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Design, Construction and Characterization of a Sliding- Plate-Evaporator Freezer (Spef)

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ABSTRACT
This work embodied the design, construction and characterization of a sliding plate evaporator freezer, a modified version of the conventional freezer. The presence of a sliding plate evaporator reduces the freezing area, to increase the freezing rate and with a reduced freezing time. The freezer is intended to freeze agro and allied products in a record time. This is achieved by incorporating sliding plate evaporators to a conventional freezer to have two or more freezing sources, thereby, also giving the freezer with the option of a deferring freezing area to increase freezing rate. The results obtained are not exactly matched with the designed objectives because of construction flaws; and modifications can be made to improve the Coefficient of performance. The Coefficient of performance of the SPFE is obtained to be 7.26. The SPEF is recommended for use in household and agro based industries for faster and effective freezing.
Keyword: Freezer, Sliding Plate, Evaporator, and Refrigerator, Freezer chamber, Compressor power, Condenser power and Co-efficient of performance.

1.1 Background of the Study

Refrigerator (colloquially fridge) is a common household appliance that consist of a thermally insulated compartment and a heat pump (mechanical, electronic, or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient. Cooling is a popular food storage technique in developed countries and works by decreasing or arresting the production rate of bacteria. The device is used to reduce the rate of spoilage of food stuffs.
A refrigerator maintains a temperature of a few degrees above the freezing point of water. Optimum temperature range for perishable food storage is 3 to 5^0C. A similar device which maintains a temperature below the freezing point of water is called a freezer. Conventional food preservation is done by keeping the food inside chambers having evaporator coils around it. This chamber is insulated from the surroundings by a casing. The vapor compression system is the most widely used system.
Vapor Compression cycle is used in most household refrigerators, refrigerator – freezers and freezers. In this cycle, a circulating refrigerant such as R134a enters a compressor as low pressure vapor at or slightly above the temperature of the refrigerator interior. The vapor is compressed and exits the compressor as high- pressure superheated vapor. The superheated vapor travels under this pressure through the coil of condenser, which is passively cooled by exposure to air in the environment. The condenser cools vapor, which turns to liquid. As the refrigerant leaves the condenser, it is still under pressure but is now only slightly above room temperature. This liquid refrigerant is forced through the throttling device (expansion valve) to an area of lower pressure. The sudden decrease in pressure results in explosive – like flash evaporation of a portion of the liquid. The latent heat absorbed by this flash evaporation is drawn mostly from adjacent still- liquid refrigerant, (auto – refrigeration). This cold and partially vaporized refrigerant continues through the coil or tube of evaporator unit. Refrigerant leaves the evaporator, now fully vaporized and slightly heated and returns to the compressor inlet to continue the cycle.

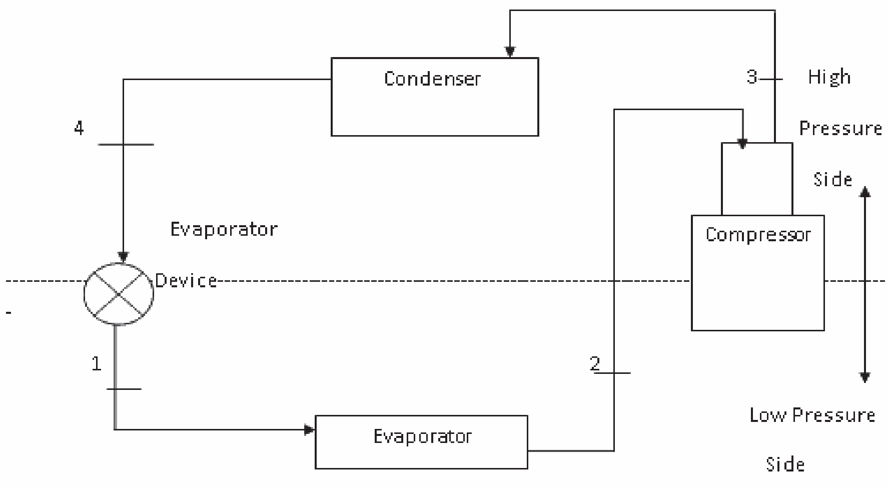

Figure 1: Schematic Vapor Compression Cycle

All Vapor compression refrigeration systems are designed and built around certain basic thermodynamic principles.

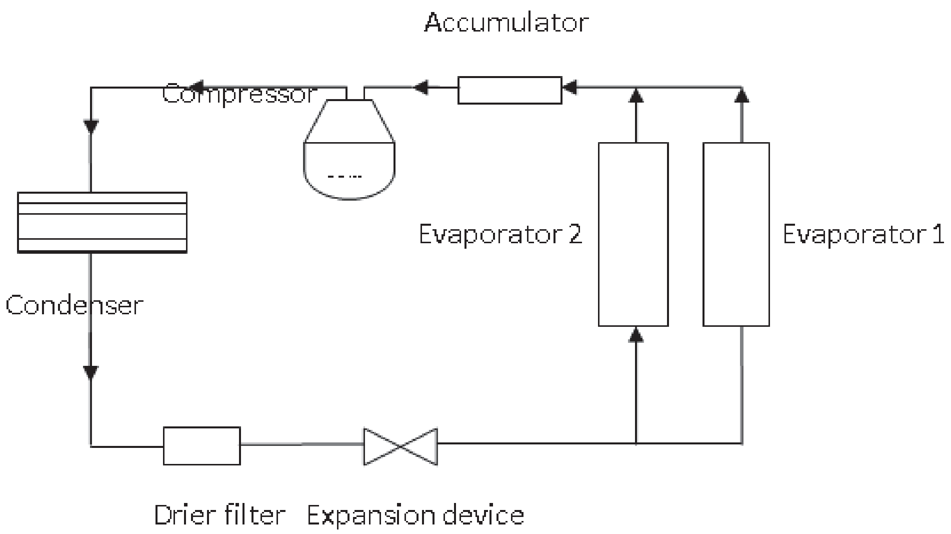

Figure 2: A Sliding Plate Evaporator Freezer

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 was increased by the development of this model of freezer.

