

Design & Development of Cascade Refrigeration System for Testing at Low Temperature Applications

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Abstract - The environmental temperature in North India is significantly lower (below 0°C) so the necessity of testing automobile electrical component come forward because of failure of electrical component at that much lower temperature. Providing refrigeration for very low temperature Cascade refrigeration system is most suitable. In this system two different refrigerants with different boiling point are used. Evaporator of the first stage is cascade with condenser of second stage around the chamber whose temperature is to be maintained lower. The selection of refrigerant is done on the basis of safety, environmental effect and boiling point of refrigerant. The design of condenser and capillary tube is decided on the basis of heat rejection or condenser load and pressure drop across the capillary. The selection of compressor is also validated by using software. After designing and selection of component temperature of chamber can be maintained lower for testing electrical component. The cascade refrigeration setup can be used for following applications:

1. For storage of special medicine.
2. Aero plane, Satellite components can be tested at below ambient temperature.

Keywords: freezing cycle, COP, VCR System, Oil Wandering, Cascade.

1. INTRODUCTION

Today, for some applications, it is difficult to procure parts that meet engineering, economic, logistical, and technical integration requirements of product manufacturers, and that are rated for an extended temperature range. There are products to be supported and new products to be built which require parts that can operate at temperatures beyond the industrial temperature range (-40 to 85°C).

Automobile Industry requires technology to test Electrical Components below the ambient temperature. Hence it is mandatory that while testing electrical components at low temperature.

Regular VCR system can't achieve this temperature. The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components: a compressor,

a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator.

Hence, we are going to use Cascade Refrigeration System. By using this system, we can easily maintain temperature of enclosed space below the ambient temperature. The cascade refrigeration system is a freezing system that uses two kinds of refrigerants having different boiling points, which run through their own independent freezing cycle and are joined by a heat exchanger.

2. IMPACT OF LOW TEMPERATURE ON ELECTRICAL COMPONENTS:[2]

There are many reasons that motivate the operation of electronic circuits at temperatures below the ambient temperature. Some of these reasons include: lower thermal noise and parasitic effects, improved carrier mobility, and the possibility to investigate quantum effects and physical phenomena such as single electron effects and super conductivity that only occur at low temperatures.

The cooling has detrimental effects on the performance of Si BJTs and this stop their application in cryogenic environments. Cooling a Si BJT will typically increase its turn on voltage, low-injection trans-conductance and base resistance, will decrease its current gain and will degrade its frequency response. As a result, the performance of Si BJTs strongly breakdown as the temperature drops.

Batteries failed in low temperature. Due to low temperature the condensation form on circuit and it can damage the circuit.

3. MULTISTAGE REFRIGERATION SYSTEM:

3.1 Available Multistage System to Achieve Low Temperature:

1. Two Compressors and Two Evaporators.
2. One Compressor and Two Evaporators.
3. Two Stage Compression with Intercooler.
4. Three Stage Compression with Multiple Expansion Valves and Flash Intercooler.

3.2 Disadvantages of Multistage Refrigeration System:

1. Multistage system suffers from oil wandering problem.
2. The change in specific volume is very large evaporation at low temperature.
3. The oil return from the evaporator is poor since the mass flow rate of the refrigerant is reduced.
4. The condenser is designed for pull down load which is maximum.
5. The thermostatic expansion valve demands more superheat for the same setting of spring force.
6. The multistage system is very expensive and therefore requires special design.

4. CASCADE REFRIGERATION SYSTEM:

4.1 Basic Working Principle of Cascade Refrigeration System:

To condense refrigerants that are capable of achieving ultra-low temperatures that would not be able to condense at room temperature. This condensation is achieved by using an evaporator of first refrigeration system.[1]

4.2 Cascade Refrigeration System Description:

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. The temperature difference in cascade condenser is an important design parameter that decides the COP of the entire refrigeration system.[1]

4.3 Advantages of Cascade Refrigeration System compared to a multistage compression system:

1. No lubricating oil wandering problem because two separate compressors is used.
2. It allows stable ultra-low-temperature operation.
3. Compressor work is saved because the cascade system allows use of refrigerants that have suitable temperature characteristics for each of the higher-temperature side and the lower-temperature side.
4. 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 for extend.

