Thermal Performance of Vapour Compression Heat Pump Using Different Refrigerants

Mohd Arif, Avatar Singh Kuntal

Abstract— **The objective of this paper is to present the thermodynamic analysis of vapor compression heat pump system with using seven different refrigerants R717, R12, R22, R134a, R407C, R410A, R404A. It is found R717 (ammonia) results best coefficient of performance (COP) for the heat pump cycle. COP depends on the evaporator temperature, condenser temperature, degree of sub cooling and compressor pressure etc. The coefficient of performance (COP) increases with decreasing the temperature difference between the evaporator and heating space. Also, it is analyzed the extent of degradation of thermal performance due to the use of various refrigerants and identified the refrigerants that is best suited.**

Index Terms— **COP, refrigerants, evaporator temperature, condenser temperature, work of compression.**

I. Introduction

Hot water production as well as space heating using heat pumps is a proven energy efficient heating method. Heat pumps offer the advantages of reducing energy consumption, improving heating performance and reducing the negative effects on the environment compared with other heating methods. 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. 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 heating methods in their current forms unsustainable at present and in the future. Therefore to overcome these problems, alternative heating 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. One such heating method is the use of heat pumps. Heat pumps are devices which have an increased efficiency when compared to other traditional heating methods and have the possibility of meeting the requirements of both an environmental and economic sustainable future with regard to domestic energy use.

There are the various applications where vapour compression heat pump system is used such as for conditioning the building, hot water supply for domestic purposes and other heating demands, etc. In this system working fluid used is known as refrigerant which is the medium of heat transfer. The first refrigerant used in vapour compression refrigeration system was sulphur dioxide which is highly flammable and toxic. In 1930 Freon group refrigerant was start in use in order to reduce the flammability and toxicity. The performance of the vapour compression heat pump system can be calculated by two methods i.e. energy and exergy analysis. Energy analysis is based on the first law of the thermodynamic while exergy analysis based on the both first and second law of thermodynamic. The first law of the thermodynamic deals with quantity of energy and assert that energy cannot be created or destroyed. Basically in energy analysis we calculate the work done by compressor (W_{comp}), heat output in condenser (Q_{cond}) and coefficient of performance (COP).

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II. Theoretical background

Vapour compression heat pumps are refrigeration systems whose operational cycle is based on the reversed Rankine cycle, requiring work input to accomplish their objective of transferring heat from a lower temperature source to a higher temperature sink as shown in Fig. 1. Their operational mode is virtually identical to that of refrigerators, being only different in its purpose. The low pressure liquid refrigerant is evaporated by absorbing heat in an evaporator at the heat source. It is then compressed and passed through a condenser at the heat sink, where it is condensed and heat is released to the heat sink. The high pressure liquid refrigerant is then passed through the expansion device and returns to the heat source heat exchanger. To accomplish this, work is done on the working fluid (refrigerants) through the use of a compressor. From a thermodynamics point of view, the performance of a heat pump is evaluated by its heating capacity and coefficient of performance COP.

