ISSN 2250-3153

A Performance Comparison of Vapour Compression Refrigeration System Using Eco Friendly Refrigerants of Low Global Warming Potential

A.Baskaran[1], P.Koshy Mathews[2]

[1] Department of Mechanical Engineering, P. A. College of Engineering and Technology, Pollachi 642002, India
[2] Department of Mechanical Engineering, Kalaivani College of Technology, Coimbatore 641105, India

Abstract- A performance analysis on a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, HFC32, HC290, HC1270, HC600a and RE170 were done and their results were compared with R134a as possible alternative replacement. The results showed that the alternative refrigerants investigated in the analysis RE170, R152a and R600a have a slightly higher performance coefficient (COP) than R134a for the condensation temperature of 50^{0}C and evaporating temperatures ranging between -30^{0}C and 10^{0}C.Refrigerant RE170 instead of R134a was found to be a replacement refrigerant among other alternatives. The effects of the main parameters of performance analysis such as refrigerant type, degree of sub cooling and super heating on the refrigerating effect, coefficient of performance and volumetric refrigeration capacity were also investigated for various evaporating temperatures.

Index Terms- Refrigeration**,** Alternative Refrigerants**,** R152a**,** R32**,** Propylene**,** Di methylether**,** Propane**,** Isobutane, R134a

I. Introduction

The ozone depleting potential (ODP) and global warming potential (GWP) have become the most important criteria in the development of new refrigerants apart from the refrigerants CFCs due to their contribution to ozone layer depletion and global warming. In spite of their high GWP, alternatives to refrigerants CFCs and HCFCs such as hydro fluoro carbon (HFC) refrigerants with the zero ODP and hydro carbon refrigerants (HC) have been preferred for use in many industrial and domestic applications. The HFC refrigerants are considered as one of the six target greenhouse gases under Kyoto protocol of united nations frame work convention on climate change (UNFCCC) In 1997 [1, 2]. Kyoto protocol was approved by many nations called for the reduction in emission of green house gas including HFC refrigerants. The presence of fluorine atoms in HFC134a is responsible for the major environmental impact (GWP) with serious implications for the future development of the refrigeration based industries.

A number of investigators reported that GWP of HFC refrigerants is more significant even though it has less than CFC refrigerants. Fatosh and kafafy [3] theoretically assessed the mixture composed of 60% propane and 40% commercial butane is the best drop in substitute for HFC134a based domestic refrigerators. Park et al [4] tested two pure hydrocarbons and seven mixtures composed of propylene, propane, HFC152a and dimethylether as an alternative to HCFC22 in residential air conditioners and heat pumps.

Their experimental results show that the coefficient performance (COP) of this mixture was up to 5.7% higher than that of HFC22. Mani and Selladurai [5] performed experiments using a vapour – compression refrigeration system with the new R 290/R600a refrigerant mixture as a substitute refrigerant for CFC12 and HFC 134a.According to the results of their experiments, the refrigerant R290/R600a had a refrigerating capacity 28.6% to 87.2% higher than that of R134a. B.O Bolaji [6] performed experimental study of R152a and R32 to replace R134a in a domestic refrigerator. According to the result of the experiments, the average COP obtained using R152a is 4.7% higher than that of R134a. G.D Mathur [7] conducts theoretical investigation to compare the COP of vapour compression refrigeration system using various refrigerants under conditions -6^{0}C evaporator temperature and 48^{0}C condenser temperature.

According to the results, the COP of the hydrocarbons increases from 6% to 9% than COP of R134a.The present study mostly concentrates on a theoretical investigation on the performance of the vapour compression refrigeration cycle .The refrigerants HFC152a, HFC32, HC290, HC1270, HC600a and RE170 were used as the working fluid for the comparison with the conventional refrigerant R134a.The effects of the main parameters of performance analysis such as refrigerant type, degree of sub cooling and super heating on the refrigerating effects, coefficient of performance and volumetric refrigeration capacity are also investigated for various evaporating temperatures ranging between -30^{0}C and 5^{0}C and a constant condensation temperature of 50^{0}C.

