A COMPARATIVE STUDY OF REFRIGERANTS R12, R134A, R407 & R717 FOR VAPOUR COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT

The present paper explains the comparative performance analysis of vapour compression refrigeration system with four different refrigerants R12, R134a, R407 and R717. The vapour compression refrigeration system consist of compressor, condenser, expansion valve and an evaporator. The comparative study of refrigerants has been carried from which the results has been obtained is plotted in the graph. The evaporator temperature has been varied from -10 to -40℃ and degree of subcooling from 0 to 10℃. The parametric study reveals the effect of these parameters on performance of vapour compression system. The four configurations are Simple Vapour Compression system , Multiple Compression System with flash chamber, Multiple compression system with water intercooler and liquid subcooler and Multiple compression system with Flash intercooling and multiple expansion valve, The results showed that the refrigerant R717 have highest COP for Simple Vapour Compression system , Multiple Compression System with flash chamber and MCS with Flash intercooling and multiple expansion valve followed by the R12 in Simple VCS, R134a in Multiple Compression System with flash chamber and R407 in Multiple compression system with Flash intercooling and multiple expansion valve but in Multiple compression system with water intercooler and liquid subcooler the highest COP is of R12 followed by R717 for the condensation temperature of 48℃ and evaporating temperature is -10℃.The effects of the main parameters of performance analysis such as refrigerant type, mass flow rate and condenser discharge temperature also investigated for various configuration.

Keywords: Refrigeration, R12, R134a, R407, R717, Vapour Compression System

I. INTRODUCTION

Energy consumption in buildings has become an important aspect on a global scale. Energy costs and environmental concerns have made energy optimization a crucial issue for buildings. Therein energy efficiency is a prime mover in reducing global warming emissions. In respect to this, new technologies to conserve energy, to use energy effectively, to use alternative energy sources and to reduce the energy running costs of buildings such as solar energy, geothermal energy, wind energy etc. are under continuous development.

There in energy efficiency is a prime mover in reducing global warming emissions. The rapid escalation in energy costs, the issues of security of supply, the emission of polluting substances as well as global climate change, have all made refrigerating methods in their current forms unsustainable at present and in the future. Therefore to overcome these problems, alternative solutions must be studied which focus on the reduction of energy consumption and the improvement of heating performance while reducing adverse effects on the environment.

II. LITERATURE REVIEW

S.Venkataiah et al (2013) in his paper presents the simulation results of a 1.5Ton (5.276kW/18000BTU/Hr) Capacity room air conditioner with some selected refrigerants thathave been assessed for their suitability as alternative refrigerants to R-22 for air-conditioning applications.

The Performance of the selected refrigerants viz., R-22, R-134a, R407C, R410A, R404A, R507A, R290, and R600a is considered in the analysis whereas A.Baskaran et al(2012) performed analysis on a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, HFC32, HC290, HC1270, HC600a, RE170 were done and their results were compared with R134a as possible alternative replacements. 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 -30C and 10C.M.Mohanraj et al (2011) in his studies reported about new refrigerant mixtures in domestic refrigerators, commercial refrigeration systems, air conditioners, heat pumps, chillers and in automobile air conditioners. In addition, the technical difficulties faced with new refrigerant mixtures, further research needs in this field and future refrigerant options for new upcoming systems have been discussed in detail. This paper concludes that HC based refrigerant mixtures are identified as a long-term alternative to phase out the existing halogenated refrigerants in the vapour compression-based systems also in the same year. Hailei Wang et al (2011) in his study introduced a novel thermally activated cooling concept – a combined cycle couples an ORC (organic Rankine cycle) and a VCC (vapor compression cycle).A systematic design study was conducted to investigate effects of various cycle configurations on overall cycle COP. With both subcooling and cooling recuperation in the vapor compression cycle, the overall cycle COP reaches 0.66 at extreme military conditions with outdoor temperature of 48.9 °C. M.I. Karamangil et al (2010) presents a literature review, especially in recent years, on the absorption refrigeration systems (*ARS*s), the currently used refrigerant–absorbent pairs and their alternatives. It was concluded that performances of the cycles improve with increasing generator and evaporator temperatures, but reduce with increasing condenser and absorber temperatures. Zaghdoudi et al (2010) have simulated the performance of ten alternate refrigerants such as [R134a, R290, R600, R404A, R407A, R407C, R407D, R410A, R410B and R417A] to replace R22 in Air conditioner of 9000BTU/hr (0.75TR) capacity by using NIST Cycle-D.

