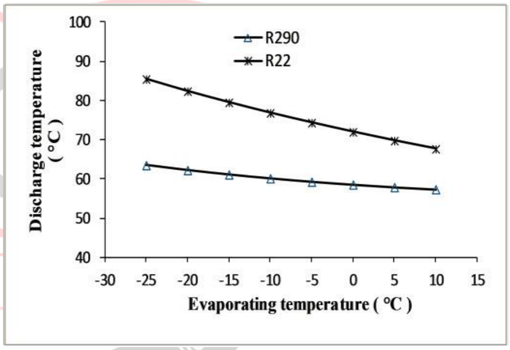


Fig B. Variation in discharge temperature

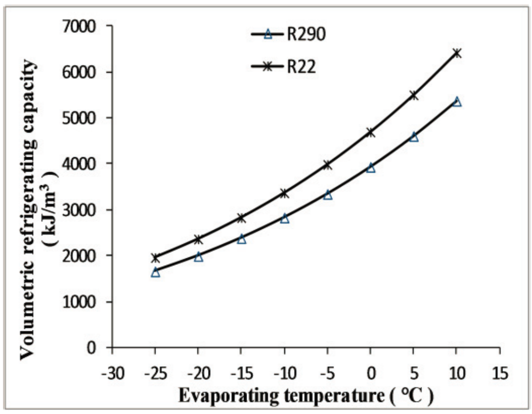


Fig C. Variation in volumetric capacity

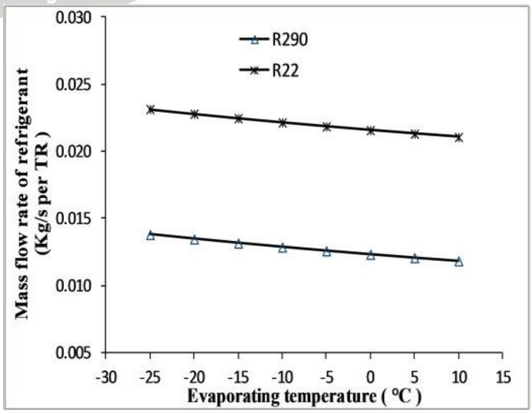


Fig D. Variation in refrigerant mass flow rate

Fig. 8: Show variation in different parameters with respect to evaporator temperature.

Angeloa et al. has examined the performance of vapor compression refrigeration system working with mixture of refrigerant R290/R600a. He found maximum COP with 40 wt% R290 and 60 wt% R600a.

 DOI : 10.35291/2454-9150.2019.0315

ISSN : 2454-9150 Vol-05, Issue-04, July 2019

Yu et al. [54] has used hydrocarbon mixture refrigerant in refrigerator for analysis. Performance and suitability of these refrigerants were also studied. R290 is used in the composition from 0 to 65% with R600a. He concluded that all hydrocarbon mixtures give better performance coefficient than R134a. He also found that system consumes less electricity for all HCs with respect to R134a.

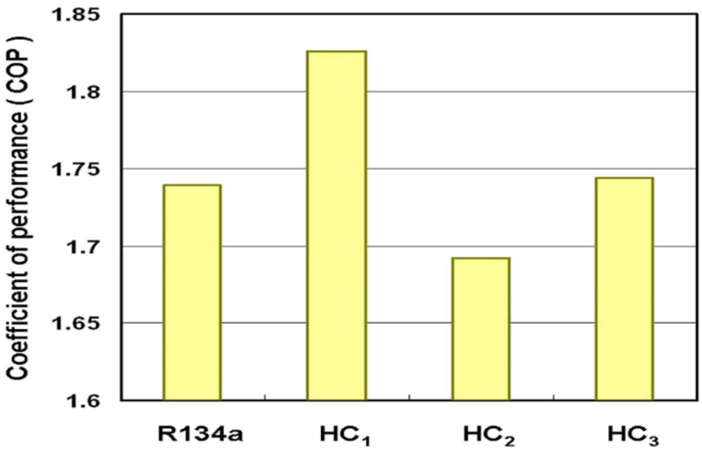


Fig. 9: COPs of the refrigerator when using the different refrigerants, HC_1 is mixture of 65% R290 and 35% R600a., HC_1 is mixture of 50% R290 and 50% R600a, HC_1 is mixture of 0% R290 and 100% R600a.

Saravanakumar et al. [55] has compared the energy and exergy analysis of domestic refrigerator system utilizing eco-friendly mixture of R290/R600a and R134a. He found that the coefficient of performance of R290/R600a is larger than R134a with 28.5%. At an evaporator temperature of 263 K, exergetic efficiency was found 42.1%.

