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Investigation of New Eco Friendly Refrigerant Mixture Alternative to R134a in Domestic Refrigerator

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ABSTRACT

In the present study, the possibility of using refrigerant blend of RE170 and R600a as alternative to the refrigerant R134a in domestic refrigerator working on Vapour Compression System has been assessed theoretically. R134a is currently used as the refrigerant in refrigerator replacing the ozone depleting refrigerant R12. Although R134a has no ozone depletion potential, it has relatively larger global warming potential (1300). For this reason the performance of refrigerant mixtures containing RE170 and R600a are measured. The performance characteristics of domestic refrigerator were studied over a wide range of evaporation temperatures (-30°C to 30°C) and condensation temperatures (30°C, 40°C, 50°C) for working fluids R134a and refrigerant mixtures RE170/R600a.This study has been carried out by comparing parameters such as pressure ratio, refrigerating effect, isentropic work, coefficient of performance, compressor power, volumetric cooling capacity discharge temperature and mass flow rate. The present study indicates a drop in replacement for R134a with blend (RE170/R 600a) with the mass fractions of 80%/20%.

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INTRODUCTION

For the past half century, chlorofluorocarbons (CFCs) have been used extensively in the field of refrigeration due to their favorable characteristics. In particular, CFC12 has been predominantly used for small refrigeration units including domestic refrigerator/freezers. Since the advent of the Montreal Protocol, and as the CFC12 has high ODP and GWP the refrigeration industry has been trying to find out the best substitutes for ozone depleting substances. For a past decade, HFC134a has been used to replace CFC12 used in refrigerators and automobile air conditioners. HFC134a has such favorable characteristics as zero ozone depleting potential (ODP), non-flammability, stability, and similar vapor pressure to that of CFC12. A recent study, however, showed that the performance of HFC134a in refrigerators with a proper compressor and lubricant is quite comparable to that of CFC12.

In 1997 the Kyoto protocol was agreed by many nations calling for the reduction in emissions of greenhouse gases including HFCs. Since the Global warming potential (GWP) of HFC134a is relatively high (GWP1300) and also expensive, the production and use of HFC134a will be terminated in the near future.

The research and development in the field of Refrigeration and Air-Conditioning apply the use of natural refrigerants is not only associated with the need to preserve the environment itself, and also has great importance in the latent need for enhanced efficiency energy equipment. Such a feature is observed in Decision XIX/6 of the Montreal Protocol. Hydrocarbons, such as liquefied petroleum gas (LPG) and Di methyl ether are environmentally friendly and their products are available in abundance in nature. In this sense, the use of these substances as refrigerants in domestic refrigerators is very attractive. Sekhar, *et al*. (2004) investigated the mixture of HFC134a/hydrocarbons in two systems of low temperature (household refrigerator and freezer) and two medium-temperature systems (vending machine and bottle cooler). The authors concluded that a mixture containing 9% of hydrocarbon mixtures (mass) has the best performance, resulting in 10-30 % and 5-15% reduction in energy consumption in systems of medium and low temperature, respectively.

Fatouh and El Kafafy (2006) evaluated theoretically a mixture of hydrocarbons composed of

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60% and 40% R290/R600 as a better drop-in replacement for domestic refrigerators based on HFC -134a under abnormal weather conditions, subtropical and tropical regions.

Mohanraj *et al*. (2007) presented an experimental results of the energy efficient hydrocarbons mixture consisting of 45% HC290 (propane) and 55% HC600a (isobutane) as drop-in replacement for the HFC134a under various loads (40 g, 50 g, 70 g, 90 g) in a household refrigerator of 165 liters (class tropical) using synthetic oil as a lubricant and R134a (100 g). Tests were performed at room temperature of 30°C, without thermal load and the refrigerator door closed as ISO 8187. The results showed that the load of 70 g of the hydrocarbon mixture has a better COP, lower power consumption, lower pull down and low temperature discharge in relation to the R134a and the equipment need not change.

Dimethyl ether (RE170, DME) makes a better refrigerant than R290 / R600a blends as it has no temperature glide and doesn't separate during leakage. It has been extensively adopted by the aerosol industry as the most cost effective replacement for R134a in propellant applications (Nicholas Cox, 2010). Valentine Apostol etl (2009) conducted a comparative thermodynamic study considering a single-stage vapor-compression refrigeration system (VCRS) using as working fluids DME, R717, R12, R134A, R22 (pure substances) and R404A , R407C (zoetrope mixtures), respectively. The result of this study is that DME could be used as a refrigerant and, more, that DME could be a good substitution alternative for R12 and R134a.

The Dimethyl ether (DME, C2H6O) possesses a range of desirable properties as a replacement for R-134a. These include better heat transfer characteristics than R-134a, a pressure/temperature relationship very close to R-134a, compatibility with mineral oils, low cost and ready availability. It is also highly environmentally friendly. (ODP =0; GWP =1; atmospheric lifetime = 6 days). DME is compatible with most materials commonly found in refrigeration systems (Adamson, B.M, 1998).

