Performance Analysis of Water (R718) As a Refrigerant in Medium Range Temperature

Renu Singh, Alka Bani Agrawal

Abstract -Water as a refrigerant (R718) is compared with itself for sub-cooling and superheating conditions regarding various performance parameters in medium range temperature (5^0C to 35^0C). These performance parameters i.e. COPs, Pressure ratios , outlet temperature of refrigerants from the compressor and evaporator temperature , are simulated with the help of computer program in language C++ . " In this paper study of sub-cooling and superheating effect of water(R718) as a refrigerant is compared. In case of superheating evaporator temperature is changed in which throttling valve exit temperature, evaporator temperature, and compressor outlet is kept constant, while condenser temperature varies (5^oC to 35^oC)". It is found that for small range of degree of superheat COP is highest, and decreases with increase in degree of superheat. Assuming exactly the same cycle parameters, with increase in degree of sub-cooling, it increases again.

Keywords: comparison, compressor, cycle, refrigeration, refrigerants, water, sub-cooling, superheating.

I. INTRODUCTION

Water as a refrigerant is one of the oldest refrigerants being used for refrigeration applications down to freezing because of its easy availability and excellent thermodynamics and chemical properties. Beside these advantages, there are technical challenges that result from its high specific volume at low temperatures, necessary high pressure ratios across the compressor, and resulting high compressor outlet temperature. These challenges have been overcome by designing and manufacturing special compressors for water vapor compression applications .Because of having excellent features, being an environmentally safe (ODP=0 and GWP=0), non-toxic, non-flammable, non-explosive, easily available, and the most inexpensive refrigerant, water (R718) is one of the oldest natural refrigerants being used for refrigeration applications except freezing. It also has the highest COP over other refrigerants at higher evaporator temperatures. Beside these advantages, there are technical challenges that result its high specific volume at low temperatures. These challenges include high pressure ratios across the compressor and high compressor outlet temperatures. These challenges have been overcome by designing and manufacturing special compressor for water vapor compression applications [1]. Water vapor compression applications have been classified according to the compressor type used in the refrigeration cycle, which include single and multistage centrifugal, multistage axial, Roots, liquid ring, cycloid, and jet/ejector compressors, [2] . The use of water as a refrigerant in vapor compression system does offer several potentially significant advantage and fulfills most of the fundamental requirements of a refrigerant.

Manuscript received on July, 2013.

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Water is an ecological sound refrigerant with no Ozone Depletion Potential (ODP) and a global warming Potential (GWP100yr) less than 1[3]. The viability of water vapor based compression refrigeration system revolves around its life-cycle cost competitiveness with current technology. The life-cycle cost associated with water cycle is evaluated using a multiplier method known as the "P1-P2" approach, [4]. Furthermore, there have been some studies in which water as a refrigerant has been compared with other refrigerants in some aspects including COP, refrigeration capacity, compression ratio, and compressor outlet temperature, mass flow rate, heat-capacity, heat in evaporator (Q_{evapo}), heat in condenser (Q_{cond}). By means of a computer program in C++ language, which has been developed to determine the thermodynamic properties of some working fluids used in vapor compression refrigeration cycle, water has been compared with other refrigerants [5]. The study also has shown that water is compared for sub-cooling and superheating effect in respect to various performance parameters by using computer program developed in C++ language. They have used a simple refrigeration cycle model consisting of assumptions of no pressure drop through the cycle, constant superheating between evaporator outlet and compressor inlet. From the literature survey, it is clear that the studies that are related to the performance analysis of water as a refrigerant have been generally based on a theoretical vapor compression refrigeration cycle, but there have been also some studies in which the results for the sub-cooling cases of an actual vapor compression refrigeration cycle have been presented, but the studies based on investigating the effect of superheating on a vapor compression cycle is very scarce. For medium temperature range lifts, this evaporator temperature is above 35^oC, whereas for even greater temperature lifts it decreases again [6]. However, the present study is different from the studies published by presenting a detailed analysis of an actual vapor compression refrigeration cycle with water as working fluid. Superheating is analyzed in detail and their effects on the system performance are discussed extensively. The main objective of this study is to compare the coefficient of performance (COP) of water (R718) when sub-cooling is considered with condition when superheating is considered by using the computer evaporator temperature cases by using the computer program developed [7]. Water vapor compression applications have been classified according to the compressor type used in the refrigeration cycle, which include single & multistage centrifugal, multistage axial, roots. Most of the studies in the literature have been based on the application. The effect of superheating of vapor refrigerant on the refrigeration effect changes to the place where the superheating of a refrigerant takes place.