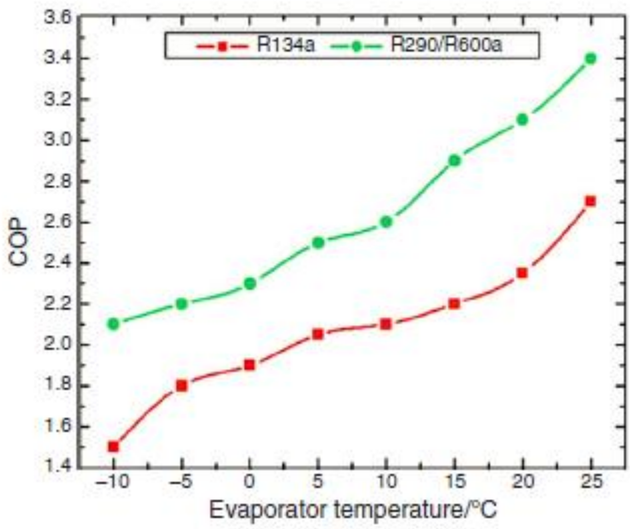


Fig. 10: Variation of COP with varying evaporator temperature.

Kabul et al. [56] has used hydrocarbon (600a) for the performance and exergy analysis of vapor compression refrigeration system consisting an internal heat exchanger. Here refrigeration capacity is assumed 1 kW, the evaporator temperature of -10°C and condenser temperature of 40°C. He concluded that the values of COP, efficiency and exergetic efficiency were increased with increase in evaporator temperature. But condenser temperature, COP, efficiency and exergetic efficiency were decreased with increase in condenser temperature.

Jwo et al [57] has examined domestic refrigerator working with hydrocarbon refrigerants. He compared mixture of R290/R600a with 50% in proportion each to the R134a. He concluded that refrigerating effect is improved by using hydrocarbon refrigerant. Up to 4.4% and 40%, there is save in total energy consumed and applied mass of refrigerant respectively.

DOI : 10.35291/2454-9150.2019.0315

ISSN : 2454-9150 Vol-05, Issue-04, July 2019

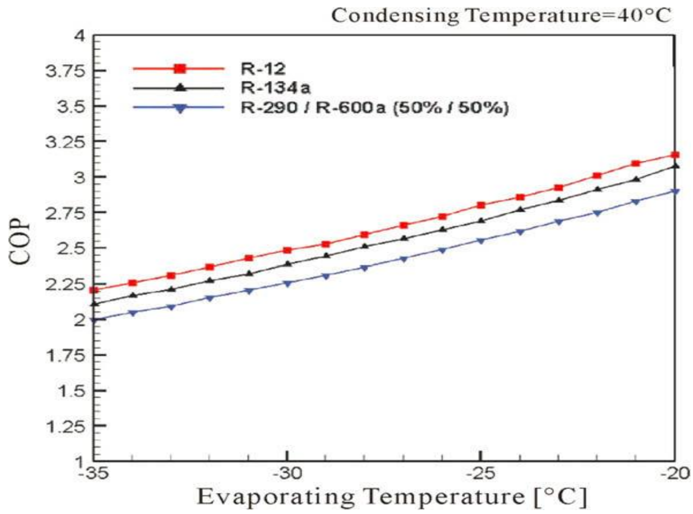


Fig. 11 - COP value comparisons of refrigerants R-12, R-134a, and R-290/R-600a by increasing evaporating temperature, where condensing temperature 40°C.

Halimic et al. [58] has compared performance of alternative refrigerants. R401A, R290 and R134A were compared with R12 with respect of refrigerating capacity and COP. He found that performance of R134a and R22 is nearly same. But R290 have best performance when green house impact was considered.

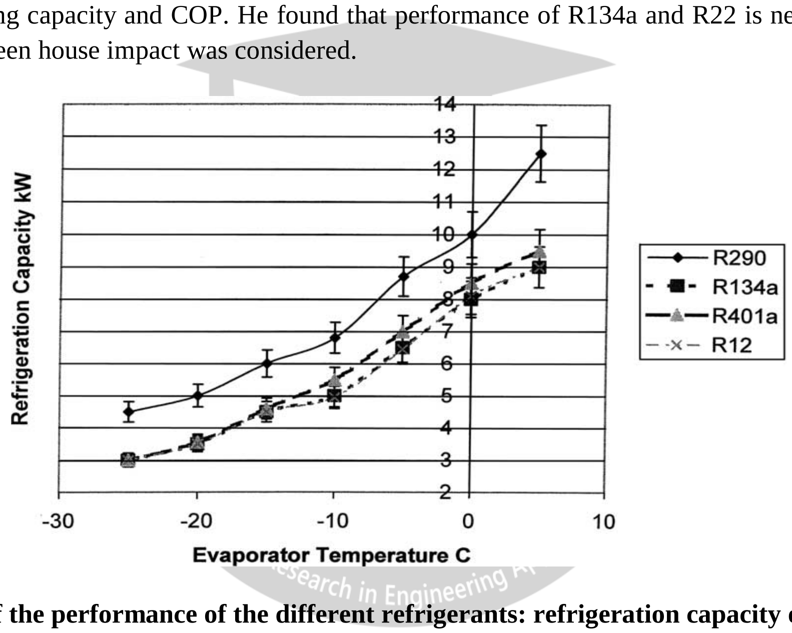


Fig.12 - Comparisons of the performance of the different refrigerants: refrigeration capacity of different refrigerants.

