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Design Analysis of Plate Freezer

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Abstract

In a country like Myanmar, meat, fruit, vegetables and fish are very affected to microbial and spoilage and required severe preservation methods. One such method is by the use of a plate freezer for the storage of frozen food. The convection freezer could not confront with this higher rate of freezing. The plate freezer consists of two plates connected in parallel. Refrigerant R-134a flows inside the plate type evaporator tube and it can reduce causing the ozone depletion. In this paper, the experimental data of plate freezer were found with the conditions that evaporating temperature is -16.5°C, condensing temperature is 43.7°C and meat temperature is -12.9 °C. The temperature of meat decreases with increasing time in operation. From calculations, total cooling load of plate freezer is 228 kW, the refrigeration capacity is 297 W (0.0844 TR), refrigerant effect is 125, the mass flow rate is 2.375×10^{-3} kg/s, motor power is 139 W, the coefficient of performance is 2.98, the mass flow rate is 2.375×10^{-3} kg/s, evaporator tube length is 9.22m, condenser tube length is 11.77m and capillary tube length is 2.89m.

Keywords: Freezer; Refrigerant and meat temperature

1. Introduction

Freezers have become a household necessity since they were first introduced to consumers in the late 1940s. Not only do freezers have the ability to keep foods, freezing meats protects them from bacteria, mildew and rot. [1]Today it can be difficult to plan the home without at least one freezer though. They have become one of the most common ways for people to preserve meat. [2] An every product requires deferent storage temperature for maintaining the quality of eatable or potable material. It is the process of removing heat from an enclosed space, from a substance, and rejecting it elsewhere for the primary purpose of lowering the temperature of the enclosed or substance. [3] Many people prefer to shop less frequently and buy large quantities in order to save money and time. [2]

There are two types of freezer. They are upright freezer and chest freezer. Upright freezer opens like a basic refrigerator. [4] Advantages: An upright freezer may cost a little more than a chest freezer, but the convenience they offer makes the extra cost more than worth it. It is keep in the main kitchen or basement, usually auto defrosting, perfect for freezing foods , saving in floor space. [2] Their height is at eye level. [5] The food can be easily stored on shelf of plate and took because the compartments are stacked. Refrigerant R-134a was now widely used in most of the domestic freezers. This research is to construct the plate upright freezer using locally available materials.

2. Design and selection of Plate Upright Freezer components

In this paper, the design procedures are considered and calculated total cooling load and the design main components of the plate upright freezer, the compressor, condenser, evaporator and expansion device, each have their individual characteristics which are functions of evaporator and condenser temperatures. This various design aspects of components used in the existing system are explained.

Plate freezer is based on a vapour compression cycle. The vapour compression is one type of cyclic refrigeration where the refrigerant will flow through all the components process in a cycle. [3] The dimension of Plate upright freezer is 0.79×0.62×0.52 m³.The plate type evaporator freezer designed and constructed with two evaporator plates and the refrigerant enters the plate's evaporator coil which is arranged in parallel. The dimension of the plate tray is 0.47×0.05×0.44 m³.It formed inner surface of the evaporating chamber. The plate tray is used by zinc because it is cheaper than other materials and easy to buy from market. Line diagram of upright plate freezer is shown in Figure.1.

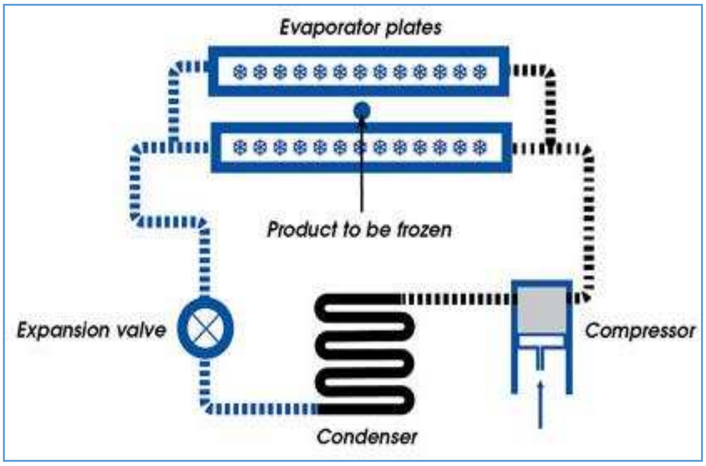

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Fig. 1 Line diagram of an experimental upright plate freezer

2.1. Total Cooling Load

The following are the various sources considered of the total cooling load can be divided into four separated loads the chilling load, the freezing load, the cooling load and the wall gain load. When a meat enters a storage space at a temperature above and below the temperature of the space, the product will give off heat until it cools to the space temperature.

