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Construction of a Home-Made Refrigeration System (9.72cc Capacity Deep Freezer) From Locally Sourced Materials

Madu, Kingsley Ejikeme[1]

[1]Mechanical Engineering Department, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria

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ABSTRACT

Nowadays, almost all our home and office appliances and gadgets are imported from foreign manufacturers. In the olden days efforts were made to locally develop items and equipment used by people- carved or wooden spoons and other materials used domestically were produced by farmers and local artisans. The use of these imported appliances, though not bad, has obviously led to the dearth of most of our inherent skills and talents. In this work, the focus is centered on harnessing local talents to develop and produce a deep freezer from locally sourced materials. The aesthetics of the fabricated deep freezer may be far from its imported counterpart, but the continuous development of the system ultimately leads to a more refined product overtime. Encouragements from the government by way of incentives to local manufacturers and fabricators, policies that protect local producers, stable and affordable power supply, establishment of innovation hubs for our youths will go a long way in curbing over reliance on imports.

1. Introduction

1.1 An overview of Early Refrigeration History

In prehistoric times, man found that his games would last during times when food is not available, if stored in the coolness of a cave or packed in the snow. For past centuries, ice served as the principal refrigerant. In China, before the first millenium, ice was harvested and stored. The Hebrews, Greeks and Romans placed large amounts of snow into storage pits dug into the ground and insulated with wooden straw. The ancient Egyptians filled earthen jars with boiled water and put them on their roofs, thus exposing them to the night's cool air. In India, evaporative cooling was employed [1]. [2], [3], [4] and [5]. When a liquid vaporizes rapidly, it expands quickly. The rising molecules of vapor abruptly increase their kinetic energy and this increase is drawn from the immediate surroundings of the vapor. Their surroundings are therefore cooled [6], [7].

All these processes became too ambiguous that refrigerators are extensively needed to chill water and to preserve food stuffs which can deteriorate in ambient temperature in order to avoid spoilage from bacterial growth [8], [9].

In the early 1980s, due to development of artificial refrigeration techniques, various mean of preserving and cooling food stuffs were utilized. However, the Indians and Egyptians were foremost in developing an ice making technique that served as the conceptual basis for the first modern refrigerators developed during the nineteenth century [10].

Embarking on a more primitive means of producing ice, the ancient Chinese went to the mountains to cool their food[11]. After some time, the Romans and the Greeks adopted this practice, stored ice in pits or insulated caves with wood to preserve ice. The ice therefore served as the primary method of chilling food in the nineteenth century, when people inserted ice block in cabinets that are insulated alongside with the food. Even in most developing nations, ice remains the sole refrigerant [12].

The first known attempt at developing an artificial refrigerator took place in Scotland at the University of Glasgow, where, in 1748, William Cullen revived the ancient Indian/Egyptian practices of freezing liquid by means of evaporation [13]. In 1856, an American known as Alexander Twining began selling a refrigeration machine based on a vapor compressor principle that was built and developed by an American doctor named John Gorrie in 1844 [19], [14], [15], [16], [17] and [18], [19], [20].

2. Materials and Methodology

For effective refrigeration to be achieved, a number of factors are considered with respect to the refrigerated space. These include among other factors, corrosivity of the refrigerant, environmental factors, and weight. And these factors determine the selection of materials for this construction. These refrigerants have the following characteristics shown in table 1.

Moreover, there are two (2) refrigeration systems namely the vapor compression refrigeration system (VCRS) and the vapor absorption refrigeration system, (VARS) (also called refrigeration system, GRS). table 1 below shows the difference between both refrigeration systems. The normal heat load pattern would be: net sensible heat gain and net latent heat gain [22].

Table 1: Comparison between vapor compression refrigeration system (VCRS) and vapor absorption refrigeration system (VARS) [19], [20], [21], [22].

S/N	Item	VARS	VCRS
1	The basic cycle	Heat operated	Work operated

2	COP	0.6 to 1	3 to 5
3	Maintenance	Requires negligible, maintenance because of lesser moving parts	Applicable maintenance for huge moving parts
4	Power requirement	Applicably less. For similar capacity plant of VCRS, 20% to 30% more power is required	Huge power is required
5	Noise level	Noiseless	High noise because of compressor
6	Operating cost	Very less	High because of high electrical power requirement for lubricating oil and refrigerant replacement
7	Compactness	Very compact, less floor space is required	More floor space is required. Huge piping work is also required

Table 2: Refrigerants and their Characteristics

Halogenated Refrigerants (CFCs, HCFCs, HFCs)	Break down and form hydrochloric or hydroflouric acid in the presence of moisture
Ammonia (NH_3)	Highly corrosive to copper and its alloys but less to steel
Carbon Dioxide (CO_2)	Relatively non-corrosive under dry conditions but can formcarbonic acid in the presence of water
Hydrocarbons (Isobutane R-600a)	Low in corrosivity but highly flammable

Psychrometry is the study of moist air, which is a mixture of dry air and water vapour (humidity). It also encompasses the behaviour of this air–vapour mixture under various conditions of temperature, pressure, and moisture content [19].

