Design of An Innovative Refrigerated Display Cabinet

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***Abstract*—An innovative refrigerated display cabinet is an open refrigerator designed with a PVC curtain and air curtain. This is acts as an artificial door between the cabinet and outside area. In this paper we have discussed the comparison between air curtain and PVC curtain. Due to transparency of PVC material customer can see the product and access the product. The purpose of using PVC strip curtain is to keep cabinet temperature between -2°Cto +6°C and food product temperature between 0°C to +6°Cwhere as air curtain, cabinet temperature can be obtained +6°C to +9°C and food product temperature +12°C to +22°C. Thus it has been observed that electrical energy consumption including compressor power and fan power is to be 1.63KWh/day for air curtain and 1.12KWh/day for PVC curtain.**

Keywords*—*PVC Curtain, Air Curtain

I. Introduction

In market, there are two types of refrigerators available according to their applications that is open refrigerated display cabinet and closed refrigerated display cabinet. An open refrigerated is most commonly used in big markets, malls and grocery shops. And the closed type refrigerated is having limited use for domestic purpose.

A. Closed refrigerated display cabinet-

A closed refrigerated is most widely used for domestic purpose. It is not used in supermarkets,malls because of more number of door opening frequency. An experimental study was performed to investigate the effect of operating conditions such as door opening frequency, product ambient temperature,volume occupied by the product, ambient conditions inside the closed refrigerated display cabinet. Due to higher door opening frequency the food product temperature inside the cabinet is affected[1].

B. Open refrigerated display cabinet-

Open type refrigerated is used in supermarkets because it has an extra use over the closed type refrigerated display cabinet. Feature of an open type refrigerated display cabinet is that it provides an ample space which is more than convenient to use. A night curtain is introduced when operating at night to enable power saving. CFD comparisons of open-type refrigerated display cabinets with/without air guiding strips result show that the air guiding strips decrease both the temperature of the chilled food products and the cooling capacity consumption [2].

In the present paper, comparison between refrigerator enclosed with PVC strip curtain and air curtain has studied. In open type refrigerated display cabinet there is absence of door between the inside cabinet and warm ambient air. This type of arrangement gives easy access of food to the consumer to choose their product. Here, a refrigerator is designed with air curtain and PVC curtain which behaves similar to the door provided in the close type refrigerated display cabinet. It consists of two shelves including grill shelf and bottom panel where food products are kept. Either air curtain or PVC curtain is introduced for obtaining lower food product temperature. Usually open refrigerated display cabinet uses air curtain. The solution provided here use of PVC curtain in place of air curtain. Design presented below is of machine which can compare open display cabinet using air curtain and PVC curtain.

a) *Innovative refrigerator with air curtain-*

Air curtain is created in the front part of the refrigerator to avoid cooling loss and protect food products from surrounding heat. Air flows over evaporator coil to get cooled. This air forced up through the duct using three fans and flows vertically downward through honeycomb which act air curtain. Air curtain velocity was 0.3m/sand air curtain temperature was

14°C. For cooling the cabinet, air is entering from backside perforated sheet to the cabinet area as shown in Fig1.

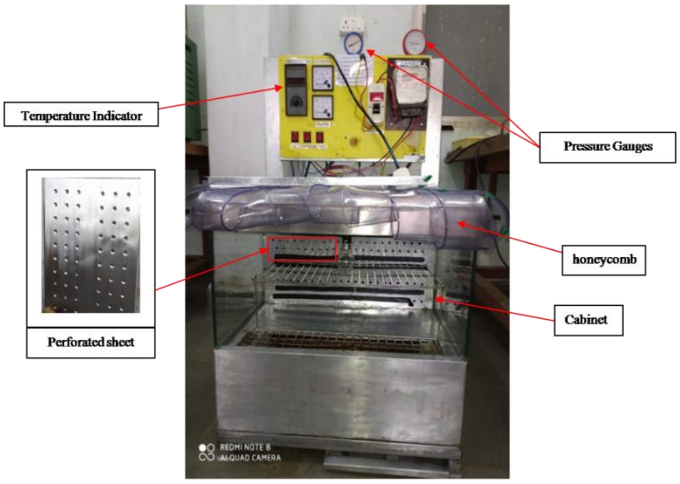

Fig.1. Innovative refrigerator with air curtain

With the use of air curtain, cabinet temperature at the back side of the cabinet is found to be +6°C and in front, it is found to be +9°C.Cooling capacity is 2.4336KW.

b) *Innovative refrigerator with PVC curtain-*

Air curtain is replaced by PVC curtain. In this type of refrigerator air flow to honeycomb is completely stopped using damper so that air curtain is closed. This Poly Vinyl Chloride (PVC) curtain is highly stretchable and transparent in nature. Due to its transparency, customer can see the food product inside the cabinet and can access it.