Nomenclature

atm	Atmosphere
CFCS	Chlorofluorocarbons
COP	Coefficient of Performance
GWP	Global warming potential
HCFCs	Hydro chlorofluorocarbons
HCs	Hydrocarbons
HFCs	Hydro fluorocarbons
ODP	Ozone depletion potential
P	Pressure kPa
RE	Refrigerating effect, kJ Kg^{-1}
MFR	Mass flow rate, kgs^{-1}
T	Temperature, °C

ISSN 2250-3153

W	isentropic compression work $kJkg^{-1}$
VRC	Volumetric refrigerating capacity, kJm^{-3}
TR	Ton of refrigeration
sh/sc	super heating/sub cooling
Nsh/Nsc	Non super heating/Non sub cooling
Subscripts	
cod	Condensing/Condenser
evap	evaporating/evaporator
comp	compressor
dis	discharge

II. 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 = -30^0C to $+10^0$C
Condenser: Average sat. Temp = 50^0C
Super heat = 10^0C
Sub cooling = 5^0C

For comparison of the theoretical data, R134a is chosen in this paper as reference fluid due to its common usage in cooling system and prohibition by Kyoto protocol. The analysis of the variation of physical properties and performance parameters of pure and blend refrigerants 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)are investigated in this theoretical study and they are plotted against the evaporating temperature (T_{evap}) as shown in figures from 1 to 10. Table 1 and 2 show the operation results and deviation of alternative refrigerants from the values of R134a.

Table: 1
Operation on a standard vapour-compression cycle using R134a and various refrigerants at T_{cod}=50°C and T_{evap}=-10°C with super heating 10°C and sub cooling 5°C

Refrigerant	P_{evap} (kPa)	P_{cod} (kPa)	Pressure ratio	W_{comp} ($kJ\ kg^{-1}$)	RE ($kJ\ kg^{-1}$)	Power per ton refrigeration ($kW\ TR^{-1}$)	VRC ($kJ\ m^{-3}$)	T_{dis}°C	Comp. Power (kW)	MFR $*10^{-3}$ (kgs^{-1})	COP
R134a	200.6	1317.9	6.57	41.42	137.28	1.057	1314	66.3	0.302	7.3	3.315
R152a	181.5	1177.4	6.49	66.24	229.76	1.008	1283.2	78.9	0.288	4.4	3.469
RE170	185.1	1143.1	6.18	92.92	327.35	0.994	1297.5	76.9	0.284	3.1	3.523
R32	582.6	3141.2	5.39	75.83	238.21	1.114	3560.7	109.7	0.318	4.2	3.141
R290	345.3	1713.3	4.96	79.4	258.66	1.074	1879.4	66	0.307	3.9	3.258
R600a	108.4	684.9	6.32	72.37	247.59	1.023	714.4	54.1	0.292	4.03	3.421
R1270	428.1	2053.8	4.8	81.85	265.03	1.081	2300.5	73.2	0.309	3.8	3.238

ISSN 2250-3153

Table: 2
Some deviation values of alternative refrigerants from R134a

R134a at T_{cod} = 50°C and T_{evap} = -10°C with super heating 10°C and sub cooling 5°C									
Refrigerant	**Pressure ratio %**	**W_{com}%**	**RE %**	**Power per ton refrigeration %**	**VRC %**	**T_{dis} %**	**Comp.Power %**	**MFR %**	**COP %**
R152a	-1.22	59.92	67.37	-4.64	-2.34	19	-4.64	-40.25	4.65
RE170	-5.94	124.34	138.45	-5.96	-1.26	15.99	-5.96	-58.06	6.27
R32	-17.96	83.08	73.52	5.39	170.98	65.46	5.3	-42.37	-5.25
R290	-24.5	91.69	88.42	1.61	43.03	0.452	1.66	-46.92	-1.72
R600a	-3.8	74.72	80.35	-3.22	-45.63	-18.4	-3.3	-44.55	3.2
R1270	-26.94	97.61	93.06	2.27	75.08	10.41	2.32	-48.2	-2.32

III. Results and Discussion

The changes in evaporating pressure (P_{evap}) and pressure ratio with the evaporation temperature (T_{evap}) were shown in fig 1 and 2 for listed refrigerants. The nearest pressure ratio of refrigerant substituted for R134a belongs to RE170 whose pressure ratio was 5.94% lower than that of R134a as shown in table 2 for the constant condensation and evaporation temperatures of 50^oC and -10^oC respectively. In addition to this R152a gives the lowest ratio as substitute for R134a according to the same table. It can be seen from fig 1 that the saturated vapour pressure for RE170 was closer to the vapour pressure curve of the refrigerant R134a than others. Fig 3 and 4 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^oC and the evaporation temperature ranging from -30^oC to 10^oC.

