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Research Article

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Design and Fabrication of a Table-Type Vapour Compression Refrigerating Unit using Locally Sourced Materials

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Abstract This research was set up to design and fabrication a table-type refrigerator unit using locally sourced materials. The objectives of the research are to: 1. Design and construct a table-type refrigerating unit using locally sourced materials. 2. to carry-out cost analysis of the fabricated refrigerator. The construction of table-type refrigerating unit using locally was carried-out applying a ten-step procedure. The construction materials include steel bar for frame and copper pipe for the inner walls. The refrigerator constructed is a storage and preserving facility, which could be used to keep food fresh for a long time. It is therefore recommended that the content of this research be widely communicated to enlighten the populace on the procedures of design and construction of refrigerator to bring about the cooling effect and which is of great importance to the survival and of living human day-to-day activities.

Keywords Table-Type Vapour, Refrigerator, Fabrication

1. Introduction

A refrigerator is a equipment that keeps food cool and fresh with some very clever science of continuous extraction of =heat from a cold space. All the time your refrigerator is humming away, liquids are turning into gases, water is turning into ice, and your food, is staying deliciously fresh, Jango-Cohen, (2005). Over the years, there has been the problem of food preservation in many countries of the world and Nigeria in particular. Man cooks his food, and if not warmed, at least every ten hours will get spoilt. For example; food items like boiled beans, yam, rice, beef etc., due to lack of adequate preservation facility gets spoilt. Moreover, after the day's work man needs to take chilled drink, in order to maintain or normalize his body temperature, Bjornlund, (2015). Before the discovery of refrigerators man achieved this; by using clay pot, to store drinking water. The clay pot, does cooling but to limited extent.

Man can preserve his food, by constant warming, drying under the sun-salting etc., but that is not efficient enough for total or adequate preservation of perishable items meet and food stuff, Bender, (1992). Nowadays, these methods of preservation are not practiced again. For this to be achieved, we need a machine that can transfer heat from a cold chamber, which is at temperature lower than that of its surroundings. This is because bacteria that would have acted on the food item cannot survive in a very low temperature. Hence the need for a refrigerator.

Prior to the invention of the refrigerator, ice houses were used to provide cool storage for most of the year. Placed near fresh water lakes or packed with snow and ice during the winter, they were once very common. Natural means are still used to cool food today in some applications. On mountain side runoff from melting snow, is a convenient way to cool drinks, and during the winter one can keep milk fresh, much longer just by keeping it outdoors, Rees, (2013). The word "refrigerator" was first used at least as early as the 17th century. {Venetum Britannica 1678 edition}.

The history of artificial refrigeration began when a Scottish professor Williams Cullen designed a small refrigerating machine in 1755. Cullen used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from the surrounding air. Ramana, *et al* (2017). The experiment successfully created a small amount of ice but had no practical application at that time.

In 1805, American inventor Oliver Evans described a closed vapour compression refrigeration cycle, for the production of ice by ether under vacuum. In 1820, the British scientist Michael Faraday liquefied ammonia and other gases by using high pressure and low temperatures. Later in 1834, an American expatriate to Great Britain, Jacob Perkins built the first working vapour-compression refrigeration system in the world. It was a close cycle device that could operate continuously. {Burstall Aubrey (1965). A similar attempt was made in 1842, by American Physician, John Gorrie (Improved process for the artificial production of ice. U.S patent office, patent 8080. 1851), who built a working prototype, but it was a commercial failure. However, American Engineer Alexander Twining took out a British patent in 1850 for a vapour compression system that is used ether.

The first practical vapor compression refrigeration system, was built by James Harrison, a British journalist, who had emigrated to Australia. His 1856 patent was for a vapour compression system using ether, alcohol or ammonia. He built a mechanical ice making machine in 1851 on the banks of the Barwon at Rocky point in Geelong, Victoria, and his first commercial ice making machine, followed in 1854. Harrison also introduced commercial vapour compression refrigeration to breweries and meat packing houses, and by 1861, a dozen of his systems were in operation, Nagengast, (2004).