Brandon et al (2007) in his paper investigated the economic feasibility of a water-based vapor compression chiller with a nominal capacity of 3520 kW (1000 ton). The results show that water-based vapor compression refrigeration systems will not be economically attractive without substantial and successful efforts to develop low-cost, high capacity compressor. James. M. Calm (2006) summarized analysis of refrigerant options for chillers. The 28 refrigerants addressed include chlorofluorocarbon (CFC), Hydro-chlorofluorocarbon (HCFC), Hydrocarbon (HC). He discussed the relative importance of the refrigerant related and energy related components of chillers emissions. Dongsoo Jung et al (1999) studied Multi-stage heat pumps composed of a condenser, evaporator, compressor, suction line heat exchanger, and low and/or high stage economizers are studied by computer simulation. The results indicate that the three-stage super heat pump with appropriate mixtures is up to 27.3% more energy efficient than the conventional single-stage system. Jameel-Ur-Rehman et al (1998) in his study developed the thermodynamic models of the two stage system (TSS) to simulate system performance with respect to the interstage temperature and heat-exchanger parameters. The TSS performance is better than for a simple cycle and depends on the interstage temperature of the flash intercooler.

S.M. Zubair et al (1996) performed thermodynamic analysis of HFC-134a vapor-compression refrigeration cycles by both the first and second laws of thermodynamics. Second-law analysis is carried out for both two-stage and mechanical-subcooling refrigeration cycles. It is found that most of the losses are due to low compressor efficiency. Irreversibilities of expansion valves and condenser are also significant. O.Badr et al (1990) studied vapour-compression units which are the most widely used refrigeration systems. Interactive computer routines have been composed, in BASIC language, in order to permit the prediction of the performances of simple, multi-evaporator multi-stage compressor vapour-compression refrigerators.

V.K. Gupta et al (1986) in his study employed two-stage compression on high temperature (HT) side and single-stage compression on low temperature (LT) side is numerically optimized for preliminary design of the system. Overall coefficients of performance of the system are found to be 2.8 to 7.4, if the system operates within the consider ranges of the operating variables/parameters. Mark R. Shelton et al (1985) based on his model, an index of performance for pure refrigeration is proposed. This index can be used to quickly identify thermodynamically efficient refrigerants, and to predict the performance of refrigeration cycles with very little computational effort. V.K. Gupta et al (1983) analysed the optimum thermodynamic performance of three stage refrigerating system. In his analysis the refrigeration efficiency, mass flows through IP and HP compressors, power input and inter-stage pressures at the optimum thermodynamic performance of three stage systems are presented graphically for the most common refrigerants, R 12, R 22 and R 717.

III. SYSTEM DESCRIPTION

The cycle consists of a compressor, discharge line, condenser, expansion device, evaporator, compressor suction line, and an optional suction line heat exchanger. The simulation cycle is outlined by different states as shown in the Fig 1. These state points are the following: the suction gas (1) is compressed and discharged into the discharge line (2). The discharge line leads the refrigerant to the inlet of the condenser (3). The condensed and sub cooled refrigerant in the condenser outlet (4) is either lead to the liquid inlet of the suction gas heat exchanger (SGHX) if this has been selected, or directly to the inlet of the expansion valve. If a SGHX is included the exit condition (5) will be different from condition (4). From the expansion valve outlet (6) the refrigerant is lead to the evaporator. The evaporated and superheated refrigerant in the evaporator outlet (7) is lead through the suction line, either to the gas side inlet of the SGHX, if this has been selected, or to the compressor inlet (1). If a SGHX is included the exit condition (8) will be different from condition (1).