Bayrakci et al. [49] has examined exergy analysis of vapor compression refrigeration system utilizing hydrocarbon as refrigerant. He used four different pure HCs propane (R290), butane (R600), isobutane (R600a) and isopentane (R1270) for analysis. He found that R1270 and R600 are having higher exergetic efficiency than R600a and R290.

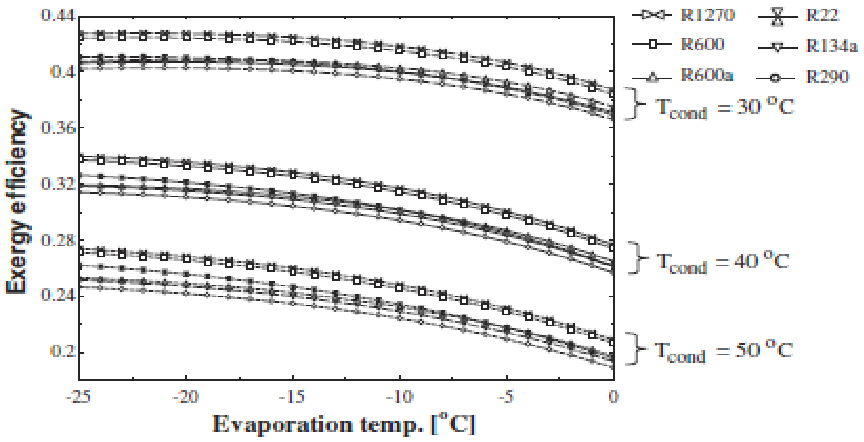
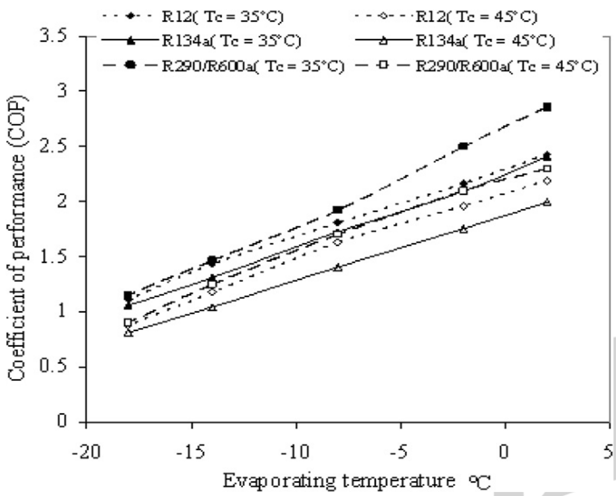


Figure 13 - Exergy efficiency variations of the refrigerants with the evaporation temperature.

DOI : 10.35291/2454-9150.2019.0315

Li et al. [50] has studied Rankin cycle base vapor compression refrigeration system working with hydrocarbon refrigerant. In examined refrigerants, butane was the best refrigerant used in this system. The system reaches a COP of 0.470 working in low grade energy.

Mani et al. [51] has investigated about the mixture of refrigerants. Mixture of R290/R600a was compared with R12 and R134a. He concluded that R290/R600a had 19.9% to 50.1% higher refrigerating capacity than R12 and 28.6% to 87.2% than R134a. Refrigerating capacity of R134a is lower than R12. The mixture R290/R600a consumed 6.8% to 17.4% more energy than R12. The coefficient performance of R290/R600a mixture increases from 3.9% to 25.1% than R12 at lower evaporating temperatures and 11.8% to 17.6% at higher evaporating temperatures. The R290/R600a (68/32 by wt %) mixture can be used as an alternative.



