EFFECT OF SUB COOLING AND SUPERHEATING ON VAPOUR COMPRESSION REFRIGERATION SYSTEMS USING R-22 ALTERNATIVE REFRIGERANTS

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ABSTRACT

This paper present performance of three hydrofrulocarbon (HFC) refrigerants (R-410A, R -507A, R-407C) selected to replace R-22 in a vapour compression refrigeration system using thermodynamic simulation. 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 temperature. The result showed that R410A and R407C have thermodynamic performance similar to R-22.

Keywords: Vapour compression refrigeration cycle ,COP , theoreitical analysisR-410a,R-407c etc.

I. INTRODUCTION

During the last decade, the number of refrigerants likely to be used in refrigerating machines has dramatically increased as a consequence of the elimination of the.CFC's and HCFC's. Recently, 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 refrigerant CFCs and HCFCs, both of which have high ODP and GWP, due to the their contribution to ozone layer depletion and global warming. In spite of their high GWP alternatives to refrigerant CFCs and HCFCs such as hydrofluorocarbon (HFC) refrigerants with their zero ODP have been preferred for use in many industrial and domestic applications intensively for decade. HFC refrigerants also have suitable specifications such as non-flammability, stability, and similar vapour pressure to the refrigerant CFCs and HCFCs.
R22 is one of the important refrigerant used in air conditioning all over the world. R22 is controlled substance under the Montreal Protocol. It has to be totally phased out by 2017. In Europe, HCFCs have already been phased out in new equipment in 2002, and the total phase out of HCFCs is scheduled in 2015.HCF 22 replacements options for A/C, heat pumps and refrigeration systems can be grouped in three categories, Fluorocarbons that are used in conventional vapor compression cycles such as R134a, R410a, R407C, alternatives fluids which include propane R290 and R717 and are also used in vapor compression cycles, and finally alternatives cycles that include absorption systems, and use Tran critical fluids (CO2)and air cycle. In general these alternative technologies do not currently offer the same energy efficiency as the vapor compression cycle.
Several investigations have been carried out in order to determine the efficiency of potential substitutes to R22.

In this paper, a vapour compression refrigeration cycle for three HFC refrigerants is used to obtain better performance. The present study mostly concentrates on therotical investigation of vapour compression refrigeration cycle. The three HFC refrigerants (R410A,R507C,R407C) are used as working fluid for comparison with conventional fluid R22. The effect of main parameters of performance analysis such as refrigerant type on refrigerating effect (RE) ,volumetric refrigerating capacity(VRC) are investigated for various evaporating temperature ranging -15^0 C to 15^0 C and constant condensation temperature 40 ^{0}C.

REFRIGERATION CYCLE

The refrigeration cycle studied is a standard vapor compression cycle composed mainly of four main equipments: Evaporator, Compressor, Condenser and a throttling valve as illustrated in figure1. The following assumptions are made

-An evaporation at constant pressure, in the evaporator with an evaporator temperature, Tev, from point 4 to point 1 (h4 to h1)

-An adiabatic isentropic compression process in the compressor, corresponding from point 1 to point 2 (h1 to h2).

-A de superheating at constant pressure followed by a condensation at constant temperature (Tc) and pressure in the condenser, from point 2 to point 3. (h2 to h 3).

-An expansion at constant enthalpy in the throttling valve, corresponding from point 3 to Point 4 (h3= h4).

The vapour leaving the evaporator as well as the liquid leaving the condenser are supposed to be at saturated states, and therefore neither superheating of the vapour nor sub cooling of the liquid are required.

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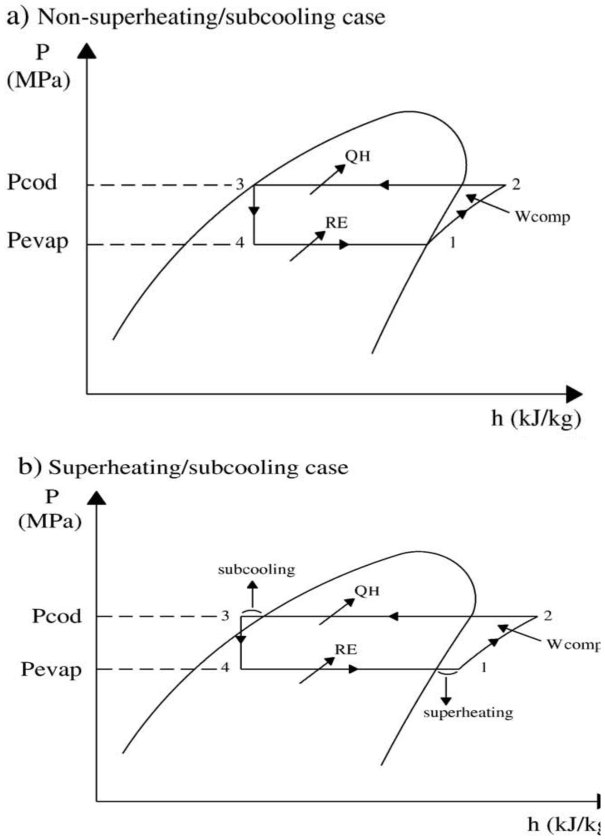

Fig. 1. Traditional vapour-compression refrigeration cycle used in the analysis.