The Sliding plate Evaporator freezer designed and construction is a multi plate freezer that comprises of two or more evaporator plates through refrigerant expands, and food is placed between the plates and are brought closer so that the area of cooling reduces. As the plates are in direct contact with the food, there is better heat transfer and hence the freezing rate is increased. The Evaporator plate is of aluminum having a high heat transfer coefficient. The plates are brought closer manually.

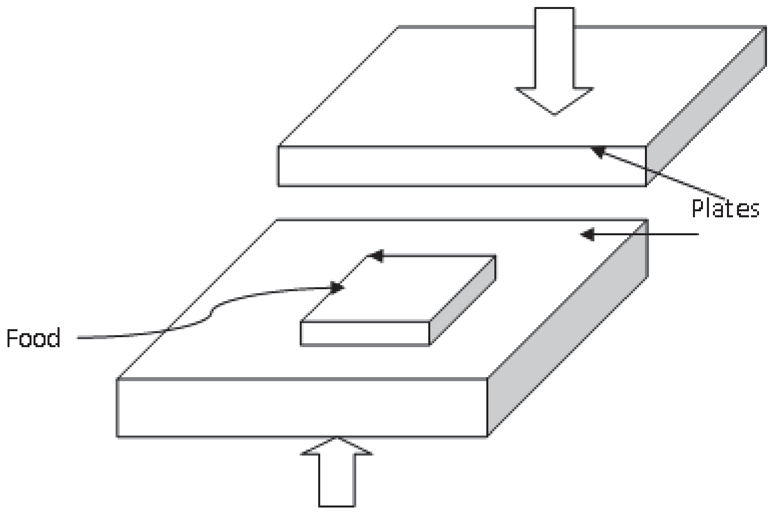

Fig. 3 Food between two evaporator plates

Compared to the conventional method of freezing, this method takes only a quarter of the time required to bring 1kg of water from 29^oC to – 5^oC, 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.

Objective of the Study

I To design and construct a freezer that freezes agro and allied products faster than conventional freezers.

II To modify and correct the design flaws of the work of Lijuish Paul, Midhun Mohan, Rajesh K.R. and Sunil of Thapar University of India.

III To achieve accelerated cooling using plate evaporators and environmentally friendly refrigerants.

Review of Literature

1 Timeline and Development of Refrigeration

The first known artificial refrigeration was demonstration by William Cullen, 1748 at the University of Glasgow. However, he did not use his discovery for any practical purposes.

Then Benjamin Franklin and John Hardly, 1758; Professors of chemistry at Cambridge University, conducted an experiment to explore the principle of evaporation as a means to rapidly cool an object; there are after an American inventor Oliver Evans, 1805 designed the first refrigeration machine. In 1820 a British scientist named Michael Faraday Liquefied ammonia and other gases by using high pressures and low temperatures. Jacob Perkins built the first practical refrigerating machine in 1834 it was used either in a vapor compression cycle.

An American physician named John Gorrie, in 1844 built a refrigerator based on Oliver Evans design to make ice to cool the air for his yellow fever patients.

In 1859, Ferdinand Carre' developed gas absorption refrigeration system using gaseous ammonia dissolve in water (aqua ammonia).

A German engineer, Carl Von Linden in 1876 patented a process of liquefying gas; and in 1911 the first mechanical refrigerators came into existence in the United State.

Refrigerants

Until concerns about depletion of the Ozone layer arose in the 1980s, the most widely used refrigerants were the halmoethanes R-12 and R-22, with R-12 being more common in automotive air conditioning and small refrigerators, and R-22 being used for residential and light commercial air condition, refrigerators, and freezers. Some very early systems used R-11 because its relatively high boiling point allows low-pressure systems to be constructed, reducing the mechanical strength required for components. New production of R-12 ceased in the United States in 1995, and R-22 is to be phased out by 2020. R-134a and certain blends are now replacing chlorinated compounds. One popular 50/50 blend of R-32 and R-125 now being increasingly substituted for R-22 is R-410A often marked under the trade name Puron. Another popular blend of R-32, R-125, and R-134a with a higher critical temperature and lower GWP (Global Warming Potential) than R-410A is R-407C. While the R-22 and other ozone depleting refrigerants are being phased out, they still have value and can be easily sold.

Following the ban on chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), substances used as substitute refrigerants such as fluorocarbons (FCs) and hydrofluorocarbons (HFCs) have also come under criticism. They are currently subject to prohibition discussions on account of their harmful effect on the climate. In 1997, FCs and HFCs were included in the Kyoto Protocol to the Framework Convention on Climate Change. In 2006, the EU adopted a Regulation on florinated greenhouse gases, which makes stipulations regarding the use of FCs and HFCs with the intention of reducing their emissions. The provisions do not affect climate-neutral natural refrigerants.

Early mechanical refrigeration systems employed sulfur dioxide gas or anhydrous ammonia, with small home refrigerators primarily using the former. Being toxic, sulfur dioxide rapidly disappeared from the market with the introduction of CFCs. Ammonia (R717) has been used in industrial refrigeration plants for more than 130 years and is deemed to be environment-friendly, economical, and energy-efficient. The natural refrigerant carbon dioxide (R744) has a similarly long tradition in refrigeration technology.

Occasionally, one may encounter older machines which used other transitional refrigerants such as methyl formate, chloromethane, or dichloromethane (called carrene in the trade). Perhaps the most common of these to still retain a charge are the methyl formate Monitor Top refrigerators produced by General Electric.

Use of highly purified propane as a refrigerant is gaining favor, especially in systems designed for R-22. Although propane is non-toxic its mixture with air in certain proportions is explosive. An odorant, such as ethyl mercaptan, can be added in trace amounts to alert persons of system leaks.

2.4 Heat Transfer Models

The heat transfer coefficient is used for calculating the heat transfer by convection or phase transition between a fluid and a solid. To determine the overall heat transfer coefficient, the heat transfer for both the solid and liquid are needed.

$$\frac{1}{U} = \frac{1}{h_1} + \frac{x}{k} + \frac{1}{h_2} \qquad (1)$$

Where U = overall heat transfer coefficient
h_1 = refrigerant side heat transfer coefficient
h_2 = air side heat transfer coefficient
x = thickness of insulator
k = thermal conductivity of insulator

When calculating the heat transfer coefficient of the fluid and solid side, a dimensionless number called the Nuselt number is used (it can be calculated or found in a chart)

$$N_u = \frac{h_1 D}{k} \qquad 2$$

2.4.1 Nusselt number, Reynolds number and Prandtl number

These are all dimensionless number essential for calculating the heat transfer coefficient of a system.