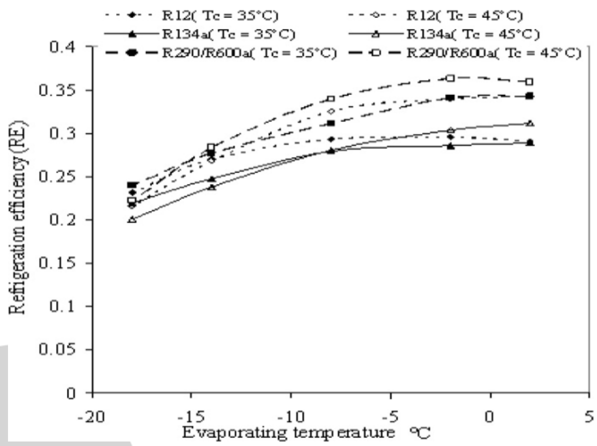


Fig. A

Fig. B

Fig. 14

Fig. A - COP vs. evaporating temperature for Tc = 35 °C and 45 °C / Fig. B - RE vs. evaporating temperature for Tc = 35 ◦C and 45 ◦C.

Rasti et al. [52] has investigated about the substitution of R134a with a mixture of R290 and R600a with a mass ratio of 56/44 in a domestic refrigerator. He concluded that the charge amount of mixture was reduced by 48% and energy consumption decreases up to 5.3% in 24 hours.

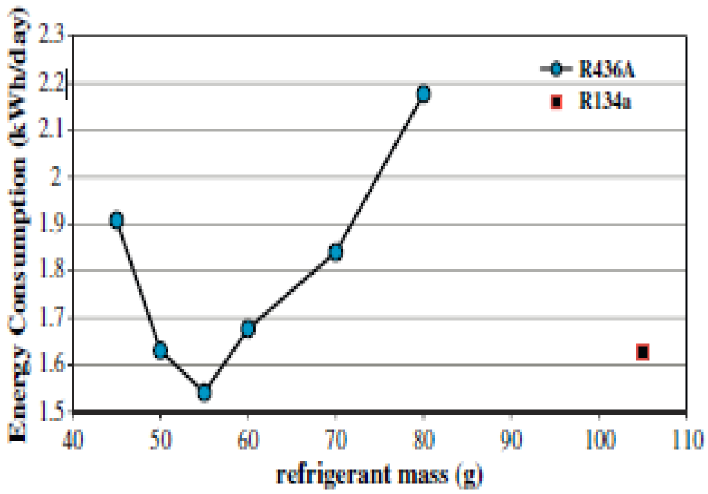


Fig.15 - Comparisons of energy consumption level per day R134a and R436A for -20 °C thermostat setting.

A.S. Dalkilic [33] has compared CFC12, CFC22 and HFC134a with different blends of HFC134a, HFC152a, HFC32, HC290, HC1270, HC600 and HC600a in different proportions in vapour-compression refrigeration system. He concluded that the refrigerant mixtures of HC290/HC600a (40/60 by wt. %) and HC290/HC1270 (20/80 by wt. %) are observed to be the most reasonable options among refrigerants tried for R12 and R22.