II.THEORETICAL COMPUTATIONAL MODEL

The pressure–enthalpy diagram prepared for theoretical data for two different cases is shown in Fig. 1. The ideal refrigeration cycle in Fig. 1 is considered for the working substances that change phase during the cycle. It is known that the actual refrigeration cycle systems have some deviations from the ideal one due to pressure losses of fluid flow and heat transfer exchange between the surroundings. The superheated state of vapour exists at the inlet part of the compressor as shown in Fig. 1b, the pressure of the liquid at the exit part of the condenser is lower than the pressure at the inlet part of it, there is a pressure drop greater than the ideal one between the condenser and expansion valve, and also a larger pressure drop occurs on the evaporation line.

The equations for the cycle analysis can be obtained by means of mass and energy conservation. The data reduction of the theoretical results can be analysed below. The pressure ratio of the cycle can be seen below as follows:

The pressure ratio = Pcod /Pevap: (1)

The refrigerating effect (RE), in other words, the heat transfer rate of the evaporator (Qevap), is calculated as follows:

RE = Qevap = h1−h4 kJ/kg (2)

Isentropic compression work of the compressor (Wcomp) is expressed as follows

Wcomp = h2−h1 kJ/kg (3)

The coefficient of performance (COP) of the refrigeration system's cycle can be determined by:

COP = RE /Wcomp: (4)

In the vapour-compression system in Fig. 1, volumetric refrigerating capacity (VRC) is given as:

VRC = ρ1·RE kJm^{-3} (5)

Power per ton of refrigeration is calculated as follows:

Power per ton of refrigeration (P /TR) = 3.5Wcomp / RE $kWTR^{-1}$ (6)

Suction vapour flow per KW of refrigeration can be determined as:

SVFR = 1/ ρ1 ·RE L/S (7)

III.FLOW CHART FOR COMPUTATIONAL ANALYSIS

A Simulation model was developed in order to investigate the effect of the evaporator and condenser temperatures on the physical properties of refrigerants such as evaporation pressure (P_{evap}), pressure ratio, refrigerating effect (RE), isentropic compression work (W), coefficient of performance (COP), refrigeration power, volumetric refrigeration capacity (VRC) and suction vapour flow rate (SVFR) is investigated in this theoretical study. They are plotted against the evaporating temperature (T_{evap}) . 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	= -15^{0}C to +15^{0}C
Condenser: Average sat. Temp	= 40^{0}C
Super heat	= 10^{0}C
Sub cooling	= 5^{0}C

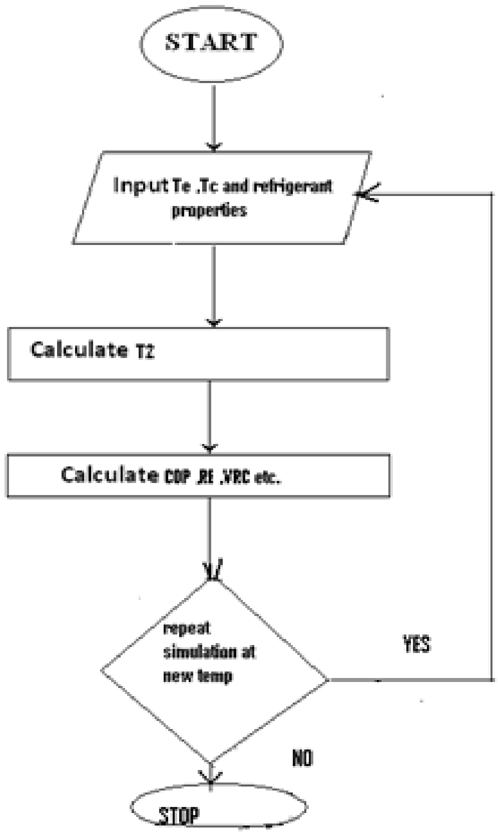

Fig 2 flow chart for simulation

IV.RESULT AND DISCUSSION

The analysis of the variation of physical properties of refrigerants such as evaporation pressure (P_{evap}), pressure ratio, refrigerating effect (RE), isentropic compression work (W), coefficient of performance (COP), refrigeration power, volumetric refrigeration capacity (VRC) and suction vapor flow rate (SVFR) is investigated in this theoretical study, and they are plotted against the evaporating temperature (T_{evap}) as shown in Figs. 3to10

The changes in evaporation pressure (Pevap) and pressure ratio with the evaporation temperature (T_{evap}) are shown in Fig. 3 and fig. 4 for listed refrigerant. Evaporation pressure for R-410a is higher in comparison with other refrigerants. pressure ratio for all refrigerants are having almost same value in all evaporating temperature.

Fig. 5 and fig.6 shows that the refrigerating effect (RE) increases with increasing evaporation temperature (T_{evap}) while the compressor power (W_{comp}) decreases with increasing T_{evap} for the constant condensation temperature of 40 °C and the evaporation temperatures ranging from −15 °C to 15 °C. Refrigerant R-410A have higher refrigerating effect and compressor work than other refrigerants as shown in fig. 5 and fig.6.

The variation of performance coefficient (COP) with evaporation temperature (T_{evap}) is illustrated in Fig. 7 From this figure, the coefficient of performance (COP) increases as the evaporation temperature (T_{evap}) increases for the constant condensation temperature of 40 °C and evaporation temperatures ranging from −15°C to15 °C. COP of R-22 is higher than all other refrigerants.

