Design And Fabrication of Plate Freezer

Piyush Chaudhari[1] **, Sahil Thombare**[2] **, Prof.Swapnil Mane**[3]
Department of Mechanical Engineering
[1,2,3] Vidyavardhini's College Of Engineering And Technology Vasai Road (West) .Mumbai

Abstract*- Techniques of freezing vary for each application. Generally used R-12 refrigerant cannot be used for rapid cooling application. Later it is discovered that number of viable vegetative microorganisms in food are greatly reduced by quick freezing implementation. By the development of plate freezer this challenge has been met to enhance effective preservation. Plate type evaporators may be used in single or in banks. The plates may be manifold for parallel flow of refrigerant or they can be connected in series. This paper deals with the design and development of horizontal type plate freezer. In this paper , horizontal plate freezer consisting of two plates connected in parallel and having a cooling load of 0.496 kw is to be designed. Installing formed square tubing between two metal plates , which are brazed together at edges , forms the plate surface evaporator. The refrigerant used is R-134a which is now found out in market as a replacement of R-12.*

Keywords- Horizontal plate freezer , plate type evaporator , rapid cooling, perishable food preservation.

I. INTRODUCTION

Conventional food preservation is done by keeping the food inside chambers having evaporators coil around it. This chamber is insulated from the surroundings by a casing. The vapor compression system is the most widely used system.

The heat transfer takes place from the food to the freezer(chamber) surface through the air gap. As air is a bad conductor of heat, the freezing rate is low and time consuming. The freezing rate was increased by the development of the freezer. Only compactable foods can utilize this method.[4]

The plate freezer under con sideration is a multi-plate freezer. In the plate freezer there are two plates through which the refrigerant expands. The food is placed between the plates and are brought closer so that the food gets pressed to a pre-determined pressure. As the plates are in direct contact with the food, there is better heat transfer and hence the freezing rate is increased. The plate used is aluminum plate, which is having a high heat transfer coefficient. The two plates are brought closer manually. Compared to the conventional method of freezing this method takes only a half of the time to bring 2 kg of chocolate from 30 °C to -20.5 °C, the freezing rate is increased about four times. This is the most important reason why plate freezers are replacing conventional freezing equipment in the recent past.

II. WORKING PRINCIPLE OF PLATE FREEZER

This horizontal plate freezer works on basic vapor compression cycle. It comprises of basic four components i.e. compressor, condenser, expansion device, plate surface evaporator. The compressor receives low temperature and low-pressure refrigerant at initial and compresses it to the high pressure and high temperature.[3] The condenser receives high pressure and high temperature refrigerant and condenses it low temperature. Further this low temperature and high-pressure refrigerant enters the expansion valve i.e. capillary tube where pressure drop occurs and temperature also drops considerably. This low temperature and low-pressure refrigerant enter the evaporator section where it extracts heat from the body which is to be cooled. The body is subjected to the predetermined pressure between metal plate evaporators. The combined effect of cooling and pressure application causes rapid freezing of the product which is kept between plates.