 DOI : 10.35291/2454-9150.2019.0315

ISSN : 2454-9150 Vol-05, Issue-04, July 2019

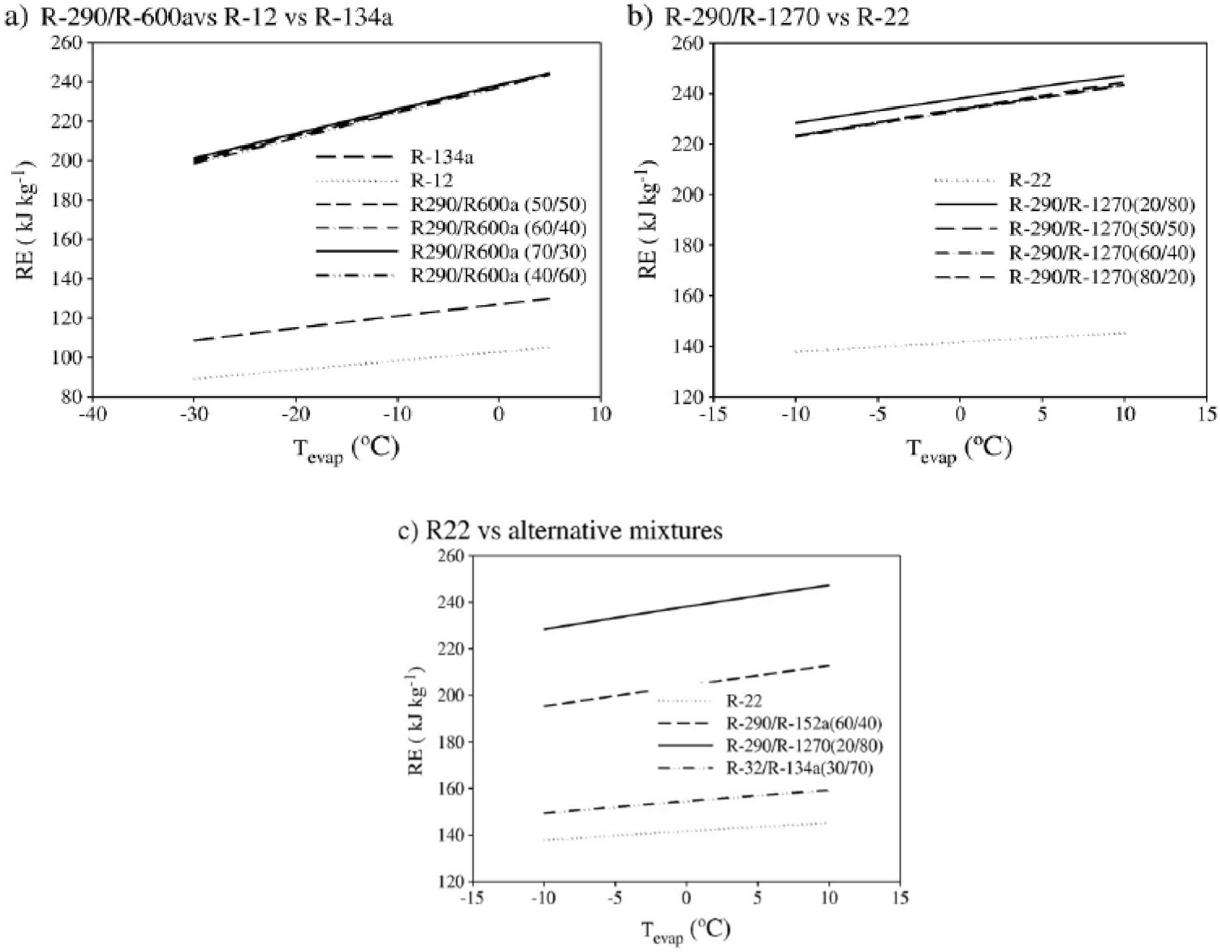


Fig.16 - Refrigerating effect (a, b, c) vs. evaporating temperature.

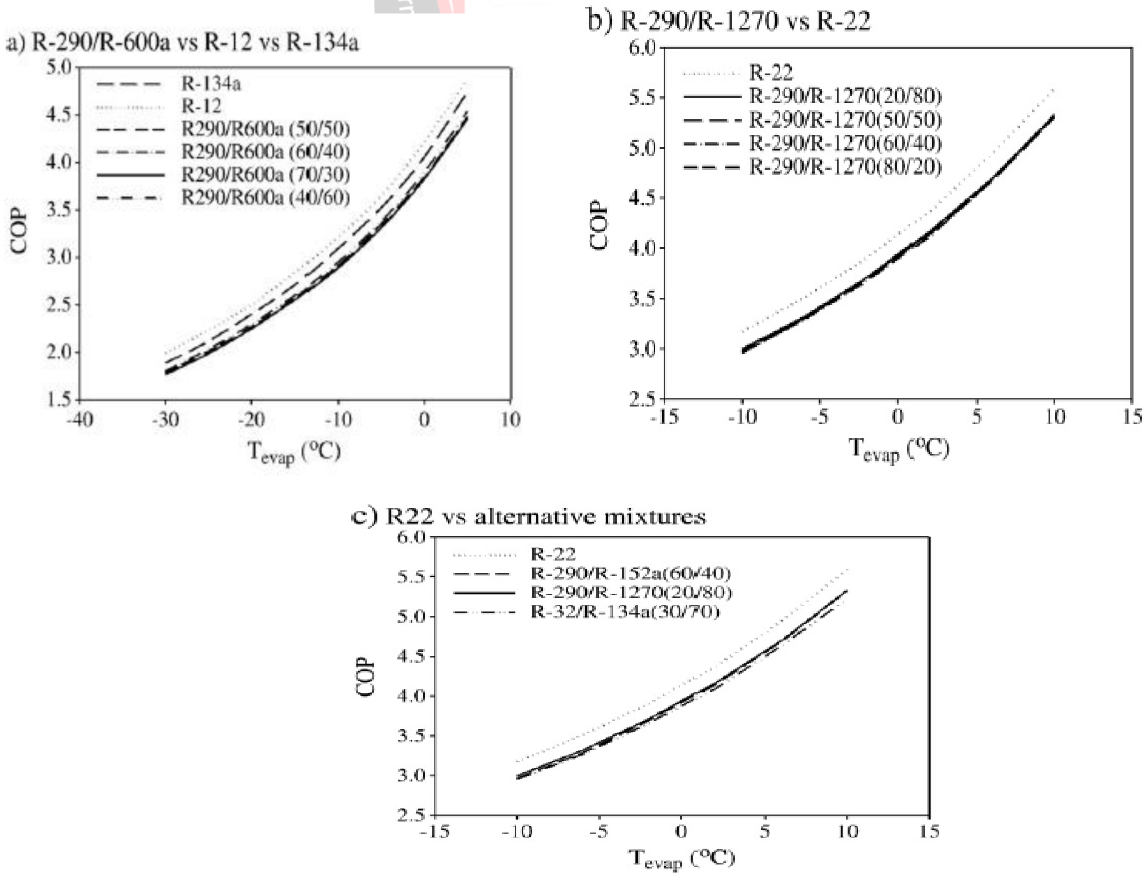


Fig.17 - Coefficient of performance (a, b, c) vs. evaporating temperature.

