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Design And Development Of Cascade Refrigeration System

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Abstract - *This paper deals with the study of cascade refrigeration system. Cascade refrigeration system is the combination of two refrigeration cycle for maximum refrigeration effect can be obtained. In this system series of single stage vapor compression system are thermally coupled with the evaporator of HTC and condenser of LTC, this combination is known as cascade. This system is developed to achieve temperature up to -20°C for the applications like cold storage in malls and stores and in blood banks. The working fluid in system are R22 (LTC) and R134a(HTC), these particular refrigerant s are used due there suitable difference in boiling point for the desirable outcome from the system. These fluids are harmless to environment and GWP and ODP is negligible and do not violate the kyoto protocol. COP , work done , Refrigeration effect are the parameters studied from the system*

Key Words: Cascade refrigeration system, low temperature circuit (LTC), high temperature circuit(HTC), coefficient of performance (COP), global warming potential (GWP), ozone depletion potential (ODP).

1. INTRODUCTION

Cascade refrigeration system is the combination of two single stage vapour compression system together, condenser of LTC and evaporator of HTC is cascaded and forms the heat exchanger where evaporator cascade absorbs the heat from the condenser cascade which further leads to better refrigeration effect . Many industrial applications like food storage, liquefaction of petroleum vapour and natural gases precipitation of special alloys, etc. requires low temperature refrigeration in the temperature range from -30°C to -100°C[1].in simple vapour compression system it is difficult to obtain temperature below -30°C due to poor volumetric efficiency due to high compression ratio. In cascade refrigeration system two independent refrigerants can be used selected on the basis of their suitable important properties like boiling point, critical pressure, temperature and freezing point this enhances the working of the system and increases the refrigeration effect. Refrigerants like ammonia, carbon dioxide and other natural refrigerant have drawn increased attention as working fluid to protect the environment[2]. Environment safety is a prime concern in today's scenario where GWP and ODP is increasing due to release of harmful CFC's so selection of the refrigerant is also important criteria and considering the GWP and ODP

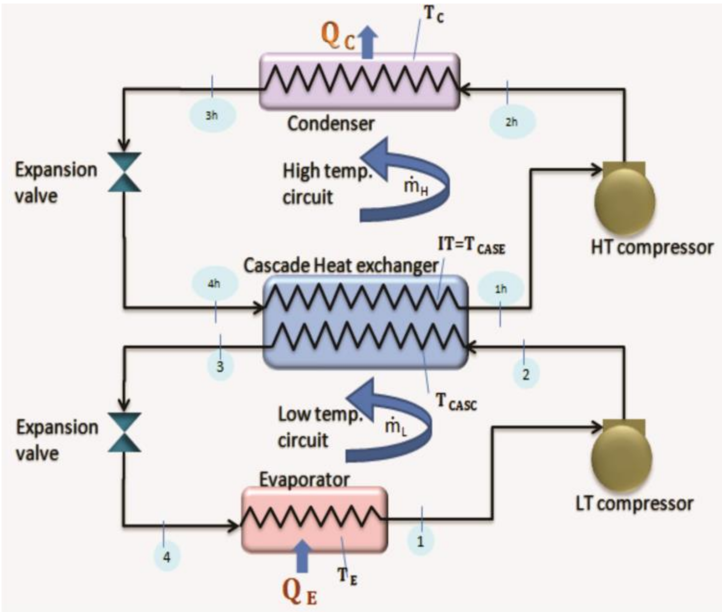

Fig -1 : line diagram of cascade refrigeration system

1.1 Impact of refrigerant on compressor

Selection of refrigerant plays an important role in the development and efficiency of the system. In today's scenario larger no. of different and versatile refrigerant are available. While selection of the refrigerant few important properties are considered such as boiling point , freezing point , molecular mass, critical temperature, critical pressure, critical volume etc. Now a day's industries are focusing towards natural refrigerant due to their properties like less GWP and ODP, odourless, non toxic so the refrigerants like CO_2 (R744) , NH_3 (R717) are highly considered but, for the compression of the refrigerant CO_2 (R744) requires high pressure up to 10Mpa and the temperature rating point leads to super critical pressure as the temperature increases pressure also increases due to which specific volume of the compressor also increases thus reducing the volumetric efficiency of the compressor and it is obvious that reduction of mass inside the compression chamber due to the temperature increase which leads to low process pressure[3] . On the other hand refrigerants like R22 and R134a have low critical pressure(722Kpa and 590Kpa respectively) as compared to CO_2 and NH_3 so this help built a compact system and also increases the efficiency of compressor.