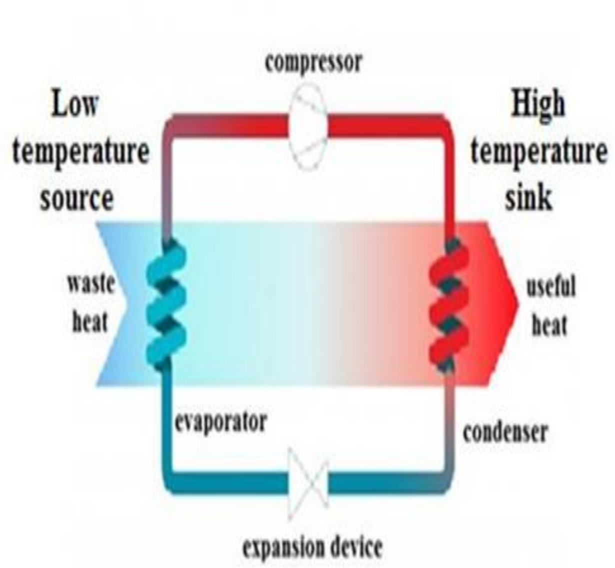

Fig. 1 Vapour compression heat pump

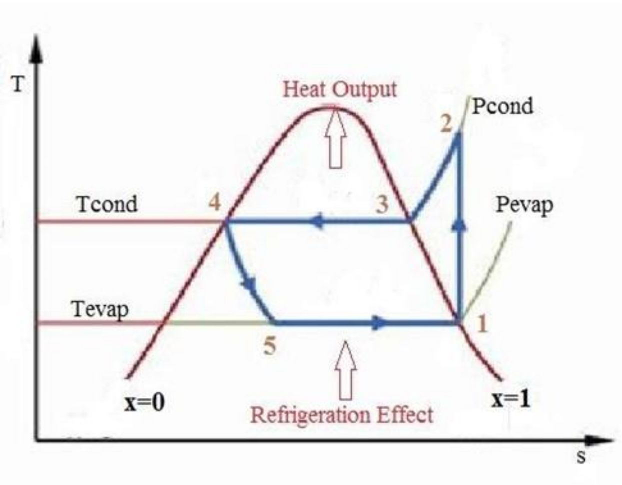

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Fig. 2: T-S diagram of heat pump cycle

From above fig. 2, we can write following thermodynamic equations:

Work given to the compressor, $W_{comp} = m_r \times (h_2 - h_1)$

Entropy, $s_1 = s_2 \quad s_2 = s_3 + c_p \ln (T_2/T_3)$
$h_2 = h_3 + c_p (T_2 - T_3)$

Heat output in condenser, $Q_{cond} = m_r \times (h_2 - h_4)$
Heating COP = $Q_{cond}/W_{comp} = [(h_2 - h_4)/(h_2 - h_1)]$

Where 'h' represents enthalpy (kJ/kg) of a thermodynamic state, m_r represents the mass flow rate (kg/sec) of refrigerant flowing in the circuit, 's' represents specific entropy (kJ/kg-K) of a state and 'T' represents temperature (K).

Following assumptions are made when calculating the performance of the thermodynamic cycle:

(a) At the inlet of expansion valve, the refrigerant is saturated liquid.
(b) The refrigerant is fully saturated vapour at the inlet of compressor and compression process is isentropic.
(c) There is no pressure drop in the tubes and pipes.
(d) The value of m_r is taken 1 kg/s throughout the calculation.

III. Refrigerants

The efficiency of a thermodynamic cycle depends mainly on its operating temperatures. However, important practical issues such as the system design, size, initial and operating costs, safety, reliability, and serviceability etc. depend very much on the type of refrigerant used for a given application. Due to several environmental impacts such as ozone layer depletion and global warming and their relation to the various refrigerants used, the selection of suitable refrigerant has become one of the most important issues in recent times. Replacement of an existing refrigerant by a completely new refrigerant, for whatever reason, is an expensive proposition as it may call for several changes in the design and manufacturing of refrigeration systems. Hence it is very important to understand the issues related to the selection and use of refrigerants.

Selection of refrigerant for a particular application is based on the following requirements:

(a) Thermodynamic and thermo-physical properties such as suction pressure, discharge pressure, pressure ratio and latent heat of vaporization etc.
(b) Environmental and safety properties such as low value of ozone depletion potential (ODP), global warming potential (GWP), toxicity and flammability.
(c) Economics, the refrigerant used should preferably be inexpensive and easily available.
Various refrigerants and their properties are shown in table. 1.

Table. 1: Properties of refrigerants

Refrigerant	**Mol. Mass** (kg/kmol)	**Freezing Point** (°C)	**Normal Boiling Point at 1 Atm** (°C)	**Critical Temperature** (°C)	**Critical Pressure** (kPa, abs)
R12	120.91	-157.1	-29.75	112.0	4,136
R22	86.48	-160	-40.76	96.0	4,974
R134a	102.03	-103.3	-26.07	101.1	4,059
R404A	97.60	-	-46.6	72.1	3,735
R407C	86.20	-	-43.8	86.1	4,634
R410A	72.59	-	-51.6	70.2	4,770
R717	17.03	-77.7	-33.3	132.5	11,330

IV. Refrigerants

The thermodynamic efficiency of a refrigeration system depends mainly on its operating temperatures. However, important practical issues such as the system design, size, initial and operating costs, safety, reliability, and serviceability etc. depend very much on the type of refrigerant selected for a given application.

Replacement of an existing refrigerant by a completely new refrigerant, for whatever reason, is an expensive proposition as it may call for several changes in the design and manufacturing of refrigeration systems. Hence it is very important to understand the issues related to the selection and use of refrigerants.

To analyze the thermal performance of heat pump, seven different refrigerants are evaluated to find the best candidate for the vapour compression cycle; R717, R12, R22, R134a, R407C, R410A, R404A. In the present study R717 (fig. 3), the best candidate for the cycle is selected which provides the highest coefficient of performance between two given temperature limits of 10°C and 45°C.

