

# A Performance comparison of vapour compression refrigeration system using various alternative refrigerants

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**Abstract** — A performance analysis on a vapour compression refrigeration system with various refrigerants mixture of R152a, RE170, R600a, and R290 were done for various mixture ratios and their results were compared with R134a as possible alternative replacement. The results showed that all of the alternative refrigerants investigated in the analysis except R431A, [R 152a (29%), R290 (71%)] have a slightly higher performance coefficient (COP) than R134a for the condensation temperature of 50°C and evaporating temperatures ranging between -30°C and 10°C. Refrigerant blend of R152a/RE170 (20/80 by wt%) 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, Di methylether, Propane, Isobutane, R134a

## 1 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 mixture composed of propylene, propane, HFC 152a and dimethylether as an alternative to HCFC22 in residential air conditioners and heat pumps. Their experimental results show that the coefficient performance (COP) of these mixtures 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 mix-

ture 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.

### 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
W	isentropic compression work kJ kg-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/evaporater
comp	compressor
dis	discharge

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  $-6^{\circ}\text{C}$  evaporator temperature and  $48^{\circ}\text{C}$  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 refrigerant mixture R429A [R152a(60%), R152a(10%), R600a(30%)], R430A [R152a(76%), R600a (24%)], R431A [R152a (29%), R290(71%)], R435A [R152a(20%), R600a(80%)], R509A [R290(50%), R600a(50%)] and R510A [R152a(88%), R600a(12%)] are 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  $-30^{\circ}\text{C}$  and  $5^{\circ}\text{C}$  and a constant condensation temperature of  $50^{\circ}\text{C}$ .

## 2 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
In the discharge line	= 0.0
Evaporator: average sat. temp	= $-30^{\circ}\text{C}$ to $+10^{\circ}\text{C}$
Condenser: average sat. temp	= $50^{\circ}\text{C}$
Super heat	= $10^{\circ}\text{C}$
Sub cooling	= $5^{\circ}\text{C}$

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 ( $P_{\text{evap}}$ ), pressure ratio, isentropic compression work ( $W$ ), refrigerating effect (RE), power per ton of refrigeration, volumetric refrigeration capacity (VRC), discharge temperature ( $T_{\text{Dis}}$ ), mass flow rate (MFR) and coefficient of performance (COP) are investigated in this theoretical study and they are plotted against the evaporating temperature ( $T_{\text{evap}}$ ) 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.

## 3 THERMO PHYSICAL PROPERTIES

The changes in evaporating pressure ( $P_{\text{evap}}$ ) and pressure ratio with the evaporation temperature ( $T_{\text{evap}}$ ) were shown in fig 1 and 2 for listed refrigerants. The nearest pressure ratio of refrigerant substituted for R134a belongs to R435A whose pressure ratio was 6.39% lower than that of R134a as shown in table 2 for the constant condensation and evaporation temperatures of  $50^{\circ}\text{C}$  and  $-10^{\circ}\text{C}$  respectively. In addition to this R431A [R 152a (29%), R290 (71%)] 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 R509A 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 ( $T_{\text{evap}}$ ) while the compressor power ( $W_{\text{comp}}$ ) decreases with increasing  $T_{\text{evap}}$  for the constant condensation temperature of  $50^{\circ}\text{C}$  and the evaporation temperature ranging from  $-30^{\circ}\text{C}$  to  $10^{\circ}\text{C}$ .

