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Cascade Refrigeration System: R404a-R23 Refrigerant

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Abstract - This **study is presented a cascade refrigeration system using as refrigerant (R23) in low-temperature circuit and R404a in high-temperature circuit. The operating parameters considered in this paper include superheating, condensing, evaporating, and sub cooling temperatures in the refrigerant (R404a) high temperature circuit and in the refrigerant (R23)) low-temperature circuit. Diagrams of pressure versus Enthalpy have been obtained. Results show that a Tetra fluro methane (R23)-R404a cascade refrigeration system.**

Keywords: **Cascade Refrigeration system, Refrigerant R23, R404a.**

I. INTRODUCTION

The Cascade Refrigeration System describe with the basic principles that are used to create the refrigeration effect. A cascade system consists of two or three separate simple cycles operating in conjunction with each other at different temperature levels. The connecting point is a heat exchanger between the stages. This interstate heat exchanger is the condenser for the first stage and the evaporator for the second stage[5][6]. 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 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 cycle, and for this reason has some advantages over the compound compressors [7][8]. 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, the use of “R-23” in the low stage and “R-404a” in the high stage.

II. LITERATURE REVIEW

Winkler *et.al.*[1] discussed on a cascade system simulation algorithm and implemented with the help of a component-based modeling tool for vapor compression systems. The low temperature and high temperature vapor compression systems consisted of multiple compressors and the high temperature system utilized two condensers. The simulation tool, despite using simple heat exchanger models, predicted the COP with an average error of 4.4% and a maximum error of 11.3%.

Gami *et.al.* [2] reported a thermodynamic energy and exergy analysis cascade refrigeration system using refrigerants pairs R134a R23and R290-R23 is presented in this paper to optimize the operating parameters of the system. The results show that COP and exergetic efficiency decreases when degree of superheating increases in LT system and increases when degree of superheating increases in HT system and remain constant when degree of superheating increases in HT and LT system . The results show that COP and exergetic efficiency increases when degree of sub cooling increases in all three cases as discussed above.

Messineo *et.al.*[3] the thermodynamic analysis of a cascade refrigeration system working at TE=-35^{o}c and TC= 35^{o}c is reported. In particular, six different refrigerants were analyzed in the HTC, of which three were natural refrigerants (R717, R290 and R600), and three were synthetic refrigerants (R404A, R410A and R134a). In the Low temperature circuit, carbon dioxide was considered exclusively. In conclusion, the results obtained show that a cascade refrigeration system using natural refrigerants is an interesting alternative to systems using synthetic refrigerants for energetic, security and environmental reasons.

Dopazo *et.al.* [4] analyzed of the parameters of design and operation of a CO cascade cooling system and their influence over the system’s COP and exergetic efficiency is reported. The analysis was carried out based on a general mathematical model. The system’s COP and it’s exergetic efficiency can be expressed as a function of six design/operating parameters. A statistical procedure has been used to analyse the parametric study results obtained. The analysis reveals that all the evaluated parameters have a statistically significant effect.

III. WORKING AND CONSTRUCTION OF CASCADE REFRIGERATION SYSTEM PRINCIPAL OF OPERATION

Cascade system is just similar to the binary vapour cycle used for the power plants in the binary vapour cycle a condenser for mercury works as a boiler for water similarly, in the cascade system the condenser for low temperature cycle works as an evaporator for the high temperature cycle. In a cascade system, a series of single stage unit[3].

IV. CONSTRUCTION

All the components of cascade system are mounted on the powder coated fabrication stand 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, shell and coil type condenser, desuper–heater ,water flow cut –out, expansion device, expansion chamber, cascade condenser, oil-separator and low-side evaporator[6].

The refrigerant used on the high side is R-404a,and The refrigerant used on the low side is R-23. On the high side a hermetically sealed compressor, shell and coil type condenser, drier/filter, flow meter, expansion device, and cascade condenser are connected to each other . on the side hermetically sealed compressor, oil separator .De-super heater .cascade condenser, drier/filter, expansion device low side evaporator, expansion chamber, cooling fan are connected with each other .separate pressure gauge are provided to measure the pressure at the compressor inlet and compressor outlets. HP/LP cutout is used as a safety device.

Cooling thermostats are provided in the cascade condenser and in the low side evaporator. Separate energy-meters are provided to measure the energy consumed by the compressor and the heater.

A dimmer is also provided to control the input of the heater. flow meter in the liquid line is incorporated to measure the refrigerant flow. Digital temperature indicator displays temperature at various locations as per the selection viz. temperature before and after compressor and before and after expansion.

V. WORKING

Initially, when the compressor is started, the refrigerant is compressed at high pressure, and then it enter into the shell and coil type condenser, where the flowing water absorbs all the heat. Then it enters into the drier /filter, flow meter it goes into the expansion device where its its expansion take place and pressure drops. Then it enters into the cascade condenser where it takes heat from the low side refrigerant (R23) in the low side system compressor discharges refrigerant at high pressure, then it enters into the oil separator where compressor oil gets separated from the refrigerant.