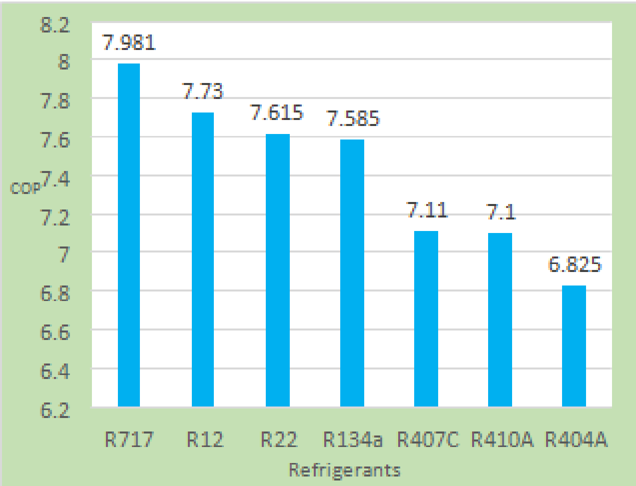

Fig. 3: COP vs. refrigerants

Variation of COP with evaporator temperature, having fix condenser temperature of 60°C, is shown in fig. 4.

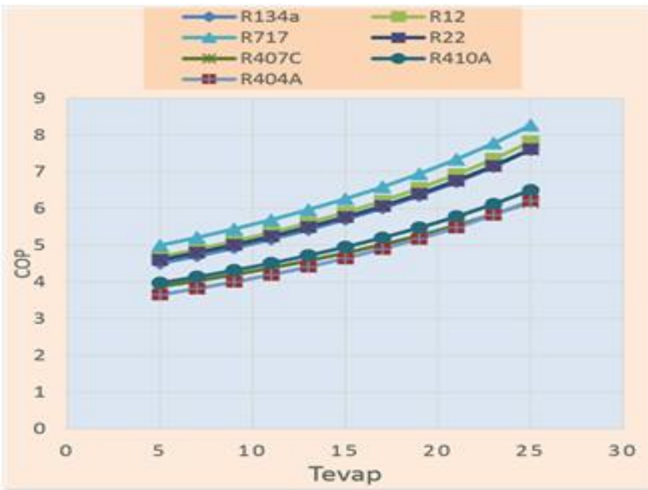

Fig. 4: COP vs. evaporator temperature

Variation of COP with evaporator temperature is shown in fig. 5 using R717.

Also it is analyzed the extent of degradation of thermal performance due to the use of various refrigerants and identified the refrigerants that is best suited. From fig. 3. Replacement of R717 by R12 degrades the system performance by 3.14 %, if system is operating between the temperature limits of 10°C and 45°C, while replacement of R717 by R134a degrades the system by 4.96 %. Therefore refrigerants should be selected appropriately according to the operating conditions.

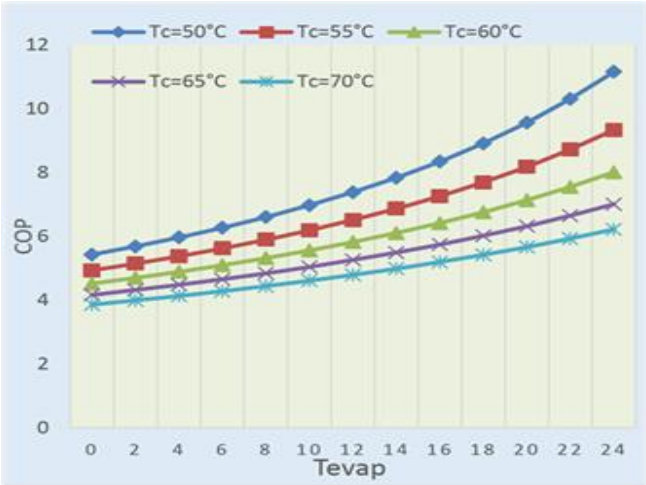

Fig. 5: COP vs. evaporator temperature with different condenser temperature.

V. Conclusions

The present calculation shows that use of heat pump is justifiable for every individual facility, where the heat of low temperature source is extracted. The COP of the pump is found 4.17 at a condensation temperature of 76°C when using evaporator temperature of 10°C, using R717 as refrigerant. The coefficient of performance of the vapour compression heat pump typically varies from 3.5 to 4.5.

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