2. System Description

Line diagram of the two stage cascade refrigeration system using two different refrigerant is shown in the fig 1. and fig 2. the system consist of components like compressor, evaporator, condenser, cascade condenser, cascade evaporator, expansion valve etc. following are the main components of the system which is a closed system. the system consist of two cycle low temperature cycle and high temperature cycle and refrigerants are accordingly selected of the respective cycle's. Refrigeration effect is achieved on the low temperature side at the evaporator

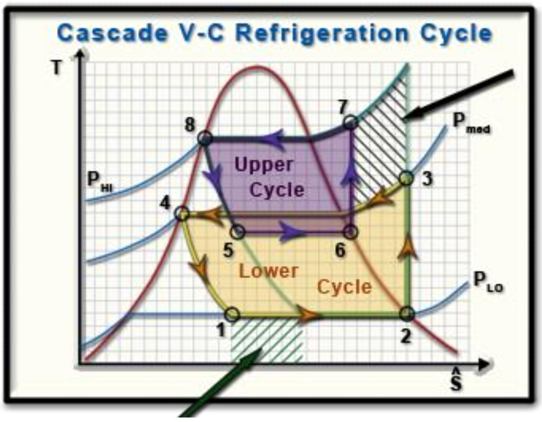

Fig-2: T-S diagram of cascade refrigeration system

In the particular system R22 is used as low side refrigerant and R134a is used as high side refrigerant

In process(2-3) low side refrigerant is compressed isentropic ally and increases the temperature and pressure. This refrigerant is then passed through the cascade condenser where the refrigerant heat is exchanged to the high side cascade evaporator this reduces the temperature and pressure remains constant. Process(3-4) low temperature constant pressure refrigerant is further process (4-1) passed through a expansion valve where it reduces the pressure as well as the temperature and then it is passed through evaporator where refrigeration effect is to be produced process(4-1) all above processes were for low temperature cycle. Higher stage refrigerant R134a coming from the evaporator is compressed isentropic ally is process (6-7)and then passed to a condenser were the temperature reduces and pressure remains constant process(7-8). Process (8-5) refrigerant is passed through a expansion valve where pressure reduces as well as temperature. Further it is passed though cascade evaporator where it absorbs the heat from the cascade condenser and thus liquid R134a gets evaporated and ready to be compressed Process(6-7).

2.1 Thermodynamic Analysis according to the observation taken from refrigeration cycle for HTC and LTC on p-h chart given below in Fig 3 and 4

Following assumptions are considered for the thermodynamic analysis's of two stage cascade refrigeration system

- Adiabatic and Irreversible compression with an isentropic efficiency of 0.8 for both high and low temperature compressor
- Negligible heat and pressure drop in the piping or system components
- heat transfer process in heat exchanger is isobaric
- change in kinetic and potential energy are negligible

Table -1: Thermo physical properties of working fluid and natural refrigerant carbon dioxide and ammonia

Properties of refrigerant				
Properties	R22	R134a	R744	R717
Molecular weight Kg/kmol	86.47	102.3	44	17
Boiling point	-40.81	-15	-78	-33.34
Critical temperature	205	214	31.41	132.4
Critical pressure	7.22	5.90	73.80	113.33
ODP	0	0	0	0
GWP	1700	1300	1	0