Some common terminologies associated with refrigeration/air conditioning are defined below.

Humidity. It is the mass of water vapour present in 1 Kg of dry air, and is generally expressed in terms of gm per kg of dry air. It is also called specific humidity or humidity ratio [23].

Absolute Humidity. It is mass of water vapour present in 1 m3 of dry air, and is generally expressed in terms of gm per cubic metre of dry air. It is also expressed in terms of grains per cubic metre of dry air. Mathematically, 1 Kg of water vapour is equal to 15,430 grains [23].

Relative Humidity. It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure[23]

Following materials were required in this building of the refrigerator. They include two (2) pieces of 1,5 mm mild steel sheet, 3/4 inch square pipe, hinges, 1.5 hp compressor, Felt material, capillary tube, copper flux, dryer/filter, silicon gum, rolls of 8 mm copper tube, aluminium foil, 1.5 mm PVC sheet, fan, compressor oil and refrigerant (CCL_2F_2).

Table 2: Composition of Dry Air [24]

S/No	Constituent	By Volume	By Mass
1	Nitrogen (N_2)	78.03 %	75.45 %
2	Oxygen (O_2)	20.99 %	23.19 %
3	Argon (Ar)	0.99 %	1.29 %
4	Carbon dioxide (CO_2)	0.03 %	0.05 %
5	Hydrogen (H_2)	0.01 %	-

Construction Procedure

The drawings layout was made to specification and the materials cut to size. The deep freezer capacity is (12 x 0.9 x 0.9) cm^3.

