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Two Stage Cascade Vapour Compression Refrigeration System

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ABSTRACT

The Cascade Refrigeration System workswith the basic Principles that are used to create the refrigerating effect. A cascade system consists of two or three separate simple vapour compression cycles operating in conjunction with each other at different temperature levels. The connecting point is a heat exchanger between the stages and is known as cascacde condenser. This interstate heat exchanger is the condenser for the first stage and the evaporator for the second stage. Beginning with the low pressure cycle, the vapor from the evaporator is compressed in the first stage compressor and goes to the interstate heat exchanger (Cascade condenser) where it gives up its heat to the second evaporator coil. The condensed liquid then flows to the first stage expansion valve and the evaporator, competing the low-pressure cycle. The vapor which is generated in the coil in the heat exchanger, due to the heat it had absorbed, is compressed in the second, its heat going to the cooling chamber. Each stage is an independent single evapour cycle, and for this reason has some advantages over the compound compressors. There is some loss in the cascade system because a temperature difference must exist in the heat exchanger in order that the heat from the first stage will flow into the second stage. At the present work, “R-404a” is used in in the low stage and “R-134a” in the high stage.

KEYWORDS: Cascade Refrigeration, Vapour Compression Refrigeration System, Cascade Condenser, Design and Fabrication.

1. INTRODUCTION

Refrigeration is a process of removing heat from one location to another in controlled conditions. The work of heat transport is traditionally driven by mechanical work, but can also be driven by heat, magnetism, electricity, laser, or other means .Vapor-Compression Refrigeration or vapor-compression refrigeration system (VCRS) in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators. It is not possible to achieve very low temperatures below -40°C by using simple VCRS. In this project we are cascading two VCRS thermally for achieving low temperatures and the system is known as Cascade Refrigeration System.

Cascade system is similar to the binary vapor cycle used for the power plants. In the binary vapor cycle, a condenser for mercury works as a boiler for water. Similarly, in the cascade system the condenser

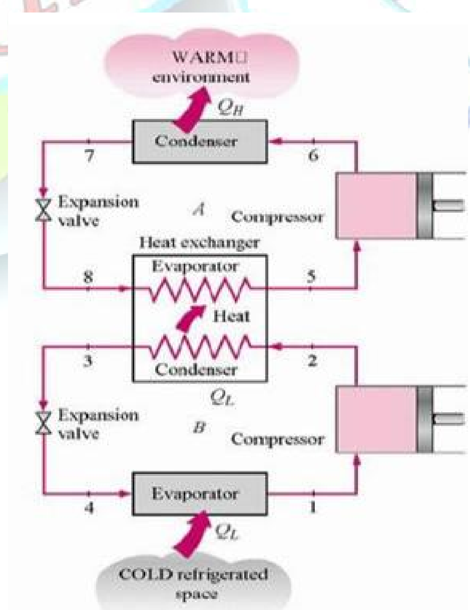

Fig 1 Cascade Refrigeration System

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Nomenclature

VCRS	Vapour Compression Refrigeration System	P_{CH}	Condenser pressure at HT side
HT	High Temperature	P_{CL}	Condenser pressure at LT side
LT	Low Temperature	P_{EH}	Evaporator pressure at HT side
COP	Coefficient Of Performance	P_{EL}	Evaporator pressure at LT side

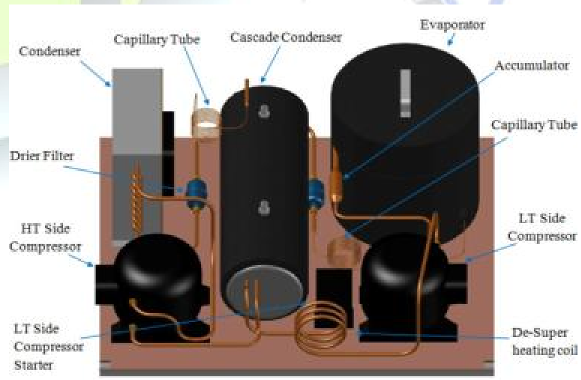
for low temperature cycle works as an evaporator for the high temperature cycle.

A two-stage cascade refrigeration system uses two types of compressor devices, they run individually with different refrigerants, connected among them so that evaporator of first cycle is used for the cooling of second cycle's condenser (i.e. the evaporator of the first unit cools the condenser of the second unit). The cascade refrigeration cycle is a combination of two vapor compression cycles which utilizes two different refrigerants.

The primary refrigerant flows from low temperature circuit evaporator to low stage compressor and condensed in cascade condenser which also acts as evaporator for high temperature circuit. The heat rejected from condenser of low temperature circuit is extracted by evaporator of high temperature circuit containing secondary refrigerant then, this secondary refrigerant gets compressed in high stage compressor and finally condensed to outer atmosphere. The desired refrigerating effect is occurred from evaporator of low temperature circuit. Each stage is an independent single cycle, and for this reason has some advantages over the compound compressors. There is some loss in the cascade system because a temperature difference must exist in the heat exchanger in order that the heat from the first stage will flow into the second stage. The temperature difference in cascade condenser is an important design parameter that decides the COP of the entire refrigeration system.