All of the investigated refrigerants have much higher refrigerating effect and isentropic compression work than R134a in fig 3, 4 and as shown in table 2.The variation of the performance coefficients (COP) with evaporating temperatures (T_{evap}) is illustrated in fig 5. It Is found that the coefficient of performance (COP) increases as the evaporation temperature (T_{evap}) increases for the constant condensation temperature of 50^oC and the evaporation temperature ranging from -30^oC to 10^oC. The performance coefficients (COP) of the alternating refrigerants RE170, R152a and R600a were found to be higher than that of R134a. The power needed for refrigeration with evaporation (Tevap) were shown in fig 6 and fig 7. The variation in volumetric refrigeration capacity, discharge temperature and mass flow rate were illustrated in fig 8, fig 9 and fig 10 in order to verify the advantages of cycle. The cycle performance can be improved by the sub cooling and super heating applications. The comparison of the super heating / sub cooling with the non-super heating / sub cooling was illustrated in figures from 11a to 11g for the refrigerant RE170. The performance coefficient (COP) values of the super heating / sub cooling case are found to be higher than those of the non super heating sub cooling case. The reason for the improvement is the increase in the compressor inlet temperature and thus the increases in refrigerating effect and volumetric refrigerating capacity.

The thermo-physical properties restriction related to safety, environmental impact, and associated legislation are the most significant factors in choosing a new refrigerant. Low viscosities of liquid and vapour phases, high liquid specific heat and high thermal conductivities of liquid are the desired thermo physical properties of refrigerants in the literature. As a result of the analysis, RE170 instead of R134a seems to be the best alternative refrigerant.