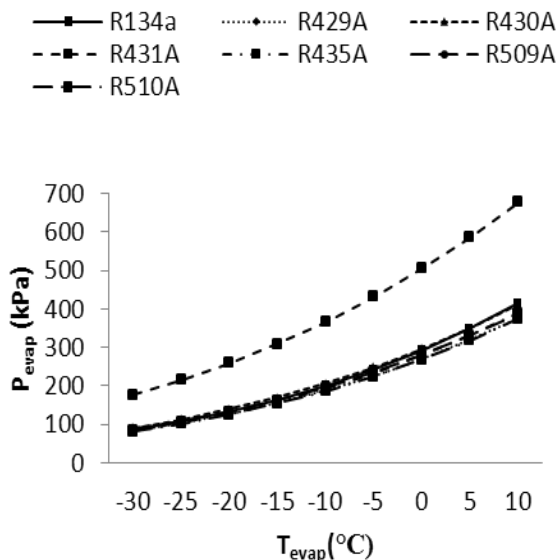


Fig.1. Evaporating Pressure vs evaporating temperature

Fig. 2. Pressure Ratio vs evaporating temperature

Refrigerant	Pevap (kPa)	Pcod (kPa)	Pressure ratio	Wcomp (kJ kg <sup>-1</sup> )	RE (kJ kg <sup>-1</sup> )	Power per ton refrigeration (kW TR <sup>-1</sup> )	VRC (kJ m <sup>-3</sup> )	Tdis °C	Comp. Power (kW)	MFR (kgs <sup>-1</sup> )	COP
R134a	201	1318	6.57	41.42	137.28	1.057	1314	66.3	0.302	7.2842	3.315
R152a	182	1177	6.49	66.24	229.76	1.008	1283.2	78.9	0.288	4.3523	3.469
RE170	185	1143	6.18	92.92	327.35	0.994	1297.5	76.9	0.284	3.0548	3.523
R429A	189	1130	5.98	80.87	280.12	1.012	1250.7	69.1	0.289	3.5699	3.464
R430A	206	1243	6.03	63.61	215.65	1.033	1334.1	70.1	0.295	4.6371	3.39
R431A	366	1838	5.02	71.85	231.8	1.085	1989.9	68.2	0.31	4.3142	3.226
R435A	194	1190	6.15	86.76	304.02	0.998	1344.2	77	0.285	3.2892	3.504
R509A	197	1138	5.77	79.53	268.11	1.04	1220.3	63.8	0.297	3.7299	3.371
R510A	187	1136	6.09	89.02	311.84	0.998	1279.1	73.6	0.285	3.2068	3.503

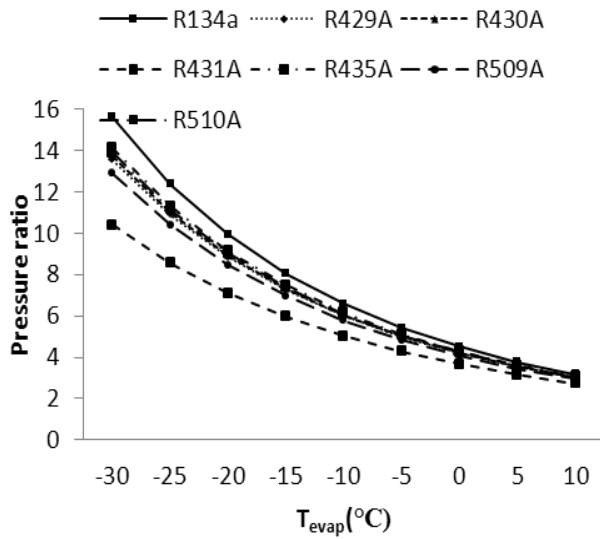


Table.1

Operation on a standard vapour-compression cycle using R134a and various refrigerants at Tcod=50°C and Tevap=-10°C with super heating 10°C and sub cooling 5°C

Table.2

Some deviation values of alternative refrigerants from R134a

R134a at Tcod = 50°C and Tevap = -10°C with super heating 10°C and sub cooling 5°C
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Refrigerant	Pressure ratio %	Wcom%	RE %	Power per ton refrigeration %	VRC %	Tdis %	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
R429A	-8.98	95.24	104.05	-4.26	-4.82	4.22	-4.3	-50.99	4.49
R430A	-8.22	53.57	57.09	-2.27	1.53	5.73	-2.32	-36.34	2.26
R431A	-23.59	73.47	68.85	2.65	51.44	2.87	2.65	-40.77	-2.68
R435A	-6.39	109.46	121.46	-5.58	2.29	16.14	-5.63	-54.84	5.7
R509A	-12.18	92	95.3	-1.61	-7.13	-3.77	-1.66	-48.79	1.69
R510A	-7.31	114.92	127.16	-5.58	-2.66	11.01	-5.63	-55.98	5.67