The Nusselt number, Nu for forced convection is a function of both Reynolds number and Prandtl number;

$Nu = f(Re, Pr)$; $Nu = 0.026 \times Pr^{0.3} \times Re^{0.8}$ 3

The Reynolds number, Re is mostly used to characterize fluid flow (turbulent or laminar; laminar flow occurs at low Reynolds number while turbulent occurs at high Reynolds number). This number is usually calculated for fluids in relative motion to a surface.

$$Re = \frac{D_i}{\mu_r}\frac{m_r}{A_i} \qquad 4$$

Where D_i= internal diameter; M_r= mass flow rate; U_r= absolute viscosity
A_i= internal surface area

The Prandtl number, Pr is the ratio of momentum diffusivity to thermal diffusivity. It is a dimensionless number.

$$P_r = \frac{\mu_r}{k} CP_r \qquad 5$$

Where μ_r = absolute viscosity
CP_r = specific heat capacity
K = thermal conductivity

2.5 Review of Previous Words

Lijush Paul, Midhum Mohan, Rajesh K. R and Sunil K.K of Thapar University of India worked on designed and constructed a plate freezer of 0.48m x 0.5m x 0.2m dimensions with an insulation of 0.06m thick PUF having a thermal conductivity of 0.033 w/mk. Their plate freezer was designed in a portrait manner, when in the plates here horizontal to one another. Their aim was to achieve freezing of 4kg of meat in two hours to a temperature of -5^0c using an environmental friendly refrigerant (Tetrafluoroethane R134a).

After design and testing it showed that there was shortage of the refrigerant through the top plate. They could get the temperature inside the plate freezer to exactly the same required temperature. Also they could use this system at different temperatures depending on their need. Akabor et al of the department of mechanical engineering, university of Benin designed an ice cream/ice block making machine to produce 20kg of ice per hour but to have deficiencies in their designs and calculations, the machine after construction was only able to make 3kg of ice per hour.

2.6 Review of Present Work

The current research is designing and constructing a sliding plate evaporator freezer (SPEF), of 1200mm x 900mm x 750mm dimensions, to achieve fast and effective freezing in large quantity using an environmental friendly refrigerant through the following hypotheses:1) Using an environmental friendly refrigerant 2) Using a non corrosive metal as cooling plates; 3) Placing the plates parallel to each other in landscape to aid flow rate of refrigerant and 4) Using standard design calculations and materials to make theory possible.

Material Selection

Material selection was considered for all the components fabricated for the SPEF as:1) For a cooling coil (evaporator coils) is copper and most suitable material; 2) For internal chamber lining, most suitable is aluminum; 3) For the external cover (casing) most suitable is fibre plastic material ; 4) Insulator material- poly urethane form; 5) For slider roller- fibre reinforced plastics; 6) Channel rolled component- fibre reinforced plastics; 7) Other standard components were selected out of design specifications: compressor, condenser Thermostat, control switches and lightening gadgets; 8) Glossy paint material selected for its advantages and 9) Flexible pressure rubber hoses and their couplers (ideal for car air- conditions) and flexible pressure rubber hoses (ideal for air condition work).

3.2 Refrigerant Selection

Refrigerant is to be selected based on the following criteria:

a) Chemical: Stable and inert; b) Health, Safety and Environmental: Non-toxic, non-flammable, does not degrade the atmosphere; c) Thermal (Thermodynamic and Transport): Critical point and boiling point temperatures appropriate for the application, low vapor that capacity low viscosity and high thermal conductivity and

d) Miscellaneous: Satisfactory oil solubility, high dielectric strength of vapor low freezing point, reasonable containment materials, easy leak detection, low cost.
The refrigerant that best fit the critical mentioned above is the R-134a (Tetra-fluoro-ethane).
Refrigerant 134a (R134a)- The refrigerant used is R-134a (Tetra-fluoro-ethane). R-134a does not contain any chlorine or bromine atoms and therefore is widely accepted by scientists as unlikely to cause any destruction of stratospheric ozone. Furthermore, R-134a also possesses boiling point and thermodynamic properties that are very close to those of R-12 (Ammonia). R-134a has the boiling point as that of R-12 (-29.8^{0}C). R-134a is not a drop in placement for R-12 because the refrigerating effect is slighting different. It does not seem to be compatible with conventional lubricants or motor winding insulation. It gives higher benefit than R-12 in using in conventional air conditioning and refrigeration plants where reasonable condensing temperatures can be specified. Thus R-134a has lower life time compared to R-12 and it is the key for its environmental acceptability. These would appear to be non-flammable and non-toxic substitute for R-12 at extreme pressure ratios apart from R-134a.