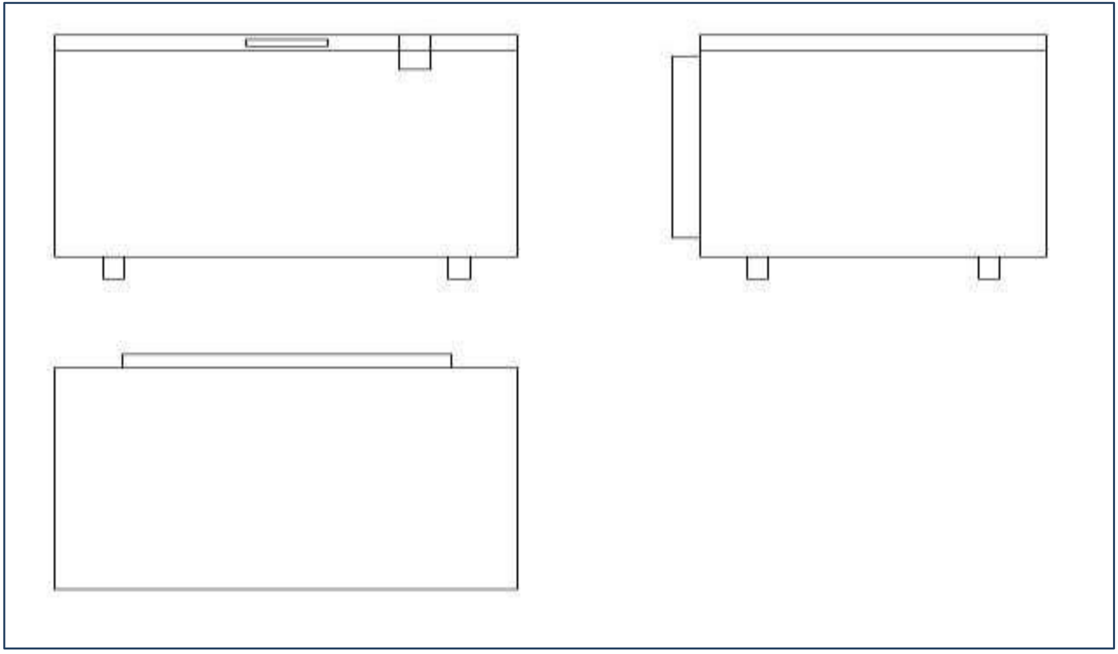

Fig. 1: Orthographic views showing the plan, front and end elevations of freezer

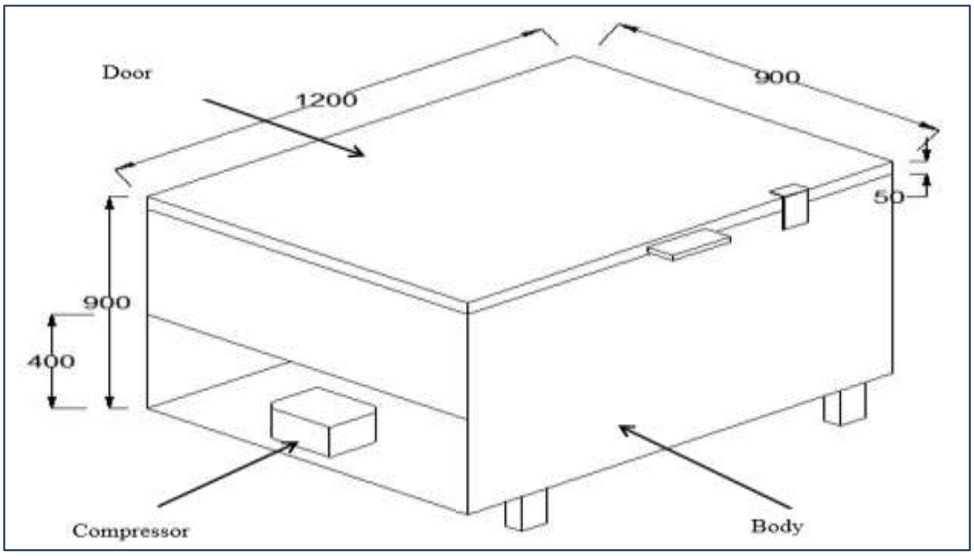

Fig. 2: Pictorial (Isometric) view of deep freezer

The mild steel steel was wrapped about the 3/4 inch square galvanized pipe.The felt material was spread or laid on the inner side of the mild steel steel and then another layer of mild steel sheet was laid over, to form an insulating medium to reduce energy loss to the outer surrounding. The inner surface was overlaid with the 1.5 mm PVC sheet to further insulate the interior of the refrigerated space. The copper tubing was wound round the inner walls of the space to form the evaporator. Holes were bored to allow passage of the copper tubing to the compressor. On the outer surface and behind the box (freezer), another set of copper tubing was wound around it to form the condenser. The capillary tube, filter/dryer, thermostatic expansion valve and the compressor were appropriately connected. A fan was provided to cool the compressor to cool it down while working [16], [25], [26], [27], [28].

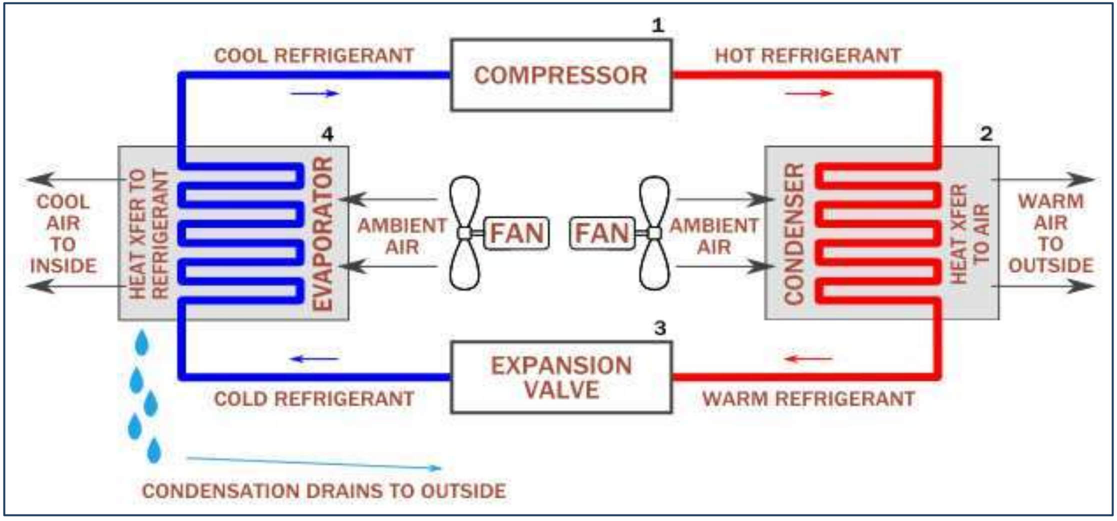

Figure 3: A Typical Air-conditioning Cycle [9], [29], [30]