Ki-Jung Park, *et al*, (2010), investigated both numerically and experimentally in an effort to replace HFC134a used in the refrigeration system of domestic water purifiers. Test results show that the energy consumption and the compressor discharge temperature of R429A is 28.9% and 13.4^{0} C lower than that of HFC134a with 50% of the refrigerant charge, Overall,R429Ais a new long term environmentally safe refrigerant and it is a good alternative for HFC134a requiring little change in the refrigeration system of the domestic water purifiers. Ki-Jung Park *et al*. (2010) investigated both numerically and experimentally in an effort to replace HFC134a used in the refrigeration system of domestic water purifiers. Test results show that the energy consumption and the compressor discharge temperature of R510A is 22.3% and 3.7^{0} C lower than that of HFC134a with 50% of the refrigerant charge, Overall, R510Ais a new long term environmentally safe refrigerant and it is a good alternative for HFC134a requiring little change in the refrigeration system of the domestic water purifiers.

Selection of Mixtures:

For drop-in acceptance of a working fluid in a refrigeration system that already exists, some important performance characteristics such as operating pressure, volumetric cooling capacity, coefficient of performance and compressor discharge temperature should be considered. (Fatouh and El Kafafy, 2006). The refrigerant must have a minimum number of essential characteristics favorable like low density in the liquid phase, high latent heat of vaporization, low specific volume in the vapor phase and low specific heat in the liquid phase. Volumetric cooling capacity and performance compared with the original refrigerant are required to accept a working fluid as a replacement.

Thermodynamic Cycle Analysis:

The cycle analysis was performed for HFC134a and DME/R600a in the composition of 0.0 to 1.0 mass fractions of DME by CYCLE_D 4.0 Software. All thermodynamic properties needed for the simulation were computed by REFPROP program. Table 1 lists the simulation conditions used in the analysis while Fig.1 illustrates the Volumetric Refrigerating Capacity (VRC) and COP for HFC134a and mixtures DME/R600a at various concentrations. Baseline COP and VRC of HFC134a are 2.467and 682.1 kJ/m^3, respectively. The predicted COP of the mixture is 2.621 (+6.24%) higher than that of HFC134a in the composition range of 0.8 mass fraction of DME. The VRC increases linearly as DME is added and at 0.8 mass fraction of DME, the VRC of the mixture becomes very close to that of HFC134a. Since the same compressor is used in the experiments, the composition of the mixture to be analyzed is fixed to be 0.8 mass fraction of DME.

Effect of Dimethyl-Ether Mass Fraction:

The condensation and evaporation pressure decreases with the increase in mass fraction of the DME. The influence of the DME mass fraction on the performance of domestic refrigerator for mixture is shown in the fig. (1, 2). In mixture it is observed that the VRC increases with the increase in mass fraction .It is also observed that COP slightly increases as the mass fraction of dimethyl-ether increases. The main reason behind this is the rate of change of refrigerating effect which is higher than that of the specific work. Thus the average COP increases approximately 5.12% when the mass fraction rises for mixture.

Table 1: Effect on VRC and COP at various mass fractions of DME under simulation condition of T_{cod} = 45^{0}C T_{evap} = -25^{0}C T_{sh} = 20^{0}C.

MF(DME)	VRC	COP
0.1	427.9	2.564
0.2	477.7	2.569
0.3	524.5	2.575
0.4	567.4	2.581
0.5	605.6	2.589
0.6	637.9	2.599
0.7	662.6	2.61
0.8	679.8	2.621
0.9	690.6	2.633
1	696.3	2.646

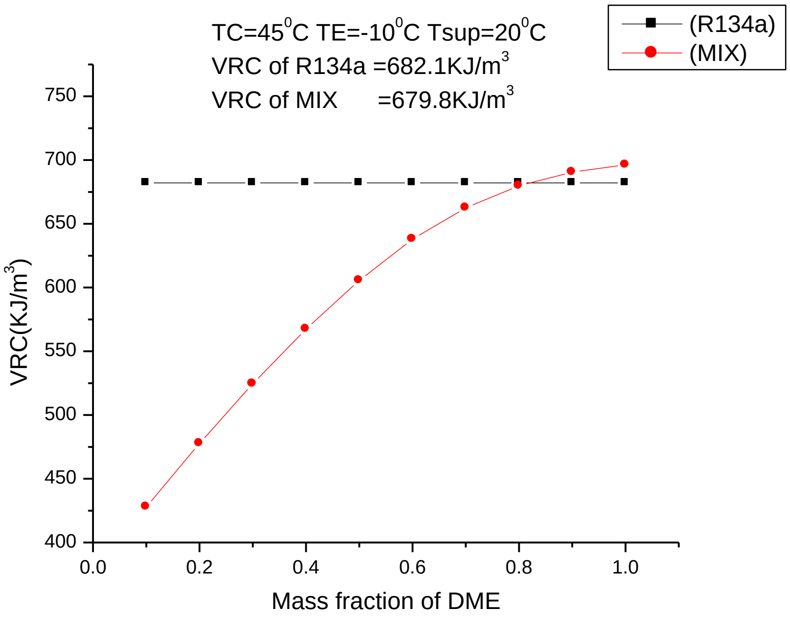

Fig. 1: VRC of RE170/R600a (mixture) as a function of Mass Fractions of DME.