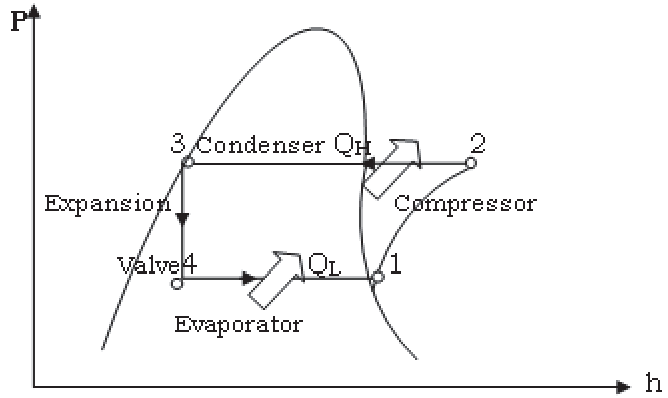

Fig 4: P-h diagram for refrigeration Cycle

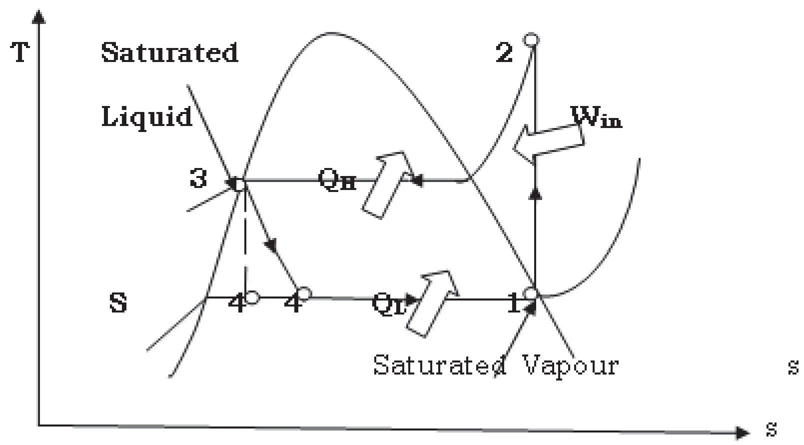

Fig 5: T- s diagram for sliding plate evaporator freezer

The Refrigeration Cycle Processes:
1-2 isentropic compression in a compressor
2-3 P = const, heat rejection in a condenser
3-4 Throttling in an expansion device
4-1 P = constant, heat absorption in an evaporator
Using the mollier charts for thermodynamic properties of R134a, the enthalpy stages 1,2,3,4 are obtained thus;
s = specific entropy

h= specific enthalpy
At -5^0C and a pressure of 1.418 bars refrigerant leaves the evaporator dry and saturated, h_4= 380.81 kJ/kg s_4= 1.74 kJ/kg k
Assuming isentropic compression, $s_4 = s_3$
At a 29^0C and a pressure of 6.439 bar refrigerant is passed through the throttle, h_2= 405.5 kJ/kg, s_2 = 1.64kJ/Kg
$h_2 = h_3$ = 405.5 kJ/kg
Using linear interpolation to get h_1;

Interpolation factor, $X = \frac{s_2 - s_4}{s_2 - s_1} = 1$

$$X = \frac{h_1 - h_4}{h_2 - h_4} = 405.5\text{KJ/Kg} \qquad 6$$

3.3 Tube Selection

The following factors are considered while selecting the tube diameters:

a. The pressure drop should be quite low.
b. There should be as small contraction or expansion of tubes as possible. At the same time expansion and contraction should be very close to the matching parts in view of least distortion in the system.
c. Workability should be easily shaped and brazed or soldered if necessary. Copper tube factors, the pipe diameter and material are selected based on recommended practical value.

Thus copper tube with an inside diameter of 6.35 x 10^{-3} m and an outside diameter of 7.825 x 10^{-3} m is selected.

3.4 Convective Heat Transfer Coefficient

3.4.1 Refrigerant-side Convective heat transfer coefficient

Assume a 7^0C drop in the temperature of Refrigerant as it flows through the condenser. Mean temperature of refrigerant (R-134a) in the condenser room temperature
= 55- (7/2) = 51.5 ^{0}C
Take the properties of R-134a at room temperature as:
Mass flow rate Mr. = 10353 x 10^{-3}kg/sec
Thermal conductivity, kr = 0.0172 W/ m K
Density, Pr = 1095.215kg/m^3
Absolute viscosity, μ_r = 1.5 x10-4kg/ms
Specific heat, Cp_r = 1.59 kJ/kg k

Inside Area of Condenser Tube, Ai

= $\pi D^2/4$ = 9.8528 x $10^{-5}m^2$= 3.17 x$10^{-5}m^2$ = A_i
Reynolds numbers, Re = D_i x m_r/ μ_r x A = 1807. 14
Prandtl number, Pr =$\mu_r Cp_r/ k_r$ = 13.8
Nusselt number, Nu =0.026 x $(P_r)^{1/3}$ $(R_e)^{0.8}$ = 25.12

But Nu = $\frac{h_i D_i}{k_r}$

Therefore, refrigerant-side heat transfer coefficient, h_1 = Nu x k_r d
= 53.67 W / mk

3.4.2 Air side heat transfer coefficient

Quantity of air to be circulated, $Q_a = \frac{CP_{Condenser}}{\rho_a \times CP_a \times \Delta t_a}$ = 0.2175 m^3/s (7)

Velocity of airflow over the condenser, V_a = 3m/s
Face area, A_f = Q_a/V_a = 0.21175/3 = 0.072m^2

Equivalent diameter, $D_a = \sqrt{\frac{4A_f}{\pi}}$ = 0.303m

Mean temperature of air (Tm_a) while flowing through condenser, Tm_a = 42.5^{0}C. Properties of air at Tm_a
Thermal conductivity, K_a = 0.0274 W/m K
Density, ρ_a =1.1193kg/m^3 Absolute viscosity,
μ_a = 2.008x 10^{-5}kg ms

Prandtl Number, Pr = 0.705kJ/kg K

Reynolds Number, Re = $\frac{PaDaVa}{\mu_a}$ = 66555.986

3.5 Heat Flow Analysis through a Composite Wall

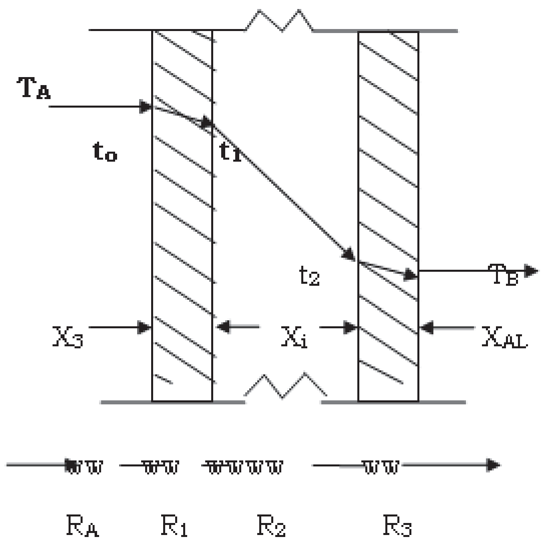

Figure 7: A heat flow through a Composite wall

Considering the cross section of the refrigeration wall above, each layer of the wall has a certain thickness, x and thermal conductivity, k. the wall above is a typical example of a composition wall.