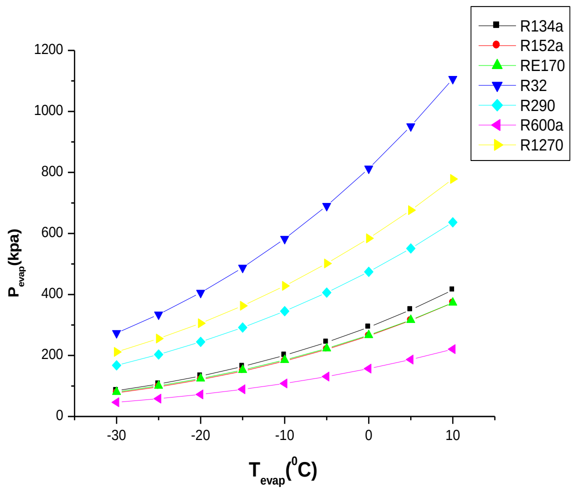

Fig.1. Evaporating Pressure Vs evaporating temperature

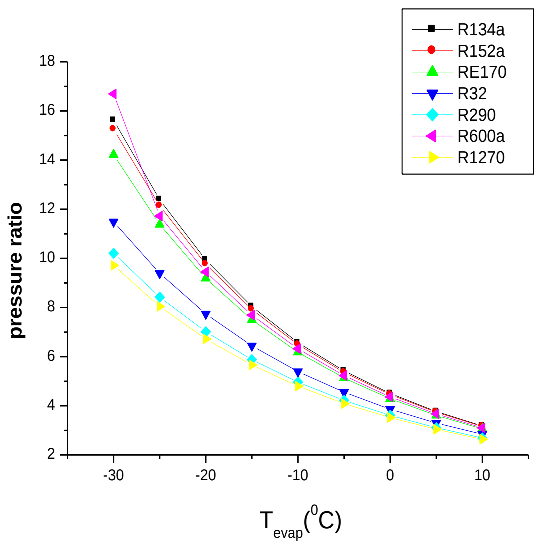

Fig.2. Pressure Ratio Vs evaporating temperature

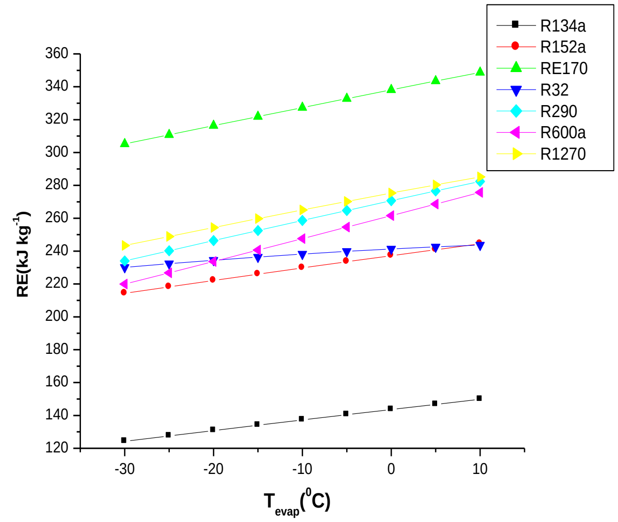

Fig.3. Refrigerating effect Vs evaporating temperature

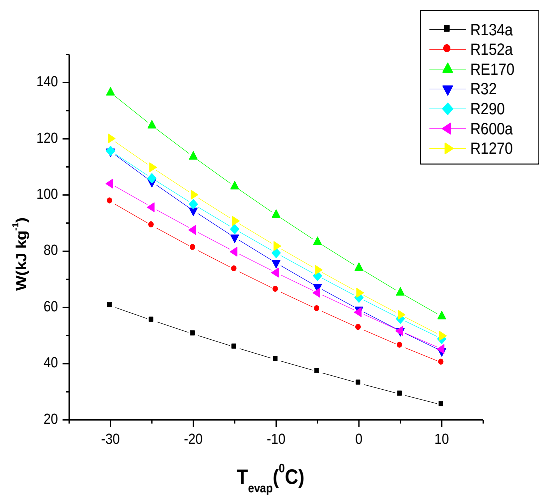

Fig. 4.Compression Work Vs evaporating temperature

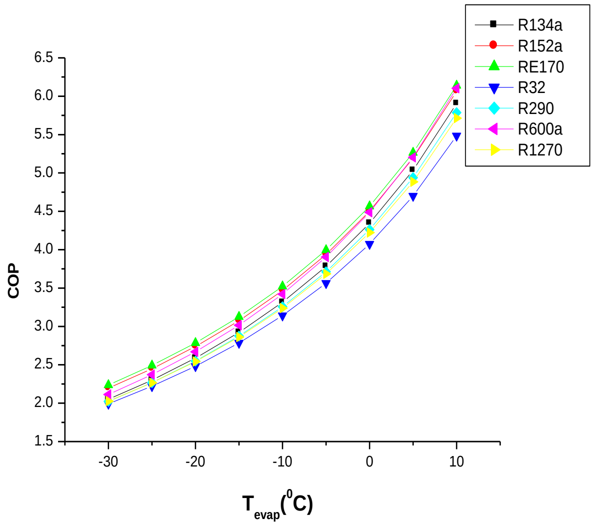

Fig.5.Coeffiecient performance Vs Evaporationtemperature.

