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A Review on Cascade Refrigeration System by using R134a and HC

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***Abstract*: 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 -40 to -80°C for the applications like cold storage in malls and stores and in blood banks. The working fluid in system are HC (HTC) and R134a (LTC), this particular refrigerant is used due their 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. The concept is that the cooling produced in first cycle evaporator is used to cool the condenser of second cycle, which reduces the cooling capacity in condenser and enables to produce very low temperature for various cold storage applications**

***Keywords*: 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

Many industrial applications require low temperature refrigeration such as quick freezing biomedical preservations, manufacturing of dry ice, liquefaction of petroleum vapors, pharmaceutical reactions etc. where evaporating temperature requires between -40ºC to- 80ºC. Condensing temperature is governed by temperature of cooling tower water which is about 35 ºC. Thus, system has to work for wide range of temperature. Single stage vapor compression system is not feasible for such application and its performance decreases below -35 ºC. Multistage or compound systems can be useful but no refrigerants available to work efficiently for high temperature lift. Also, it will be difficult to balance the oil level in compressor because of large difference in suction pressures of low stage and higher stage compressors. Cascade refrigeration system has two different stages which permits appropriate selection refrigerants to maximise system performance. Synthetic refrigerants prominently used in till now due to their excellent thermodynamic properties but owing to higher ODP (Ozone Depletion Potential), GWP (Global worming Potential) they are contributor to ozone depletion and global warming. Cascade refrigeration system is the combination of two single stage vapor 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 vapor and natural gases precipitation of special alloys, etc. requires low temperature refrigeration in the temperature range from -30°C to -100°C. In simple vapor 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. 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.

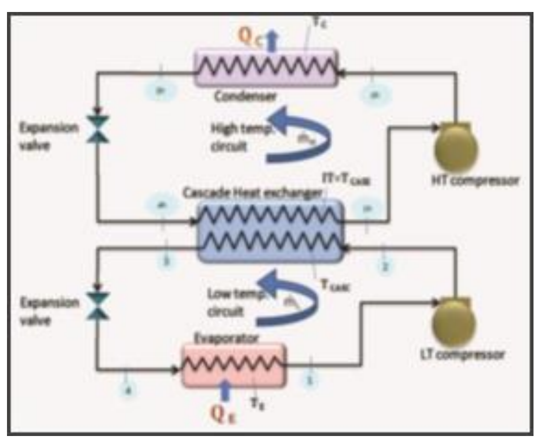

Fig. 1. Cascade refrigeration system

2. Literature survey

Ashutosh Mate et..al [1] proposed that, the study of cascade refrigeration system. Cascade refrigeration system is the

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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), this particular refrigerant is used due their 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.

R. Hanuma Naik et..al [2] proposed that, As the technology is developing in the field of refrigeration and air conditioning, remarkable comfort and saving are achieved. Maintaining the required low temperature and the cost is low. The main aim is to improve & extend the self-life. The low temperature is obtained mostly by vapor compression refrigeration cycle, but it has its own limitations in producing low temperature. Hence for low temperature production multiple compression binary vapor cycle is used. The concept is that the cooling produced in first cycle evaporator is used to cool the condenser of second cycle, which reduces the cooling capacity in condenser and enables to produce very low temperature for various cold storage applications. Further the low temperature side cooling is given to a Phase Change Material (PCM) and the cooling is stored in PCM, this cooling is sustained up to 20 hours without operation of cycle, thus maintaining the low temperature of the products even without continuous power supply. In this project a binary vapour cycle is designed to produce a temperature of -200C.