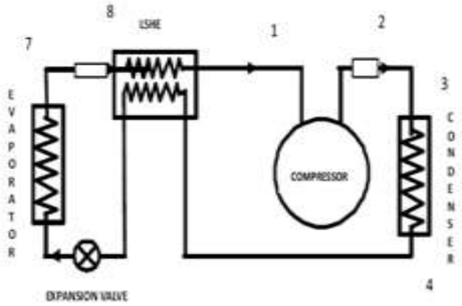

Fig. 1: Schematic Diagram of System Layout

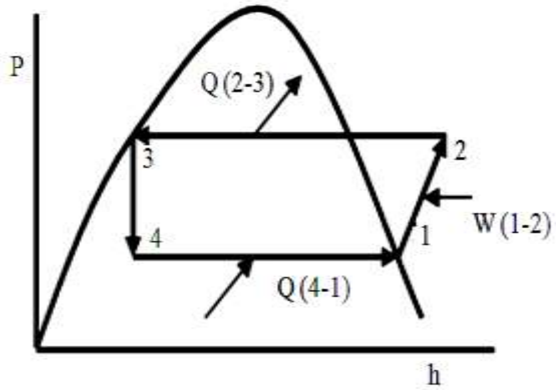

Fig. 2. Pressure Enthalpy Diagram of Vapour Compression System

IV. METHODOLOGY

Cool Pack Software: It covers calculation of refrigeration properties (property plots, thermodynamic and thermo physical data, refrigerant comparisons), cycle analysis- comparison of single stage and multi stage, system dimensioning- calculation of component sizes from general configuration criteria, System simulation-calculation of operating conditions in a system with known components with their operating parameters, evaluation of operation and evaluation of the system coefficient of performance with less power consumption. Fig 3 shows typical screen shots during the usage of COOLPACK in the analysis

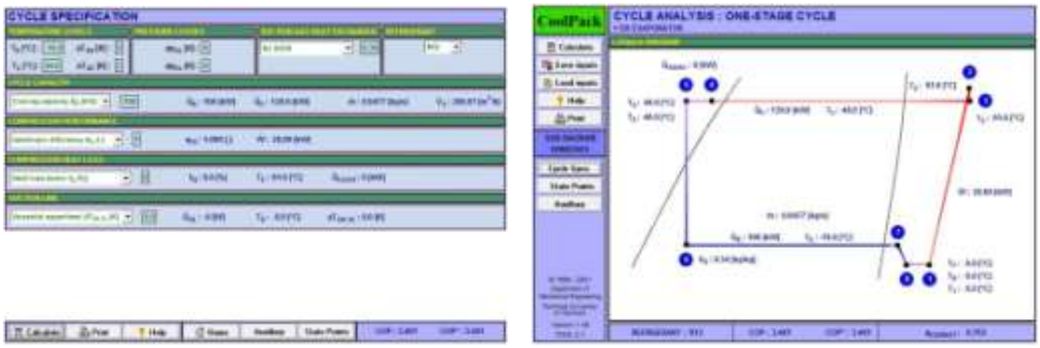

Fig. 3: Screenshots of Coolpack Software

4.1 Thermodynamic Analysis

This topic presents the simulation results of a 100 Ton Capacity of freezing plant with selected refrigerants that have been assessed for their suitability. The Performance of the refrigerants R-12, R-134a, R407Cand R717 is considered

Table 1. Properties of Different Refrigerants used for the Analysis

S.No	Property	R12	R134a	R407a	R717
1	Chemical formula / blend composition	CCl_2F_2	CH_2FCF_3	20%R32/40% R125/40%R134a	NH3
2	Molar Mass (kg/kmol)	120.914	102.03	86.204	17.03
3	Critical Point Temperature Tc (℃)	113.23	101.06	86.034	132.25
4	Critical Pressure (Pc) (bar)	42	40.593	46.298	113.3
5	Critical Density (kg/m^3)	565	511.9	484.23	225
6	Boiling Point	-21.6	-26.074	-43.8	-33.33
7	ODP	1	0	0	0
8	GWP	2400	1300	1770	0

4.2 Cycle Specifications for Simulation

The cycle inputs are evaporating temperature ranging from -10ºC to -40°C and condensing temperature is 48ºC. Condenser sub cooled temperature ranges from 0 to 10°C.Pressure losses in the condenser and evaporator are neglected. Cooling capacity in the evaporator is selected as 29 Ton, isentropic efficiency of compressor is taken as 1, compressor heat loss factor is considered as zero also suction line super heat is considered as zero.