The changes in power needed for refrigeration with evaporation temperature (T_{evap}) in Fig. 8 volumetric refrigeration capacity (VRC) with evaporation temperature (T_{ev}) in Fig. 9 and suction vapour flow needed for refrigeration (SVFR) with evaporation temperature (T_{evap}) in Fig. 10 are shown. The power needed for refrigeration is higher for refrigerant R-507A. Volumetric refrigeration capacity is higher for refrigerant R 410A. Suction vapour flow rate per kW of refrigeration is higher for R407C.

The cycle performance can be improved by the sub cooling and superheating applications. The comparison of the super heating / sub cooling with the non-super heating / sub cooling was illustrated in figures from 11 to15 for the refrigerant R-410a and in figures 16 to 20 for R 407-C. 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.

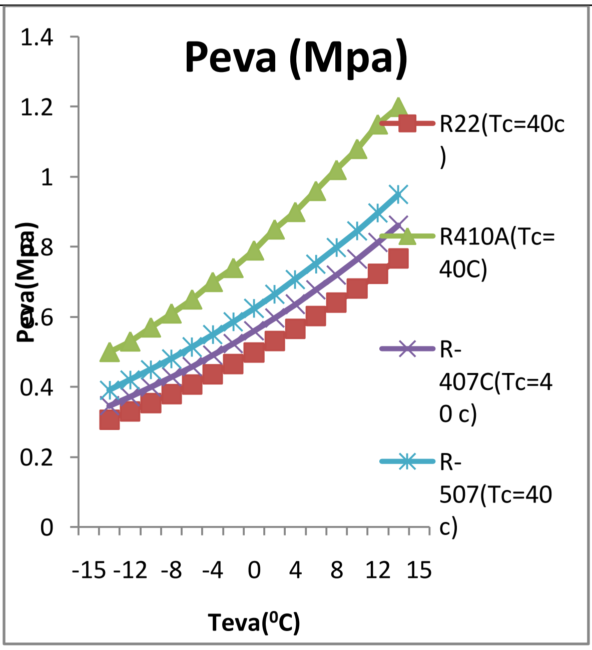

Fig 3 evaporating pressur vs. evaporating temperature

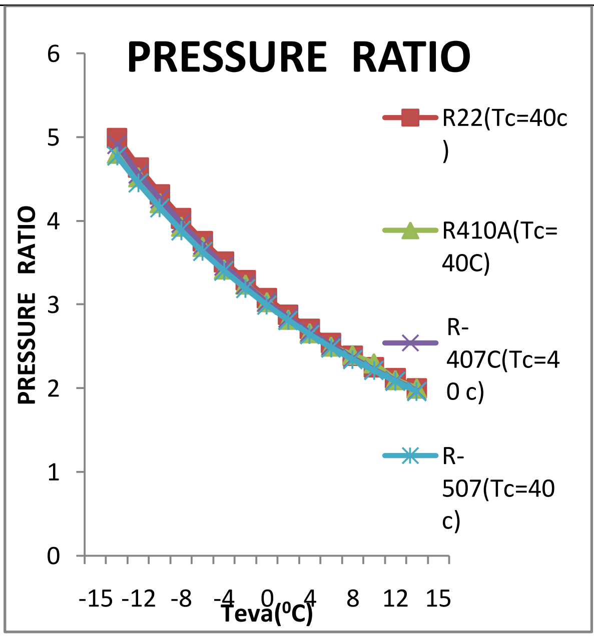

Fig 4 pressure ratio vs. evaporating temperature

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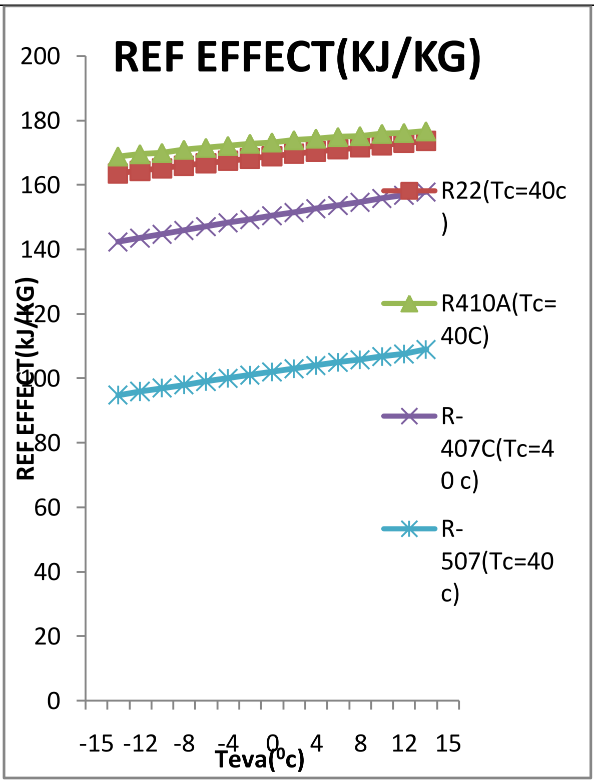

Fig.5.refrigerating effect vs. evaporating temperature.