In chilling load, the heat is removed from a meat to reduce its temperature above freezing (sensible heat).

$$Q_1 = \frac{W\, C_p\, \Delta T}{\text{chilling factor} \times \text{chilling time}} = 0.0489 \text{ KW}$$

In freezing load, the heat is removed from a meat for the latent heat of freezing.

$$Q_2 = \frac{W\, h}{\text{freezing time}} = 0.1031 \text{ KW}$$

In cooling load, the heat is removed from a meat to reduce its temperature below freezing. (Sensible heat)

$$Q_3 = \frac{W\, C_p\, \Delta T}{\text{freezing time}} = 0.0107 \text{ KW}$$

In wall gain load,

$$Q_4 = \frac{KA\,(T_1 - T_2)}{\Delta x} = 0.0657 \text{ kW}$$

Total cooling load is the sum of all the above loads are 228W. A factor of safety of 30% was used during the design of the upright plate freezer .This was found and added to the total cooling load. The required refrigerant capacity is usually taken as the load determined by the total cooling load calculations. Refrigeration Capacity is 297 W or 0.0844 TR. [6, 7, 8]

From ph chart of R-134a of condensing 43.7ºC and evaporating temperature−16.5ºC to calculate,

Refrigerant effect,

$$RE = h_1 - h_4 = 125$$

Mass flow rate of refrigerant,

$$m^o_R = \frac{\text{Refrigeration Capacity}}{\text{R.E}} = 2.3754 \times 10^{-3} \text{ kg/s}$$

2.2. Design of Compressor

The compressor capacity is based on the saturated suction and discharge temperatures. The compression of suction vapour from the evaporator to the condenser pressure can be achieved by the use of compressor .It should take least power, within a wide range of operating conditions. It must run trouble free for a long time. The compressor is located at the bottom of the plate freezer and accessed at the back. Figure.2 shows compressor of plate freezer. [6, 7, 8]

Design procedure,

Enthalpy of refrigerant at compressor suction, h_1=388kJ/kg

Enthalpy of refrigerant at compressor discharge, h_2=430kJ/ kg

Capacity of compressor,
$Q_{com} = m^{o}_{R} (h_2-h_1)$ = 0.09976 kW
Motor power required,
$Pmotor = \frac{Wmotor}{\eta_e \times \eta_m}$ = 139 Watt
Coefficient of Performance, $COP = \frac{h_1 - h_4}{h_2 - h_1}$ = 2.976

Fig .2The Hermetic type of reciprocating Compressor

2.3. Design of Plates Surface Evaporator

Fig.3 Zinc Plate with evaporator coil

A refrigerant in liquid form will absorb when it evaporates and it is this conditional change that produces cooling in refrigerating process. The capacity of an evaporator is the rate at which heat will pass through the evaporator tubes from the refrigerated. The surface area, the value of U and the capacity of the evaporator depend upon air and refrigerant temperature between the cooling coil and the refrigerated space and is in tube coil with refrigerant flow. The plate surface evaporator formed inner surface of the evaporating chamber. The evaporator is connected at one end to the capillary tube and at the other end to the compressor. The material of copper is used for evaporator. Figure.3 shows plate surface evaporator.

