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Research Article

Design and Fabrication of Ultimate Chilling System

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Abstract

This project demonstrates the working of ultimate chilling system which can be used in pharmeuacticals industry, to preserve medicines, R&D centres etc. Ultimate chilling system is a three stage cascade refrigeration system. The main purpose of this system is to produce temperature less than -60˚C and to maintain that temperature constant in conditioned space. This system has one main system and two sub systems. Each system has different refrigerant (R134A, R404A, R23).Main system as R23 as refrigerant. Sub system 1as R134A as refrigerant, sub system 2 as R404A as refrigerant .Sub system 1 evaporator act as a condenser for sub system 2,then sub system 2 evaporator act as a condenser for main system. By using these three systems temperature less than -60˚C can be achieved. Then coefficient of performance calculation done .

Keywords: *maintain temperature at -60˚C, by two subsystems and one main system, R23, R404A, R134A three stage cascade refrigeration system*

1. Introduction

A cascade refrigeration system can be considered to be equivalent to two independent vapor-compression systems linked together in such a way that the evaporator of the high-temperature system becomes the condenser of the low-temperature system. However, the working media of the two systems are separated from each other. This therefore, allows the use of different refrigerants working at different temperature ranges to achieve the desired effect, which would otherwise, need to be achieved by a single refrigerant working at a bigger operating pressure range.

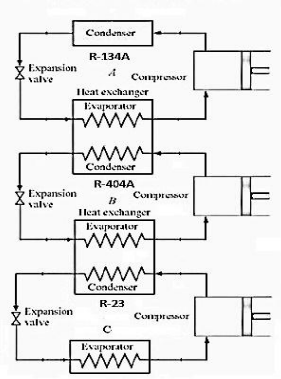

Fig. 1 block diagram of ultimate chilling system.

Cascade refrigeration system is most commonly used in low temperature application such as pharmeuacticals industry, preserve medicines; R&D etc .This system can achieve refrigeration effect at a slower rate. Cascade refrigeration system can achieve up to -50˚c .To rectifies this drawback. In ultimate chilling system three systems is used .One main system and two subsystems. This system can achieve refrigeration effect at a faster rate and it can archive temperature less than -60˚c.It can maintain temperature for any requirement. In this R23 refrigerant used in main system.R404A and R134A refrigerant used in subsystems.

2. Components of ultimate chilling system

Subsystem 1:

Refrigerant: R134A, reciprocating compressor, air cooled condenser, capillary tube& tube in tube heat exchanger1.

Subsystem 2:

Refrigerant: R404A, reciprocating compressor, air cooled condenser, capillary tube& tube in tube heat exchanger 2.

Main system:

Refrigerant: R23, reciprocating compressor, air cooled condenser, capillary tube, evaporator coil & fan.

3. Working principles of ultimate chilling system

When the system is switching on. Timers are used to switch on the subsystem 2 and main system. First subsystem1 is switching on after two minutes delay

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subsystem 2is switching on. After four minutes delay main system switching on. Subsystem1 (R134A) compressor starts running .compressor compress the low temperature and low pressure gas refrigerant from the suction line to high temperature and high pressure gas refrigerant. Then the refrigerant is sent to air-cooled condenser .In this gas refrigerant condense to liquid refrigerant .Liquid refrigerant is passes through capillary tube to the tube in tube heat exchanger1. In capillary tube liquid refrigerant expands at low temperature and low pressure . Tube in tube heat exchanger1 act as an evaporator for subsystem 1and secondary condenser for subsystem 2.In tube in tube heat exchanger low temperature and low pressure liquid refrigerant from subsystem1(R134A) condense the refrigerant from the subsystem2(R404A).Then low temperature and low pressure gas refrigerant from the tube in tube heat exchanger is send to the suction line of compressor. Cycle continues in subsystem 1.

In Subsystem2 (R404A) compressor starts running compressor compress the low temperature and low pressure gas refrigerant from the suction line to high temperature and high pressure gas refrigerant. Then the refrigerant is sent to air-cooled condenser .In this gas refrigerant condense to liquid refrigerant .Liquid refrigerant is passes To tube in tube heat exchanger1.In this further condensation take place . Then low temperature liquid refrigerant send to the tube in tube heat exchanger2 through capillary tube. In capillary tube liquid refrigerant expands at low temperature and low pressure. Tube in tube heat exchanger 2 act as an evaporator for subsystem 2 and secondary condenser for main system. In tube in tube heat exchanger2 low temperature and low pressure liquid refrigerant from subsystem2 (R404A) condense the refrigerant from the main system(R23).Then low temperature and low pressure gas refrigerant from the tube in tube heat exchanger send to the suction line of compressor. Cycle continues in subsystem 2.