Rate of heat transfer, Q through a wall;

$$Q = \frac{Ki \times A \times \Delta T}{X_i} \qquad 8$$

Where; Q = rate of heat transfer

K_i = thermal conductivity of insulator

A = area to be cooled

ΔT = change in temperature

X_i = insulation thickness

Also Q can be written as; $Q = \frac{\Delta T overall}{\Sigma R_{th}}$ 9

$$\sum R_{th} = \frac{1}{h_i} + \frac{X_s}{K_s A} + \frac{X_i}{K_i A} + \frac{X_{AL}}{K_{AL} A} + \frac{1}{h_o}$$

Rewriting Q;

$$Q = \frac{\Delta T}{\frac{1}{h_i} + \frac{X_s}{K_s A} + \frac{X_i}{K_i A} + \frac{X_{AL}}{K_{AL} A} + \frac{1}{h_o}}$$

Where; Q = rate of heat transfer

H_i = refrigerant side heat transfer coefficient

H_o = air side heat transfer coefficient

X_s = thickens of external mild steel

X_i = insulation thickness

X_{AL} = thickness of aluminum sheet

K_s = thermal conductivity of mild steel

K_i = thermal conductivity of insulator

K_{Al} = thermal conductivity of aluminum

ΔT = charge in temperature

Making X_i subject of the equation;

$$X_i = \left\{ \frac{T_A - T_B}{Q} Ae - \left(\frac{1}{k_i} + \frac{X_S}{K_S A} + \frac{X_i}{K_i A} + \frac{X_{AL}}{K_{AL} A} + \frac{1}{k_o} \right) \right\} K_i \qquad 10$$

Calculating Ae, effective cooling area;
Dimension of cuboid; 1.2m x 0.9m x 0.75m

$Ae = 2ab + 2bc + 2ac = 5.31m^2$

$K_i = 0.033W/mK$; $K_{AL} = 250W/mK$; $X_s = X_{AL} = 0.008m$

$\Delta T = 29 - (-5) = 34^0C$

Q will be 40% of the power required to freeze 1Kg of water;
40% of 23817W = 95.27W; substituting in equation10 above

$X_i = 0.06m.$

3.6 Designs for Compressor

3.6.1 Calculation of Thermal Losses and Freezing Power

Determining the thermal losses during refrigeration and the freezing power of the refrigerating system gives an accurate power of compressor to be used.

I Thermal losses

This includes heat losses through the door and walls of the refrigerating system, neglecting the bottom of the system.

For each area of the system to be considered;

$$P = \frac{1}{s} \times K \times A \times \Delta T \qquad 11$$

Where P = power per each single surface in Kcal/h;
S = Thickness of single surface in m;
K = Thermal conductivity of insulating material
A = Surface in m^2 of area to be considered
ΔT = Temperature displacement between the 2 sides of dispersant surface.

Analysis of K; using polyurethane foam insulation (PUF) with a thermal conductivity of 0.033W/mK
X_i = thickness of insulator = 0.06m
$\Delta T = 29-(-5) = 34^0C$

(a) Considering the sides of the freezer;

$P = \frac{1}{s} \times K \times A \times \Delta T = 26.06W$

For both sides = 52. 12W

(b) Considering the back and front area;

$P = \frac{1}{s} \times K \times A \times \Delta T = 41.69W$

For front and back area =83.38W

(c)Considering the freezer door cover;

$P = \frac{1}{s} \times K \times A \times \Delta T = 34.75W$

Total heat losses = 170.25W = 0.17kW

II Freezing Power

Assume 1kg of water in 2 hours

$P = \frac{1}{2} [(W \times s \times \Delta T_1) + (W \times L) \times (W \times s \times \Delta T_2)]$

Where, W- weight of water = 1kg
S- Specific heat of water = 4.187kJ/kg k
L- Latent heat of water = 334kJ/kg
ΔT_1- difference between room temperature and $0^0C = 29^0C$
ΔT_2- difference freezer temperature and $0^0C = 5^0C$

$P = 238.174W = 0.24KW$

Total power losses = 0.41kw = 410W
50% factor of safety, n
The required power will be approximately, 615W.

3.7 Designs for Condenser

3.7.1 Condenser Capacity

$CP_{condenser} = m\,(h_1 - h_3)$

$$\dot{m} = \frac{CP\ compressor}{H_1 - H_3}$$

$Cp_{\ condenser}$ - capacity of condenser
$Cp_{\ compressor}$ - capacity of compressor
$\dot{m}$ = mass flow rate

$$\frac{P_{loss}}{H_2 - H_4} = 0.072\text{kg/sec.}$$

$Cp_{\ condenser} = \ m\,(h_1 - h_2)$ or $m\,(h_1 - h_3) = 0.45$kw

3.7.2 Overall heat transfer coefficient based on condenser surface area

Since the tube wall thickness is very small, tube wall can be neglected.

$$\frac{1}{U_t A_t} = \frac{1}{k_i A_i} + \frac{1}{k_0 A_0};$$ A_t and A_0 are neglected.

$U_t = 10.88\text{W/m}^2\text{K}$

3.7.3 Log Mean Temperature Difference

This is used to determine the temperature driving force for heat transfer, mostly in heat exchangers. It is the logarithmic average of the temperature difference between the hot and cold streams at each end of the exchanger.

$$\text{LMTD} = \frac{T_A - \Delta T_B}{\ln \frac{\Delta T_A}{\Delta T_B}}$$

Temperature of the refrigerant in the condenser = 55^0C
Temperature of the air reaching the condenser = 30^0C
Temperature of the air leaving the condenser = $42.\ 5^0$C