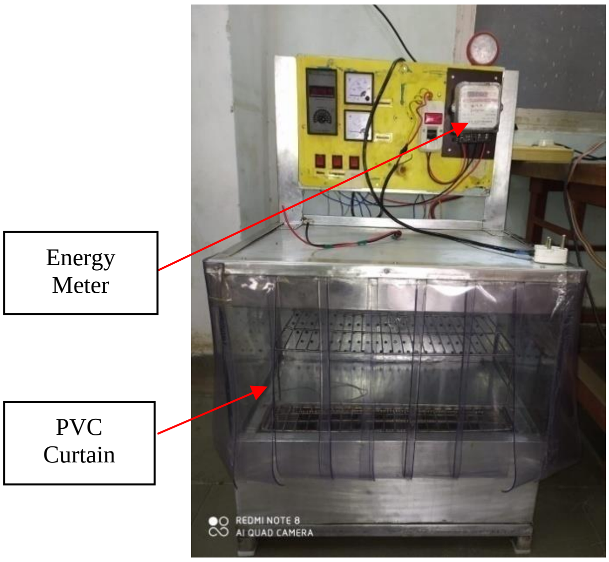

Fig. 2. Innovative refrigerator with PVC curtain

This curtain is created in the form of strips. This completely closes the front part of the refrigerator. Therefore, it protects the food product temperature inside the cabinet from the atmosphere. With the use of PVC curtain, cabinet temperature at the back side of the cabinet is found to be -2°C to 0°C and at the front side of the cabinet it is found to be +3°C to +6°C. Cooling capacity is 2.6325 KW. Electrical energy consumption including compressor power and fan power is calculated 1.6278KWh/day for air curtain and 1.118KWh/day for PVC curtain.

II. DESIGN CALCULATION FOR PVC CURTAIN

Calculation is done with the help of [3],[4],[5]

Assumed

Evaporator temperature = -5°C

Condenser temperature = 62°C

Hence, from Ph chart

High pressure = 9.6 bar

Low pressure = 2.66 bar

$$h_1 = 414 \text{ KJ/kg}$$

$$h_2 = 448 \text{ KJ/kg}$$

$$h_4 = h_3 = 238 \text{ KJ/Kg}$$

Compressor capacity= $\frac{3}{4}$ Ton

$$\therefore Q_{evp} = \frac{3}{4} \times 3.51$$

$$\therefore Q_{evp} = 2.6325\text{KW}$$

Calculation of mass flow rate

$$Q_{evap} = \dot{m}_r \times (h_1 - h_4)$$

$$\therefore 2.6325 = \dot{m}_r \times (414 - 238)$$

$$\therefore \dot{m}_r = 0.0149 \text{ kg/sec}$$

$$\therefore \dot{m}_r = 53.84 \text{ kg/hr}$$

Calculation of heat transfer rate of compressor

$$Q_{comp} = \dot{m}_r \times (h_2 - h_1)$$

$$\therefore Q_{comp} = 0.0149 \times (448 - 414)$$

$$\therefore Q_{comp} = 0.5066 \text{ KW}$$

Calculation of heat reject rate of condenser

$$Q_{cond} = \dot{m}_r \times (h_2 - h_3)$$

$$\therefore Q_{cond} = 0.0149 \times (448 - 238)$$

$$\therefore Q_{cond} = 3.129 \text{ KW}$$

Calculation of coefficient performance

$$C.O.P = \frac{Q_{evap}}{Q_{comp}}$$

$$C.O.P. = \frac{2.3625}{0.5066}$$

$$C.O.P. = 4.66$$

A. *Design of Evaporator*

a) *Refrigerant side*

$$\dot{m}_r = \rho_v \times A \times V_{rv}$$

$$\therefore 0.0149 = 12.071 \times \frac{\pi}{4} \times (9 \times 10^{-3})^2 \times V_r$$

$$\therefore V_r = 19.40 \text{ m/s}$$

Calculation of Reynolds number for heat transfer coefficient between the evaporator tubes

$$\text{Re} = \frac{\rho_v \times D \times V_{rv}}{\mu_v}$$

$$\therefore \text{Re} = \frac{12.071 \times 9 \times 10^{-3} \times 19.40}{10.53 \times 10^{-6}}$$

$\therefore \text{Re} = 200.15 \times 10^3$ (hence Re > 4000 = Turbulent flow)