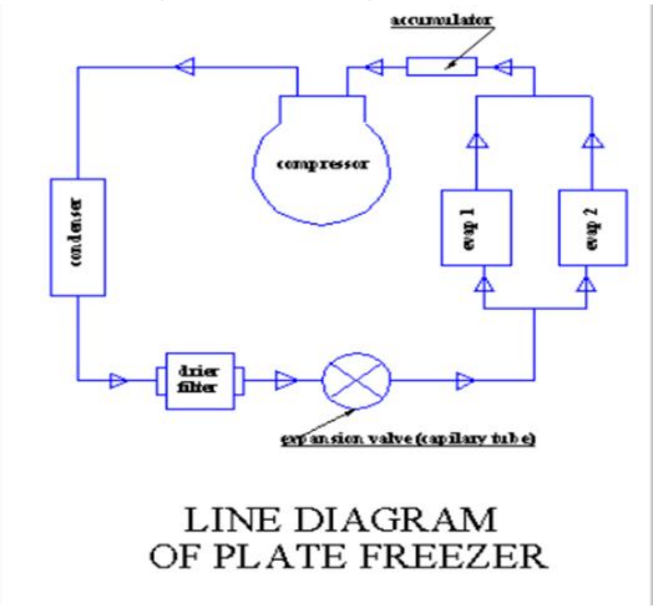

Fig.1 Schematic diagram of plate freezer

III. INPUT DATA FOR DESIGN

CHILLING LOAD CALCULATION: -[1]

Let’s select chocolate of quantity 2kg to get cool in 20 min
t_1=space that is chamber temp= -5°c
t_2= initial temp=30°c
Chilling load

$$Q_1 = w \times s \times \frac{t_2 - t_1}{\{\text{chilling time} \times \text{chilling factor}\}}$$

Where,
w=weight of product that must be frozen=2 kg
chocolate heat=latent heat for 1-day storage=2.32 kj/kg
specific heat before freezing=2.34 kj/kg k
specific heat after freezing =1.26 kj/kg k
chilling factor =0.5
latent heat of fusion =93 kj/kg

$$Q_1 = \frac{2 \text{ x } 2 \text{ x } (303\text{-}268)}{20 \text{ x } 60 \text{ x } 0.5}$$

Q_1= 0.273kw

$$\text{Freezing load } (Q_2) = \frac{\text{w x latent heat}}{\text{freezing time}}$$

$$Q_2 = \frac{2x93}{20x60}$$

Q_2 = 0.155kw
Cooling load below freezing
T_1=-5°c
T_2=-25°c
Q_3={w x specific heat after freezing x (t_1-t_2)}/freezing time
Q_3={2x1.26(25-5)}/20x60
Q_3=0.042kw

Volume of space
wall gain load=0.48 x0.5x0.2
=0.048m^3
Total surface area = 2 x(0.48x0.5+o.5x0.2+o.2x0.48)
= 0.872m^2
Q_w= k x s x (t_1-t_2)/ΔX
Where k=thermal conductivity of polyurethane foam insulation =0.033 w/mk
Where s=surface area of outer wall of insulating chamber
ΔX=insulation thickness =60mm=0.06m
Q_w= 0.033xo.872(30+25)/0.06
= 0.026 kw
Q = Q_1+Q_2+Q_3+Q_w
Q = 0.496KW
REFRIGRATION CAPACITY= Q/3.516
REFRIGERATION CAPACITY=0.141 TR

1] COMPRESSOR CAPACITY & DESIGN: -
At compressor entry of refrigerant
h_1=383 kj/kg;
h_2=438 kj/kg
h_3=h_4=232.23 kj/kg
At comp discharge of refrigerant
T_2=30°c;
R.E.= (h_1 - h_4)
= 383-232.234
RE = 150.77 kJ/kg
Work done by compressor = h_2 - h_1 = 55 kJ/kg
RC= m x RE
m =3.28 x 10^{-3} kg/sec
compressor capacity = m x Δh
= 3.28 x 10^{-3} x 55
= 0.18 kw

Compressor selection
Compressor power=1/3 hp
Motor specification=Power-300 W; Single phase; 50 Hz; 230 V; 2.7A