2. CONSTRUCTION AND ARRANGEMENT

All the components of cascade system are mounted on the Medium Density Fiber Core Hardwood Plywood (MDF). The cascade system is divided in the three parts. These are as follows: High side, Intermediate stage and low stage. The cascade system consist of hermetically sealed compressors, fan forced type finned condenser unit, expansion device, cascade condenser, drier filter, accumulator and low-side evaporator. The refrigerant used on the high temperature side is R-134a, and the refrigerant used on the low temperature side is R-404a. On the high temperature side a hermetically sealed compressor, fan forced type finned condenser unit, drier filter, expansion device, and cascade condenser are connected to each other. On the low temperature side hermetically sealed compressor, cascade condenser, drier filter, expansion device, low temperature side evaporator, accumulator and cooling fan are connected with each other. separate pressure gauge are provided to measure the pressure at the compressor inlet and compressor outlets. Circuit breaker is used as a safety device form over load. Volt meter and ammeter are provided to measure the voltage and current input to the system. Digital temperature indicator displays temperature at various locations as per the selection viz. Temperature before and after compressor and before and after expansion.



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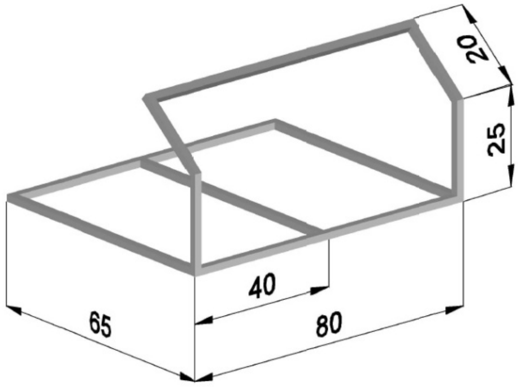

Fig 4 Assembly of Components and Frame

The components of cascade refrigeration system are arranged in a manner such that it will occupy only minimum space.

The components are arranged over an 800×650mm Medium Density Fiber Core Hardwood Plywood (MDF). MDF is made from fine wood dust mixed with a binder and heat-pressed into panels. It can carry large amount of load without any failure. Both the compressors are fixed on the MDF by using 4 nut and bolt. All other components are screwed on to the board. The MDF is screwed to ¾ ×¾" MS square pipe structure. The mid steel frame and its dimensions are shown in figure.

The steel frame also consists of a vertical frame work on its front portion; it is used for carrying the pressure gauges, thermometers and other control units for the system. Simple arc welding method is used for joining the MS pipes. [8] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

3. WORKING

Initially, when the compressor is started, the refrigerant (R134a) is compressed at high pressure, and then it enters into the fan forced type finned condenser, where the heat is dissipated through the fins of the condenser and the fan provided on the condenser unit will helps to draw fresh air from the atmosphere. Then it enters into the drier filter, and it goes into the expansion device, here the expansion device is used are the capillary tubes where it's expansion take place and pressure drops. Then it enters into the cascade condenser where it takes heat from the low temperature side refrigerant (R404a).

In the low temperature side system compressor discharges refrigerant at high pressure, then it enters into de-super heater where its heat gets absorbed by fan forced air, then it goes into cascade condenser (i.e. high temperature side evaporator) where its heat is rejected and it becomes in liquid from. The cascade condenser is a counter flow type heat exchanger in which cold and hot refrigerant are flow in opposite direction. The high temperature side evaporator will condense and sub cool the liquid refrigerant before entering the expansion device. After passing through drier filter, expansion device it goes into low temperature side evaporator where it absorbs heat from chamber, it converts into low pressure vapor state, and then it goes into the compressor through the accumulator. Accumulator is used to trap the liquid refrigerant from entering into the vapor compressor. It is connected in series with the compressor inlet line.

The p-h diagram of both the cycles are shown in p-h diagram. Different process are:

Process 1-2 & 5-6: isentropic compression
Process 2-3 & 6-7: condensation
Process 3-4 & 7-8: expansion
Process 4-1 & 8-5: evaporation

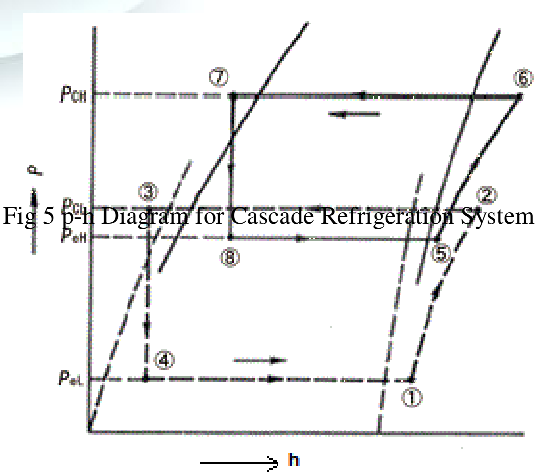

Fig 5 p-h Diagram for Cascade Refrigeration System

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4. SYSTEM SPECIFICATIONS

LOW TEMPERATURE SIDE

Compressor

Type : Reciprocating, Connecting Rod Type
Refrigerant used : R404a
Model : KCN418LAL
No of cylinders : 1
Capacity : 426W
Power : 385W
Rated current : 2A
Displacement at 50Hz : 1.57 m^3/hr
Bore/ Stroke : 2.5/1.8 mm
Net weight : 11.5 kg
Oil quantity : 0.38 lit