Calculation of heat transfer coefficient for turbulent flow

$$h_i = 0.023 \times \frac{K_v}{D} \times (\text{Re})^{0.8} \times \left(\frac{C_{pv}}{K_v} \times \mu_v \right)^{0.4}$$

$$\therefore h_i = 0.023 \times \frac{11.085 \times 10^{-3}}{9 \times 10^{-3}} \times \left(200.15 \times 10^3\right)^{0.8} \times \left(\frac{0.8755 \times 10^3}{11.085 \times 10^{-3}} \times 10.53 \times 10^{-6} \right)^{0.4}$$

$\therefore h_i = 458.44$ W/m^{2}K

b) Evaporator tubes

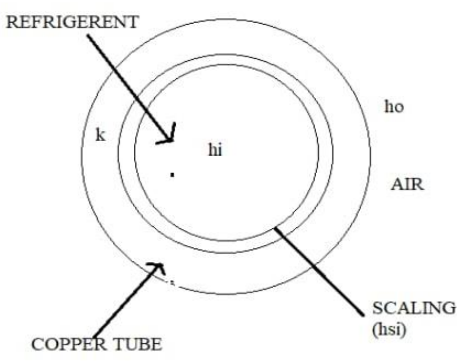

Fig. 3. Evaporator Tube

Calculation of overall heat transfer coefficient

$$U_o A_s = \frac{1}{\frac{1}{h_i A_i} + \frac{1}{hs_i A_{si}} + \frac{1}{2\pi L K_{Cu}} \times \ln\left(\frac{r_2}{r_1}\right)}$$

Considering fouling factor as 0.0002

$\therefore U_O \times \pi \times 10 \times 10^{-3} \times L$

$$= \frac{1}{\frac{1}{458.44 \times \pi \times 9 \times 10^{-3} L} + \frac{0.0002}{9 \times \pi \times L \times 10^{-3}} + \frac{1}{2\pi L \times 385} \times \ln\left(\frac{5}{4.5}\right)}$$

$\therefore U_O$=377.74 W/m^{2}K

c) Pressure drop in Evaporator

f = friction factor = 0.046(Re)$^{-0.2}$

$$f = 0.046 \times (200.15 \times 10)^{-0.2}$$

$$f = 4.003 \times 10^{-3}$$

$$\text{pressure drop} = \Delta P = \frac{f L V_{rv}^{\ 2} \rho_v}{2D}$$

$$\Delta P = \frac{4.003 \times 10^{-3} \times 4.8 \times 19.40^2 \times 12.071}{2 \times 9 \times 10^{-3}}$$

$\Delta P = 4849.54$ Pa

B. Design of Condensor

a) Refrigerant side

Calculation velocity of liquid refrigerant in condenser

$$\dot{m}_r = \rho_l \times A \times V_{rl}$$

$$\therefore 0.0149 = 1042.2 \times \frac{\pi}{4} \times (9 \times 10^{-3})^2 \times V_{rl}$$

$\therefore V_r = 0.224$ m/s

Calculation of Reynolds number for heat transfer coefficient between the condenser tubes

$$\text{Re} = \frac{\rho_l \times D \times V_{rl}}{\mu_l}$$

$$\therefore \text{Re} = \frac{1042.2 \times 9 \times 10^{-3} \times 0.224}{120.6 \times 10^{-6}}$$

$\therefore \text{Re} = 17.42 \times 10^3$ (hence Re >4000 = Turbulent flow)

Calculation of heat transfer coefficient for turbulent flow

$$h_i = 0.023 \times \frac{K_l}{D} \times (\text{Re})^{0.8} \times \left(\frac{C_{pl}}{K_l} \times \mu_l \right)^{0.4}$$

$$\therefore h_i = 0.023 \times \frac{65.2 \times 10^{-3}}{9 \times 10^{-3}} \times \left(17.42 \times 10^3\right)^{0.8} \times \left(\frac{1.684}{65.2} \times 120.6 \right)^{0.4}$$

$\therefore h_i = 648.55$ W/m^{2}K

b) Air Side

Assuming air flowing at condenser be 400CFM and size of inlet air cabinet be of diameter 35cm

$\dot{Q}_a = 400$ CFM $= 0.1887$ m^3/sec

$$A = \frac{\pi}{4} \times 0.35^2$$

$$A = 0.0962\ m^2$$

Inlet air velocity

$$V_a = \frac{\dot{Q}_a}{A}$$

$$V_a = \frac{0.1887}{0.0962} = 1.96 \text{ m/sec}$$

$$\text{Re} = \frac{\rho_a D V_a}{\mu_a}$$

$\rho_a = 1.225$ kg/m^3 *and* $\mu_a = 1.81 \times 10^{-5}$ N-s/m

$$\text{Re} = \frac{1.225 \times 9 \times 10^{-3} \times 1.96}{1.81 \times 10^{-5}}$$

