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Improving the Performance of Vapour Compression Refrigeration System by using Useful Superheating

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Abstract

Vapour compression refrigeration systems are widely used refrigeration method in industries as well as domestic applications from a long times. There were many improvements made to get higher performance of such systems. In this paper we discuss about improvement way of such systems by useful superheating of refrigerant before entering to the compressor. The analysis shows that how could increase the performance of vapour compression systems by useful superheating occurring in evaporator to producing extra refrigerating effect. This might be possible if the heat absorbed for superheating purpose produce the additional cooling effect. The superheating of refrigerant also provide the safe working condition of compressor. The working conditions are: condenser and evaporator pressures of 7.2 bar and 2.2 bar respectively, R-12 used as a refrigerant and superheating of 10 ℃. The analytical comparison shows the way to give the preference to such superheating under the working conditions mention above.

Keywords : Improved vapour compression system; useful superheating; vapour compression cycle; superheating.

Introduction

The refrigeration means a continued extraction of heat from a body whose temperature is already below temperature of its surroundings. In a refrigerator, heat is virtually pumped from a lower temperature to a higher temperature. According to Second Law of Thermodynamics, this process can only be performed with the addition of some external work. It is thus obvious that supply of power is regularly required to drive a refrigerator. Now a days most of the domestic refrigeration appliances working on vapour compression refrigeration cycle. As the name implies, these systems belong to the general class of vapour cycles, wherein the working fluid (refrigerant) undergoes phase change at least during one process. In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. The input to the system is in the form of mechanical energy required to run the compressor. Hence these systems are also called as mechanical refrigeration systems.[1] Vapour compression refrigeration systems are available to suit almost all applications with the refrigeration capacities ranging from few Watts to few megawatts. A wide variety of refrigerants can be used in these systems to suit different applications, capacities etc. The actual vapour compression cycle is based on Evans-Perkins cycle, which is also called as reverse Rankin cycle. [2]

During the operation time, When the compression inlet condition is saturated (point 1), then the exit condition will be in the 2-phase region, as a result it is not necessary to superheat the refrigerant. However, these refrigerants experience significant throttling losses. Since the compressor exit condition of Type 3 refrigerants may fall in the two-phase region, there is a danger of wet compression leading to compressor damage. Hence for these refrigerants, the compressor inlet condition is chosen such that the exit condition does not fall in the two-phase region. This implies that the refrigerant at the inlet to the compressor should be superheated, the extent of which depends on the refrigerant. The superheating of refrigerant prevents the damage of compressor vanes, this superheating of refrigerant may give the additional cooling effect on account of improving co-efficient of performance if the superheating take place inside the evaporator during cycle operation under given working conditions. [3,4]

Cycle Description

Vapour compression refrigeration cycles have two advantages. First, a large amount of thermal energy is required to change a liquid to a vapour, and therefore a lot of heat can be removed from the air-conditioned space. Second, the isothermal nature of the vaporization allows extraction of heat without raising the temperature of the working fluid to the temperature of whatever is being cooled. [5] This means that the heat transfer rate remains high, because the closer the working fluid temperature approaches that of the surroundings, the lower the rate of heat transfer.

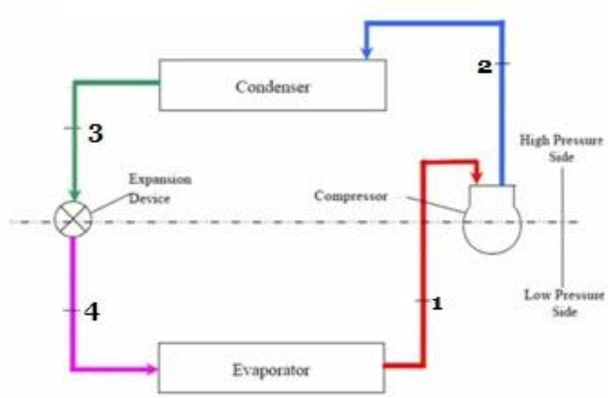


Figure: Schematic representation of the vapour compression refrigeration cycle.

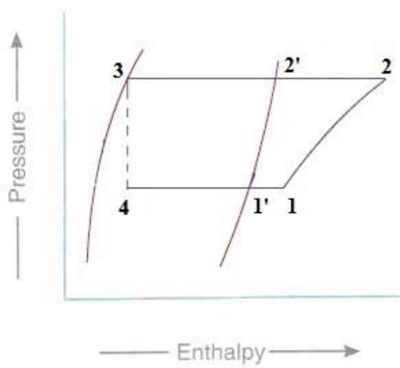


Figure: Vapour compression cycle on p-h curve.

The refrigeration cycle is shown in Figure below and can be broken down into the following stages:

1 – 2 The superheated vapour

Enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

2 – 3 The high pressure superheated gas

Passes from the compressor into the condenser. The initial part of the cooling process (2-2') superheats the gas before it is then turned back into liquid (2'-3). The cooling for this process is usually achieved by using air or water.