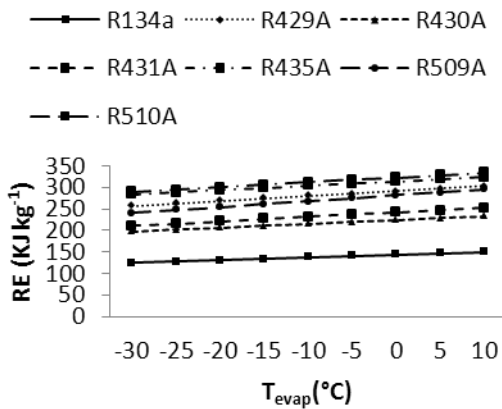


Fig.3. Refrigerating effect vs evaporating temperature

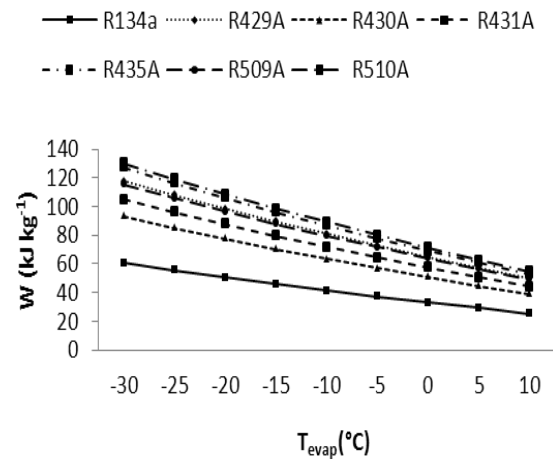


Fig. 4. Compression Work vs evaporating temperature

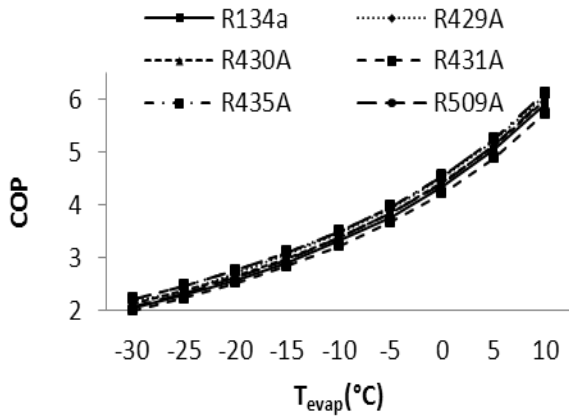


Fig. 5. Coefficient performance vs Evaporation temperature

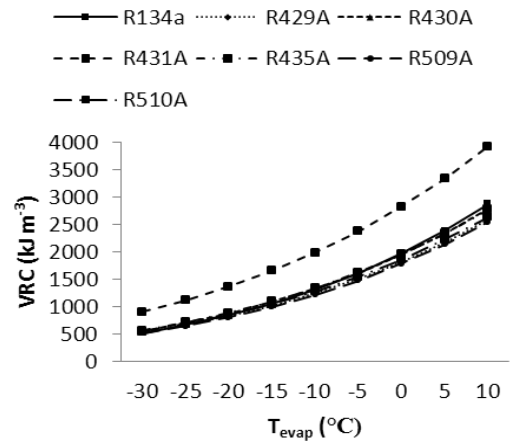


Fig. 8. Volumetric refrigerating capacity vs Evaporation temperature

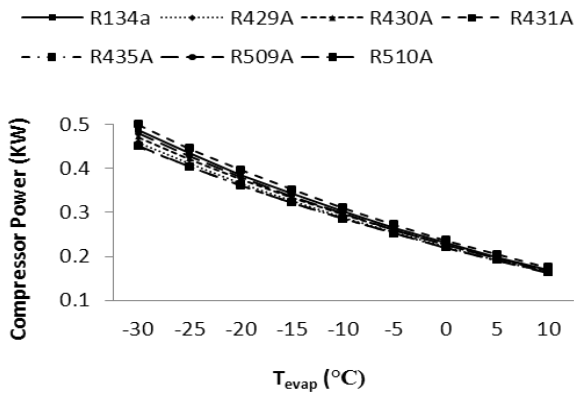


Fig. 6. Compressor Power vs evaporating temperature

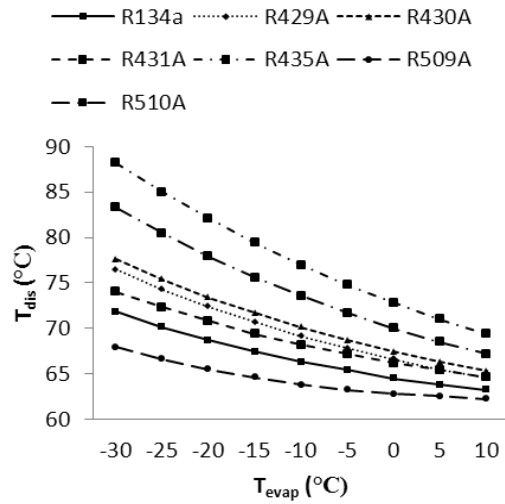


Fig. 9. Discharge temperature vs evaporating temperature

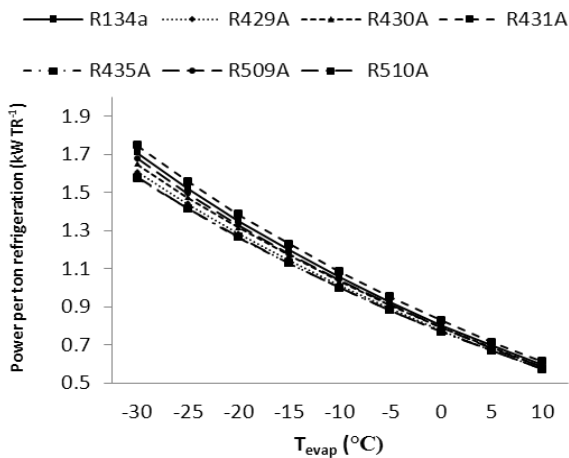


Fig. 7. Power per ton of refrigeration vs evaporating temperature

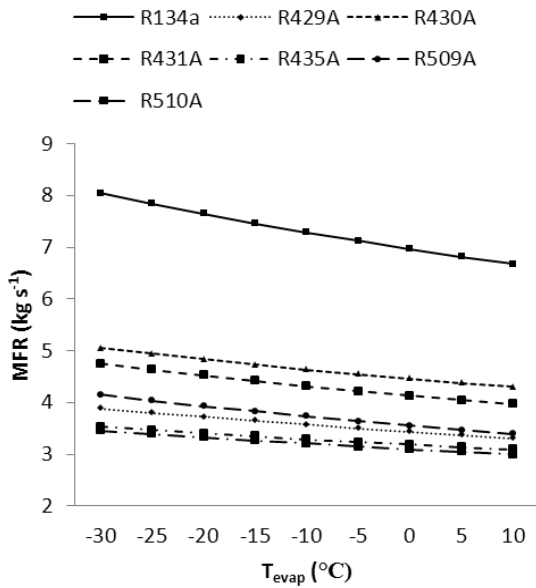


Fig.10. Mass flow rate vs evaporating temperature

All of the tested 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°C and the evaporation temperature ranging from -30°C to 10°C. The performance coefficients (COP) of all the alternative refrigerants except R431a were found to be higher than that of R134a.

The power needed for refrigeration with evaporation ( $T_{evap}$ ) was shown in fig 6 and 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 comparisons of the super heating/sub cooling with the non-super heating/sub cooling were illustrated in figs from 11a to 11g for the refrigerant blend of R435A.

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, high thermal conductivities of liquid and small temperature glide are the desired thermo physical properties of refrigerant mixture in the literature. As a result of the analysis, R435A [RE170 (80%), R152a (20%)] instead of R134a seems to be the best alternative refrigerant.