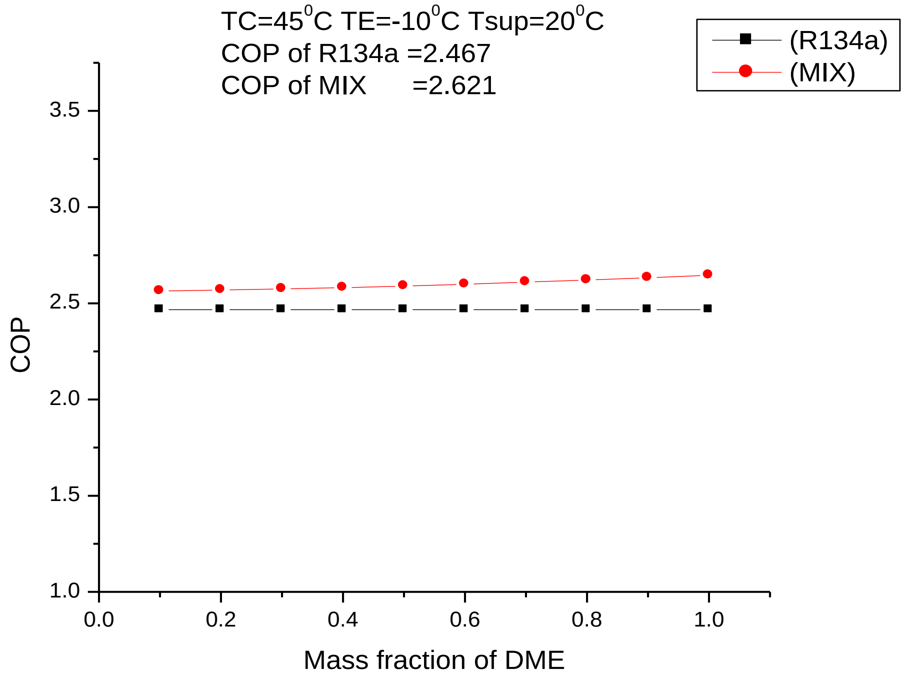

Fig. 2: COP of RE170/R600a (mixture) as a function of Mass Fractions of DME.

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Method of Analysis:

The software CYCLE_D 4.0 vapour compression cycle design program was used for the analysis to find the performance of the system. The ideal refrigeration cycle is considered with the following conditions.

System cooling capacity (kW) = 1.00
Compressor isentropic efficiency = 1.00
Compressor volumetric efficiency = 1.00
Electric motor efficiency = 1.00
Pressure drop in the suction line = 0.0
Pressure drop in the discharge line = 0.0
Evaporator: average sat. Temp =-30^{0}C to +10^{0}C
Condenser: average sat. Temp = 50^{0}C
Degree of Super heating = 10^{0}C
Degree of Sub cooling = 5^{0}C

The analysis of the variation of physical properties and performance parameters such as evaporation pressure (P_{evap}), pressure ratio, isentropic compression work (W), refrigerating effect (RE), power per ton of refrigeration, volumetric refrigeration capacity (VRC), discharge temperature (T_{Dis}), mass flow rate (MFR) and coefficient of performance (COP) of R134a and mixture are investigated in this theoretical study and they are plotted against the evaporating temperature (T_{evap}) as shown in the figures from 3 to 12. Table 2 shows the operation results and deviation of alternative refrigerant mixture from the values of R134a.

Table 2: Operation on standard vapour-compression cycle using R134a and alternative Refrigerant mixture at T_{cod}=50^{0}C and T_{evap} =-10^{0}C with superheating 10^{0}C and Sub Cooling 5^{0}C.

Parameters	R134a	MIXTURE	Deviation %
Evaporating pressure (kPa)	200.6	186.1	-7.22
Compression Ratio	6.57	6.04	-8.07
Refrigeration Effect (kJ/kg)	137.3	302.3	120.26
Compressor Work (kJ/kg)	41.42	86.61	109.1
Coefficient of Performance(COP)	3.315	3.491	5.31
Volumetric refrigerant capacity (kJm^{-3})	1314	1259	-4.14
Discharge Temperature(°C)	66.3	71.5	7.8
Compressor Power(kW)	0.302	0.29	-5.3
Mass Flow Rate (kg/sec)	7.28	3.31	-54.6
Power per ton of refrigeration (kW)	1.057	1.003	-5.11