5. The running cost is less.
6. Maintenance is easy.

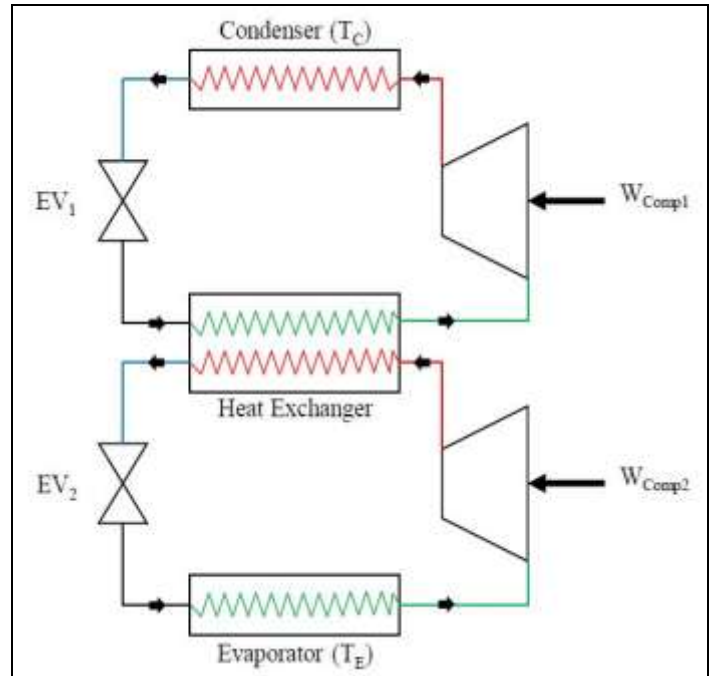


Fig.1: Systematic cascade refrigeration cycle with Evaporator, condenser and cascade condenser

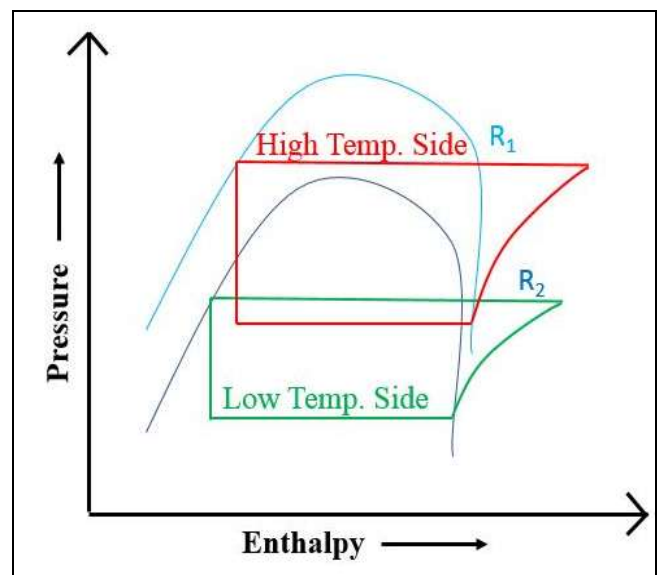


Fig.2: P-H diagram for Two Stage Cascade Refrigeration System

4.4 COP of Cascade Refrigeration System:

$$COP = \frac{COP_1 \times COP_2}{1 + COP_1 + COP_2}$$

5. REFRIGERANT SELECTION:

In a cascade refrigeration system, the higher-temperature side uses a normally used refrigerant -12, R-22, ammonia, etc. and the lower-temperature side uses R-13 or R-13 BI, which is an HFC refrigerant.

5.1 Introduction of Refrigerant:

The working fluid used for energy exchanges in refrigeration system is called as Refrigerant. It absorbs heat while undergoing a phase change (in evaporator) and compressed to high pressure and temperature allowing it to transfer heat energy directly or indirectly to atmosphere.

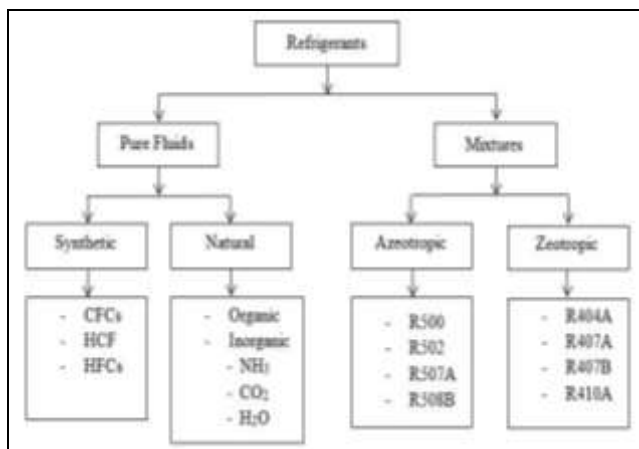


Chart 1: Classifications of Refrigerants [3]