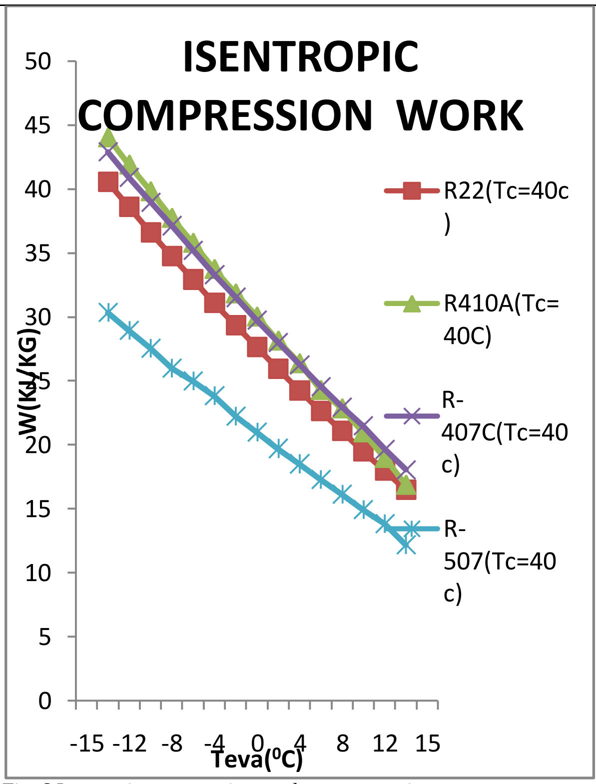

Fig. 6 Isentropic compression work vs evaporating temperature

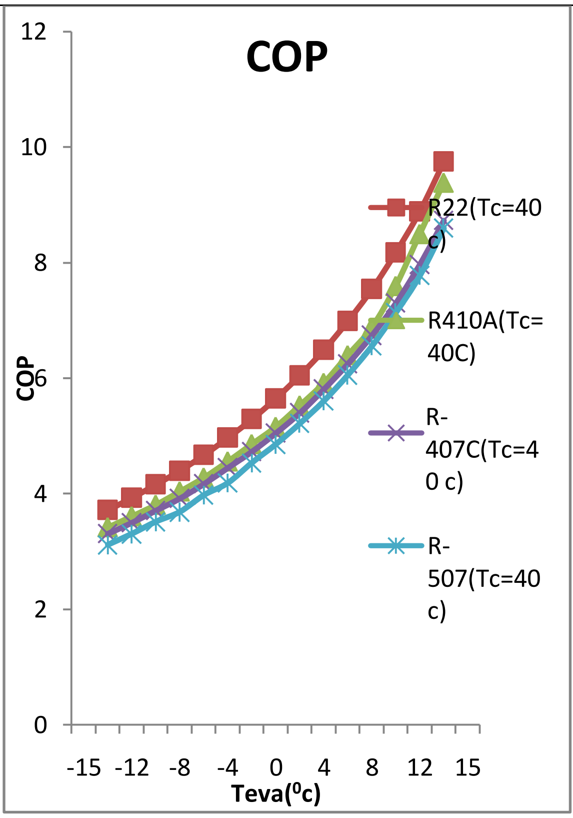

Fig. 7 coefficient of performance vs evaporating temperature

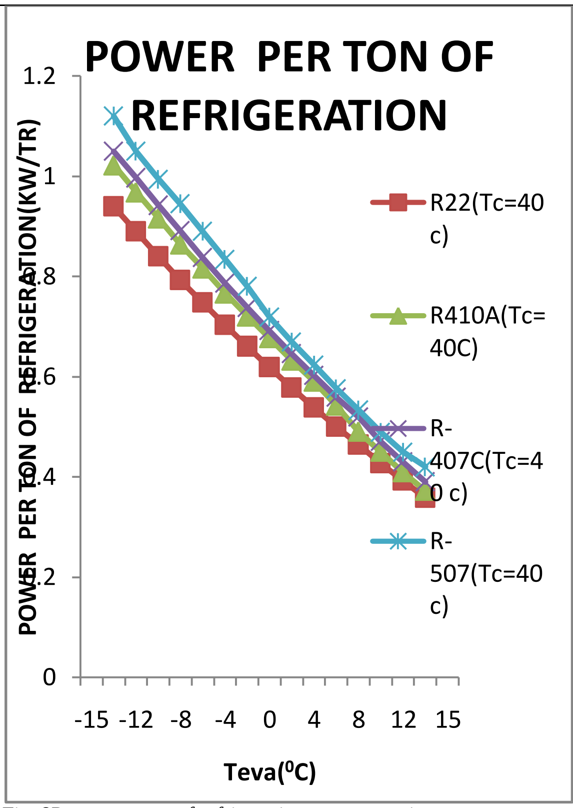

Fig. 8Power per ton of refrigeration vs evaporating temperature