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Baskaran et al. [53] have compared the performance of Vapour Compression refrigeration system using eco friendly Refrigerants. He examined the performance by using different eco-accommodating refrigerants such as HFC152a, HFC32, HC290, HC1270, HC600a and RE170 and their outcomes were collated with R134a on vapour compression refrigeration system. The outcomes demonstrated that for the condensation temperature of 50ºC and evaporating temperatures extending between - 30ºC and 10ºC, the elective refrigerants researched in the examination RE170, R152a and R600a have a marginally higher coefficient of performance (COP). He concluded that the refrigerant RE170 was observed to be the most reasonable option among refrigerants tried for R134a for better coefficient of performance and by considering ODP and GWP.

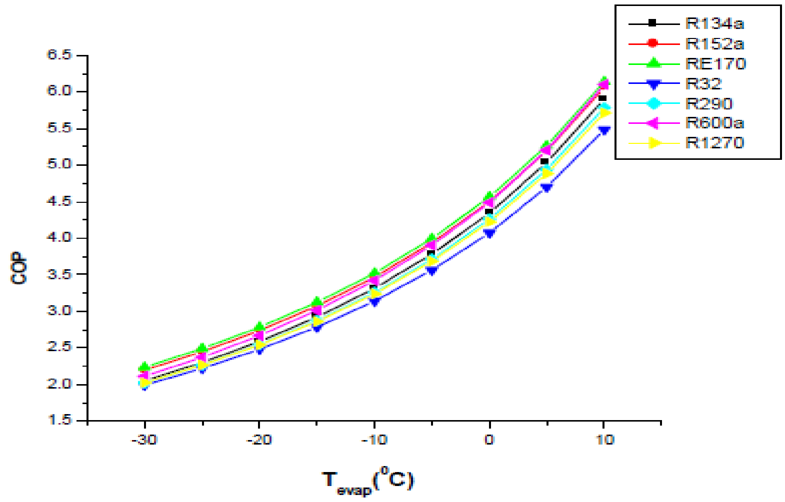

Fig.18 - Coefficient of performance Vs Evaporation temperature

Ahamed et al. [54] have studied on exergy analysis of vapor compression refrigeration system. He compared their exergy efficiency working with refrigerants R407a, R600a, R410a and R134a. He concluded that blends of hydrocarbons with R134a likewise show better execution as for different refrigerants. Significant piece of exergy misfortunes is happened in the compressor among the parts of the vapor compression refrigeration system. To diminish the exergy misfortunes in the compressor he used nanofluid and nanolubricant. He stated in his conclusion that diminishing the temperature contrast of the evaporating and condensing temperature and by sub-cooling up to 5°C exergy effectiveness can be promoted.

K. Harby [55] has studied about hydrocarbons and their blends as options in contrast to natural unpleasant halogenated refrigerants. He has been made an Endeavour to cover the present status, conceivable outcomes and issues identified with the utilization of hydrocarbons as elective refrigerants. He has also displayed hydrocarbon attributes, combustible properties, and precaution contemplations (shown in table 1). He concluded that the utilization of hydrocarbons as refrigerants is not only useful for the condition, yet in addition it can decrease the vitality utilization and offer great drop-in substitutes for the current halogenated refrigerants. R290 has been effectively marketed to supplant R22 in low charge, room and versatile air conditioning system. HC blends, for example, R432A and R433A and HC/HFC blends (like R470c/R600a/R290) are acknowledged as a situation benevolent alternative for supplanting R22 in cooling applications. HC and HFC/HC blends are observed to be the great substitutes for supplanting R12 and R134a in residential refrigeration system. R290/R600/R600a and HC/HFC blends (R134a/R290:R600a) were observed to be an alluring option to R143 and R12 in car air conditioning systems.

Bayrakci et al. [56] has used four different pure hydrocarbons propane (R290), butane (R600), isobutane (R600a) and isopentane (R1270) in vapour compression refrigeration system and compared their energetic and exergetic performance. For reference he used refrigerants R22 and R134a. He found from his study that there is much small difference in their COP. From detailed study, he concluded that R1270 has maximum energy and exergy efficiency. R600 almost has same efficiency as R1270. R22, R600a and R134a give nearly same efficiency. Therefore among all hydrocarbons, R1270 gives us best option to use as alternative refrigerant.