Manoj Dixit et..al[3] proposed that, an Absorption-Compression Cascade Refrigeration, comprising of a VCR system in low temperature stage and a VAR system at the high temperature stage, is analyzed. CO2, NH3 and R134a have been considered as refrigerants in the compression stage and the H2O-LiBr refrigerant absorbent pair in the absorption stage. The analysis has been realized by means of a mathematical model of the refrigeration system. The study presents the results obtained regarding the performance of the refrigeration system based on energy and exergy analysis. The comparative study helps to find out the best refrigerant and appropriate operation parameters. It is found in the study that cascade condenser, compressor and refrigerant throttle valve are the major source of exergy destruction

Messineo et..al[4] proposed that, In this study is presented a thermodynamic analysis of a cascade refrigeration system using as refrigerant carbon dioxide in low-temperature circuit and ammonia in high-temperature circuit. The operating parameters considered in this paper include condensing, evaporating, superheating and subcooling temperatures in the ammonia (R717) high temperature circuit and in the carbon dioxide (R744) low-temperature circuit. Diagrams of COP versus operating parameters have been obtained. In addition, values for R744-R717 cascade refrigeration system are compared with the values obtained for a partial injection two-stage refrigeration system using the synthetic refrigerant R404A, a nearly azeotropic blend, specially used for commercial refrigeration. Results show that a carbon dioxide-ammonia cascade refrigeration system is an interesting alternative to R404A two-stage refrigeration system for low evaporating temperatures (–30°C, –50°C) in commercial refrigeration for energy, security and environmental reasons.

3. System description

The two stage cascade refrigeration system using two different refrigerants is shown in the following figure. the system consists of components like compressor, evaporator, condenser, cascade condenser, cascade evaporator, expansion valve etc. 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.

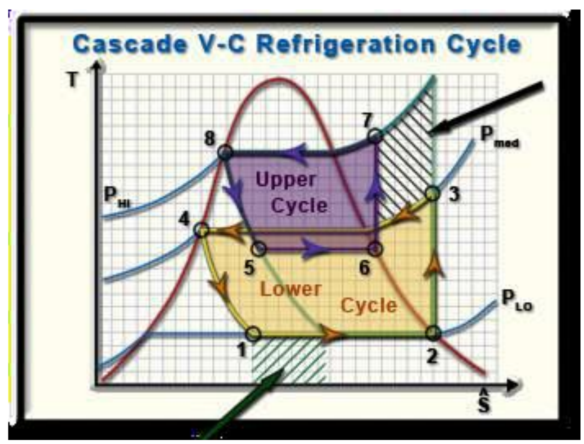

Fig. 2. T-S diagram of cascade refrigeration system

In the particular system HC 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).

4. Heat load calculations

At evaporator:

Heat load is calculated as:

$$Q = \frac{m.Cp.\Delta T}{t}$$

Where, Q – Heat load capacity.
m – Mass of brine solution.
C_p – Specific heat of brine solution at 40
ΔT – Temperature difference.
t – Time required to achieve -30 ºC.

Consider the mass of brine solution

m = 2 litres = 1.70 kg

Specific heat of brine C_p = 3.428 KJ/kg ºC

Temperature of brine at room temperature T_i = 25 ºC

Temperature of brine after freeze T_O = -30 ºC

Time required to freeze t = 1800 sec

By using above formula heat load is calculated as,

$$Q = \frac{1.70*3.428*55}{1800} = 0.1780 \text{ KW}$$

We know the conversion factor between KW and TR is as follows: \

1 TR = 3.517 KW

So calculating heat load in terms of TR

0.1780 KW = 0.05061 TR

The total heat load on the system is 0.05061 TR. So during selection of compressor we have to select the compressor of load capacity similar to 0.0561TR

5. Thermodynamic analysis of cascade refrigeration system

Table 1
Thermo physical properties of working fluid and natural refrigerant R134a and HC

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

The thermodynamic analysis of the two-stage cascade refrigeration system was performed based on the following general assumptions:

- Adiabatic compression with an isentropic efficiency of 0.78 for both high- and low-temperature compressors,
- Negligible pressure and heat losses/gains in the pipe networks or system components,
- Isenthalpic expansion of refrigerants in expansion valves, and
- Negligible changes in kinetic and potential energy.

Thermo physical properties of working fluid and natural refrigerant R134a and HC.