Design procedure,

Evaporating temperature of refrigerant, $T_{eva} = -16.5°C$

Enthalpy of refrigerant at entering evaporator,

$h_1 = 388$ kJ/kg

Enthalpy of refrigerant at leaving evaporator,

$h_4 = 263$ kJ / kg

Outside diameter of the tube taken, $D_o = 8mm$

Inside diameter of the tube taken, $D_i = 6mm$

$\Delta T = T_{air} - T_r = 40.1°C$

$Q_{eva} = m°_R (h_1 - h_4)$ = 0.296925 KW

$Nu = 0.026 \times Pr^{0.333} Re^{0.8}$ = 21.3

$h_i = Nu \times \frac{K}{D_i}$ = 214.2×10^3 W/m^2K

Overall heat transfer coefficient,

$\frac{1}{U} = \frac{1}{h_i} + \frac{X_2}{K_{zi}} + \frac{1}{h_a}$ U = 32 W/m^2 K

$Q = U \times A \times \Delta T$, $A = 0.23917 m^2$

$A = \pi \times D_o \times L$, L= 9.219m

2.4. Design of Condenser

Fig.4 Condenser

This is the Natural convection of air-cooled used the in the plate freezer. The condenser is located at the bottom of the plate freezer and accessed at the back. The purpose of the condenser is to remove the amount of heat that is equal to the sum of the heat absorbed in the evaporator and the heat produced by compression. While designing the actual refrigeration cycle, the condenser load is expressed. However, the required capacity which is more than the refrigeration load, so in designing the condenser coil we have to consider this load to be the refrigeration load, as this increases the load on capacity of the condenser. The condenser is connected at one end to the capillary tube and at the other end to the compressor. The material of iron is used for condenser. Figure.4 shows condenser of plate freezer. [6, 7, 8]

Design of procedure,
The desired temperature and pressure of condenser is 43.7°C and 11.21bar respectively
Enthalpy of refrigerant entering the condenser,

$$h_2=430 kJ/kg$$

Enthalpy of refrigerant leaving the condenser,

$$h_3=263 \text{ kJ/kg}$$

Temperature of the air reaching the condenser = 23.6ºC
Temperature of the air leaving the condenser = 33.6ºC
Temperature before passing condenser, $T_2 = 50ºC$
Outside diameter of the tube taken, $D_o = 5mm$
Inside diameter of the tube taken, $D_i = 3mm$
Condenser capacity,

$$Q_{con} = m^o{}_R (h_2 - h_3) = 0.397 \text{ kW}$$

Refrigerant-side heat transfer coefficient,

$$A_i = (\frac{\pi}{4}) D_i^2 \quad = 7.0686 \times 10^{-6} \text{ m}^2$$

Reynolds number, $Re = \frac{D_i \times m}{\mu A} = 6474$

Prandtl number, $Pr = \frac{C_p \mu}{K_r} = 3.24$

Nusselt number, $Nu = 0.026 \text{ x } (Pr)^{1/3} (Re)^{0.8} = 43$

$$h_i = \frac{(Nu \text{ x } K_r)}{D_i} = 1048 W/m K$$

Air side heat transfer coefficient,
Condenser capacity,

$$Q_a = \frac{\text{condenser capacity}}{q_a c_p \ \Delta T_a} = 0.0178 \text{ m/ s}$$

Face area, $A_f = \frac{Q_a}{V_a} = 8.9 \text{ x } 10^{-3} \text{ m}^2$

Reynolds Number, $Re = \frac{\rho \times D_e V}{\mu} = 11042$

Nusselt Number, $N_u = 0.026 \text{ x } (Pr)^{1/3} (Re)^{0.8} = 39.83$

$$h_o = \frac{(Nu \text{ x } K_r)}{D_i} \quad = 10.21$$

$$A_t = \frac{4}{\pi \ (D_i^2 + D_o^{\ 2})} \quad = 2.6703 \times 10^{-3}$$

Overall heat transfer coefficient,

$$\frac{1}{U_t} = \frac{1}{h_i} + \frac{A_t}{A_i} + \frac{1}{h_o} \quad , \qquad U_t = 9.85 \text{ W/m}^2 \text{ K}$$

Log Mean Temperature Difference,
Maximum temperature difference, $\Delta T_A = T_r - T_{ar}$
Minimum temperature difference, $\Delta T_B = T_r - T_{al}$

$$LMTD = \frac{\Delta T_A - \Delta T_B}{Ln\,(\frac{\Delta T_A}{\Delta T_B})} \qquad = 14.54$$