 DOI : 10.35291/2454-9150.2019.0315

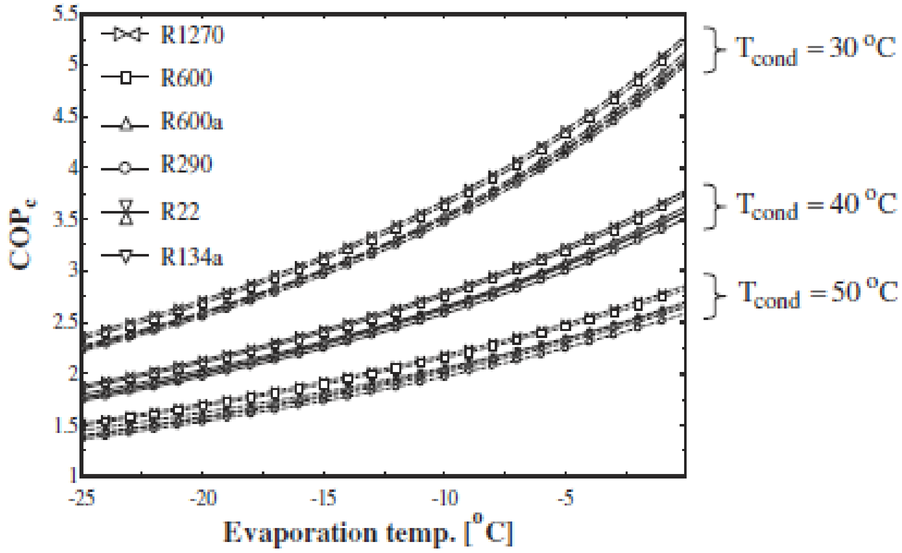

Figure 19 - The COPc variations of the refrigerants with the evaporation temperature for three different condensing temperatures.

Niraj Kumar Mahato [57] has studied about vapour compression refrigeration system using refrigerant R-134a and HC with water cooled and air cooled condenser. He concluded that hydrocarbon gives better refrigerating effect compared to R134a.

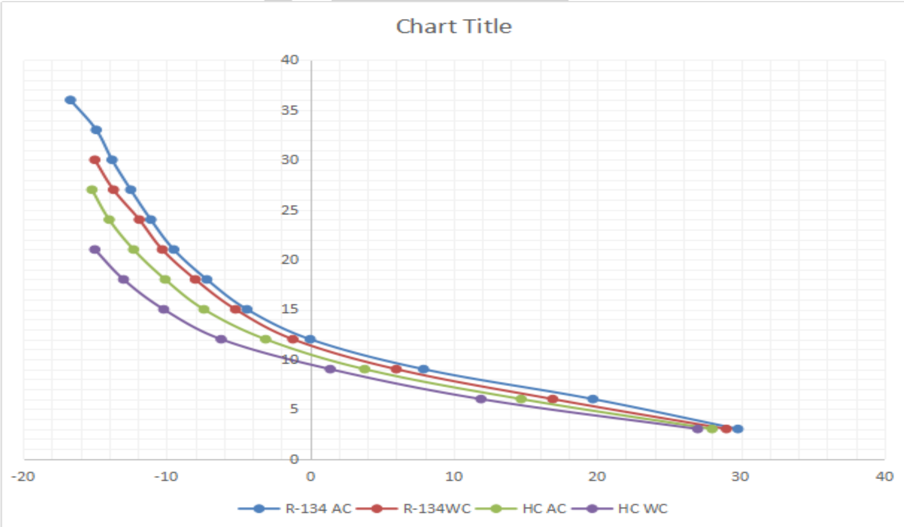

Fig.20: Graphical representation of Time vs. Evaporator temperature for refrigerant R-134a& HC.

Sattar et al. [58] have used pure hydrocarbons and blends of hydrocarbons as refrigerants for examine the performance of domestic refrigerator. Refrigerants used were pure butane, isobutene and mixture of propane, butane and isobutene. At an ambient temperature of 28°C, he concluded that iso-butane and butane was consumed 3% and 2% respectively less energy with respect of HFC-134a. He stated that hydrocarbons can be used as refrigerant in the domestic refrigerator.

Soni et al. [59] has studied about vapour compression refrigeration system. He determined exergy utilizing new refrigerants (to replace CFCs and HCFCs). He found that in domestic refrigeration system, hydrocarbon mixtures and R152a has better substitutes. R11, R12 and R22 can be replaced by the R123 in chiller application.

Barathiraja et al. [61] has examined vapour compression refrigeration system using refrigerants R290 and R600a. He also compared their mixtures (different proportion used) with R134a. He concluded that, the mixtures of R290 and R600a gives better performance coefficient than R134a. Power consumption also decreased for R290/R600a blends and due to more environments friendly blends, it can be used as substitute for R134a.