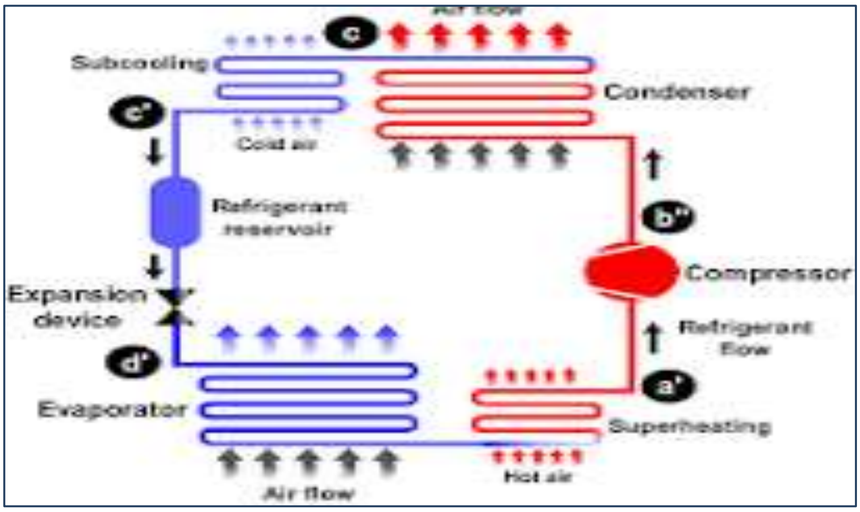

Fig. 4: Flow diagram of a simple vapor compression system [31], [32]

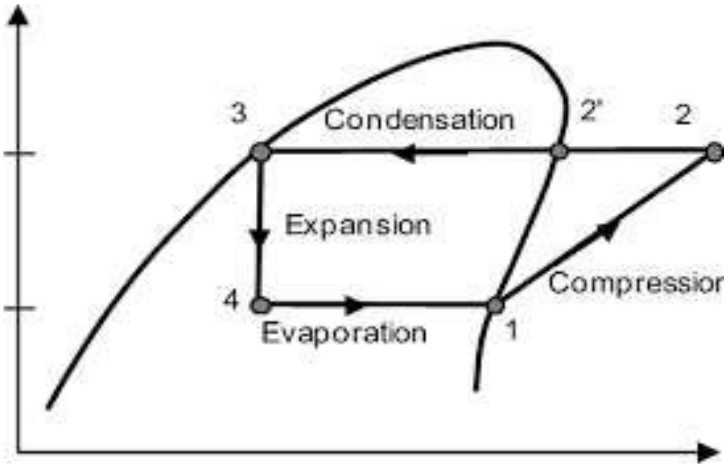

Fig.5:T-S Diagram of a simple vapor compression cycle [33], [34], [35].

3. Results and Discussions

From Figure 2 above,
$h = u + pv$ 1
$dh= du + pdv + vdp$
But $Q = dQ + pdv$
$dh= dQ + vdp$ 2
At constant pressure, $dp=0$
Hence $vdp = 0$
$Dh= Q$ 3

3.1 (A) For Evaporation Process:

Heat absorbed in evaporator QE is given as, using equation (3), also known as refrigeration effect is,
$Q_{evaporation} = Q_E = (h_2 - h_1)$
Or
$Q_{evaporation} = (h_2 - h_5)$KJ/kg 4
Since $h_1 = h_5$

3.2 (B) For Condenser Process:

Heat rejected by the condenser, using equation 3, is
$Q_{condenser} = (h_3 - h_5)$KJ/kg 5
By first law of thermodynamics,
$Q_{condenser} = Q_{evaporator} + W_{compressor}$
$\therefore (h_3 - h_5) = (h_2 - h_5) + W_{compressor}$
$\therefore$Wcomp. $= (h_3 - h_2)$KJ/kg 6
The above equation is based on the assumption that compressor is working on adiabatic process.

3.3 (c) Mass of refrigerant circulating in the system:

Refrigeration effect is the amount of heat absorbed by the evaporator in order to maintain the desirable condition in the refrigerated space.
$\therefore$Refrigeration effect $= Q_{evaporator} = (h_2 - h_1)$KJ/kg 7
Recall that:
1 Ton = 210KJ/min

1 Ton = 3.5KJ/sec
$\therefore$For the capacity of 1 Ton of the system,
1 Ton - M_R x Refrigeration effect = 210KJ/min
$\therefore M_R$ = mass flow of refrigerant

$$= \frac{210}{(h2-h1)} \text{ kg/min-ton}$$

$$= \frac{3.5}{(h2-h1)} \text{ kg/sec-ton} \qquad 8$$

3.4 (D) Power required

If the compressor is compressing the vapor isentropically, then
Work of compressor = $Wcomp=h3-h2[kJ/kg]$
Power required = $Preq=\dot{m}(h3-h2)[kJ/min]$
$\therefore$Power required = $Preq=\dot{m}(h3-h2)/60[kW]$ 9