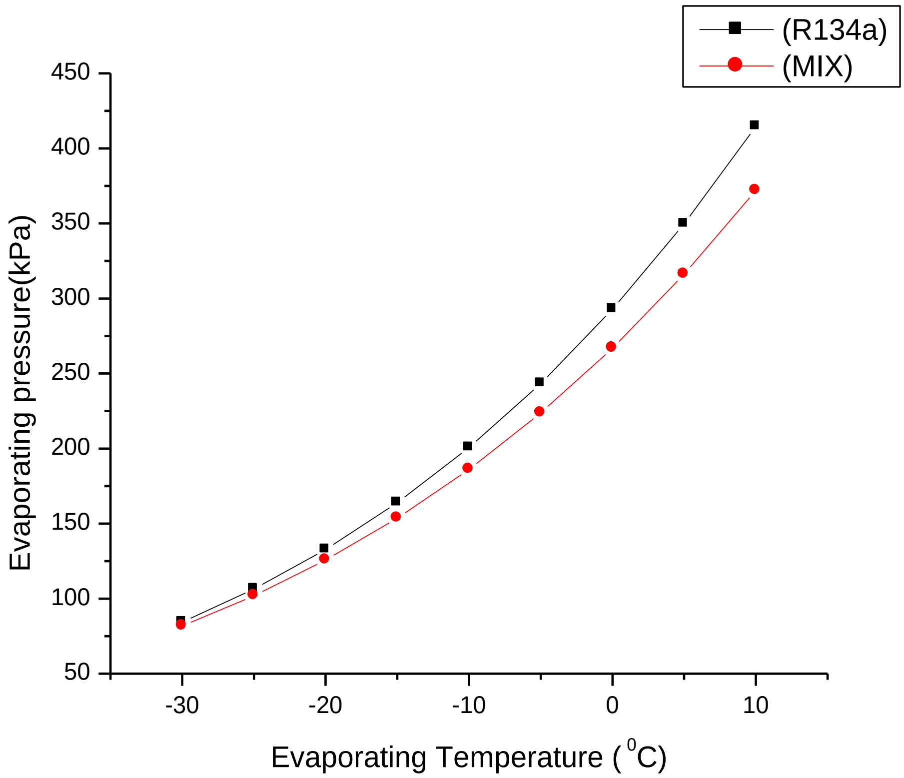

Fig. 3: Evaporating Pressure Vs evaporating temperature.

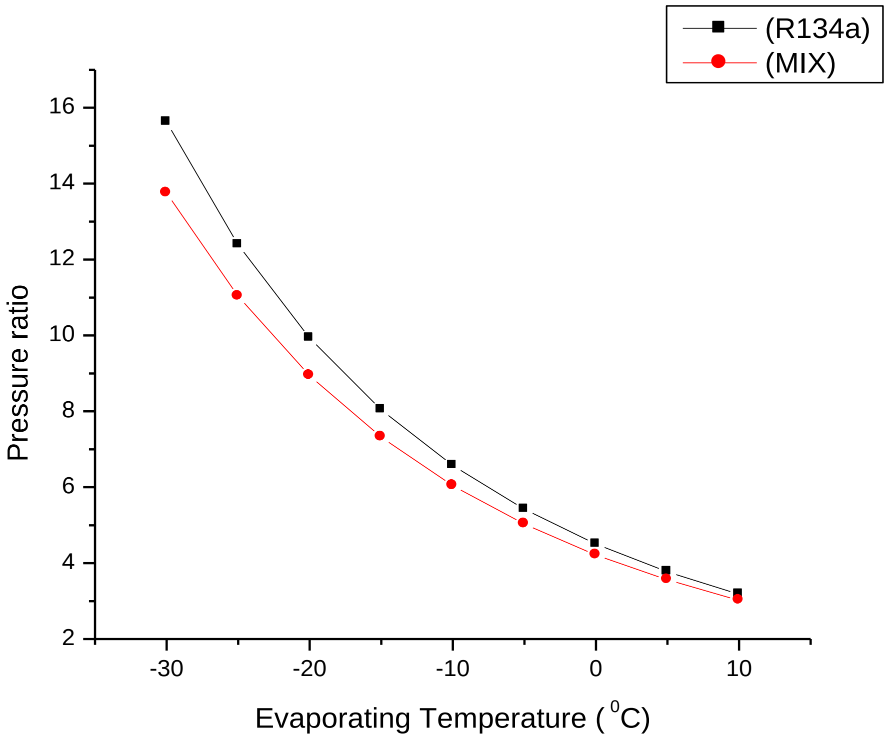

Fig. 4: Pressure Ratio Vs evaporating temperature.