Then refrigerant goes into de-super heater where its heat gets absorbed by flowing water, then it goes into cascade condenser (i.e. high side evaporator) where its heat is rejected and it becomes in liquid from .After passing through drier/filter, expansion device it goes into low side evaporator where it absorbs heat from chamber ,it converts into low-pressure vapour state, Then it goes into the compressor. R23 is having high standing pressure so it becomes trouble for compressor starting .so to avoid it refrigerant is stored in the expansion chamber where the pressure takes place. It is connected in series with the compressor inlet line.

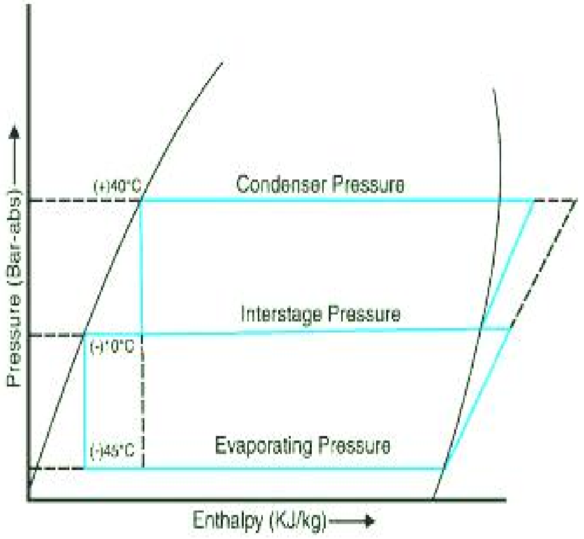

Fig.1 Pictorial view of Pressure vs enthalpy

VI. EXPERIMENTAL PROCEDURE

1. Put the machine in the proper position where its level is horizontal and it is well ventilated. The machine must have at least 2.0 meters clearances from all sides.
2. Start the main switch and after that start compressor.
3. Check suction & discharge pressures,
4. Allow the unit to run for 15-20 minutes to bring down the temperature of after expansion in the range -10°c to -15°c.
5. After attaining the temperature of after expansion starts the compressor for low side.
6. Again allow the unit to run for 1½-2 hours to bring down the temperature of cascade temperature (i.e. temperature for low side on thermostat)to -40°c.
7. Now, start the heater after that set the dimmer so that cascade temperature remains constant.
8. Take all the readings (temp at various points and pressures, energy meter reading etc.)as per the observation table for LOW SIDE SYSTEM and HIGH SIDE SYSTEM.

VII. OBSERVATION TABLE

TABLE 1 HIGH SIDE SYSTEM

Sl. No	Time	Suction pressure Kg/cm^2	Discharge Pressure Kg/cm^2	Refrigerant temperatures				Cascade condenser temperature	Energy meter	Refrigerant flow LPH
				After compression	After condensation	After expansion	After evaporation			
1	2.15	0.8	19	59	40	-16	7	9	7.1	40
2	2.45	0.8	19	64	38	-25	-2	-2	7.8	20
3	3.15	0.5	19	65	39	-24	0	0	8.4	21
4	4.08	1	19	65	39	-24	0	0	8.9	21
5	4.30	1	19	67	39	-24	0	0	9.2	21

TABLE 2 LOW SIDE SYSTEMS

Sl. No	Time	Suction pressure Kg/cm^2	Discharge Pressure Kg/cm^2	Refrigerant temperatures				Cascade condense	Energy mete	Energy mete
				Aft	Aft	Aft	Aft			
1	2.15	4	14	69	-20	-63	27	-25	2. 6	-
2	2.45	4.2	13	84	-23	-63	14	-32	2.8	0. 6
3	3.15	4	14	91	-21	-60	11	-41	3.0	0. 6
4	4.08	4	14	90	-22	-61	4	-43	3.2	0. 6
5	4.30	4.1	14	91	-22	-61	10	-41	3.3	0.7

VIII. CALCULATION

Low Side Calculation

1. Refrigeration effect at low side N2=heater load
   =final energy meter reading-initial energy meter reading
   =0.7-0.6
   =0.7-0. 6
   =0.1
2. Compressor work at low side W2 =energy meter reading for compressor
   =3.3-2.8
   =0.5
3. C.O.P. =N2/W2
   =0.1/0.5
   =0.2

High Side Calculation

1. Refrigerant effect on high sideN1 =compressor work on low side + refrigerant effect on low side
   =0.5+0.1
   =0. 6
2. Compressor work at low side W1 =energy meter reading for compressor
   =9.2-7.1
   =2.1
3. C.O.P. =0. 6-/2.1
   =0.2857

   Overall C.O.P. =Net refrigerating effect/total compressor work
   =(0.1+0. 6)/(0.5+2.1)
   =0.2692

IX. CALCULATION FOR COMPONENT BALANCING

The heat absorbed in the high side temperature cycle must be equal to heat rejected in low side temperature cycle.