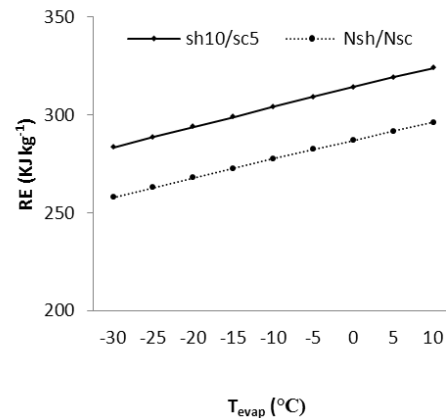


Fig. 11-a Refrigerating effect vs evaporating temperature

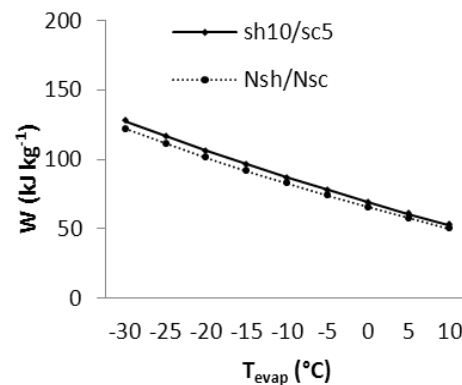


Fig.11-b compression work vs evaporating temperature

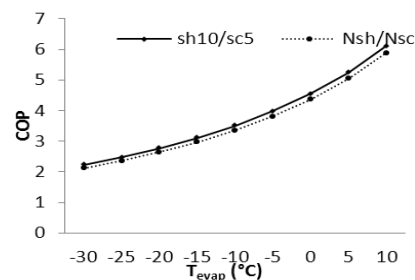


Fig.11-c. Co-efficient of performance vs evaporating temperature

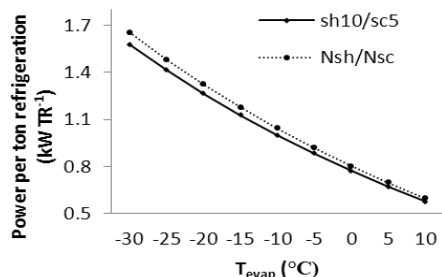


Fig.11-d. Power per ton of refrigeration vs evaporating temperature

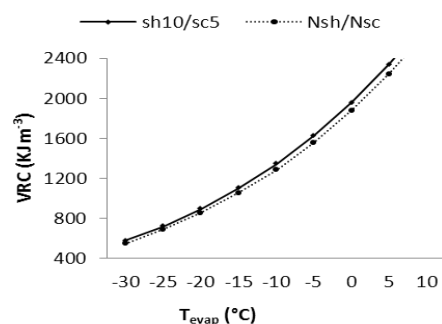


Fig.11-e. Volumetric refrigerating capacity vs evaporating temperature

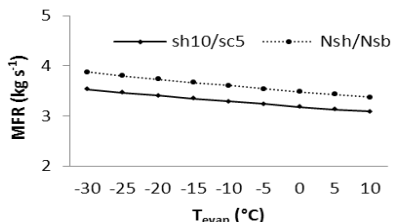


Fig.11-f. Mass flow rate vs evaporating temperature

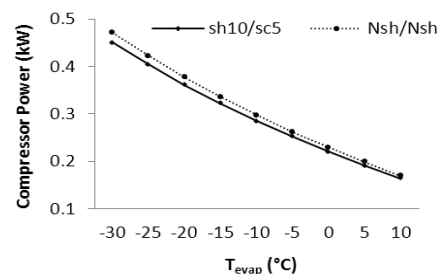


Fig.11-g. Compressor power vs evaporating temperature

#### 4. CONCLUSIONS

In this study, an ideal vapor-compression system is used for the performance analysis of alternative new refrigerant mixture as 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 blend R435A [RE170 (80%), R152a (20%)] were found to be the most suitable alternative among re-

frigerants 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 system including various refrigerant blends 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.

#### 5. ACKNOWLEDGMENT

The work reported here was supported through the Department of Mechanical Engineering, P.A.College of Engineering and Technology, Pollachi-2.

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