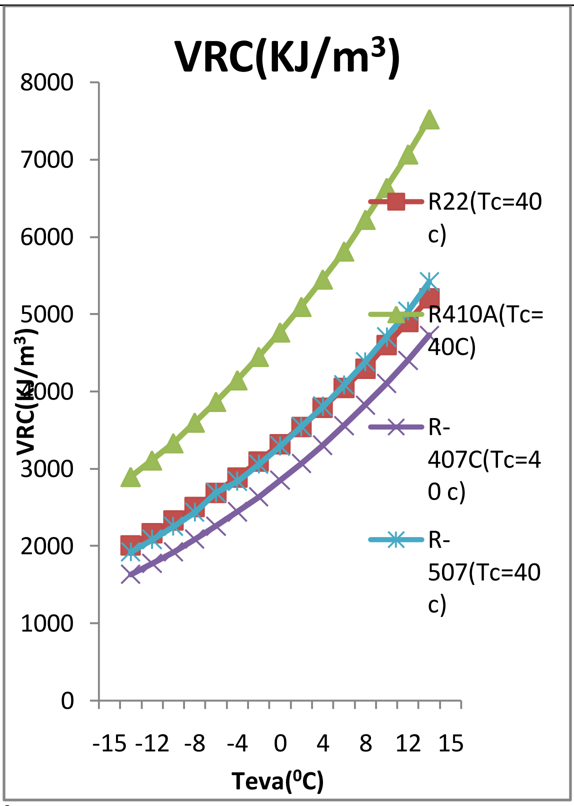

fig 9volumetric refrigeration capacity vs.evaporation temperature

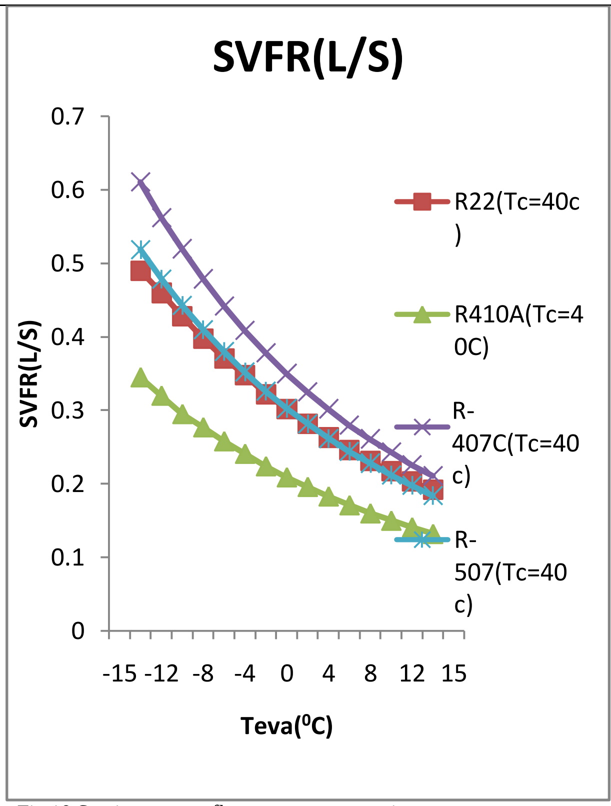

Fig.10 Suction vapour flow rate vs evaporating temperature

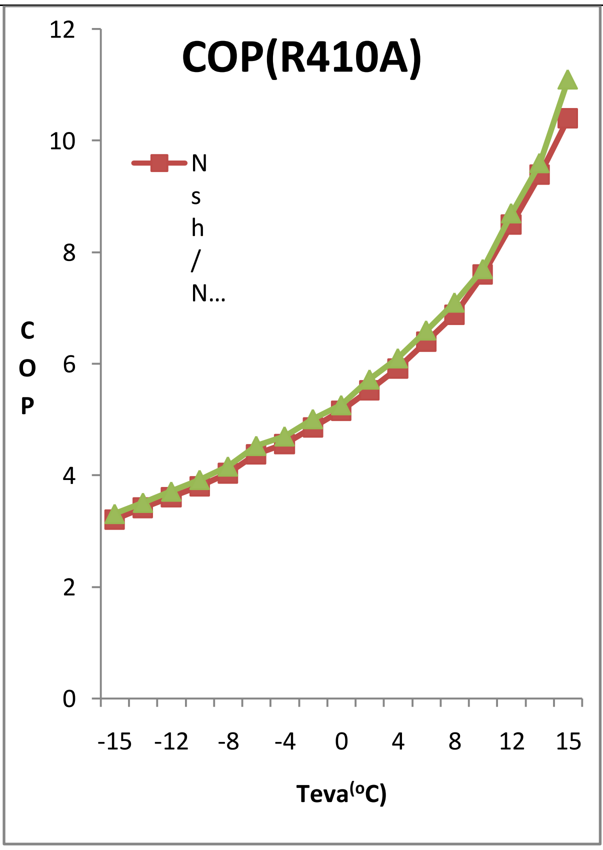

Fig. 11 coefficient of performance vs evaporating temperature (R-410A)