If the superheating takes place inside the refrigerated space, an additional amount of refrigeration is provided to the cycle. When it takes place outside the refrigerated space, there is no benefit for the cycle.

This is called a useless cooling effect. As it was mentioned before, it has been assumed that superheating of vapor refrigerant occurs inside the refrigerated space. At constant evaporator and condenser temperatures, the amount of heat for superheating vapor refrigerant is absorbed from the refrigerated space. This heat is added to the refrigeration effect of the cycle. This causes the specific volume of vapor refrigerant to increase. An additional amount of energy for the compressor is necessary to compress this extra specific volume of refrigerant. As a result, the compressor power increases. In the superheating process, both refrigeration effect and compressor power increases.

II. THEORETICAL ANALYSIS:

It is assumed that superheating occurs in the suction line and the suction line is placed inside the refrigerated space. It is also assumed that there is no sub-cooling and pressure drop in the refrigeration cycle. states 3 and 4 coincide due to no sub-cooling. Therefore power required for the cycle, W, can be expressed for superheating case :

$$W_1comp,sh = m^o (h_2-h_1) \quad \text{-- ------} \quad (1)$$

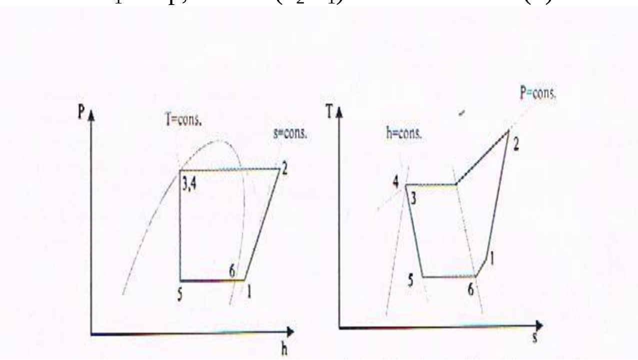

Figure 2:- Pressure-enthalpy & Temperature–entropy diagram of the vapor compression cycle

Where h1 and h2 are specific enthalpies at inlet and outlet of the compressor, respectively. Specific work of compression (Wcomp) for the compressor can be written as :

$$W_2comp,sh = (h_2-h_1) \quad \text{---------} \quad (2)$$

During throttling process in the expansion valve , it is assumed that there is no heat transfer to the environment which result in :

$$h_4 = h_5$$

where h4 and h5 are the enthalpies of refrigerants at the expansion valve inlet and evaporator inlet, respectively . The refrigeration effect of the vapor compression refrigeration cycle can be expressed as :

$$q_{r,sh} = (h_1-h_5) \quad \text{----------} \quad (3)$$

The specific enthalpy of superheat vapor at state 1 can be expressed by :

$$h_1 = h_6 + C_{p,v} (T_1-T_e) \quad \text{------} \quad (4)$$

h_6 is enthalpy of saturated vapor at the evaporator outlet and $C_{p,v}$ is the constant specific heat of refrigerant in vapor state between state 6 and 1, T_e is the evaporator saturation temperature, and T_1 is the temperature at the compressor inlet coefficient of performance of the refrigeration cycle COP_{sh} can be expressed by :

$$COP_{sh} = \frac{Qr,sh}{Wcomp,sh} \quad \text{-------} \quad (5)$$

Based on the above model a computer program was developed calculating COPs for R718 for superheating case Later when sub-cooling is considered with zero pressure drop point 3,4 does not coincides as shown in fig.3 pont 3' represent exit point of condenser , point 3 represents exit point of throttling valve. Here enthalpy at point 3' and 4' and 3,4 are same.

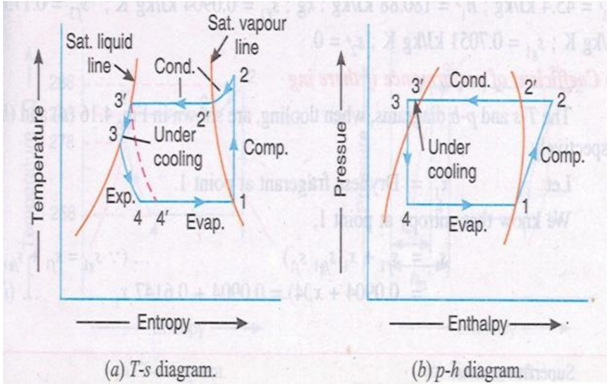

Fig.3(a) T-s diagram of refrigeration cycle with sub-cooling (b) P-h diagram of refrigeration cycle with sub-cooling.