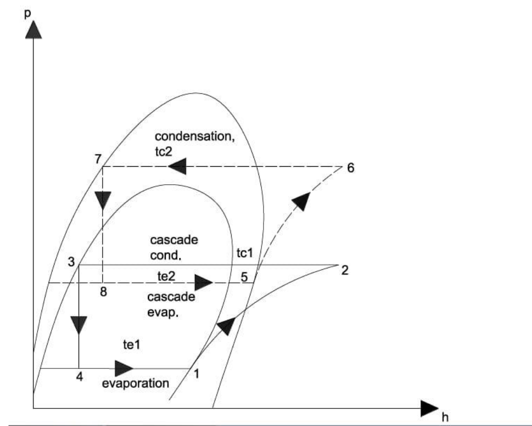

Fig. 3. P-h dig. for cascade refrigeration system

The following sequence of equations can be applied for the analysis.

The capacity of the evaporator is defined by:

$$\dot{Q}_E = \dot{m}_L(h_1-h_4) \quad (1)$$

Compressor power consumption for high-temperature circuit is given by:

$$\dot{W}_H = \dot{m}_H(h_2-h_1) \quad (2)$$

whereas for low-temperature circuit, it is given by:

$$\dot{W}_L = \dot{m}_L(h_2-h_1) \quad (3)$$

The rate of heat transfer in the cascade heat exchanger is determined from:

$$\dot{Q}_{CAS} = \dot{m}_L(h_2-h_3) = \dot{m}_H(h_1-h_4) \quad (4)$$

The mass flow ratio can be derived from Eq. (4):

$$\dot{m}_H/\dot{m}_L = (h_2-h_3)/(h_1-h_4) \quad (5)$$

The rate of heat rejection by the air-cooled condenser is given by:

$$\dot{Q}_H = \dot{m}_H(h_2-h_3) \quad (6)$$

The overall COP of the system is determined by:

$$COP = \frac{Q_E}{\dot{W}H + \dot{W}L} \quad (7)$$

6. Component selection and specification

A. Compressor

Compressor is the heart of refrigeration system. It sucks the vapor of refrigerant from evaporator at its low pressure, compresses it to high pressure and discharged to condenser. There are two type of compressor 1/8 HP compressor is easily available in market as standard size having heat load capacity of 0.02650 TR. But there are two compressors in the system so total heat load should be 0.053 TR. As we see total calculated load on system is nearly same as that of the total heat load capacity of compressor. Hence we are selecting 1/8 HP compressor.

B. Condenser coils

Condenser is usually made of copper tubing`s. High temperature and high pressure refrigerant vapors coming from compressor discharge are condensed in a condenser. This high pressure high temperature is then passed to the receiver. An air cooled condenser is one in is the removal of heat if done by air. It consists of steel or copper tubing through which the refrigerant flows air may be steel or force depending upon the rate of cooling design. For higher cooling rate fan is used to circulate air over condenser coil. Through the air circulated by fan the rate of cooling is achieved is less than that in water cooled condenser.

Specs: length=20 feet diameter=3/16m.

C. *Evaporator coils*

An evaporator is a device in a process used to turn the liquid form of a chemical substance such as water into its gaseous-form/vapor. The liquid is evaporated, or vaporized, into a gas form of the targeted substance in that process. A different kind of evaporator can be used for heating and possibly boiling a product containing a liquid to cause the liquid to evaporate from the product.

Specs: Diameter=6.38mm

D. *Capillary tubes*

When the refrigerant leaves the condenser and enters the capillary tube its pressure drops down suddenly due to very small diameter of the capillary. In capillary the fall in pressure of the refrigerant takes place not due to the orifice but due to the small opening of the capillary. The decrease in pressure of the refrigerant through the capillary depends on the diameter of the capillary and the length of the capillary. Smaller is the diameter and more is the length of the capillary more is the drop in pressure of the refrigerant as it passes through it.

Specs : Diameter=0.031 inch Length=12 feet .

E. *Expected outcomes*

- The COP of the system will be increases with the application of R134a and HC.
- Low power consumption system will be expected.

7. Conclusion

This paper presented a Review on Cascade Refrigeration System by using R134a and HC.

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