In main system (R23) compressor starts running compressor compress the low temperature and low pressure gas refrigerant from the suction line to high temperature and high pressure gas refrigerant. Then the refrigerant is sent to air-cooled condenser .In this gas refrigerant condense to liquid refrigerant .Liquid refrigerant is passes To tube in tube heat exchanger2. In this further condensation take place. Liquid refrigerant is passes through capillary tube to an evaporator coil.

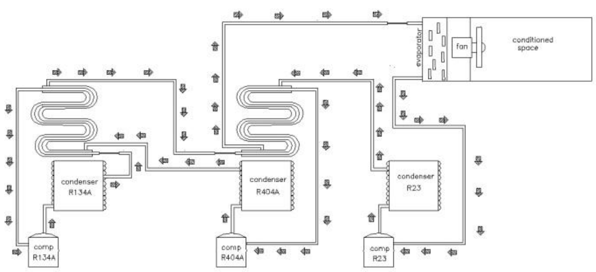


Fig. 2 schematic diagram of ultimate chilling system.

In capillary tube liquid refrigerant expands at low temperature and low pressure liquid refrigerant. Refrigerant absorbs heat in an evaporator coil. Then low temperature and low pressure gas refrigerant from an evaporator send to the suction line of compressor. Cycle continues in main system.

4. Calculation

Evaporator calculation

(Before fabrication) Available data:

1. Evaporator load = 3.516 KW
2. Shell and coil evaporator
3. Internal diameter of the copper pipe = 7.9375 x 10^-3 m
4. Outer diameter of the copper pipe = 9.525 x 10^-3 m
5. Inlet evaporator temperature = -65°c (208 K)
6. Outlet evaporator temperature = -35°c (238 K)
7. Mass flow rate of R23= 1799 kg/sec
8. Velocity = 32.546 m/sec

Table 1 From R23 property table

Temperature °c	Thermal conductivity K(w/m K)	Prandtl number -Pr-
-65	0.073	4
-35	0.073	3.5

Solution:
Inside flow:

Re= μdi/ν $= \frac{32.546 \times 7.9375 \times 10^{-3}}{0.211 \times 10^{-3}} = 1.168 \times 10^{6}$

Nusselt number =$\mathbf{0.023\ Re^{0.8}\ pr^{n}}$

Nusselt no = $0.023 \times (1.168 \times 10^{6})^{0.8} \times 4^{0.3} = \underline{2490.577}$

Nusselt number=hiDi/K

$2490.577 = \frac{hi \times 7.9375 \times 10^{-3}}{0.073} = 22905.46$ w/ m^{2}k

<u>hi = 22905.46 w/ m^{2}k</u>

Outside flow:

Re = μdo/ν $= \frac{32.546 \times 9.525 \times 10^{-3}}{0.198 \times 10^{-6}} = 1.56 \times 10^{6}$

Nusselt number =$\mathbf{0.023\ Re^{0.8}\ pr^{n}}$

Nusselt number $= 0.023 \times (1.56 \times 10^{6})^{0.8} \times (3.5)^{0.3}$ =<u>3016.115</u>

Nusselt number=h0DO/K

$3016.11 = \frac{h0 \times 9.525 \times 10^{-3}}{0.073}$ = 23115.59 kJ/kg

h0 =23115.59 w/ m^{2}k

To find U:

$U = \frac{1}{\frac{1}{hi} + \frac{1}{h0}} = \frac{1}{\frac{1}{22905.46} + \frac{1}{23115.59}} = 11505.022$ w/m^2k

U=11505.022 w/ m^{2}k

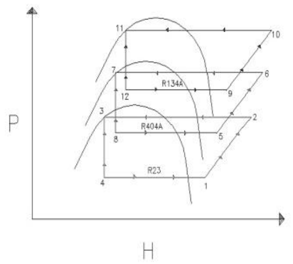
To find Q:
Q =m CP ΔT Watts
$Q = 1799\times 0.950 \times (238 - 208) = 51271.5$ W

Q=51271.5 W
To find AREA:
Q =UA ΔT Watts
$51271.5 = 11505.022\times A \times (238 - 208)$ W

A=0.1485 m^2
To find length of the evaporator:
A= πDL
$0.1485 = \pi \times 9.524 \times 10^{-3} \times L$
L =4.964 ≈ 5m

Total length of the evaporator coil =5m
After fabrication:
Total length of the evaporator coil=5.27m≈ 5m