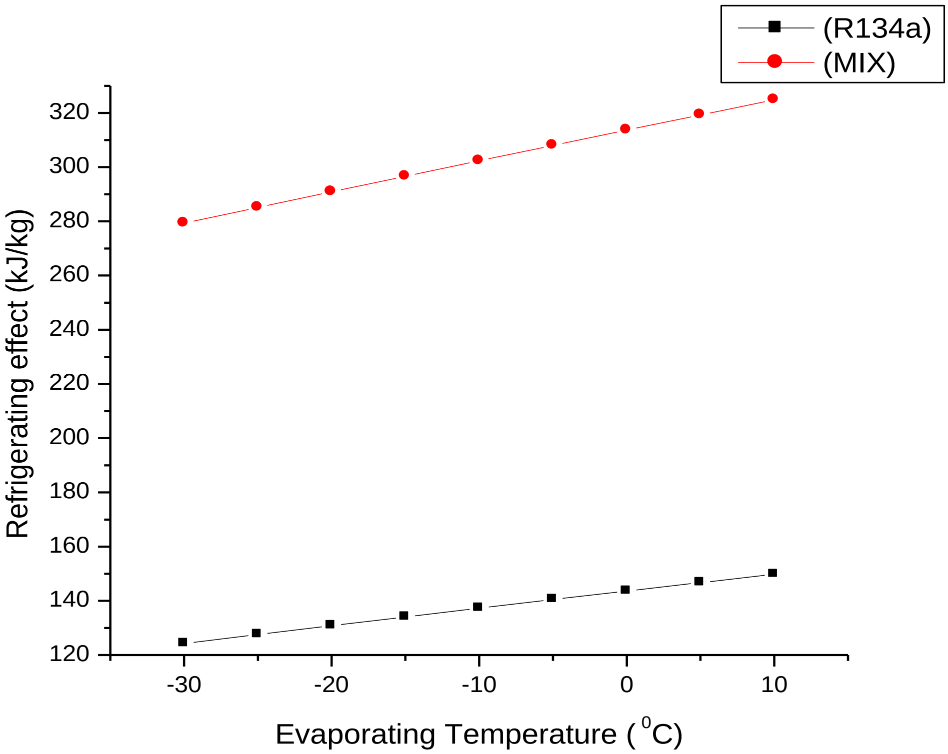

Fig. 5: Refrigerating effect Vs evaporating temperature.

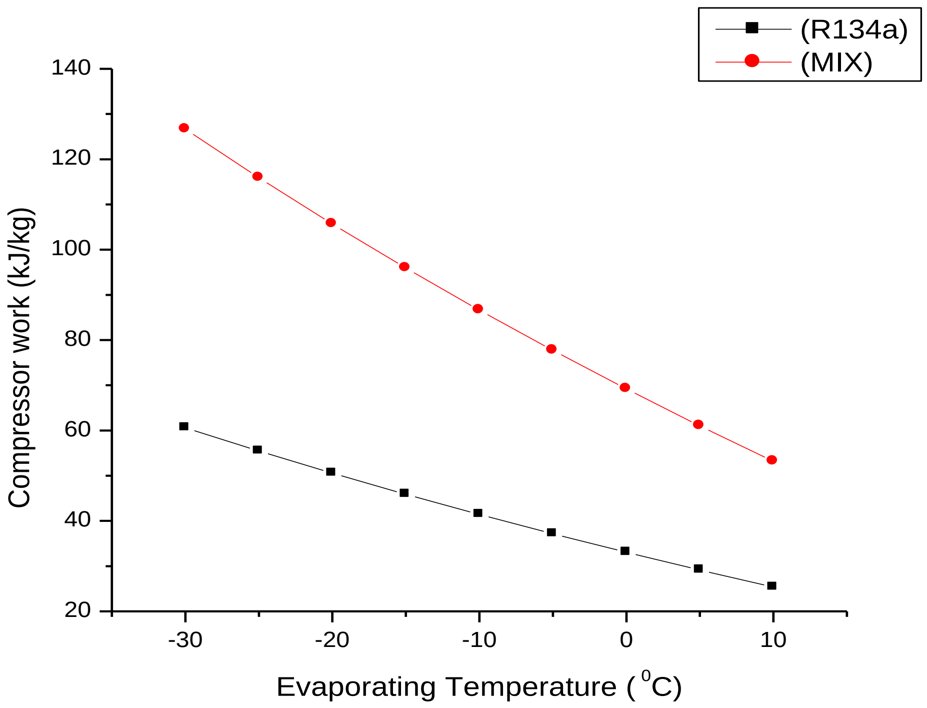

Fig. 6: Compression Work Vs evaporating temperature.