$\text{Re} = 1193.86$

$$h_a = 0.0683 \times \frac{K_a}{D} \times (\mathrm{Re})^{0.466} \times \left(\frac{C_{pa}}{K_a} \times \mu_a\right)^{0.333}$$

$C_{pa} = 1.005$ KJ/kg

$K_a = 0.024$ W/mK

$$h_a = 0.0683 \times \frac{0.024}{10 \times 10^{-3}} \times (1193.86)^{0.466}$$

$$\times \left(\frac{1.005 \times 1.81 \times 10^{-5} \times 10^{3}}{0.024}\right)^{0.333}$$

$h_a = 4.05$ W/m^{2}K

c) *Condenser tubes*

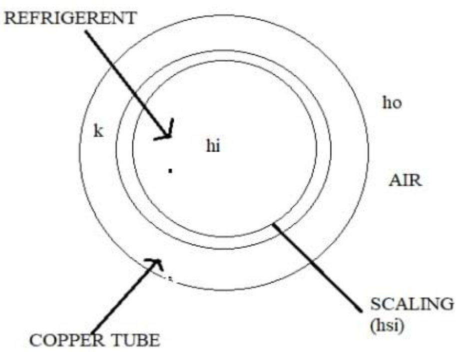

Fig. 4. Condenser Tube

Overall heat transfer coefficient

$$U_O A_s = \frac{1}{\frac{1}{h_i A_i} + \frac{1}{hs_i A_{si}} + \frac{1}{2\pi L K_{Cu}} \times \ln\left(\frac{r_2}{r_1}\right) + \frac{1}{h_o A_{so}}}$$

Considering fouling factor as 0.0002 (due to liquid refrigerant)and outer diameter as 10mm.

$\therefore U_O \times 10 \times \pi \times L \times 10^{-3}$

$$= \frac{1}{\frac{1}{648.55 \times \pi \times 9 \times 10^{-3} \times L} + \frac{0.0002}{9 \times \pi \times L \times 10^{-3}} + \frac{1}{2\pi L \times 385} \times \ln\left(\frac{5}{4.5}\right) + \frac{1}{4.05 \times \pi \times 10 \times 10^{-3} \times L}}$$

$\therefore\ U_O$=4.01 W/m^{2}K

d) *Fins*

Consider a single fin of size 200mm × 350mm and tube has external diameter of 10mm.

Thickness of fins(y) =0.5mm
No. of holes on fin=48
Total area of fin=area of square-area of circle

$$\therefore\ A = (200 \times 350) - 48\left(\frac{\pi}{4} \times 10^2\right)$$

$\therefore A = 66230.08 \times 10^{-6}$ m^2

Width of fin (b) =200mm

Perimeter of fin (P) $= 2 \times (b + y)$

$P = 2 \times (200 \times 10^{-3} + 350 \times 10^{-3})$

$\therefore$ P = 1.1 m

$A_{cs} = b \times y$

$\therefore A_{cs} = 0.2 \times 0.5$

$\therefore A_{cs} = 100 \times 10^{-6}$ m^2

Number of fins on condenser

$\therefore h = 4.05$ W/m^{2}K (from air side heat transfer coefficient)

$\therefore$ P = 1.1 m (perimeter of fins)

$\therefore K_{Al} = 225$ W/mK (thermal conductivity of fins)

$\therefore l = 350 \times 10^{-3}$ m (length of fin)

For calculation heat transfer rate of fin
Constant value for fin=m

$$m = \sqrt{\frac{h_a \times P}{K_{Al} \times A_{CS}}}$$

$$\therefore\ m = \sqrt{\frac{4.05 \times 1.1}{225 \times 100 \times 10^{-6}}}$$

$\therefore\ m = 14.07$

$$Q_{fin} = \sqrt{h_a \times P \times K_{Al} \times A_{CS}} \times (t_a - t_o) \times \tanh(ml)$$

$t_a =$ condenser outlet temperature

$t_o =$ evaporator outlet temperature

$$= \sqrt{4.05 \times 1.1 \times 225 \times 1 \times 10^{-4}} \times (62 - 27) \times \tanh(14.07 \times 0.35)$$

$\therefore\ Q_{fin} = 11.07$ W (For 1 fin)