But if the compression process is polytropic having index of compressor as ‘n’, then
Work of compressor = Wcomp=n/(n−1).(p2v2−p1v1)/1000[kJ/kg] 10
$m^{\cdot}$ = mass flow rate (kg/min)
∴Power required = Preq=$m^{\cdot}$x Wcomp/60[kW] 11
Where
h= Enthalpy
Ɵ= Entropy
V= vapor
Q= quantity of heat
p= pressure
d= Delta (Δ)
W_{comp}= work done on compressor
Q_{cond}= Net heat on the condenser
Q_{evap}= Net heat extracted from the refrigerated space
M_R= mass flow rate of the refrigerant
η_{mech}= mechanical efficiency of the compressor
η_{motor}= motor efficiency

3.5 Condenser Capacity
The heat transfer through the walls of the condenser is by conduction. The condenseris given thus:
Q_c= U.A.LMTD (Kw) 12
Q_c= Condenser capacity in Kw
A is surface area of condensser in m^2
U is the overall hat transfer co-efficient (Kw/m_2K)
LMTD is long mean temperature difference between refrigerant and the condenser medium in °C of K [21].
But equation 12 can also be written as
$Q_c= M_w \times Cp_w \times \Delta T = M_a \times (\rho m\Delta T) = Q \times 5 \times Cpw \times \Delta T$ 13
In equation 13;
Q_c= condenser capacity on Kw
M_w= Mass flow rate of water in kg/s or L/s
Cp_m= specific heat of moist air (1.0216KJ/kgK)
P= density of standard air (1.2kg/m^3)
M_a= mass flow rate of air in kg/s or L/s
Q= volume of air flow in m^3/s or L/s
DT= LMTD or TD

3.6 The refrigerant capacity of an evaporator
The rate of heat transfer or the refrigerant capacity of an evaporator Q_{eva} is given by the following equations

$$\begin{aligned} Qeva &= A_oU_o\Delta tm \\ &= M_r(h_{r1} - h_{re}) \\ &= M_wCp_w(t_{we} - t_{w1}) \\ &= M_wCp_w(t_{ae} - t_{a1}) \\ &= M_a(h_{ae} - h_{a1}) \end{aligned}$$

In the above equations,
M_r= mass flow rate of refrigerant in kg/s
M_w= mass flow rate of chilled water in kg/s
M_a= mass flow rate of water in kg/s
= Q x ρ_a
Q= Volume floe rate of air in m^3/s
P_a= density of air in kg/m^3
t_{we}, t_{w1}= temperature of water entering and leaving the evaporator in °C
h_{ae}, h_{a1} = enthalpy of air entering and leaving evaporator coil in KJ/kg
h_{re}, h_{r1}= enthalpy of refrigerant entering and leaving the evaporator coil in KJ/kg

3.7 Compressor efficiency and the co-efficient of performance
I The motor efficiency (η_{motor})

$$\eta_{motor}=\frac{\text{power input to the compressor shaft}}{\text{Power output to the motor}}$$

$$\rho_s/\rho_{motor} \qquad 14$$

II The machine efficiency (η_{mech})

$$\eta_{mech}=\frac{\text{work delivered to the gaseous refrigerant}}{\text{work input to the compressor}}$$

∴

$$W_g/W_s \qquad 15$$

III the compressor efficiency (η_c)

$$\eta_c = \frac{\text{work required for isentropic compression}}{\text{Work delivered to the gaseous refrigerant}}$$

$$W_{isen}/W_g = \frac{h2 - h1}{W_g} \qquad 16$$

$$\text{COP (Hermetic)} = \frac{\text{Capacity (Watts)}}{\text{Input power to motor}} \qquad 17$$

4. Conclusion and Recommendation

Theconstruction of the deep freezer from locally sourced materials is a testament to the fact that, given the right opportunity and with the right policy framework for domestic manufacturing, there are abundant skills and talents at the local level to add value to our technological innovation. The freezer may not have the aesthetics of the imported product. But the continuous applications of these fabrication techniques will ultimately lead to a more polished product in no distant time.

The way forward therefore are as follows.

- Government policies should be geared toward developing local technologies by providing conducive environment that will encourage local fabricators.
- Financial incentives should be provided to support those who are skilled enough to venture into technological innovations.
- Import restrictions will definitely encourage local manufacturers.
- Stable and affordable power supply are panacea for the dearth of local industries.
- Government should establish innovation hubs for artisans and young graduates to develop and perfect their skills.

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