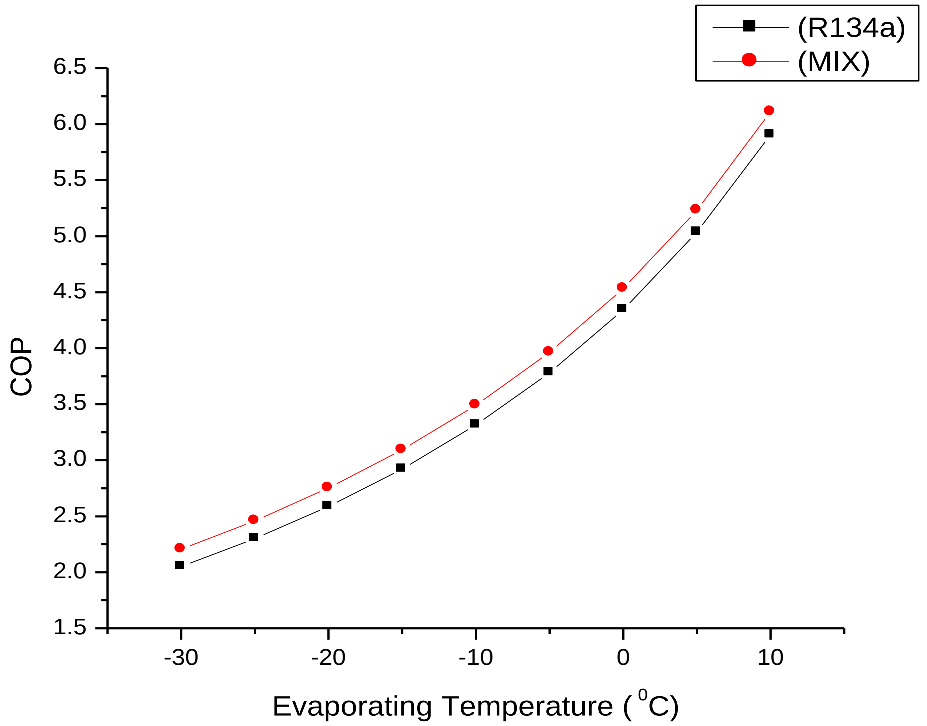

Fig. 7: COP Vs evaporating temperature.

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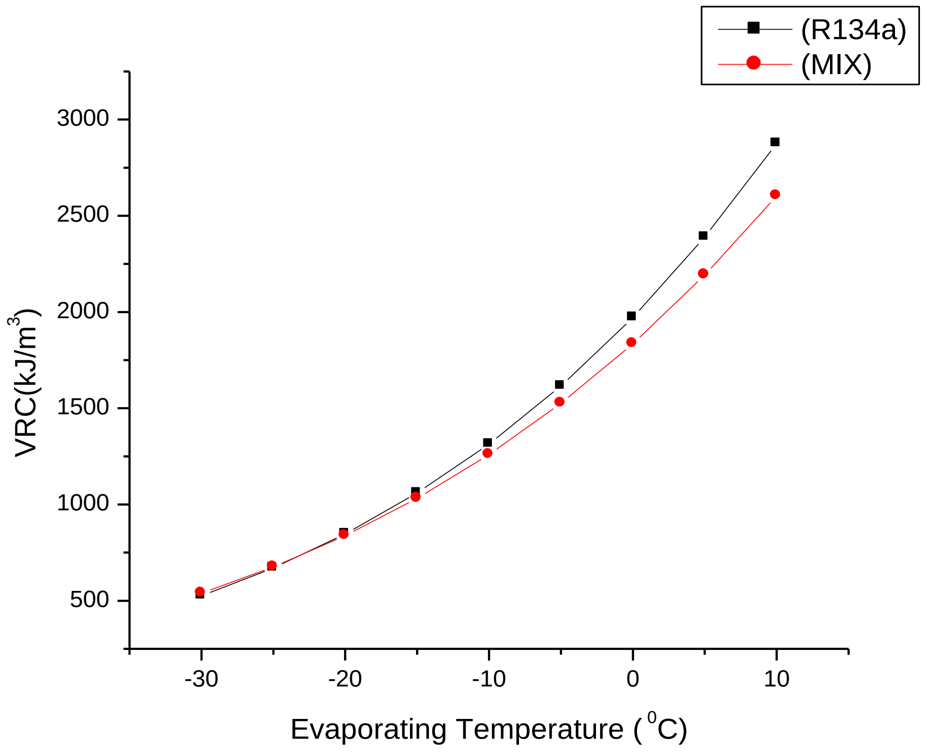

Fig. 8: Volumetric refrigerating capacity Vs evaporating temperature.

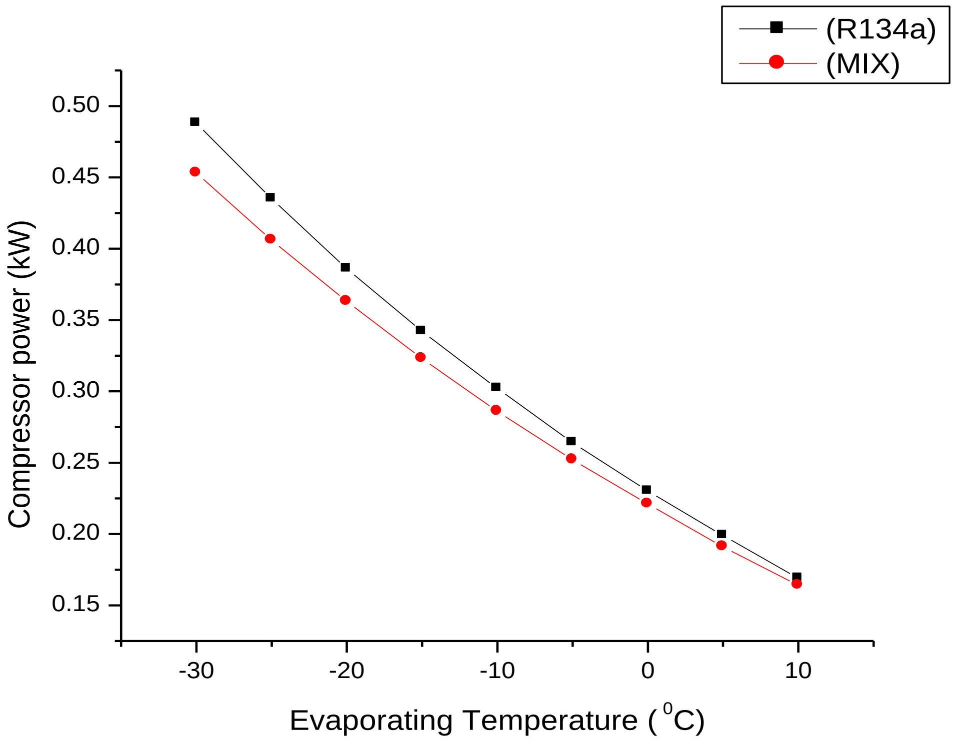

Fig. 9: Compressor Power Vs evaporating temperature.