The first gas absorption refrigeration system using gaseous ammonia dissolved in water (referred to as "aqua ammonia") was developed by Ferdinand Carre of France in 1859 and patented in 1860. Carl Von Linde, an engineering professor at the Technological University Munich in Germany, patented an improved method of liquefying gases in 1876. His new process made possible the use of gases such as Ammonia, Sulphur dioxide (SO_2) and methyl chloride (CH_3CO) as refrigerants and they were widely used for that purpose until the late 1920s.

In 1913, refrigerators for home and domestic use were invented by Fred W. Wolf of Fort Wayne, Indiana with models consisting of a unit that was mounted on the top of an ice box Nagengast, (2004). In 1914, engineer Nathaniel B. Wales of Detroit, Michigan, introduced an idea for a practical electric refrigeration unit, which later became the basis for the kelivnator. A self-contained refrigerator, with a compressor on the bottom of the cabinet was invented by Alfred Mellowes in 1916. Mellowes produced this refrigerator commercially, but was bought off by Williams Durrant in 1918 who started the Frigidaire company for the mass of production of refrigerators. {Frigidaire parts}. In 1918, Kelivnator company introduced the first refrigerator with any type of automatic control. The absorption refrigerator was invented by Baltzar Von Platen and Carl. Munters from Sweden in 1922, while they were still students at the Royal Institute of Technology in Stockholm. It became a worldwide success and was subsequently commercialized by Electrolux. Other pioneers inventors/contributors included; Charles Tellier. David Boyle and Raoul Pictet. Carl Von Linde was the first patent to make a practical and compact refrigerator.

A refrigerant is a substance or mixture, usually a fluid (liquid or gas), used in a heat pump and refrigeration cycle. In most cycle it undergoes phase transition from a liquid to a gas and back liquid. Many working fluids have been used for such purposes. Fluorocarbons, especially chlorofluorocarbons, became populace in the 20th century but they are being phased out because of their ozone depletion effects, other common refrigerant used in various application are ammonia, sulfur dioxide and non-halogenated hydrocarbon such as propane, Wiley-VCH, (2002).

The ideal refrigerant should have favorable thermodynamic properties, be non-corrosive to mechanical components and be safe, free from toxicity and flammability. It should not cause ozone depletion or climate change. Since different fluids, have these desired traits in different degree, hence the choice of refrigerant for any particular application is a matter of trade-off.

The desired thermodynamic properties are a boiling point which is usually somewhat below the target temperature, high heat of vaporization, moderate density in liquid form, a relatively high density in gaseous form and a high critical temperature. Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application, by choice of operating pressure.

1.1. Types of Refrigerants

a. **Air:** Air is one of the earliest refrigerants and was widely used during the world war I, whenever a completely nontoxic material was required. Although air is free of cost and completely safe, its low coefficient of performance makes it unable to compete with the modern nontoxic refrigerants.
b. **Ammonia:** Ammonia is one of the oldest and widely used of all refrigerants. It is flammable and highly toxic. It is widely used in commercial and large industrial reciprocating compression systems where high toxicity is secondary.
c. **Carbon Dioxide:** It is a colorless and odorless gas, which is heavier than air. It is nontoxic and non-flammable but has extremely high operating pressures. In early years carbon dioxide was used for marine refrigeration, theatre air conditioning systems, and for hotel refrigeration systems.
d. **Freon Refrigerants:** These refrigerants use ethane and methane as bases and are the most important group of refrigerants being used in modern technology. Freon Refrigerants are used in a variety of applications, such as reciprocating compression refrigeration, and rotary compressors.

2. Objectives of Research

The objectives of this research are:

- ✓ Design and construct a table-type refrigerating unit using locally sourced materials.
- ✓ Carry-out cost analysis of the fabricated refrigerating equipment.

3. Research Materials

The materials used for this reaserch include;

i. Condenser
ii. Dryer
iii. 4 by 4 iron bar frame
iv. Capillary tube
v. Compressor
vi. Evaporator
vii. Thermoflask (Cooler)
viii. Copper Pipe (Evaporator)
ix. Relay
x. Overload
xi. Refrigerant
xii. Hinges
xiii. Screw

4. Design

Engineering Design is the process by which Engineers apply his knowledge, skills and point of view to the creation of a functional, economical and otherwise satisfactory solution to given problems in accordance with some codes or standards. Design is the central activity in the practice of engineering. Machine Design is a process by which an engineer applies his knowledge, skills and point of view to the creation of machines to perform desired functions in accordance with some codes and standards. However, the design of refrigerator falls under this category.