Expansion Device

Type : Capillary Tube
Diameter : 0.4 mm
Length : 8 feet

Evaporator

Type : Plate Type
Diameter : 5/16”
Length : 35 feet

LOW TEMPERATURE SIDE

Compressor

Type : Reciprocating, Connecting Rod Type
Refrigerant used : R134a
Model : KCN372LAG
No of cylinders : 1
Capacity : 176W
Power : 159W
Rated current : 1.34A

Expansion Device

Type : Capillary Tube
Diameter : 0.36 mm
Length : 6.5 feet

Condenser

Type : Forced Convection Air Cooled Condenser
Size : 9”×9”×2rows (length×height)
Copper tube diameter : 3/8”
Condenser fan Size : 120 X 120 X 25mm, 230V, 50Hz

Cascade Condenser

Type : Counter Flow Type HE
Diameter : 5/16 “
Length : 9m

5. EXPERIMENTATION

During experimentation the variation of evaporator temperature with respect to time are plotted. Temperature versus Time graph for no load and load condition are shown below.

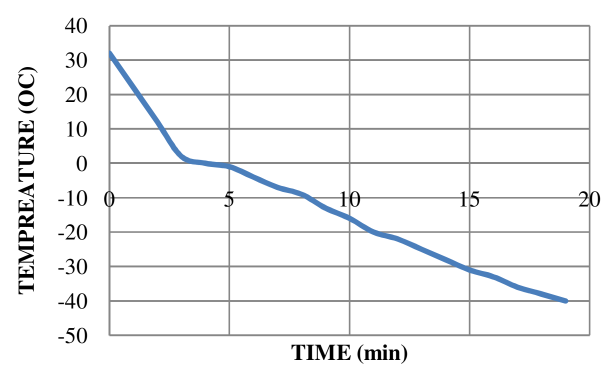

Fig 6 Evaporator with no load condition

The evaporator with no load graph is shown in figure. In this experimentation the evaporator contains only air and the graph shows that the temperature of air in the evaporator attains -40°C in 18 minutes.

The variation of temperature with time in the evaporator is almost linear from 32 to 0 °C. The temperature of air i the evaporator reach 0°C in 4 minutes and for the next one minute the variation of temperature become unvaried or varies only slightly. After 0°C the air

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temperature reduces linearly with time and achieves -40 °C within next 13 minutes.

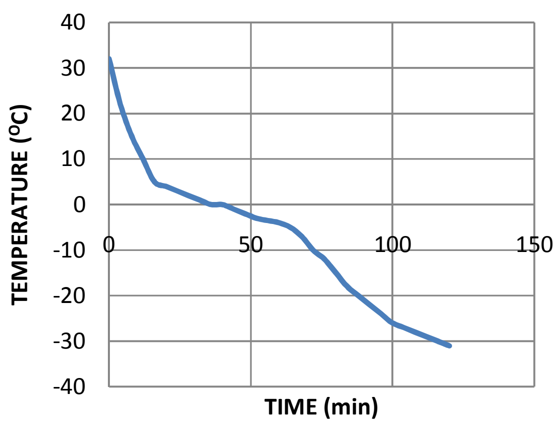

Fig 7 Evaporator with 5 litres of water

The evaporator with 5 litres of water in the evaporator of LT side versus the load graph is shown in figure. The graph shows that the temperature of water in the evaporator attains -32°C in 2 hrs. The variation of temperature with time in the evaporator is almost linear from 32 to 5°C. The temperature of air in the evaporator reaches 5 °C in 20 minutes and for the next 50 minute the variation of temperature varies only slightly from 5 °C to -5 °C. After -5°C the air temperature reduces linearly with time and achieves -40 °C within next 13 minutes

6. CONCLUSION

Cascade refrigeration is a method of refrigeration used for achieving low temperatures which is below -40°C. By cascading more than two VCR stages we can achieve temperatures near to absolute zero. I.e., it is also a, method used for cryogenics applications.

By designing the cascade refrigeration system using R134a in HT side and R404a in LT side, it is observed that the temperature of air in a 10 litre capacity evaporator will reduce to -40 °C within 18 minutes. The theoretical COP of the system was found to be 2.5 by conducting experiment on the designed system.

The advantages of using cascading for low temperature applications are:

- In cascade system using different refrigerants, so, that it is possible to select a refrigerant that is best suited for that different temperature range. In the manner of Very high or very low pressures can be avoided.
- In this system migration of lubricating oil from one compressor to the other compressor is prevented.
- The saving of energy is more because the system allows use of refrigerants that have suitable temperature limits characteristics for each of the higher-temperature side and the lower-temperature side.
- It allows especially for stable ultra-low-temperature operation.
- Repairs and maintenance are easy to carry out.

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