V. RESULTS

The comparative study for refrigerants R12, R134a, R407 and R717 has been carried out of four different configuration of vapour compression refrigeration system and the results are shown in the form of graph.

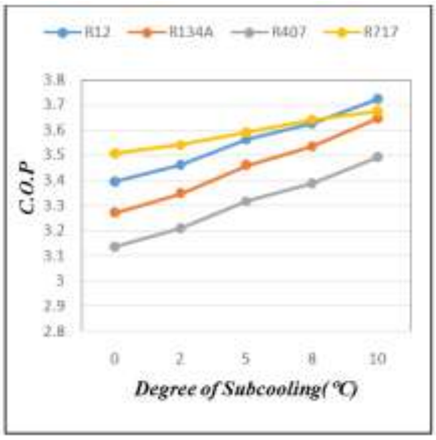

Fig.4. C.O.P vs Degree of Subcooling

Figure 4 represents the variation of C.O.P with degree of subcooling. From the graph it is observed that the C.O.P of all refrigerants increase with degree of subcooling. The C.O.P of R12 is maximum for 10°C of subcooling which is 3.724 while the C.O.P of R134A, R407 & R717 are 3.648, 3.493, and 3.677 respectively.

Figure 5 represents the variation of mass flow rate with degree of subcooling. The mass flow rate of R717 is minimum for refrigeration system and nearly same for all the values of degree of subcooling. The mass flow rate of R12 is maximum which 0.9664 is and it decreases with increase in degree of subcooling followed by R134A and R407 while the R717 has minimum mass flow rate and nearly the same value for all the values of degree of subcooling.

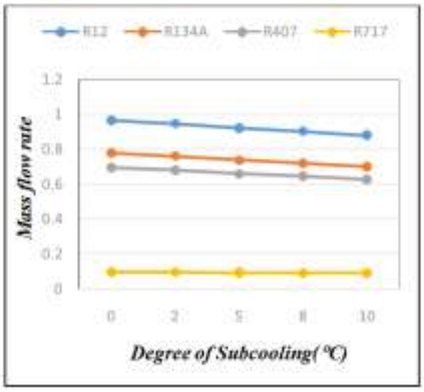

Fig.5. Mass Flow Rate vs Degree of Subcooling

In figure 6 the variation between condenser discharge and degree of subcooling is plotted on the graph, condenser discharge decreases with increase in degree of subcooling. The maximum value of condenser discharge is for R407 at 0°C is 131.9 kW and minimum is 128,6 at 10°C of degree of subcooling followed by

R134A, R12 and R717.

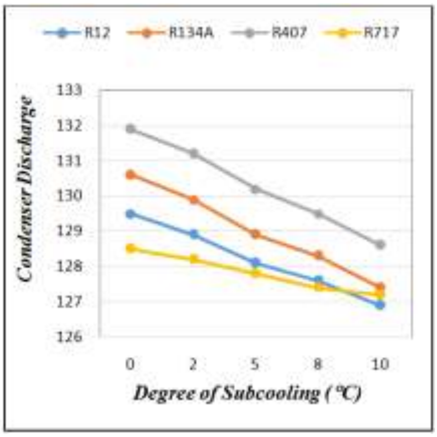

Fig.6. Condenser Discharge vs Degree of Subcooling

Figure 7 represents the variation of C.O.P with evaporator temperature. From the graph it is observed that the C.O.P of all refrigerants increase with evaporator temperature. The C.O.P of R12 is maximum for -10°C of evaporator temperature which is 3.659 followed by the R717, R134A and R407whose values are 3.643, 3.574 & 3.423 respectively.