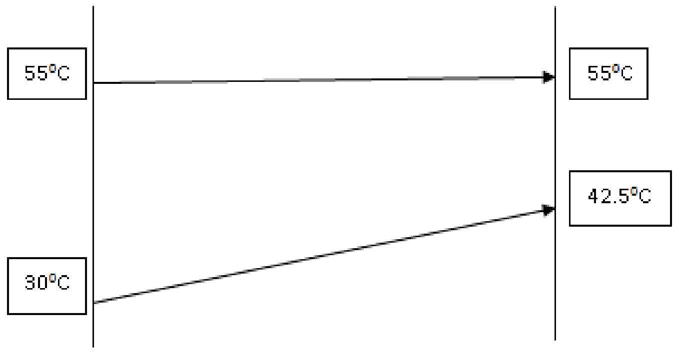

Fig 6: Temperature Profile of the Condenser

$$\text{LMTD} = \frac{T_A - \Delta T_B}{\ln \frac{\Delta T_A}{\Delta T_B}} = 18.03^0\text{C}$$

$$\text{Extended Surface area, } A_t = \frac{CP_{condenser}}{U_t LMTD} = 2.29\text{m}^2$$

$$\text{Therefore, bore surface area, } A_0 = \frac{2.29}{15} = 0.153\text{m}^2$$

$$\text{Length of tube required} = \frac{A_0}{\pi D} = 13.39\text{m}$$

3.8 Design for Expansion Device (capillary tube)

An expansion device is essentially a restriction offering resistance to the flow so that the pressure drops as in a throttling process. Capillary tube is the expansion device used in the existing system. The design of the capillary tube with the diameter selected as 0.00914 m (0.03598 inches) is as follows:

Mass flow rate, $\dot{m}$ = $3.3 \mathrm{x}\ 10^{-3}$kg/s
Area of cross section = $\pi/4D^2$ = 6.362 x 10^{-7} m^2
Let, X = m/A = 5187.27 kg/sm^2 = u/v
Y =x/2D = 2881817 kg/m^{3}s
Z =DX = 4.6685 kg/ ms

Friction Factor Calculations: Point 1 (55 ^{0}C)

Viscosities

μ_g = 0.000142 CP
μ_1 = μ_s
Re_1 = Z/μ_1 = 4.6685 /(0.000142) = 32876.76
F_1 = 0.32 /(Re)$^{0.25}$ = 0.0238
μ_2 = μ_1 at – 23 ^{0}C
μ_2 = 0.00365 CP
Re (at-23 ^{0}C) = 4.6685 /0.00365 = 1279.04
f_2 = 0.0535
f = (f+ f_2)/2 = 0.03866

Length Calculations:

At 55^{0}C i.e. before refrigerant enters the expansion device, pressure is approximately 14.9bars.
When it exits the expansion device, at -25^{0}C pressure is approximately 1.067bars
Total pressure drop
Δp = 14.9 – 1.067 = 13.833 x 10^5 N/m^2
Mean Friction Factor
f = 0.03866
Mean Velocity, u = (4.8143 + 3.801) = 4.3065 m/s
Incremental length, $\Delta L_{k-1} = \Delta p_f / Yfu$ = 2.88m

3.9 Designs of Evaporator

Outside diameter of the tube taken = 7.825 x 10^{-3}
Inside diameter of the tube taken = 6.35 x 10^{-3}m
Taking the properties of R -134a at – 25 ^{0}C
Density, p_r = 1351.67kg/m^2
Velocity, μ_r = 350 x 10^{-6} pa S
Thermal conductivity, k_r = 102 x 10^{-3} W/m k

Reynolds Number, Re $= \dfrac{D_i \times \dot{m}_r}{A_i \times \mu_r}$

Heat transfer coefficient:

$$LMTD = \frac{T_A - \Delta T_B}{\dfrac{\ln \Delta T_A}{\Delta T_B}}$$

Temperature of refrigerant in evaporator = -25^{0}C
Ambient temperature of water = 29^{0}C
Temperature of water after chilling =-5^{0}C

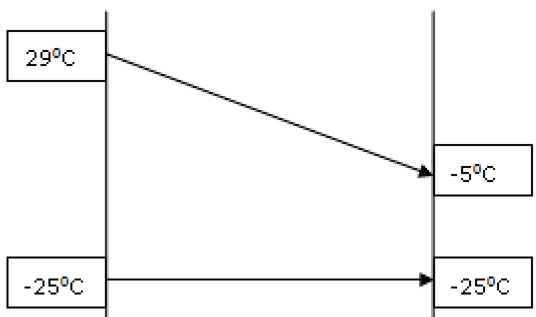

Fig 7: Temperature profile of the Condenser

Overall heat transfer coefficient,

$$\frac{1}{U} = \frac{1}{k_i} + \frac{x_1}{k_a} + \frac{x_2}{k_{al}}$$

Where u is overall heat transfer coefficient
h_i is refrigerant side heat transfer coefficient = 37.768w/m^{2}k
X_1 is average thickness in which air is filled = 0.05
X_2 is thickness of aluminum plates = 0.001m
K_{al} is the thermal conductivity of aluminum =250W/MK
K_a is the heat transfer coefficient of air =100w/m^{2}k
Adopting the equation (1) here, we obtain

U = 37.5W/m^{2}K

Length of cooling pipe; $CP_{compressor} = U \times A \times LMTD$

$$A = \frac{CP_{compressor}}{U x\ LMTD} = 0.32m^2$$

3.10 Construction of Evaporation Plate

As designed there is one evaporator plate with the ability to slide in the chest of the freezer. The evaporator plate consists of copper tube diameter 7.825 x 10^{-3}m and length as determined during construction, installed between two plates; the coils are concentrated between the plates. The plates are held together by screws tightened on flat aluminum bars along the edges so as to form a rectangular box plate of dimension (0.68 x 0.59 x 0.008m^3). The tubes in the plates are connected to the compressor and condenser as shown in the sketch in the appendix.

3.11 Design Specifications

Table 6: Design Specifications

S/N	Component	Specification
1	Compressor	1 x 1/4hp
2	Condenser	1 x 0.45kw
3	Copper tube	26.3m x 0.0079m

4.0 Testing and Characterization

4.1 Functional performance

To check the performance of the freezer, an experiment was carried out to test its ability and capacity.

4.1.1 Experimentation

To study the relationship between freezing rate and volume, experiments were conducted and the following apparatus used: 1) Freezer with a sliding evaporator; 2) Water in Stainless plate; 3) Stop watch and 4) Power source.