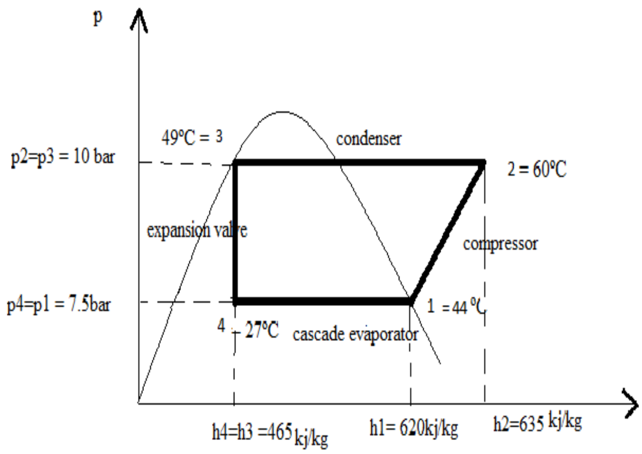

Fig-3: P-H chart of high temperature side(R134a)

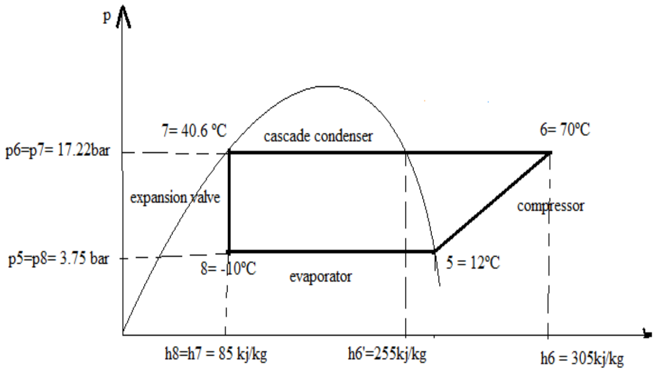

Fig-4 : P-H cycle of low temperature side(R22)

Thermo physical properties of the refrigerant are used in this paper are given in the Table 1. thermodynamic analysis in this paper are carried out using steady flow equation and mass balance equation.

Heat transfer rate is given by:

$Q = m\, cp\, \Delta T$ .... (1)

mass flow rate at LTC is given as:

$m_1 = 210Q/ (h_5 - h_8)$ ....(a)

Mass flow rate at HTC by balancing the heat of both the system heat absorbed at the high temperature cascade should be equal to heat absorbed at low temperature system thus the equation is given as :

$m_2\ (h_1 - h_4) = m_1\ (h_6 - h_7)$ ....(b)

Compressor work done for low temperature circuit is given as:

$W_L = m_1\ (h_6 - h_5)$ ....(2)

Compressor work done for high temperature circuit is given by :

$W_H = m_2\ (h_2 - h_1)$ ....(3)

Total work Done is given as:

$W_T = W_H + W_L$ ....(4)

Refrigeration effect produced by the system is given as:

RE = 210Q ....(5)

Coefficient of performance is calculated using :

$COP = RE / W_T$ ....(6)

With the help of above equations the thermodynamic state points and properties like work done, refrigeration effect, pressure, temperature are calculated . COP of the system is calculated using the equation (6) and results are discussed below

3. RESULT & DISCUSSION

From above equation and the observation from the working of the system few important properties are calculated and there result are mentioned below

1. LTC evaporating temperature: -20°C
2. LTC condensing temperature : 39°C
3. HTC condensing temperature : 44°C
4. Effectiveness of cascade heat exchanger: 0.40
5. $COP_{theoretical}$: 2.61
6. COP_{actual} : 0.71

As the effectiveness calculated is very low it can be improved by subjecting one of the fluid to maximum temperature change.

4. CONCLUSION

The simulation of R 134a- R22 cascade refrigeration system is carried out. Analysis of the system is carried out by using steady flow energy equation and mass balance equation and the result from the following equation states that COP of the system increases with the increasing LTC evaporator temperature while decreases with increase in HTC evaporator temperature. components used in the system were used and cheap to built a system which can be affordable for low scale industrial application total cost estimation of the system was ₹27000 only.
Particular system is developed to reduce the work done and attain maximum refrigeration effect in minimum work done by the system.

ACKNOWLEDGEMENT

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