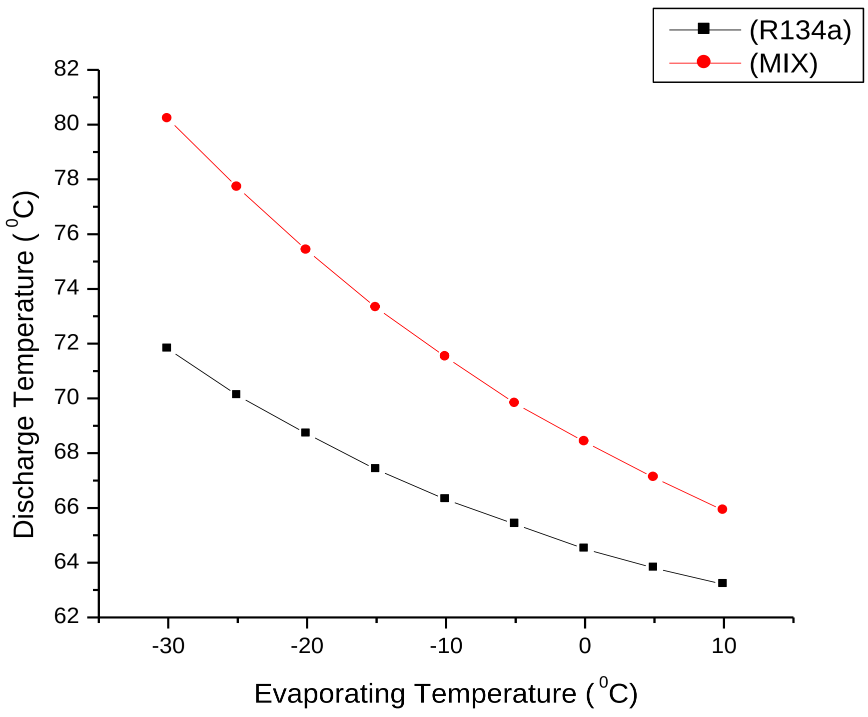

Fig. 10: Discharge temperature Vs evaporating temperature.

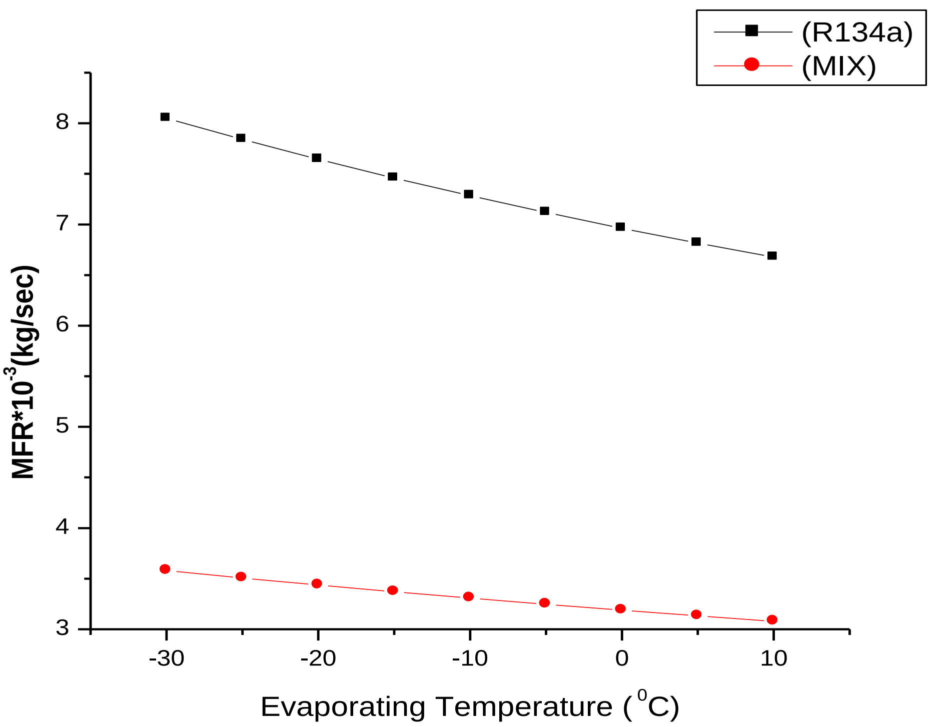

Fig. 11: Mass flow rate Vs evaporating temperature.