5.2 Selection Parameters of Refrigerants:[3]

- **Properties:** Boiling Point, Freezing point, Critical temperature, Molecular weight, Evaporating temperature.
- **Safety:** Non flammability, Non toxicity
- **Effect on Environment:** ODP (Ozone Depletion Potential), GWP (Global Warming Potential)
- **Availability:** Easily Available

5.3 Comparison of Refrigerants:

Sr. No.	Refrigerants	Boiling Point	Critical Temperature	ODP	GWP	Safety Class
1.	Ammonia	-33.33	132.25	0	<1	B2
2.	R-134A	-26.06	101	0	1430	A1
3.	R-143A	-47.24	72.71	0	4470	A2
4.	R-404A	-46.56	72.5	0	3920	A1
5.	R-407A	-45.05	82.77	0	2110	A1
6.	R-507A	-47.11	70.56	0	3985	A1
7.	R-508B	-87.60	12.05	0	13400	A1

Chart 2: Comparison of Refrigerants

5.4 Selected Refrigerants:

5.4.1 R - 404A:

R404A is a zeotropic HFC refrigerant blend of R125, R143a and R134a. It is widely used in medium and low temperature refrigeration especially in the supermarket sector and for refrigerated transport. R404A was designed as a replacement for CFC R502 and closely matches its properties.

- **Composition:** A blend of HFC refrigerants R-125, R-143a, and R-134a (44 / 52 / 4 wt. %)
- **Properties:** [4]
 - ASHRAE A1 safety classification
 - Non-Flammable & safe to use
 - Zero ODP
 - GWP of 3260
 - Molecular weight is 97.6
 - Boiling point at 1 ATM is -46.5/-45.8 °C
 - Critical Temperature is 72.1°C
- **Application:** R-404A is intended for low and medium temperature refrigeration applications where R-502 was previously used. Most new equipment has been built for R-404A (and R-507 interchangeably). It is also possible to retrofit R-502 systems with R-404A.
- **Performance:** R-404A has slightly lower pressures than R-507 (from the small amount of R-134a added), and generally both blends have slightly higher pressures than R-502. Capacity and efficiency are very similar to R502.
- **Lubricant:** R-404A requires polyolester (POE) lubricant, which is usually charged into new equipment. If retrofitting existing equipment, the original oil must be replaced with POE.

5.4.2 R - 508B:

A blend of R-23 and R-116 intended for very-low-temperature refrigeration systems, typically the low stage of a multi-stage system. R-508B has properties similar to R-503 and can be used to replace either R-13 or R-503 in an existing system. The discharge temperature does not increase significantly compared to R-13, in contrast to the increase seen with R-23. POE lubricants should be used and it may still be necessary to charge hydrocarbon oil additives to ensure proper oil return. Check with OEM for specific oil and charging recommendations.

- **Composition:** A blend of HFC refrigerants R-23 and R-116 (46 / 54 wt. %)
- **Properties:** [4]
 - Environmental Classification: HFC
 - Molecular Weight: 95.4
 - Boiling Point (1 atm.): -87.6 °C
 - Critical Pressure: 37.7 bar-abs
 - Critical Temperature: 11.2 °C

- Critical Density: 568.5 Kg/m³
 - Liquid Density: 1080.1 Kg/m³
 - Vapor Density: 6.55 Kg/m³
 - Heat of Vaporization: 165.45 KJ/Kg
 - Ozone Depletion Potential (CFC 11 = 1.0): 0
 - Global Warming Potential (CO₂ = 1.0): 13,400
 - ASHRAE Standard 34 Safety Rating A1
- **Application:** R-508B is intended for very-low-temperature refrigeration systems, typically the low stage of a multi-stage system. R-508B has properties similar to R-503 and can be used to replace either R-13 or R503 in an existing system.
 - **Performance:** The discharge temperature does not increase significantly compared to R-13, in contrast to the increase seen with R-23. Good performance match to R-503.
 - **Lubricant:** POE lubricants should be used and it may still be necessary to charge hydrocarbon oil additives to ensure proper oil return. Check with OEM for specific oil and charging recommendations.

6. CONCLUSIONS

- Cascade refrigeration system is more suitable to achieve lower temperature as compared to multistage refrigeration system.
- Refrigerants properties plays vital role for selection of it and system components.
- The refrigerants which are easily available and much eco-friendly are selected.

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