Therefore power required for cycle is represented by:

$$W = m(h_2-h_1) \quad \text{\_\_\_\_\_\_\_\_\_} (6)$$

Where h_1 and h_2 are enthalpies at entry and exit of compressor respectively. Refrigerant after condensation process 2'-3', is cooled below the saturation temperature ($T_{3'}$) before expansion by throttling. Such a process is called under-cooling or sub-cooling of the refrigerant and is generally done along the liquid line as shown in fig. The ultimate effect of the under-cooling is to increase the value of coefficient of performance under the same set of conditions.

During throttling process in the expansion valve , it is assumed that there is no heat transfer to the environment , which result in:

$$h_{f3} = h_4$$

where h_{f3} and h_4 are the enthalpies of refrigerants at the expansion valve inlet and evaporator inlet, respectively . The refrigeration effect of the vapor compression refrigeration cycle can be expressed as :

$$q_{r,sh} = (h_1-h_4) \quad \text{----------} \quad (7)$$

The value of h_{f3} may be found out from the relation,

$$h_{f3} = h_{f3'} - C_p(T_{3'}-T_3) \quad \text{------} \quad (8)$$

$h_{f3'}$ is enthalpy of saturated vapor at the evaporator outlet and $C_{p,v}$ is the constant specific heat of refrigerant in vapor state between state 4 and 1, T_e is the evaporator saturation temperature, and T_1 is the temperature at the compressor inlet coefficient of performance of the refrigeration cycle COP_{sh} can be expressed by :

$$COP_{sh} = \frac{h1-hf3}{h2-h1} \quad \text{-------} \quad (9)$$

III. PERFORMANCE ANALYSIS

Performance of water (R718) as a refrigerant is compared with itself for sub-cooling and superheating conditions, on basis of several parameters (COP, Comp. work, comp. power, heat capacity etc.) .These parameters are calculated with help of computer program developed in language C++.

In this certain value of evaporator temperature, condenser temperature, comp. isentropic efficiency, comp. volumetric efficiency, electric motor efficiency, pressure drop , is given as input . For R718 programming is done in language C++ . In this programming parameters which are to be calculated are defined then formulae used is encoded. As we input values of temperature, pressure & enthalpy it gives result when we run the program. Thus for R718 parameters are calculated by programming and compared by the result calculated manually.

IV. RESULTS AND DISCUSSION

With the computer code the evaporator temperature was increased from 5^0C to 35^0C , while the condenser temperature ,isentropic efficiency & cooling capacity is kept constant. fig.1(a) & fig.1(b) shows the variation of coefficient of performance for different evaporator temperature keeping condenser , polytrophic efficiency constant, and keeping superheat temperature constant(20^0C). With increase in temperature range COP of R718 varies from 6.27 to 4.661 kw. In case when sub-cooling is considered , evaporator temperature, compressor out-let temperature is kept constant, keeping condenser temperature changing, COP varies from 6.40 to 9.37. Further more fig.1(c) & fig.1(d) shows the variation of heating capacity in sub-cooling and superheating conditions. In case of sub-cooling heating capacity decreases with increasing degree of sub-cooling. It varies from range 5.686 to 5.070. In case of superheating it varies from 5.797 to 6.058. From fig.1(e) & fig.1(f) as sub-cooling increases compressor power decreases from 0.779 to 0.7596 . While in superheating case it increases from 0.797 to 1.07.

V. CONCLUDING REMARKS

Through the developed computer program water is compared for a simple vapor compression refrigeration cycle and refrigerant properties. Result obtained is in good agreement with the studies in literature. The computed result shows that the use of water as a refrigerant can result in higher COP at low range of temperature difference. It decreases with increase in degree of superheat and increases with increase of degree of sub-cooling at medium temperature range (05^oC-35^oC) of evaporator temperature and in superheating case and medium temperature range (15^oC to 35^oC) of condenser temperature in sub-cooling case. The disadvantage of water vapor as a refrigerant is its high Specific volume, the required high pressure ratio, and resulting high compressor outlet temperature. These technical challenges can be overcome with specifically developed compressors, especially multi-stage turbo compressors with intercooler between stages. In present scenario, a refrigeration system with high COP is the primary target, but it is not the only factor in deciding which refrigerant is to be used. Environmental parameters as ODP & GWP are becoming more restrictive. Furthermore, the economic costs and safety issues are heavily considered. With all these aspects and specific operating conditions mentioned above, water is the superior refrigerant.

ACKNOWLEDGEMENT

I express my deep sense of gratitude to Dr. Alka Bani Agrawal, Reader, Department of Mechanical Engineering, U.I.T.-RGPV,Bhopal, for her valuable guidance, encouragement and help for this work.