Coefficient of performance calculation for ultimate chilling system:



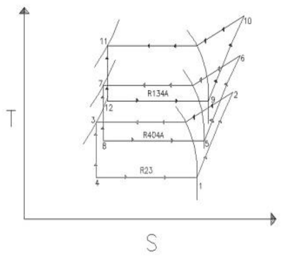


Fig.3 Pressure(P)-Enthalpy(H)diagram **Fig.4**Temperature (T)-Entropy(S) diagram

Main system (R23):
1-2 =isentropic compression in the compressor
2-3=constant pressure heat rejection in the condenser
3-4=isentropic expansion in the expansion device
4-1=constant pressure heat addition in an evaporator
Subsystem2 (R404A):
5-6 =isentropic compression in the compressor
6-7=constant pressure heat rejection in the condenser
7-8=isentropic expansion in the expansion device
8-5=constant pressure heat addition in an evaporator
Subsystem1 (R134A):
9-10 =isentropic compression in the compressor
10-11=constant pressure heat rejection in the condenser
11-12=isentropic expansion in the expansion device
12-9=constant pressure heat addition in an evaporator

Available data:

Table2 From refrigerant temperature and pressure chart

refrigerant	temperature k	pressure bar	h_g KJ/kg	h_f KJ/kg
R23	238	8.5	340.7	-
	293	30.7	365.6	208.6
R404A	253	3.071	355.16	-
	303	14.28	378.14	244.03
R134A	263	2.006	244.52	-
	323	13.85	276.01	149.41

Solution:

$$COP_{R23} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{340.7-208.6}{365.6-340.7} = 5.30$$

$$COP_{R404A} = \frac{h_5 - h_8}{h_6 - h_5} = \frac{355.16-244.03}{378.14-355.16} = 4.83$$

$$COP_{R134A} = \frac{h_9 - h_{12}}{h_{10} - h_{11}} = \frac{244.52-149.41}{276.01-244.52} = 3.02$$

$$COP_2 = \frac{COP_{R23}\times COP_{R404A}}{COP_{R23}+COP_{R404A}+1} = \frac{5.30\times 4.83}{5.30+4.83+1} = 2.347$$

$$COP_{ULTIMATE\ CHILLING\ SYSTEM} = \frac{COP_2\times COP_{R134A}}{COP_2+COP_{R134A}+1} = \frac{2.347\times 3.02}{2.347+3.02+1} = 1.11$$

$$COP_{ULTIMATE\ CHILLING\ SYSTEM} = 1.11$$

Expressions

Inside flow:

Re= μdi/ν (1)

Nusselt number=hiDi/K (2)

Nusselt number =0.023 $Re^{0.8}\ pr^n$ (3)

Outside flow:
Re= μdo/ν (4)

Nusselt number=hoD0/K (5)

Nusselt number =0.023 $Re^{0.8}\ pr^n$ (6)

$U = \frac{1}{\frac{1}{hi}+\frac{1}{ho}}$ (w/ m^{2}k) (7)

Q =m CP ΔT watts (8)

Q =UA ΔT Watts (9)

$$COP_{R23} = \frac{h_1 - h_4}{h_2 - h_1} \quad (10)$$

$$COP_{R404A} = \frac{h_5 - h_8}{h_6 - h_5} \quad (11)$$

$$COP_{R134A} = \frac{h_9 - h_{12}}{h_{10} - h_{11}} \quad (12)$$

$$COP_2 = \frac{COP_{R23}\times COP_{R404A}}{COP_{R23}+COP_{R404A}+1} \quad (13)$$

$$COP_{ULTIMATE\ CHILLING\ SYSTEM} = \frac{COP_2 \times COP_{R134A}}{COP_2 + COP_{R134A} + 1} \quad (14)$$

Abbreviations

Re = Reynolds Number (non-dimensional)
μ= velocity (m/s)
ν = kinematic viscosity (m^2/s)
di=internal diameter of copper pipe(m)
hi =inner heat transfer coefficient(w/ m^2k)
K= Thermal conductivity (w/m K)
Pr= Prandtl number (non-dimensional)
do=outer diameter of copper pipe(m)
ho =outer heat transfer coefficient(w / m^2k)
Q= heat transfer (watts)
m= Mass flow rate (kg/sec)
CP=specific heat(kj/kg k)
ΔT=temperature difference (K)
U=overall heat transfer coefficient (w/ m^2 k)
A=area (m^2)

4. Conclusions

In this paper design and fabrication of ultimate cooling system. the result obtain from the project is:
Conditioned space temperature= -60℃
Coefficient of performance =1.11

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