Heat transfer through the condenser walls is by conduction, condenser capacity equation:

$$Q = A\ U\ LMTD$$

Extended Surface area, $A_t = \frac{Q_c}{U\ LMTD} = 2.772\ m^2$

$$A_o = \pi \times D_o \times L, \quad L = 11.765\ m$$

2.5. Design of Expansion Device

Fig.5 Capillary Tube

Various expansion devices are used in refrigeration systems, in this construction is used capillary tube it is the most commonly used in small refrigeration and air conditioning systems. It is a metering device that controls the refrigerant flow by pressure drop. Pressure falls gradually as the liquid flows through the tube, until it starts to evaporate in the tube. The amount of refrigerant flow through the device is determined by the bore and length of the tube. Capillary tube is a simple drawn copper tube with a very small internal diameter. Figure.5 shows capillary tube of plate freezer. [6, 7, 8]

Design procedure,

Mass flow rate of refrigerant, $m^o{}_R = 2.3754 \times 10^{-3}$ Kg/s

Outside diameter of the tube taken, $D_o = 0.8$ mm

Inside diameter of the tube taken, $D_i = 2$mm

Point -1, $T_1 = 43.7^oC$, $P_1 = 112.1$ M Pa

Point -2, $T_2 = -16.5\ ^oC$, $P_2 = 1.542$ M Pa

$$A = \frac{\pi}{4} D_i^2 = 5.026548 \times 10^{-7}\ m^2$$

$$X = \frac{m^o{}_R}{A} = 4.73 \times 10^3\ kg/m^2s$$

$$Y = \frac{X}{2D} = 2.954 \times 10^6\ kg/m^3s$$

Mean velocity, $V_m = \frac{V_1+V_2}{2} = 3.8745$ m/s

$$F = \frac{f_1+f_2}{2} = 0.029243$$

Friction Pressure drop, $\Delta P_f = \Delta P - \Delta P_a = 9.669 \times 10^5 N/m^2$

Incremental Length, $\Delta L = \frac{\Delta P_f}{Y\ FV_m} = 2.889$ m

To get the desired temperature of meat and all of parts can be operated in the proper design condition. To perform this condition, the design all parts are important. If the dimensions of one part are larger or smaller, the operating condition cannot reach the desired temperature of meat. The Plate freezer specifications are given in Table 1.

Table 1. Plate freezer specifications

Plate upright freezer dimension	**0.79×0.62×0.52 m³**
Plates tray dimension	0.47×0.05×0.44 m³
Thickness of zinc plates	5mm
Type of compressor	Hermetic type of reciprocating compressor, $\frac{1}{5}$ hp, 123-146 W, Single Phase 50-60 Hz , 0.93-1.12 A ,230V
Type of refrigerant	HFCR-134a
Type of condenser	Natural convection air-cooled condenser
Type of evaporator	Plate of Evaporator
Type of expansion device	Capillary Tube
Weight of meat	1kg

3. Experimental Procedure

The plate freezer was constructed and tested during running. In the decreasing temperature experiment, fresh meat is used as the test sample in the plate upright freezer. Fig. 6 shows meat with plate upright freezer test in present work.

Fig. 6 Meat with Plate Upright Freezer Test in present work

Fig. A

Fig. B

Fig.7 Experimental test rig used

The experiment was carried out to determine the performance of the plate upright freezer. Plate upright freezer can also been seen in figure 7. To conduct the experiment, the following procedure has been adopted.

- A digital thermometer sensor is also used to measure the temperature of meat in the cold storage room.
- The temperature at various points on condenser and plate surface evaporator was noted using digital thermometer
- Meat with 1kg is placed between the two plate tray and which are brought closer so that the area of cooling reduces.
- As the plate area in direct contact with the meat, this is better for heat transfer and hence the freezing rate is increased in the meat and decreased their temperature in the meat.
- The experiment was carrying out one time per one hour.
- The temperature of meat decreases with increasing time in operation.
- The temperature of meat in plate tray was recorded with respect to time.
- This process was continued until the decrease temperature approached desired final in the meat.

In this work, the experimental data of plate freezer were found with the conditions that evaporating temperature, condensing temperature and meat temperature.

From the experimental data, the three graphs were plotted with variation of temperatures as a function of time.