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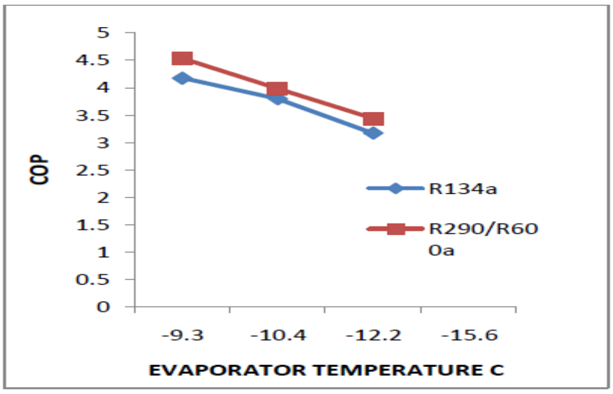

Figure 21: compressor work done vs. evaporator temperature

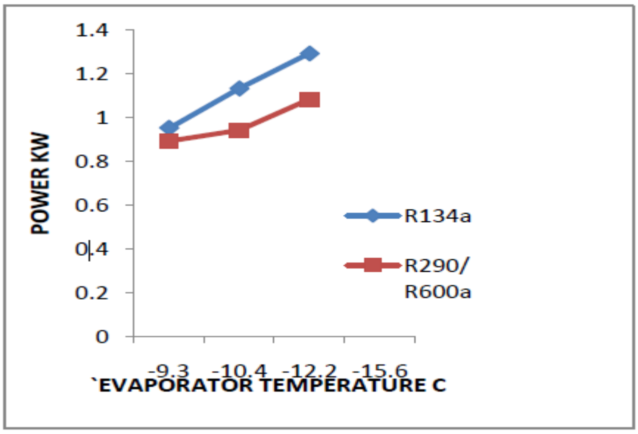

Figure 22: Variation of power consumption vs. evaporator temperature

Balakrishnan et al. [62] has searched about the alternative refrigerants of R134a used in vapour compression system. Alternative refrigerants must have zero ODP and GWP whereas relatively having more performance coefficient. He used the hydrocarbon refrigerant blend of R32/R600a/R290, which was in the proportion of 70:5:25 by weight. After their comparison he concluded that mixture of R32/R600a/R290 gives more coefficient of performance (COP). Thus this hydrocarbon mixture is an effective alternative for R134a.

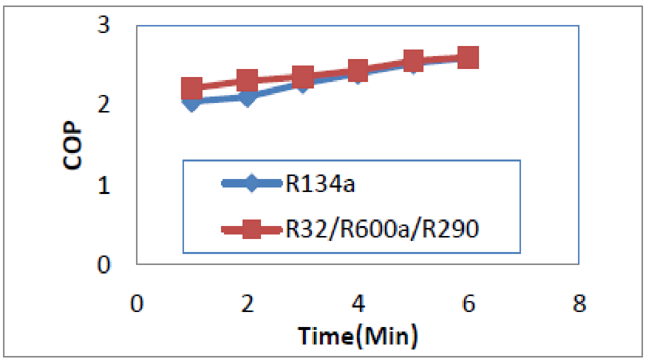

Figure 23: Time vs. COP of R32/R600a/R290 and R134a.

Reddy et al. [63] has investigated about hydrocarbon refrigerant blends as an alternative of R134a refrigerant in vapour compression cycle. The main criteria to use an alternative refrigerant, it has to give better performance with minimum losses. R134a is having zero ozone depletion potential (ODP), but it has a high Global Warming Potential (GWP). Thus, he discovered blends of hydrocarbon R290/R600a (68/32 by wt. %), R290/R 600a (40/60 by wt. %) and R123/R290 (mixture of 70/30) as alternatives of R134a.

VII. Conclusion

The use of liquid suction heat exchanger have both positive and negative influences on the plant overall energy efficiency, depending on the working fluid and the operating conditions.

The halocarbon refrigerants utilized in the refrigeration systems have turned into a subject of extraordinary worry throughout the previous couple of decades. The halocarbon refrigerants were discovered destructive for the environment due to their high ODP and GWP. Therefore, their production has been prohibited by the Montreal Protocol, Kyoto protocol and other international agreements. The utilization of hydrocarbons as refrigerants is not only useful for the environment yet additionally it can lessen the energy consumption and offer great substitutes for the current halogenated refrigerants. Hydrocarbons offer intriguing refrigerant as options for ordinary ones from the point of view of environment impact, energy efficiency and COP. The advantageous thermodynamic and thermo-physical properties of hydrocarbon guarantee that the performance of the equipment is equivalent to the conventional refrigerants.

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