3 - 4 The high-pressure sub-cooled liquid

Passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

4 – 1 Low-pressure liquid refrigerant

In the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

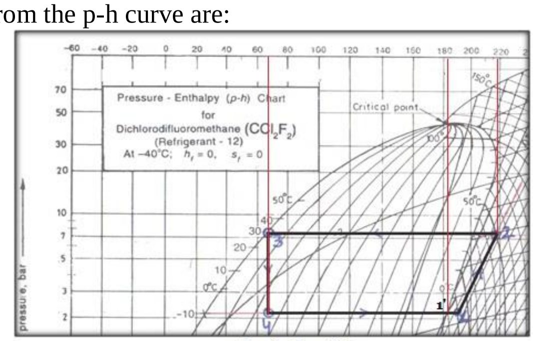
This was the general description of simple vapour compression refrigeration system. Now focus on the object of the paper i.e comparison of useful and un-useful superheating of the refrigerant, leaving the evaporator. For this purpose analysis made under given conditions:

Evaporator pressure = 2.2 bar; Condenser pressure = 7.2 bar ; Degree of superheat (before entering the compressor) = 10℃; Refrigerant used = R-12 (Dichlorodifluoromethane) [6,7]

Un-useful Superheating

Let us consider a refrigeration equipment placed in a room which running on vapour compression cycle. Note that some of the heat energy, available in the room, is also raising the temperature of the refrigerant above the Saturation Temperature within the evaporator, known as superheating. This Superheating of the refrigerant is essential to protect the compressor from taking in liquid refrigerant, which would otherwise result in mechanical damage and failure. [8] However, as superheating the vapour does not absorb much heat menergy from the conditioned space and also makes poor use of the evaporator. The term un-useful superheating meant that there is no benefit of superheating of refrigerant during operation which results lower co-efficient of performance of system. This happened when superheating take place outside the evaporator. In large capacity vapour compression refrigeration plants such type of superheating occurs generally.

The cycle under the conditions mentioned above could be represented on pressure- enthalpy curve as given in figure. The various data obtained from the p-h curve are:



Enthalpy (h)

$h_1 = 190$ kJ/kg;
$h_{1'} = 182$ kJ/kg;
$h_2 = 218$ kJ/kg;
$h_3 = h_4 = 65$ kJ/kg

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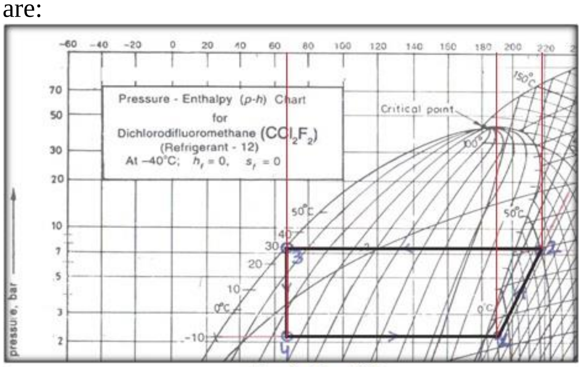
Compressor work (W_C) = h_2 - h_1 = 28 kJ/kg
Refrigerating effect (R_E) = $h_{1'}$ – h_4 = 117 kJ/kg
$\therefore$ COP = $\frac{R_E}{W_C} = \frac{117}{28}$ = **4.17**

Useful Superheating

On other hand, generally evaporator working as a heat exchanger which absorb latent heat from surrounding**.** This Superheating of the refrigerant is essential to protect the compressor from taking in liquid refrigerant, which would otherwise result in mechanical damage and failure. However, as superheating the vapour does not absorb much heat energy from the conditioned space and also makes poor use of the evaporator.The term useful superheating meant that there is additional benefit of superheating of refrigerant during operation which results higher co-efficient of performance of system. This happened when superheating take place inside the evaporator. In many domestic and small capacity vapour compression refrigeration appliances such type of superheating occurs generally. Due to superheating of vapour before entering the compressor results safe running operation of compressor.

The cycle under the conditions mentioned above could be represented on pressure- enthalpy curve as given in figure. The various data obtained from the p-h curve are:



Enthalpy (h)

h_1 = 190 kJ/kg;
$h_{1'}$ = 182 kJ/kg;
h_2 = 218 kJ/kg;
h_3 = h_4 = 65 kJ/kg

Compressor work (W_C) = h_2 - h_1 = 28 kJ/kg
Refrigerating effect (R_E) = h_1 – h_4 = 123 kJ/kg
$\therefore$ COP = $\frac{R_E}{W_C} = \frac{123}{28}$ = **4.5**

Result and Discussion

As per calculation mentioned above, it could be seen that due to un-useful superheating of refrigerant gives the COP as 4.17 whereas in case of useful superheating of refrigerant as 4.5 under the operation conditions i.e condenser and evaporator pressures are 7.2 bar and 2.2 bar respectively along with superheating of refrigerant (Dichlorodifluoromethane) by 10℃ before entering the compressor. The other advantage of superheating is safe running condition of the compressor because any liquid droplet of refrigerant enter to the compressor vanes may cause the damage of compressor vanes.

Conclusion

In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. COP of Vapour Compression Cycle is increased by lowering the power consumption /work input or increasing the refrigerating effect. The input to the system is in the form of mechanical energy required to run the compressor. For safety point of view it is required that the refrigerant enter to the compressor maintained in pure gaseous state, for that purpose the superheating is necessary. Here the comparison were made between useful and un-useful superheating. The result shows that, (at condenser and evaporator pressures are 7.2 and 2.2 bar, 10℃ of superheating and R-12 as refrigerant) useful superheating gave the cooling effect of 123 kJ/kg of refrigerant whereas in case of un-useful superheating it was 117 kJ/kg. Hence obtained higher value of COP (i.e 4.5) as compare to un-useful superheating (i.e 4.1) without any additional compressor work.

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