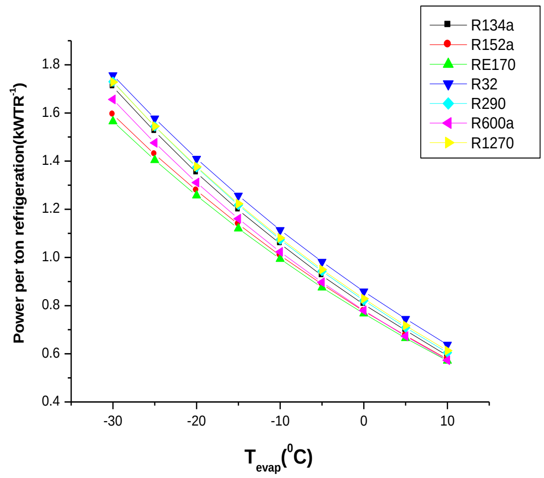

Fig.7. Power per ton of refrigeration Vs Evaporating temperature

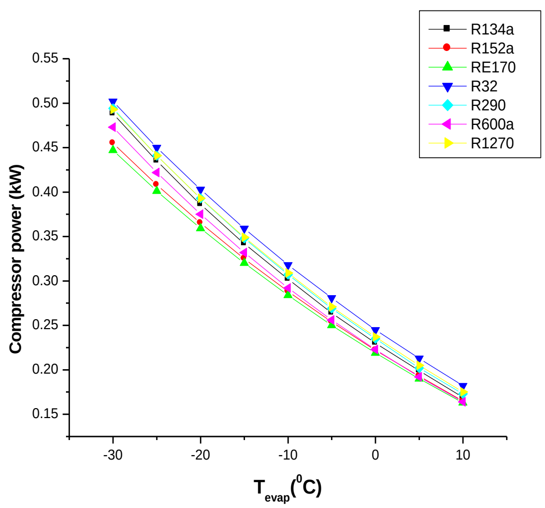

Fig.6. Compressor Power Vs evaporating temperature

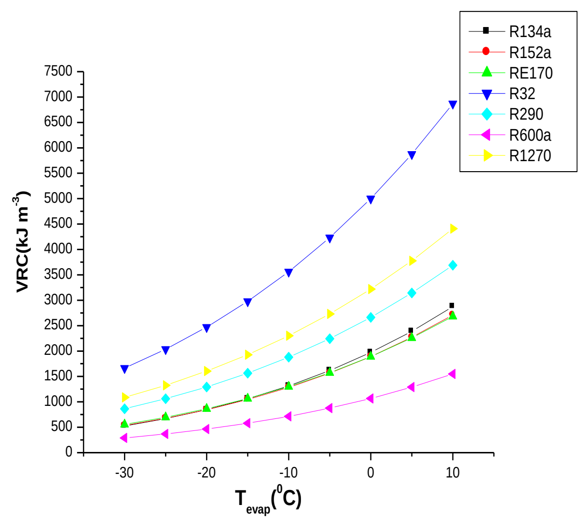

Fig.8. Volumetric refrigerating capacity Vs evaporating temperature

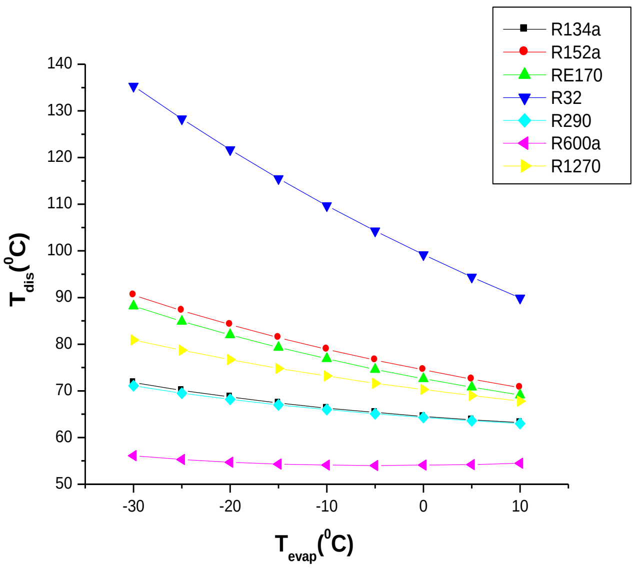

Fig.9. Discharge temperature Vs evaporating temperature

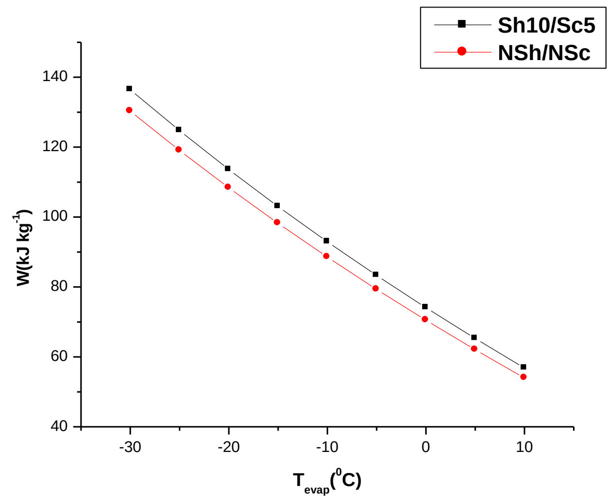

Fig.11-b Compression work Vs evaporating temperature

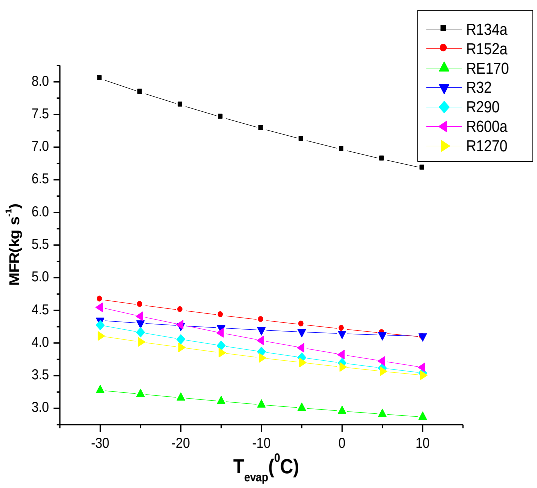

Fig.10. Mass flow rate Vs evaporating temperature

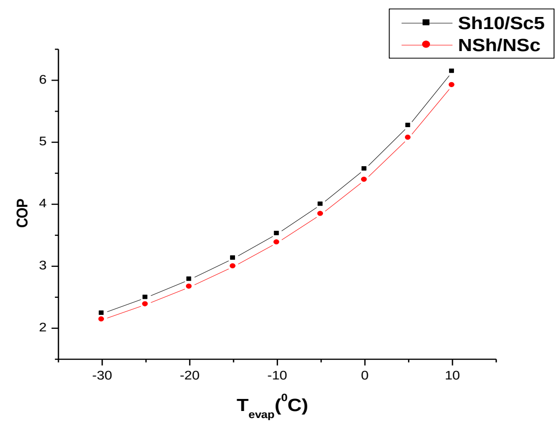

Fig.11-c. Co-efficient of performance Vs evaporating temperature

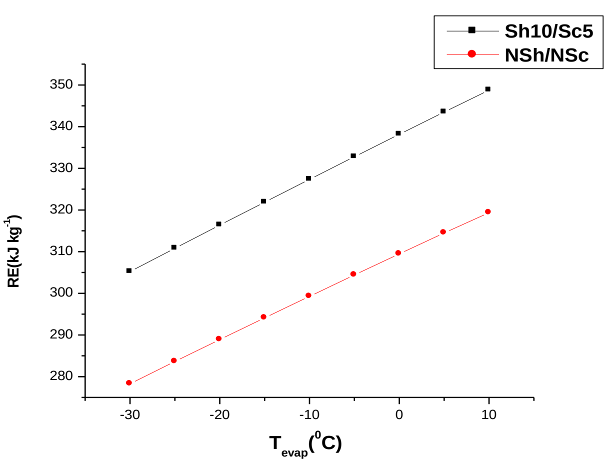

Fig.11-a Refrigerating effect Vs evaporating temperature

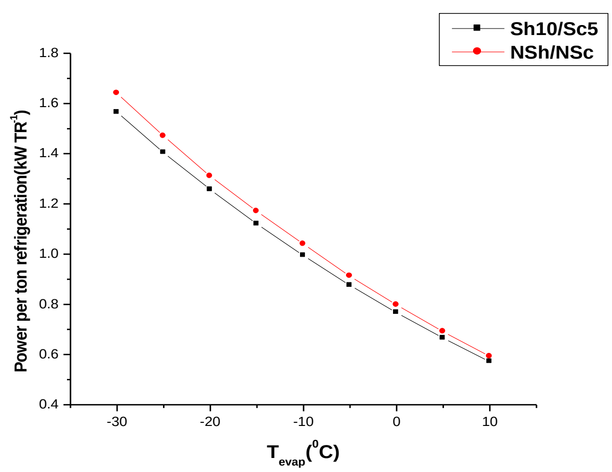

Fig.11-d Power per ton of refrigeration Vs evaporating

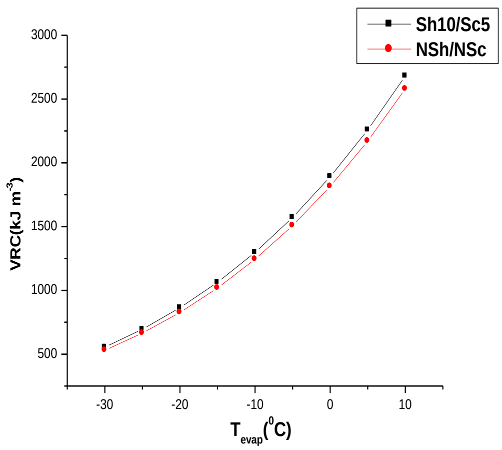

Fig.11-e.Volumetric refrigerating capacity Vs evaporating temperature

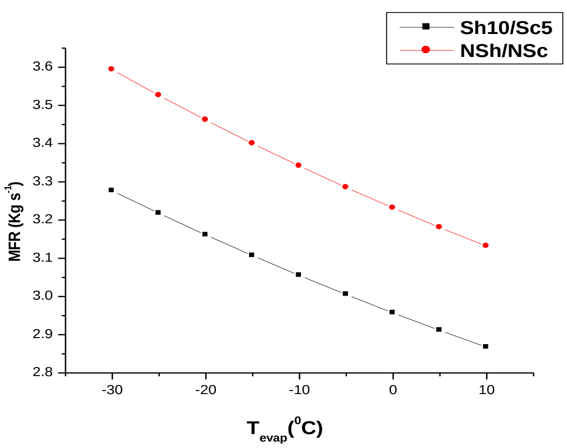

Fig.11-f. Mass flow rate Vs evaporating temperature

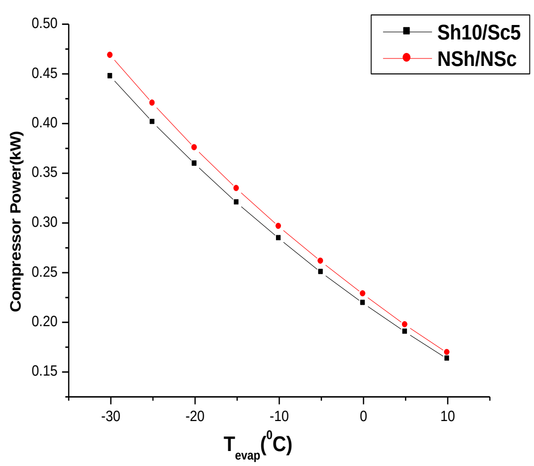

Fig.11-g. Compressor power Vs evaporating temperature