2] CONDENSER CAPACITY & DESIGN
Inside diameter =8.05 x 10^{-3} m
Outside diameter = 9.525 x 10^{-3} m
Assume 7° drop in R134 at condenser
Let’s assume desired temp of condenser be 55°c
Q_c = m_r (h_2-h_3)
= 3.28 x 10^{-3} x (438-232.23)
Q_c = 0.67 kw
Mean temp of refrigerant in condenser
Tm_r = 55-(7/2)
Taking Tm_r = 51.5°c
prop of R134a at temp k = 0.0172w/mk
$\dot{\rho}$ = 1095.215kg/m^3
absolute viscosity (μ_r) = 1.5 x 10^{-4} kg/m s
C_{pr}=1.59kj/kg k
Inside area of condenser tube A_i = (Π/4) x d^2
= (Π/4) $(8.05\text{x}10\text{-}3)^2$
= 5.0895 x 10^{-5} m^2
Remolds no.= (D_i x M_r) / (μ_r x A_i)
=3458.63
P_r = μ_r x Cp_r/k_r
P_r = 13.8
N_u = 0.026 x $P_r^{(1/3)}$ x $R_e^{0.8}$
=0.26 x $13.8^{1/3}$ x $3458.63^{o.8}$
N_u = 42.27
N_u= (H_i*D_i) / K_r
H_i = 90.31 w/mk
Where
H_i=refrigerant side heat transfer coefficient
Air side heat transfer coefficient

$$Q_a = \frac{\text{condenser capacity}}{\dot{\rho}_a \text{ x } Cp_a \text{ x } \Delta t_a}$$

$$= \frac{0.67}{1.185 \text{ x } 1.00464 \text{ x } 25}$$

Q_a = 0.022m^3/sec
A_f = Q_a/v_a
= 0.022/3
= 0.0073m^2
D_e= (0.073 x 4 /66375) x 5
= 0.023m

Tm_a=42.5°c
K_a= 0.0427w/mk
$\dot{\rho}_a$= 1.1193kg/m^3
μ_a= 2.008 x 10^{-5} kg
P_r= 0.755 kj/kg k
R_e= $\dot{\rho}_a$ x D_a x V_a/μ_a
=1.1193 x 12.67 x 3/2.008 x 10^{-5}
=2119.59 w/m^2k
$H_a < H_i$
Providing fins
Tube wall thickness is small it can be neglected
$1/u= \{(1/H_i) \text{ x } (A_o/A_i)\}+1/h_o$
U=15.43w/mk

$$\text{LMTD}=18.03 = \frac{(55-30)-(55-42.5)}{\ln\left(\frac{25}{42.5}\right)}$$

Now surface area= A_e

$$= \frac{Q_c}{U*LMDT}$$

$$= 0.866 \text{ x } \frac{10^3}{15.43 \text{x } 18.03}$$

$$A_e= 3.091m^2$$

Taking 15=ratio to bore area
Bore surface = 3.091/15=0.206m^2
Length of tube required= L = $0.206/\mathit{\Pi}\ x\ Do$
L=5.17 m

<u>Condenser specification</u>

Heating capacity = 0.67 Kw
Inside tube diameter = 8.05*10^{-3}m
Outside tube diameter = 9.525*10^{-3}m
Mass flow rate of refrigerant = 3.28*10^{-3} Kg/s
Length of tube = 5.17 m

3] EXPANSION DEVICE

Selecting expansion valve as capillary tube with 4mm outer diameter.

4] <u>EVAPORATOR PLATE</u>

Assume 9°c drop
Refrigerant temp=-25-9/2
Refrigerant temp=-20.5°c
Outside dia of tube taken=9.525x10^{-3}m
Inside dia of tube taken=8.025x 10^{-3}m

<u>Prop of R-134a at -20.5°c</u>

$\dot{\rho}$ =1351.67 kg/m^2 ,
μ=350 x 10^{-6} pa-s
Cp_r=1.25x 10^3 j/kg k
k_r=102 x 10.3 w/mk
$R_e=(D_i \text{ x } m_r) / (A_i \text{ x } \mu_r)$
R_e=1488.72
$N_u=0.026 \text{ x } pr^{1/3} \text{ x } Re^{o.8}$
N_u= 14.58
H_i=Nu x Kr/Di
H_i= 185.32w/m^2k
Ho=?
Taking mean temp of glycol 27°c
K_g =248.9 w/mk
LMTD={(27-(-25)-(-15-(-25))}/ln(52/10) ,
LMDT=25.47°c
Overall heat =$\{(1/u)+(X_1/kg)+(X_2/ K_c)\}$
where ,
H_i = refrigerant side heat transfer ; X_1=thickness of plate
K_c=thermal conductivity of Cu ; K_g=thermal conductivity of glycol
(X_1/u)=(0.05/249)
(X_2/Kc)=(0.01/386)
U=178.58 w/m^2k
Q=U*A* (LMTD)
A=Q/U*(LMTD)
A=0.514m^2
Total pipe length = A/(Π X D_o)
L_{ep} = 5.1456m