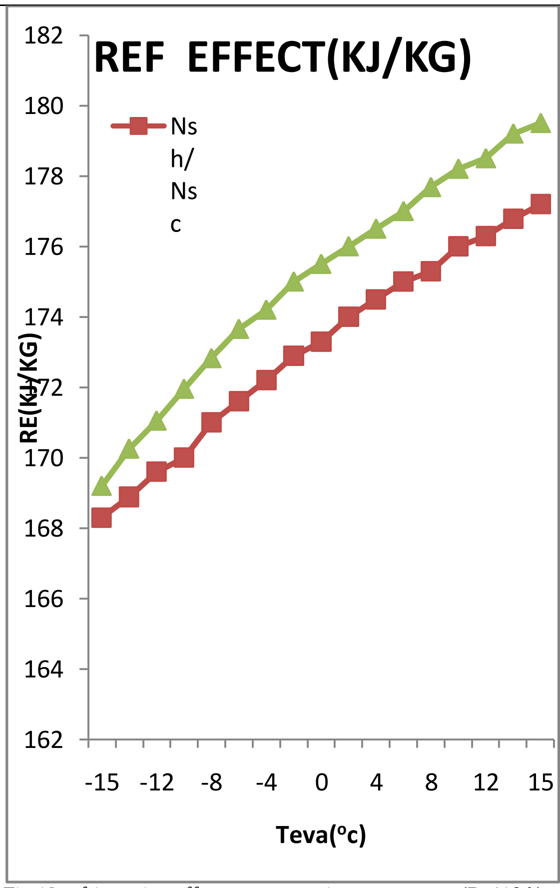

Fig.12.refrigerating effect vs evaporating temperature(R-410A)