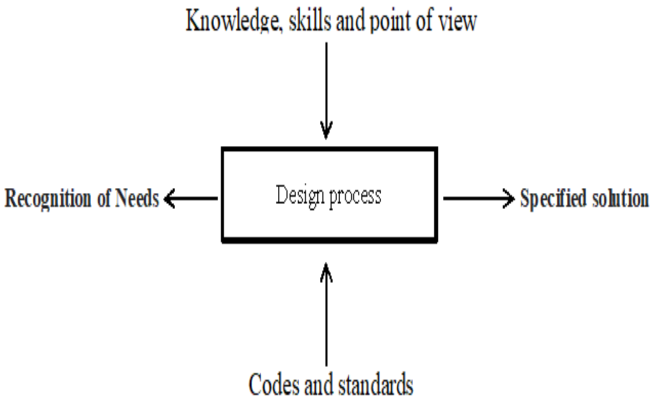

Table 1: Design Specification

S/N	Components	Dimensions/Capacity
1.	(Cooler) Thermoflask	520mm X 320mm X330mm
2.	Condenser	560mm X 390mm Ø = 4mm
3.	Dryer	150mm long Ø = 20mm
4.	Evaporator	470 X 300 X (7 coiling) Total length of copper wire used 470 + 300 X 2 = 1540 X 7 = 10780 = 10.78m = 11m, Ø = 6mm
5.	Compressor	1/10 hp Capacity
6.	Capillary tube	170mm long Ø = 1.5mm
7	4 by 4 iron bar frame	680x 530 (Total length)

5. Design Calculations and Parameters

- ✓ Operating temperature range is between lower and upper pressure of -95^{0}C and -30^{0}C.
- ✓ Refrigerant = $R_{12.}$
- ✓ Type- vapour compression refrigerating cycle.
- ✓ Dryness fraction = 0.9

Hence; based on the stated parameters above, relevant Psychometric parameters were taken from psychometric Chart and applied in design calculations are as follows;

$h_3 = h_4 = h_f$ at higher temperature

$h_2 = h_g$ at higher temperature

$= h_{f1} + x_1 (h_{gi} + h_{f1})$

hfi at lower temperature

hgi at lower temperature

$h_3 = h_4 = 8.86$

$h_2 = 174.20$

$h_{f1} = -47.56$

$h_{g1} = 144.22$

$h_1 = -47.56 + 0.9 (144.22 + (-47.56)$

$= -47.56 + 0.9 (144.22-47.56)$

$=-47.56 + 0.9 (96.66)$

$=47.56 +86.994$

$= 39.434$

Ref effect $= h_1 – h_4$

$= 39.434 – 8.86$

$= 30.574$ks/kg

$COPr = (h_1 – h_4)/(h_1 – h_2)$
$= (39.434 – 8.86)/(174.20 – 39.434)$
$COP = 30.574/134.766, = 0.23$

6. Factors of Consideration and Description of Material Selection

The factors of consideration for consstruction material selection include;

6.1 Cooler: The inner cabinet and outer cabinet are made of reinforced plastic which do not corrode and there is playfoam or fibre (insulation material) which is used to separate the outer and inner cabinet to prevnt unwanted transmission of heat between the inner and outter layers/carbinets.

6.2 Compressor: The compressor is made up of steels because of its high melting point properties and hardness. A compressor is a device that pumps the refigerant by rasing the pressure of the refrigerant and pumps the refrigerant through the entire system.

i. Hermetically sealed compressor was used: Hermetic compressor has a direct connection to the motor-compressor assembly, it has a steel casing. It is designed for low pressure pump refrigerant. Pressurized container, tightly closed so that no fluid may enter or escape.

ii. The capacity of the compressor is 1/10 horse power.