4.1.2 Experimental Procedure

Time reading was taken immediately a particular volume of water becomes frozen (i.e. from the time it was put in the freezer to the time it freezes). The volume of water being put in the freezer increases until the capacity of the freezer (approx. 380 litters) is reached.
The table below shows the data gotten after the experiments were carried out;

Table 8: Shows the relationship of Freezing Time and Volume of water Frozen

S/N	Time (hr)	Volume (litters)
1	3	1
2	3.2	2
3	3.6	3
4	4	4
5	4.3	5
6	4.3	5
7	5.3	7
8	5.8	8
9	6.2	9
10	6.5	10
11	6.9	11
12	7.3	12
13	7.6	13
14	8	14
15	8.3	15
16	8.7	16
17	9	17
18	9.3	18

Coefficient of performance, $COP_R = \frac{Q_L}{W_{in}}$

Q_H = heat removed from system.
W_{in} = work input.

$COP_R = \frac{Q_L}{W_{in}} = \frac{h_1 - h_4}{h_2 - h_1}$

By interpolation and using the temperature table of saturated refrigerant R 134a, the following values of the system enthalpies were obtained according to the design parameters as:

$T_2 = 55^0C$; $h_{2@55^0C}$ =274KJ/Kg
$T_3 = 42.5^0C$; $h_{2@42.5^0C}$ =110.9KJ/Kg
$T_4 = -25^0C$; $h_{2@-25^0C}$ =18KJ/Kg
$T_1 = -5^0C$; $h_{2@-5^0C}$ =243KJ/Kg

Therefore, $COP_R = \frac{h_1 - h_4}{h_2 - h_1} = 7.26$

The Refrigeration Capacity is given as, $\dot{Q} = \dot{m}\left(\frac{h_1 - h_4}{211KJ/min}\right)$

211KJ/min is equal to **one tone of refrigeration** and is defined as a heat transfer rate from the cold region.

$\dot{Q} = 4.32\left(\frac{243 - 18}{211}\right) = 4.61$tons.

4.1.3 Freezing Rate

Freezing rate = $\frac{\text{Frozen Volume}}{\text{Freezing time}}$

Table 9: Freezing Rate Computations

S/N	Time (hours)	Volume (liters)	Freezing rate (liters/hr)
1	3	1	0.33
2	3.2	2	0.63
3	3.6	3	0.83
4	4.4	4	1.00
5	4.3	5	1.16
6	4.8	6	1.25
7	5.3	7	1.32
8	5.8	8	1.38
9	6.2	9	1.45
10	6.5	10	1.54
11	6.9	11	1.59
12	7.3	12	1.64
13	7.6	13	1.71
14	8	14	1.75
15	8.3	15	1.81
16	8.7	16	1.84
17	9	17	1.89
18	9.3	18	1.94
19	9.7	19	1.96
20	10	20	2.00

4.2 Graphical Information of Data

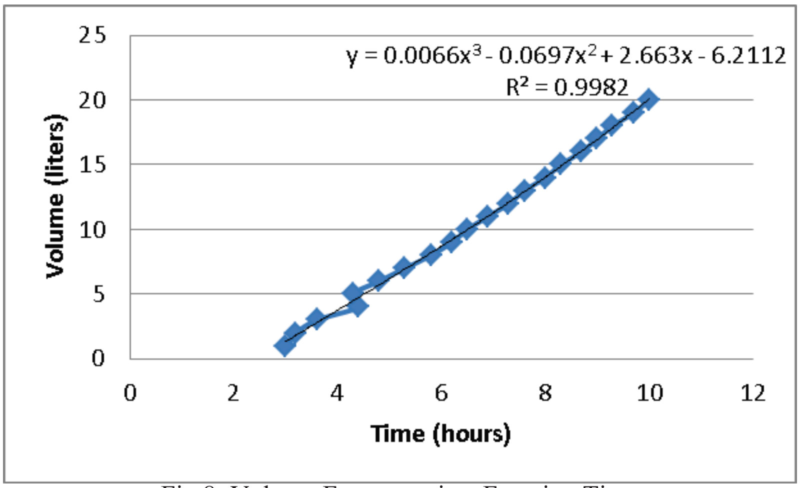

Fig.8: Volume Freeze against Freezing Time

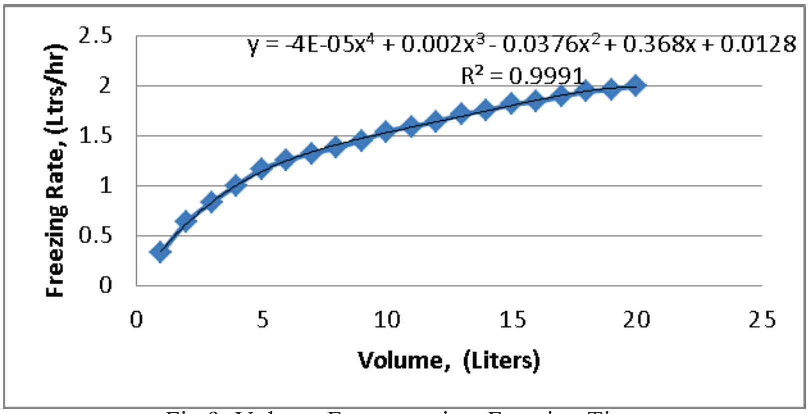

Fig 9: Volume Freeze against Freezing Time

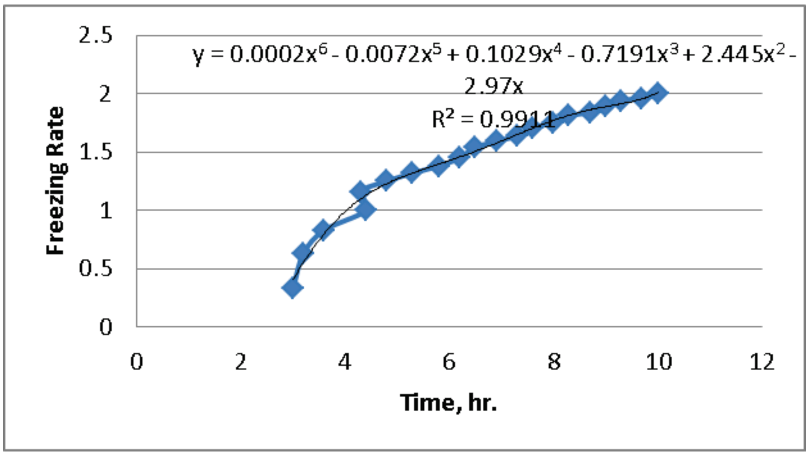

Fig 10: Freezing Rate against Freezing Time

4.3 Aesthetics and Ergonomics

Both aesthetics and ergonomics were considered during design and construction.