Number of fins=140

$\therefore Q_{fin} = 1551.19$ W

e) *Pressure drop in condenser*

$f = 0.046(\mathrm{Re})^{-0.2}$

$f = 0.046 \times (17.42 \times 10^{3})^{-0.2}$

$f = 6.52 \times 10^{-3}$

$$\text{Pressure Drop} = \Delta P = \frac{f L V_{rl}^{2} \rho_l}{2D}$$

$$\Delta P = \frac{6.52 \times 10^{-3} \times 19.2 \times 0.224 \times 1042.2}{2 \times 9 \times 10^{-3}}$$

$\Delta P = 1623.58$Pa

III. SELECTION OF EQUIPMENT

1. Compressor -

Hermetically sealed reciprocating compressor for refrigerant R134a.
Capacity- ¾ Ton
Input power- 1700 W
Input current- 7.9A

2. Condenser
Plate fin and tube type Air cooled condenser
i. Material of tubes – Copper
Length of tube- 19.2 m
Outer diameter – 10mm
Inner diameter- 9mm
ii. Fins
Material of fins – Aluminium
No of fins – 140
Thickness of fins – 0.5mm
Length of fin- 350mm
Width of fin- 200mm

3. Evaporator
Plate fin and tube type Air cooled evaporator
i. Evaporator coil
Material of tubes – Copper
Length of tube- 4.8 m
Outer diameter – 10mm
Inner diameter- 9mm
ii. Fins
Material of fins – Aluminium
No of fins – 64
Thickness of fins – 0.5mm
Length of fin- 101.6mm
Width of fin- 101.6mm

4. Expansion device
Type – capillary tube
Material – Copper
Assumed dimensions using dan cap software

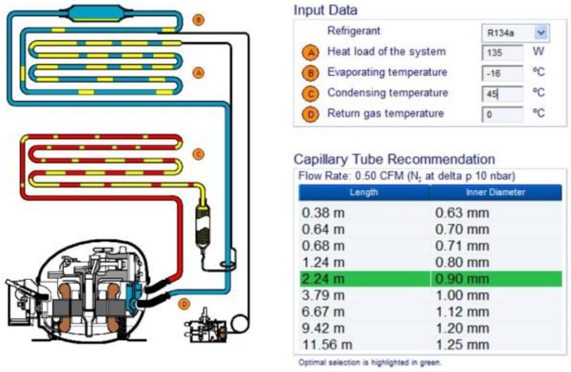

Fig. 5. Selection of capillary tube using Dancap Software

Length of tube –2.24m
Diameter of tube- 0.80 mm
Actual dimensions
Length of tube-203.2mm
Diameter of tube-0.55mm

5. Fan
No of fans used-3
Dimensions – 120×120×30mm
Ac – 220-240v
Current – 0.14A
Frequency- 50/60Hz

6. Honeycomb
Honeycomb is used for laminar flow of air curtain.
Dimensions- 500×50×50 mm

IV. CONCLUSION

An innovative refrigerated display cabinet is designed, using PVC curtain and air curtain which acts as an artificial door between the cabinet and atmospheric air. This will helpful for reducing energy consumption by refrigerator.

V. NOMENCLATURE

Symbol	Meaning	Unit
L	Length	m
b	Width	m
y	Thickness	m
A	Area	m^2
P	Perimeter	m
t	Temperature	°C,K
V	Velocity	m/s
$\dot{m}$	Mass flow rate	Kg/s
Q	Heat transfer	KW
h	Enthalpy of refrigerant	KJ/kg
ρ	density of refrigerant	kg/m^3
μ	Dynamic viscosity of refrigerant	N-s/m
v	Specific volume of refrigerant	m^3/kg
c_p	Specific heat at constant pressure of refrigerant	J/kgK
h	Heat transfer coefficient	W/m^2K
K	Thermal conductivity of refrigerant	W/mK
U_o	Overall heat transfer coefficient	W/m^2K
ΔP	Pressure drop	Pa
r	Radius of tube	m
$\dot{Q}_a$	Volume flow rate	m^3/s
f	Friction factor	
PVC	Poly Vinyl Chloride	

Subscript	Meaning
$evap$	evaporator
$cond$	condenser
$comp$	compressor
r	refrigerant
cs	cross section
i	Inner Side
o	Outer Side
l	liquid
v	vapour
a	air
$1,2,3,4$	at point 1,2,3,4 resp.
s	Surface
Cu	copper

Al	Aluminium

Dimensionless numbers	**Meaning**
Re	Reynolds number
Pr	Prandtl number
Nu	Nusselt number

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