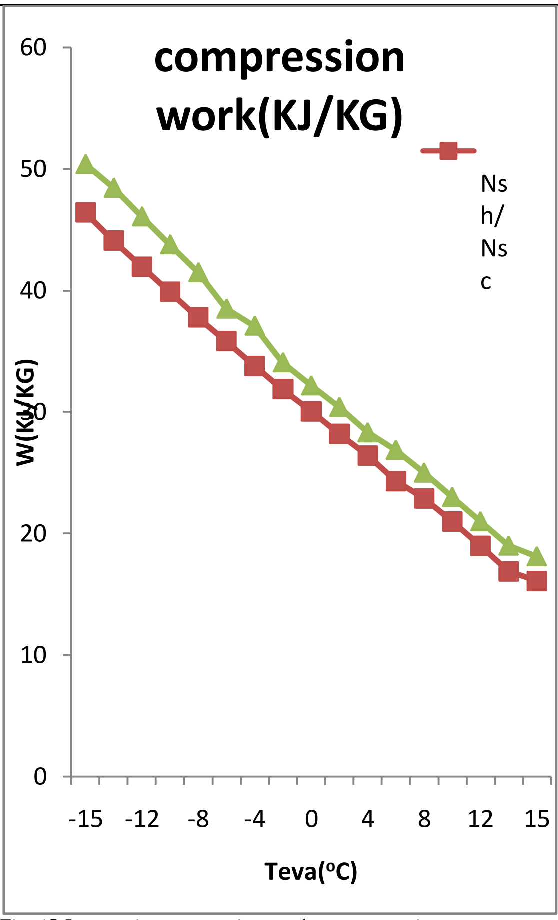

Fig. 13 Isentropic compression work vs evaporating temperature

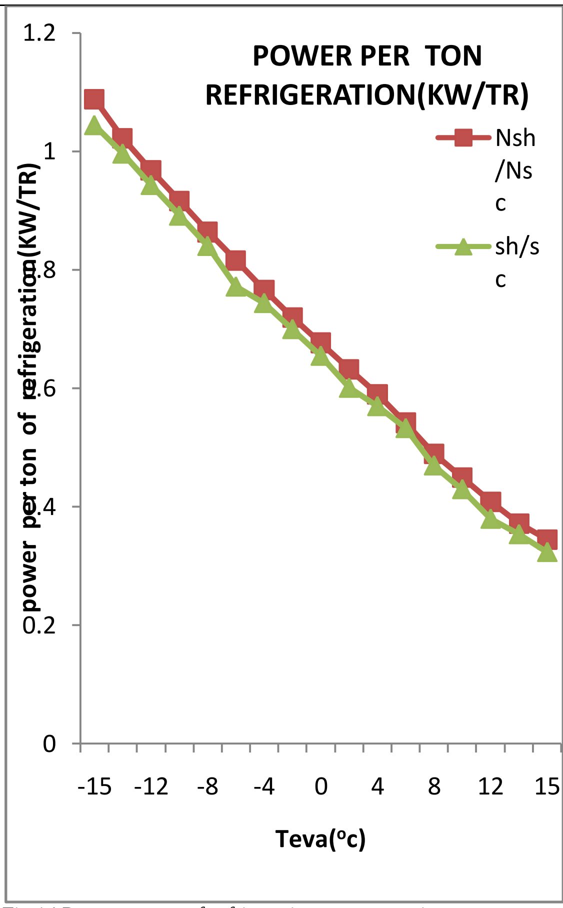

Fig.14 Power per ton of refrigeration vs evaporating temperature

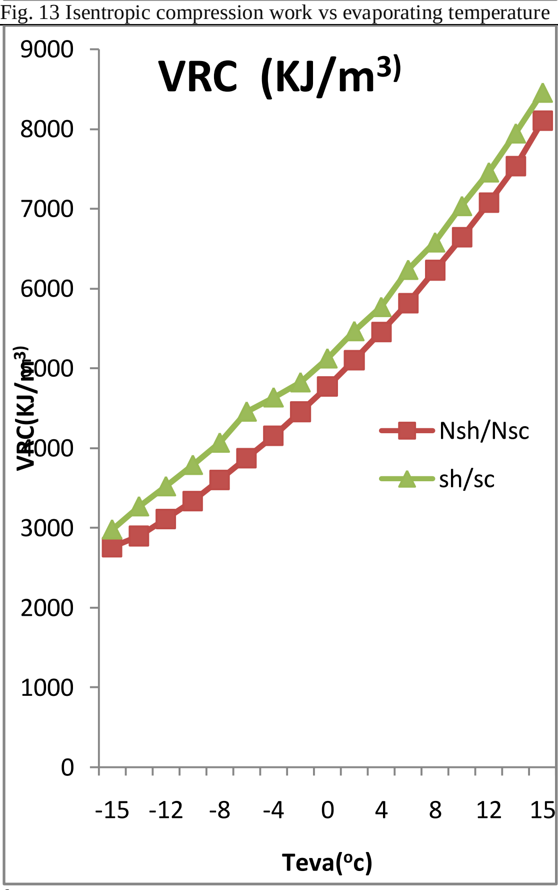

fig 15volumetric refrigeration capacity vs.evaporation temperature

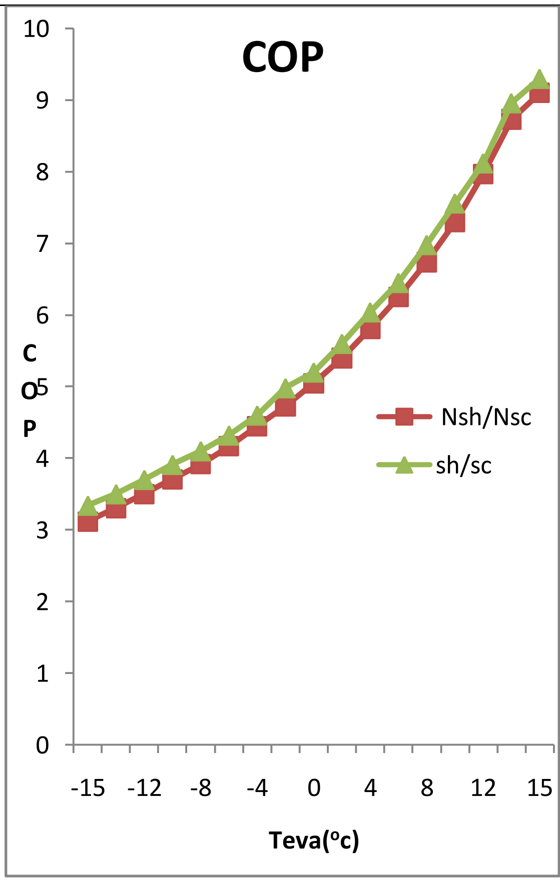

Fig.16 coefficient of performance vs evaporating temperature

R407C

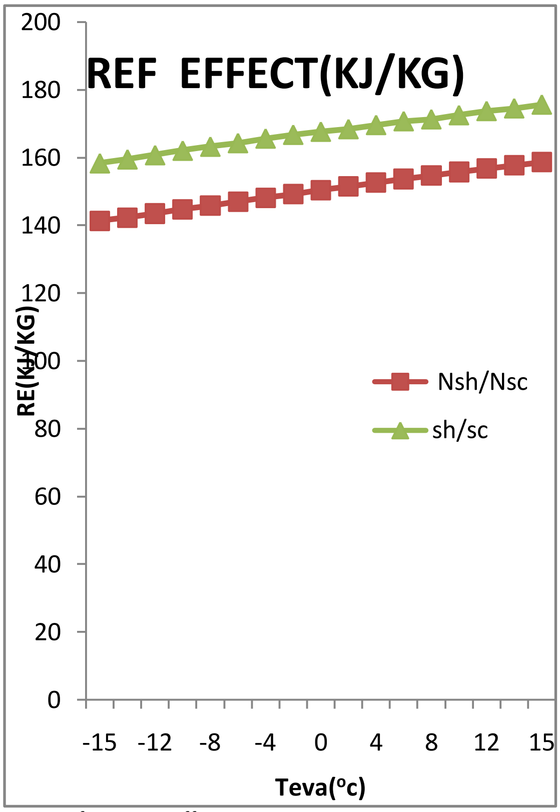

Fig.17.refrigerating effect vs evaporating temperature

R407C

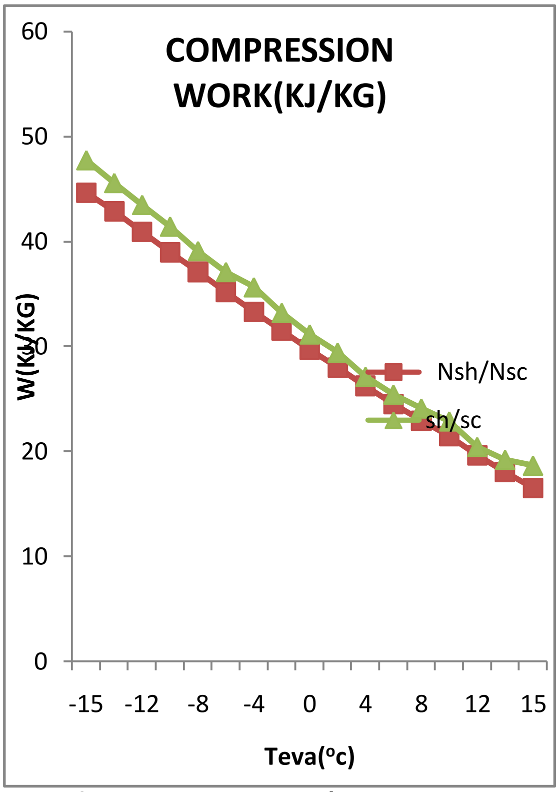

Fig. 18 Isentropic compression work vs evaporating temperature

R407C

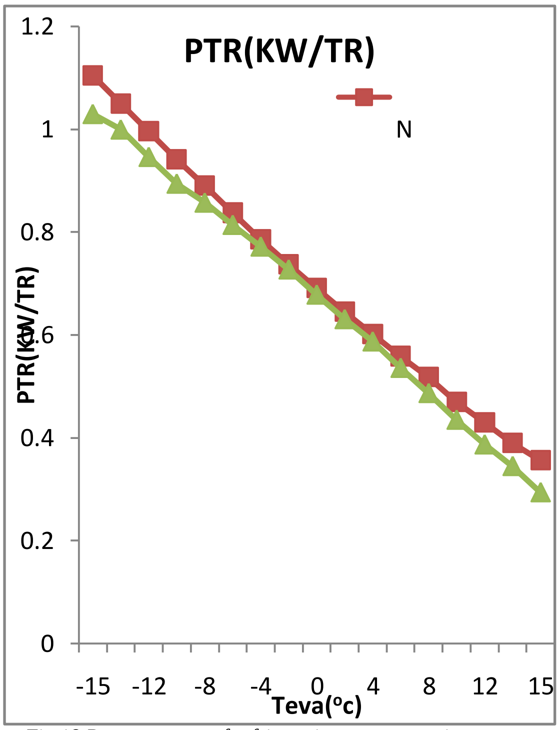

Fig.19 Power per ton of refrigeration vs evaporating temperature

R407C

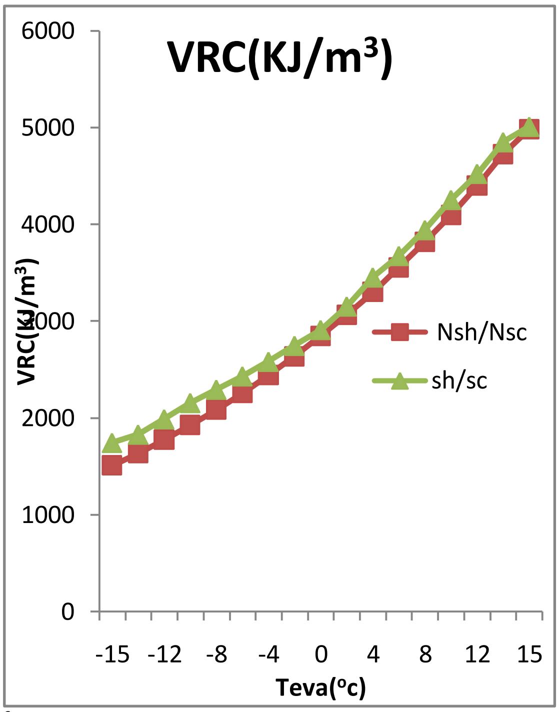

fig 20 volumetric refrigeration capacity vs.evaporation temperature

V. CONCLUSION

R22 that is commonly used as working fluid in vapour compression refrigeration system all over the world is being phased out due to their environmental hazard of ozone depletion. In this work, the performance of three HFC refrigerants (,R-410a, R-407cand R-507) regarded as R22 alternative in vapour compression refrigeration system were investigated using simulation model. The model was developed to predict the performance of the refrigerants based on their coefficient of performance, refrigerating capacity and the compressor work etc.

