Design and Fabrication of Two Refrigerant Cascade System

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Abstract - *This research paper is based on a two-stage cascade refrigeration system experimented with two different refrigerants, R-134a and R-22. This system is a combination of two different refrigeration cycle in which the first cycle is a high-temperature cycle and the second one is a low-temperature cycle. This arrangement of the cycle helps to get as low as -20° to -100° C temperature which is required in the applications like cold storage, blood banks and food preservation centers. Not only a lower temperature can be achieved in the system but also a high refrigeration effect can be achieved. "The Series of the single-stage vapour compression system is thermally coupled with the evaporator of the high-temperature circuit and condenser of the low-temperature circuit and this combination itself is known as cascade" [10]. The refrigerants used in the system have different boiling temperatures to get desired output results. And here R-134a has a bit higher boiling temperature than that of R-22, and for this reason, R-134a is used in higher temperature circuit and R-22 is used in lower temperature circuit.*

Key Words: **low-temperature circuit, high-temperature circuit, Ozone depletion potential, Global Warming potential, vapour compression refrigeration cycle, cascade system**

1. INTRODUCTION

"The cascade cooling system consists of two or more vapour compression refrigeration (VCR) systems in series which use refrigerants with successively lower boiling temperatures"[11]. A two-stage cascade system by using two refrigerants has been shown in figure a. In the given system, a cascade condenser works as an evaporator for the high-temperature cascade system and a condenser for the low-temperature cascade system. The sole useful refrigerating effect is produced within the evaporator of the low-temperature cascade system. The main benefit of the cascade system is that it permits the use of two different refrigerants. "The high-temperature cascade system uses a refrigerant with a high boiling temperature such as R-12 and the low-temperature cascade system uses a refrigerant with low boiling temperatures such as R- 13 or R- 13 BI"[11]. A smaller compressor displacement in the LTC system and a higher COP is ensured by these low boiling temperature refrigerants.

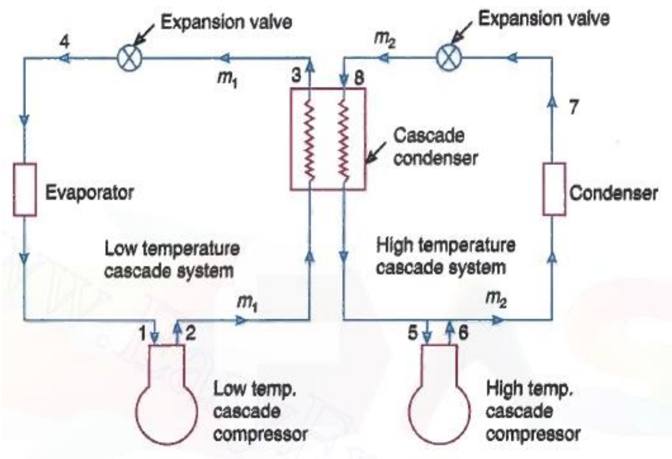

Fig -1: Cascade refrigeration system [9]

In this system selection of refrigerants plays a major role in the performance and efficiency of the system. Nowadays a larger number of different refrigerants are available. Because of which selection of the refrigerant depends on the properties such as freezing point, molecular mass, critical pressure, critical volume, boiling point, etc. And nowadays the main properties of refrigerants to look into are global warming potential and ozone depletion potential. "The temperature rating point of the refrigerant leads to supercritical pressure as the temperature of the refrigerant 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 increases leads to low process pressure" [10].

On the other hand, refrigerants like R-22 and R-134a have low critical pressure, 722 and 590 Kpa respectively, as compared to CO_2 and NH_3 which helps to build a compact system and also increases the efficiency of the working compressor.

2. DESIGN OF SYSTEM

The design of the system consists of two refrigeration cycles, i.e. LTC and HTC. So, it has two different cycles in p-h and as well as in the T-S diagram as shown (refer to figure. b). As shown there are two cycles which is got after taking readings by performing experiments at actual working conditions.

HTC Refrigerant: - R134a

LTC Refrigerant: - R22

Capacity (Q):- 0.5 Ton

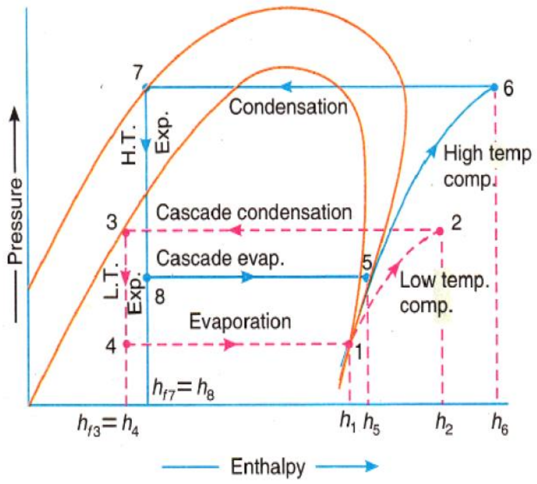

Fig -2: P-h diagram [8]

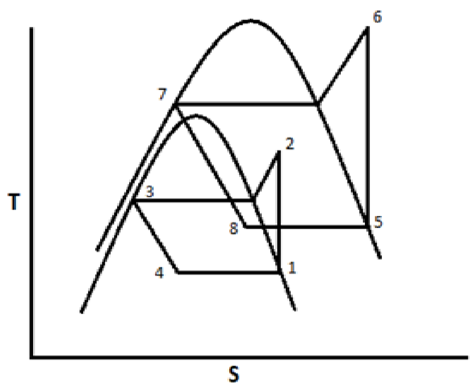

Fig -3: T-s diagram

The design of the system has been done at below temperatures.