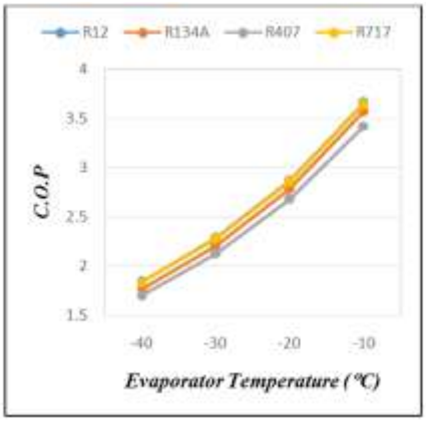

Fig.7. C.O.P vs Evaporator Temperature

Figure 8 represents the variation of mass flow rate with evaporator temperature. The mass flow rate of R717 is minimum for refrigeration system and nearly same for all the values of evaporator temperature. The mass flow rate of R12 is maximum which 0.8964 is and it increases with increase in degree of subcooling followed by R134A and R407.

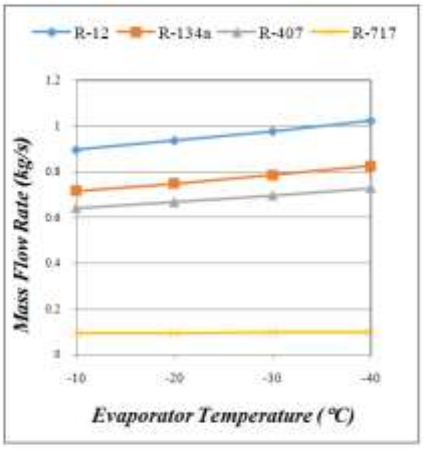

Fig.8. Mass Flow Ratevs Evaporator Temperature

In figure 9 the variation between condenser discharge and evaporator temperature is plotted on the graph, condenser discharge decreases with increase in degree of subcooling. The maximum value of condenser discharge is for R407 at 0°C is 158.8 kW and minimum is 129.2kW at -10°C of evaporator temperatue followed by R134A, R12 and R717. The values of R717 is nearly same for R12 for all the values of evaporator temperature.

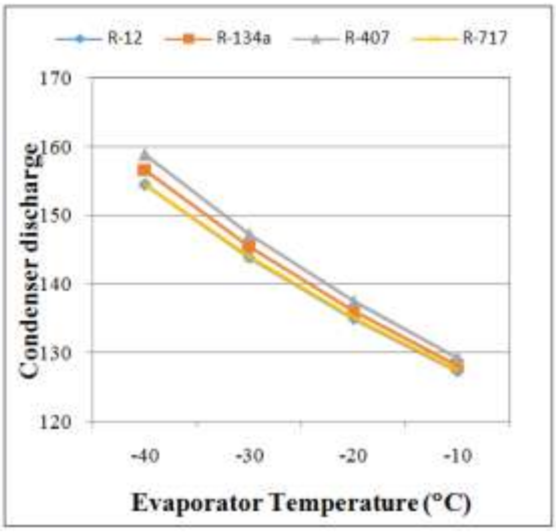

Fig.9. Condenser Discharge vs Evaporator Temperature

VI. CONCLUSION

In the present study four different refrigerants R12, R134A, R407 and R717for vapour compression refrigeration system are used for the performance analysis. Considering the comparison of coefficient of performance (COP), mass flow rate and discharge temperature of the tested refrigerants and also the main environmental impacts of ozone layer depletion and global warming, refrigerant R717 was found to be the most suitable for simple Vapour compression refrigeration system.

VII. NOMENCLATURE

VCS = Vapour Compression System
MCS = Multistage Compression System
SGHX = Suction Gas Heat Exchanger
CFCS = Chlorofluorocarbons
COP = Coefficient of Performance
GWP = Global warming potential
HCFCs = Hydro chlorofluorocarbons
HCs = Hydrocarbons
HFCs = Hydro fluorocarbons
ODP = Ozone depletion potential
TR = Ton of refrigeration

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