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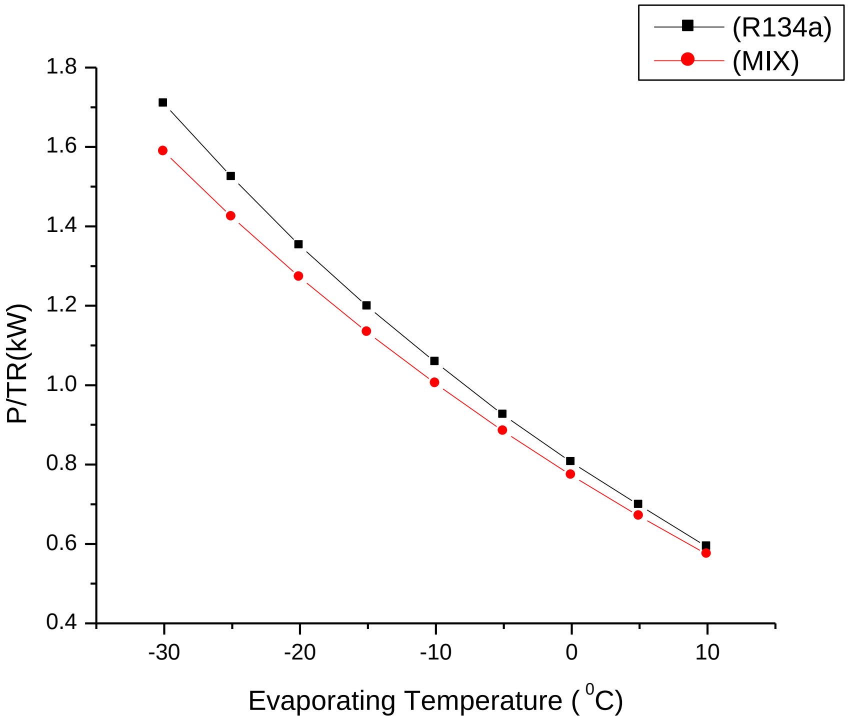

Fig. 12: Power per ton of refrigeration Vs evaporating Temperature.

RESULTS AND DISCUSSION

The changes in evaporating pressure (P_{evap}) and pressure ratio with the evaporation temperature (T_{evap}) are shown in the fig 3 and 4 for listed refrigerants. The pressure ratio of refrigerant mixture substituted for R134a was 8.07% lower than that of R134a as shown in the table 2 for the constant condensation and evaporation temperatures of 50^{0}C and -10^{0}C respectively. Fig 5 and 9 show that the refrigerating effects (RE) increase with increasing evaporation temperature (T_{evap}) while the compressor power (W_{comp}) decreases with increasing T_{evap} for the constant condensation temperature of 50^{0}C and the evaporation temperature ranging from -30^{0}C to 10^{0}C.

The alternative refrigerant mixture has much higher refrigerating effect and isentropic compression work than R134a in the Fig (5, 6) and as shown in the table 2. The variation of the performance coefficients (COP) with evaporating temperatures (T_{evap}) is illustrated in the Fig 7. It is found that the coefficient of performance (COP) increases as the evaporation temperature (T_{evap}) increases for the constant condensation temperature of 50^{0}C and the evaporation temperature ranging from -30^{0}C to 10^{0}C. The performance coefficient (COP) of the alternating refrigerant mixture was found to be higher than that of R134a. The power needed for refrigeration with evaporation temperature (T_{evap}) was shown in Fig 9 and 12. The variation in volumetric refrigeration capacity, discharge temperature and mass flow rate were illustrated in Fig 8, Fig 10 and Fig 11 in order to verify the advantages of cycle.

Comparison with Investigated Refrigerant Mixture:

The refrigeration effect of mixture RE170/R600a is 116% to 124% higher than that of R134a at (-30°C to 10°C) evaporator temperature and 50°C condenser temperature. The average pressure ratio for the mixture RE170/R600a is nearly (5.03% to 11.97%) lower than that of R134a. Specific work of the mixture RE170/R600a is 109.06% to109.62% higher than that of R134a at (-30°C to 10°C) evaporator temperature and 50°C condenser temperature. The COP of the alternative refrigerants is higher than that of R134a by about 3.47% to 7.56% over the range of operating conditions. The Compressor power for the alternative refrigerant is lower than that of R134a by about 2.96% to 7.17% over the range of operating conditions. The mass flow rate of the alternative refrigerant is lower than that of R134a by about 53.89% to 55.52% over the range of operating conditions

Conclusions:

In the present study, a theoretical investigation has been performed to evaluate the performance characteristics of the domestic refrigerator working with R134a and RE170 (80%) / R600a (20%)

Mixture. The volumetric cooling capacity of R134a and alternative refrigerant mixture are same over the considered range of operating conditions. So it is concluded that the mixture is drop in replacement for R134a. The identified alternative offers desirable environmental requirements, that is zero ozone depletion potential (ODP) and lower global warming potential (GWP).

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