The result obtained showed that R410a and R407c have physical properties and thermodynamic Performance similar to R22. R410a has slightly lower coefficient of performance (COP), higher refrigerating capacity than R22. Considering the comparison of performance coefficients (COP) and pressure ratios of the tested refrigerants and also the main Environmental impacts of ozone layer depletion and global warming, refrigerant R410A and R407Care found to be the most suitable alternatives refrigerants to refrigerant R22.

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.

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Nomenclature

atm	atmosphere
CFCs	chlorofluorocarbons
COP	coefficient of performance
GWP	global warming potential
h	enthalpy, kg kJ−1
hfg	latent heat of condensation, kJ kg−1
HCFCs	hydro chlorofluorocarbons
HCs	hydrocarbons
HFCs	hydro fluorocarbons
ODP	ozone depletion potential
P	pressure, MPa
P/TR	power per ton of refrigeration, kW TR−1
RE	refrigerating effect, kJ kg−1
SVFR	uction vapour flow per kW of refrigeration, L s−1
T	temperature, °C or K
W	isentropic compression work, kNm kg−1
VRC	volumetric refrigeration capacity, kJ m−3
sh/sc	super heating/sub cooling
Nsh/Nsc	Non super heating/Non sub cooling

Greek symbols

ρ	density, kg m−3

Subscripts

cod	condensing/condenser
evap	evaporating/evaporator
comp	compressor
1	evaporator superheat
2	compressor superheat
3	condenser saturated liquid
4	evaporator saturated mixture