Preferred aesthetics features were hatred for lack of practicability but outer finishing of the work was done with outmost care since it's the most visible part of the work.

Ergonomic factor like electric shock prevention, gas poisoning, injury from sharp edges and many others were considered and taken care of making the freezer 99 per Cent safe for use.

4.4 Operational Procedure

The use of this freezer conforms to the use of the conventional freezer except for the sliding evaporator, below is a step by step procedure on how to use the Product:

1. Open/ lift the freezer door.
2. Place any substance to be frozen on the floor of the freezer (if space is not enough move the slider to create enough room).
3. After placing the substance, move the slider plate towards the substance until they are firmly touch one another.
4. Then close the freezer door.
5. Power **ON** the Freezer as connected to the mains.
6. Whenever required the substance being frozen, ensure Power **OFF**.

NB: Do not slide the evaporator when freezer is frozen.

4.5 Maintenance Guidelines

1. Maintenance guideline for the Entire Cooling Unit:

a. Clean the Coils: the coils at the back remove the heat. If they are clogged, they become inefficient and the compressor will work harder. Unplug the fridge, pull out from the wall and reach behind with a long- handled broom or vacuum cleaner nozzle.
b. Keep it away from Heat Sources: Position the freezer away from sunny windows, hot water heaters, warm air from heating ducts, radiators, stoves and other heat sources. The heat makes cooling harder for your refrigerator.
c. Check Door Gaskets: Check for holes & gaps. To achieve a good seal, close the ref door on a piece of paper and try to remove the paper. If it's not held snugly in place, adjust the door or replace the seal.
d. Wash exterior of cabinet with detergent solution; rinse and dry. A creamy appliance wax may be used occasionally to protect painted exterior and make spots easier to wipe off.
e. Position the freezer to allow good airflow on all sides.

2. Maintenance Guidelines for Freezer Unit

a. For short a vacation, leave freezer on but use or discard perishable food
b. Do not cram freezer so full that cold air can't circulate freely to chill food. Cover or wrap all foods stored, to prevent drying out and transfer of odor.
c. Clan freezer compartment regularly, even though it does not require defrosting. Turn Freezer off and unplug. Remove all foods and all removable interior parts. Wash with a solution of 1-2 tablespoons full of baking soda in 1-quarter of warm water. Rinse and wipe dry.
d. Unpleasant odors develop, either from improper storage of food or from spoilage, make sure you cover the food stored, and throw away food, which is very old. Also wipe out spills in the refrigerator promptly to avoid staining and odors

5.1 Conclusion

The sliding plate evaporator freezer has been successfully designed and constructed with minimal errors that were corrected. The freezer was constructed using both recycled and new materials sourced locally, achieving an environmental friendly freezer. During performance and functional evaluation, the freezer showed high efficiency by freezing 1 liter of water in 3hrs and its Coefficient of performance is evaluated to be…..

5.2 Recommendation

The sliding plate evaporator freezer is highly recommended for household use and agro industries. Further work is recommended that a new design for the slider be invented to improve internal and external aesthetics, by using rubber tubes and eliminating any outside copper piping.

5.3 Acknowledgements

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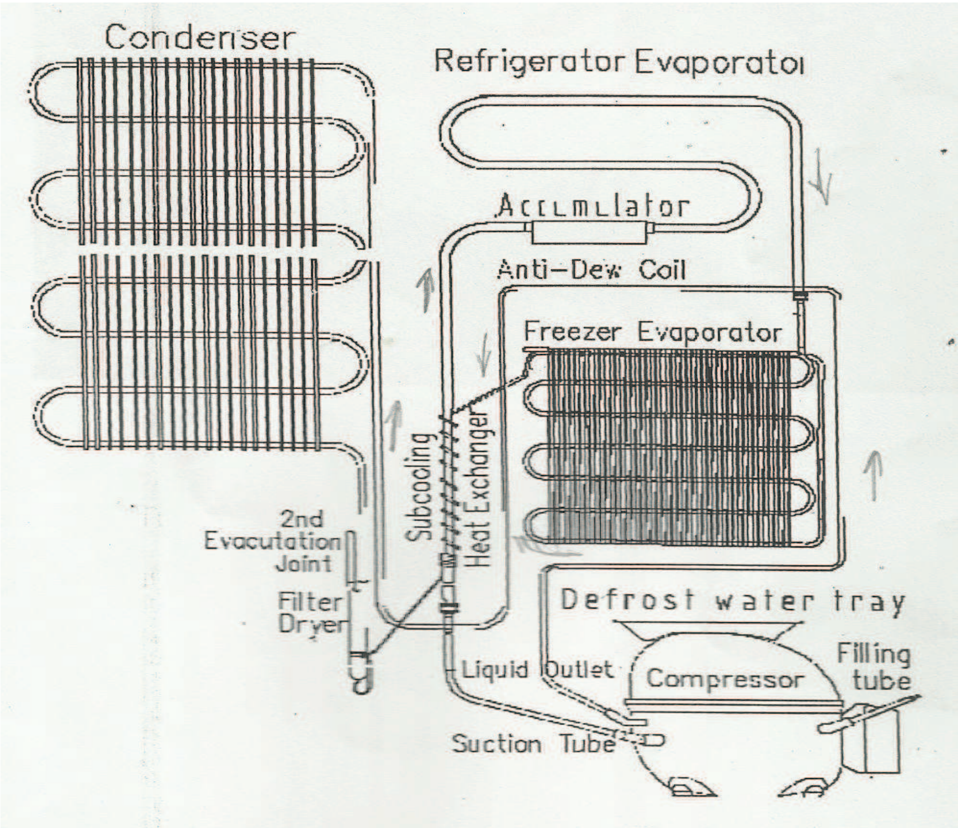
APPENDIX



Conventional Refrigerator / Freezer System