T_E = Evaporator temperature (R22) = -30° C

T_C = Condenser temperature (R134a) = 35° C

T_{CC} = Cascade condenser temperature (R22) = 14° C

T_{CE} = Cascade evaporator temperature (R134a) = 10°

Compression ratio(r):-

For R22 = P_2/P_1 (1)

For R134a = P_6/P_5 (2)

Mass flow rate (m):-

For R22, $m_1 = 210\ Q\ /\ h_1 - h_4$ (3)

For R134a, $m_2 = m_1\ [(h_2 - h_3)/\ (h_5 - h_8)]$ (4)

Refrigeration effect:-

For R22, $R_{E1} = m_1\ (h_1 - h_4)$ (5)

For R134a, $R_{E2} = m_2\ (h_5 - h_8)$ (6)

Work done in the compressor:-

For R22, $W_1 = m_1\ (h_2 - h_1)$ (7)

For R134a, $W_2 = m_2\ (h_6 - h_5)$ (8)

Equations (1) and (2) are used to find out the compression ratio by using the ratio of pressure at point 2 and 1 for R22 refrigerant cycle whereas at 6 and 5 for R134a refrigerant cycle. And mass flow rate for R134a refrigerant is got by energy balance which has been mentioned in equation (4). Refrigeration effect and work done of the system has been calculated by using equation (5), (6), (7) and (8) which could lead us to find other values required for further calculations.

3. EXPERIMENTAL READINGS

The experimental readings have been taken at actual working conditions so that we could get the actual performance of the system in real world. Pressure, Enthalpy and Entropy of both the cycles at different working conditions are as follows (refer to Table 1 and Table 2).

Table -1: Readings of LTC

Cycle	LTC (R- 22)
P_1 [Bar]	1.638
P_2 [Bar]	7.67
h_1 [KJ/Kg]	392.63
h_2 [KJ/Kg]	409.6
S_1 [KJ/Kg.K]	1.8013

S_2 [KJ/Kg.K]	1.7306
h_3 [KJ/Kg]	216.74
h_4 [KJ/Kg]	216.74

Table -2: Readings of HTC

Cycle	HTC (R- 134a)
P_5 [Bar]	4.145
P_6 [Bar]	8.933
h_5 [KJ/Kg]	304.276
h_6 [KJ/Kg]	317.23
S_5 [KJ/Kg.K]	1.7219
S_6 [KJ/Kg.K]	1.7131
h_7 [KJ/Kg]	149.1135
h_8 [KJ/Kg]	149.1135

As shown in table 1 and 2 the values of pressure at point 1 and point 2 is lesser than that of 5 and 6 from which we could also find that the temperature is higher in R134a cycle than R22. And these values could also vary if the capacity of the system increases from 0.5 ton and as the pressure and temperature difference of these two cycle increases the performance increases.

4. RESULTS

By operating the system at different conditions and as well as on different loads we have got the readings as shown in Table 1 and Table 2. And by putting those values in design equations we have got the desired results as shown in table 3. From which we could see that the COP of the individual system is quite higher but when the combined effects are taken then the performance of the system turned out to be decreased. Which has been calculated by using COP formula, R_E / W. by which we have got the COP of whole system as

Table -3: Result table

Cycle	LTC (R- 22)	HTC (R- 134a)
r	4.681	2.15
m [Kg/min]	0.5969	0.742
R_e [KJ/min]	105	115.13
W [KJ/min]	10.12	9.612
COP	10.37	11.98

From these data the COP of whole system is,

$$COP = R_E / W$$
$$= 210\ Q / (W_1 + W_2)$$
$$= 210 * 0.5 / (10.12 + 9.612)$$
$$= 5.321$$

And power consumption of the system is,

$$P = (W1 + W_2) / 60$$
$$= (10.12 + 9.162) / 60 = 328\ W$$

5. CONCLUSIONS

By experimenting we got to know that to operate and to achieve as low as -30° C temperature is also possible with a high performance of the system. And to go below this temperature is also possible by increasing the capacity of the compressor because as the capacity of the compressor increases the refrigerating effect also increases. So, to get still lower temperature we could change the capacity and size of the system.

As we increased the load on the system the COP or the performance of the system get decreases. And to maintain a certain performance level, stable condition is required. And the performance of the system could also be increased by increasing the number of cycles used in the system, by increasing the number of LTC.

6. FUTURE SCOPE

This same system could also be made from R410a and R600 and to get the required temperature and performance of the system and analysis of this system can also be done and effects could be studied.

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