<u>EVAPORATOR SECTION SPECIFICATION FOR ONE PLATE [6]</u>

Outer cross section of tube = 12x12x10-6 m
Inner cross section of tube = 10.5 x 10.5 x 10-6m
Length of aluminum tube in each evaporator plate = 3.3 m
Area of plate = 35.4 x 33 cm2
Plate thickness = 1cm

IV. EXPERIMENTAL EVALUATION

From the experimental evaluation shown below

T1	T2	T3	T4
-9	55	42.5	-20
-6	57	44	-22
-5	59	46.5	-24

Table 1.Experimental temperature

P1 [PSI]	P2 [PSI]
35	230.6
38	232
40	235

Table 2. Pressure gauge readings

VOLUME KEPT IN EVAPORATOR [LIT]	FREEZING TIME [MIN]	FREEZING RATE [LPM]
1	35	0.028
1.5	47.5	0.0315
2	59.8	0.033

Table 3. Water readings

V. RESULT

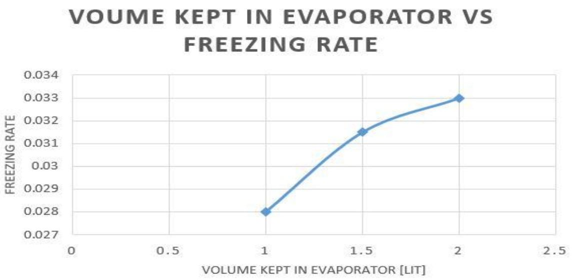

Figure 2. Volume kept in evaporator vs freezing rate

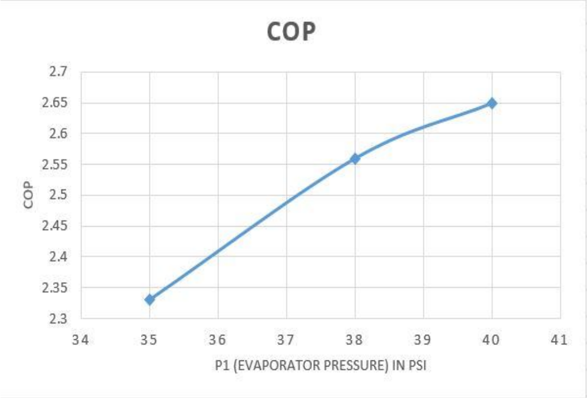

Figure 3.COP vs P1 (evaporator pressure)

Generally normal refrigerator has COP about 2.3
For our system COP can be estimated as follows:-
COP IDEAL $=(T_1-T_4)/(T_2-T_1)$
Where.
T_1= Refrigerant temp before compressor
T_2=Refrigerant temp after compressor.
T_3= Refrigerant temp at the end of condenser.
T_4=Refrigerant temp at evaporator entry.
t= time required to solidify the liquid chocolate.

%Increase in COP $= \frac{2.51-2.3}{2.5}*100$
%increase in COP = 8.36

VI. CONCLUSION

The proposed system of plate freezer enhances the COP by 8.36% as compared to the normal conventional refrigerator.

The system reduces the large mass flow rate requirement very efficiently because of parallel flow system through the evaporator section.

The freezing rate is considerably reduced for the same volume as compared to the conventional refrigerator nearly by half of the time required.

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