IV. Conclusions

In this study, an ideal vapor-compression system is used for the performance analysis of alternative new refrigerants substitute for R134a. Considering the comparison of performance coefficients (COP) and pressure ratio of the tested refrigerants and also the main environmental impacts of ozone layer depletion and global warming, refrigerant RE170 was found to be the most suitable alternative among refrigerants tested for R134a.The performance coefficient (COP) of the system, increases with increase in evaporating temperature for a constant condensing temperature in the analysis.

All systems including various refrigerants were improved by analyzing the effect of the super heating / sub cooling case. Better performance coefficient values (COP) than those of non-super heating /sub cooling case are obtained as a result of this optimization.

References

[1] Johnson 1998, Global warming from HFC, environment impactassessment rev,18, 485 – 492

[2] Wen-tientasi, 2005, An over view of environmental hazards and exposure, and explosive rise of hydroflurocarbon HFCs,chemosphere,61,1539-47

[3] Fatouh M and KafafyM. EI, 2006, Experimental evaluation of a domestic refrigerator working with LPG, applied thermal engineering

[4] K.J. Park, T. seo. D.Jungperformance of alternative refrigents for residential air conditing applications, Applied energy 84 (2007) 985-991

[5] K.Mani,V.Selladurai, Experimental analysis of a new refrigerant mixture as drop in replacement for CFC12 and HFC 134a, International journal of thermal sciences 47(2008) 1490-1495

[6] B.O.Boloji, Experimental study of R152a and R32 to replace R134a in a domestic refrigerator,Energy, volume 35 issue 9, sept 2010. 3793-3798

[7] G.D.Mathur, Performance of vapour compression refrigeration system with hydro carbons, proceedings of the 1996 international conference on ozone protection technologies,Washington,DC,USA 1996 pgs 835-844

[8] CYCLE _D vapour compression cycle design.NIST Standard reference data base 49-version 4.0.Gaithersberg,MD:National institute of standards and technology (2004)

Authors

First Author – A.Baskaran, Department of Mechanical Engineering, P. A. College of Engineering and Technology, Pollachi 642002, India, Email:boss120367@gmail.com
Second Author – P.Koshy Mathews, Department of Mechanical Engineering, Kalaivani College of Technology, Coimbatore 641105, India, Email:pkoshymathews@yahoo.co.in