1. Heat absorbed in high side = Heat rejected in low side

$$Q_{23} = Q_{404a} + Q_{DESUPERHEATER}$$

Now,

$$Q_{404a} = (m.C_p.\Delta T)_{404a,}$$

Where,

Q_{404a} = Heat absorbed by 404arefrigerant
M_{404a} = mass flow rate of 404a refrigerant
Cp_{404a} = Specific heat of 404a refrigerant
= 1.541kj/kg k
ΔT= change in temp. of evaporator (°k)
=-24°C =249°k
m_{404a} = 21 Lit/hr
$\therefore$ m= p.v.
P = liquid density of R404a
$\therefore$ m404a in kg = p. v. $(\frac{l}{hr})$
= 1.05* 21000 (mm^3/hr)
= 22050(kg/hr)
= 367.5 kg/min
$\therefore$ Q404a = mCp ΔT
= 367.5 *1.541 *249
=141.013* 10^3 kj/mim

Value of enthalpy at every point,

From P-H table of R23

h_1 at 10°C = 336 kj/kg
h_2 at 91°C = 452 kj/kg
h_3 at -22°C = 166.7 kj/kg
h_4 at -61°C = 113.9 kj/kg

From P-H table of R404a

h_5 at 0°C = 365.82 kj/kg
h_6 at 67°C = 371.84 kj/kg
h_7 at 39°C = 258.51 kj/kg
h_8 at -24°C = 167.72 kj/kg

$$\therefore m_{23}=\frac{m404a(h2-h4)}{h5-h8}$$

Heat absorbed by 404a = heat rejected by R23

$$=\frac{367.5*(452-113.9)}{365.82-167.72}$$

= 627.21 kg/min

$Q_{23} = m_{23} * Cp_{23} * \Delta T$

m_{23} = mass flow rate of R23
Cp_{23}= specific heat of R23
=0.8131 kj/kg k
ΔT= change in temperature at condenser

ΔT= 386 ° K

$Q_{23} = m_{23} * Cp_{23} * \Delta T$

= 627.21 * 0.8131 * 386
= 196.8539 * 10^3 kg / min
$\therefore Q_{desup} = Q_{23} - Q_{404a}$
= (196.85 * 10^3) – (141.013* 10^3)
= 55.837 * 10^3 kg/min.

GRAPHS

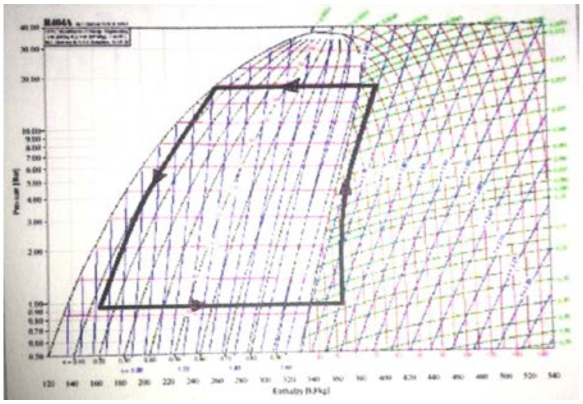

Fig.2 p-h Diagram for R404a

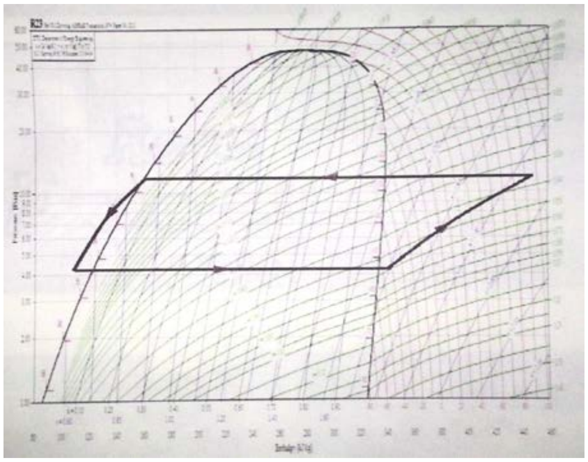

Fig.3 p-h Diagram for R23

XI. CONCLUSION

By using cascade refrigeration system, it is found that very low temperature & cascade refrigeration system is efficient than single stage refrigeration system. The actual C.O.P. of system (on low side) is 0.2. The actual C.O.P. of the system (on high side) is o.2857 and the overall C.O.P. of the system is 0.2692. Heat absorbed by R404a is 141.013* 10^3 kj/mim and Heat absorbed by R23 is 55.837 * 10^3 kg/min

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