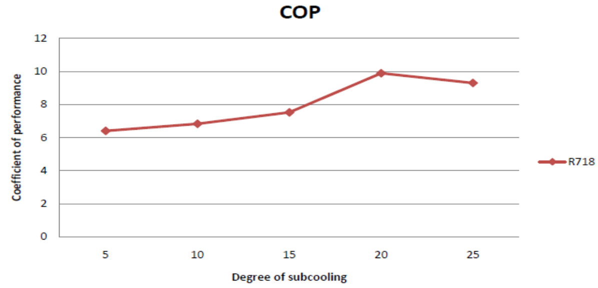

Fig.1(a)

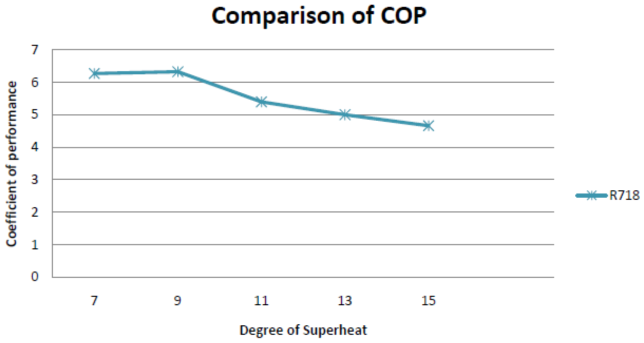

Fig.1(b)

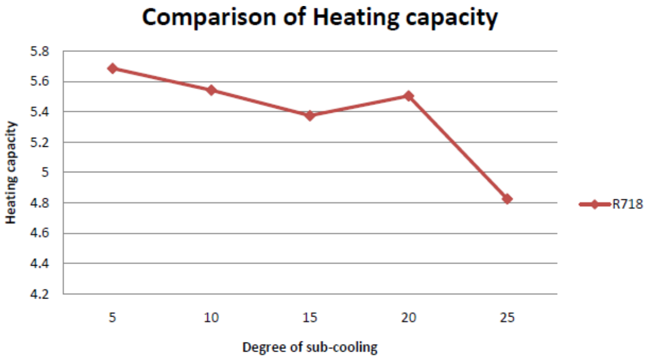

Fig.1(c)

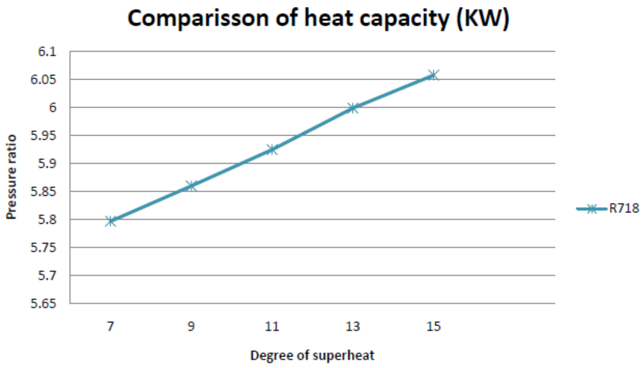

Fig.1(d)

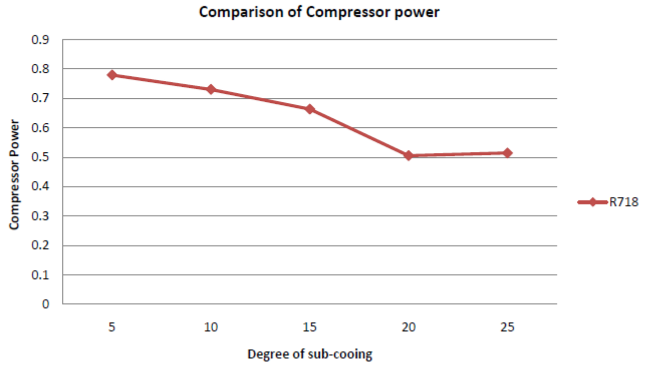

Fig.1(e)

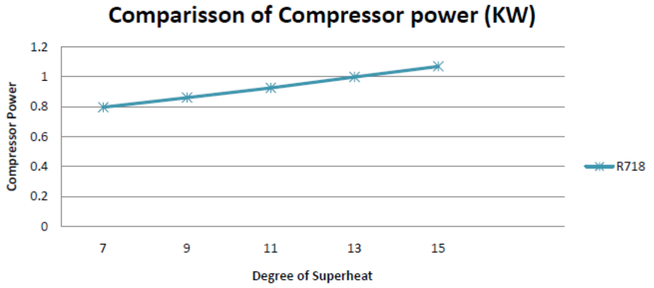

Fig.1(f)

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