4. Results and Discussion

From the experimental results of the design analysis of plate freezer affects the meat temperature; the evaporating temperature and the condensing temperature are compared by varying time. Experimental Results of variation of Vapour Compression Refrigeration System with respect to time was obtained and continued until the decrease temperature approached desired final in the meat.

Figure.8 shows the variation of meat temperature with time. The value of meat temperature high at the beginning of test and then the value of meat temperature low after nine hour. The evaporating temperature of vapour compression refrigeration system for experiment results by varying time is shown in Figure.9. The Condensing temperature of vapour compression refrigeration system for experiment results by varying time is shown in Figure.10.

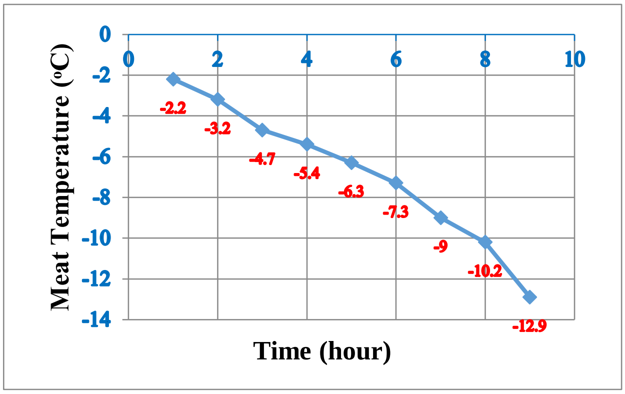

Fig. 8 Meat Temperature & Time

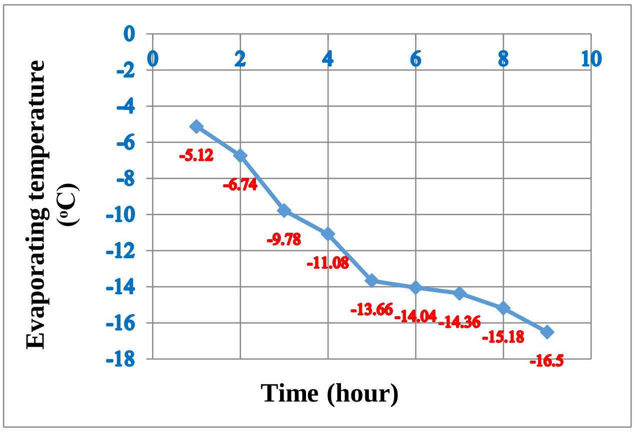

Fig. 9 Evaporating Temperature & Time

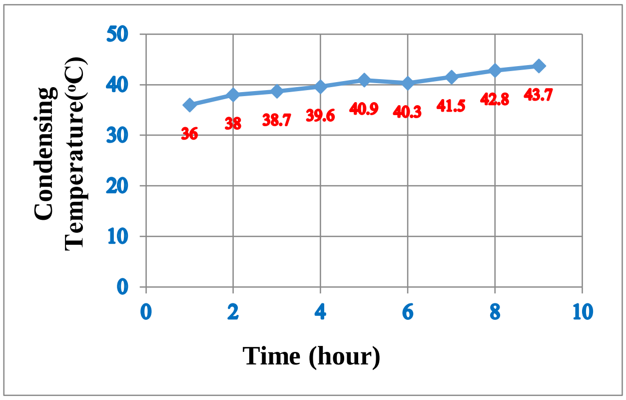

Fig.10 Condensing Temperature & Time

5. Conclusions

In summary, the plate upright freezer was constructed to decrease temperature of meat for long-lasting purposes. The experimental attended of the existing system shows the shortage of the flow rate of the refrigerant through the top plate. Experimental design analysis of plate freezer was carried out by testing a known temperature of meat in the system. We can get the temperature inside the plate freezer to be exact the same required temperature.

Also we can get different meat temperatures, evaporating temperature and condensing temperature by using this system. The temperature of meat decreases with increasing time in operation. The lowest temperature of meat is obtained -12.9^{o}C, evaporating temperature is obtained -16.5^{o}C and condensing temperature is obtained 43.7^{o}C after nine hour. The material of copper is used for evaporator and capillary tube, iron is used for condenser tube and zinc is used for plate tray.

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