6.3 Evaporator/Copper Pipe: The evaporator is made up copper tubings, due to its ductility, ability to resist corosion and malleability. It serves as the evaporator, which is a device or part of refrigeration system in which the refrigrants, absorbs heat and changes from a liquid state to gaseous state. The type of evaporator used for this construction is bare tube evaporator and it is made up of steel or copper coil.

6.4: Condenser: The condenser is maed up of copper due to its ductility, malleability and its thermal conductivity. A condenser is a device for reducing gas to to liquid. It is an important component in a refrigeration. The type of condenser used is air cooled condenser (Natural convection) They are usually called coil condenser which is made of copper or aluminium coil.

6.5 Dryer: The dryers made-up of copper, due to its thermal conductivit property copper. Dryer removes any form of moistures or impurities associated with hot refrigerant gasses during refrigeration cycle (The gasses that comes in from the condenser). It is made up of copper.

6.6 Capillary Tube: The capillary tube is made up of thin copper wire with a hole passage inside. copper was used due to its ductility. The tube is usually soldered along the exterior of the dischange line, forming a heat exchange which helps to cool the hot refrigerant.

6.7 Iron Bar Frame: 4 by 4 iron bar was used to construct the frame to house all the components. It is made from steel. It was selected as a suitable material for the frame, due to its ability to withstand heavy weight without deformation or breakage (high tensile strenght).

6.8 Overload Control Unit: This is usually part of the compressor units that helps to reduce, the amount of heat entering the condenser. It is made up of plastic, copper and steel materials.

6.9 Relay: A relay is made up coil, armature, spring and yoke which is used to jump starts the compressor.

6.10 Refrigerant: The refrigerant used is R-12 (Dichlorofloro Methane). R12 was used because it is widely used and it is economical.

6.11 Hinges: A hinges is a jointed or flexible device that allows the pivoting of a Refrigerator door. Hinges was used to join the cover of the cooler with the Plastic carbinet itself to enable opening and closure of the refrigerator to retain its cooling effect.

6.12 Screw: A screw is metal fastener consisting of a shank partially or completely threaded shank, sometimes with a threaded point and a head which is used to hold the top material and to drive the screw either directly into a soft material or into a prepared hole.

6.13 Iron Bar Frame: Iron bar frame is made from steel, 4 by 4 size was used in building the housing for all the components.

7. Construction Procedures

The constructional procedures of the table-type refrigirator using locally sourced materials was carried out applying a ten step methodology as follows:

Step 1: The boring of two holes on the side of the thermoflask (cooler) thermoflask, for the inlet and outlet of the refrigerant during the refrigeration cycle.

Step 2: The thermoflask (cooler) was placed in the already constructed iron bar frame so as to provide the framework for housing the other components of the refrierator.

Step 3: At this stage; the coper pipe (evaporator) was wound round the internal waslls of a plastic cooler with the aid of aluminium sheets and then screwed firmly to the wall of the cooler, so as to provide the cooling effect when the refrigerator is at work.

Step 4: Then the two ends of the copper pipe (evaporator) were made to come aside, passing through the two bore holes,so as to allow the intake and the outlet of the refrigerant,during the refrigerating working cycle.

Step 5: The condenser was attached to the body of the thermoflask cooler with screws (mechanical fastners.

Step 6: The compressor was placed on the compressor housing that is attached to the main iron bar frame and screwed down to prevent shifting out due to excessive vibration during operation.

Step 7: Then then condenser (having an inlet and outlet) was attached to the compressor at the inlet end and at the oulet, the dryer was attached to it with the aid of oxy-acetelyn flame to prevent likage of refrigerant from the system.

Step 8: The capillary tube was then attached to the dryer and at the end point of the dryer was attached to the condenser.

Step 9: The capillary tube was also attached to the copper pipe (evaporator) at the inlet point of the copper pipe (evaporator) where the cooling effect is noticed or visible.

Step 10: The outlet end of the copper pipe (evaporator) was attached to the compressor. Steps 7-10 were joined using dry-acetylene flame. After all the different components had been joined together by the use of oxy-acetylene flame. Then bubble testing was used to test for leakages in every joints using snoop where oxy-acetyene flame was used for welding. The Bill of Engineering Measurement and Evaluation of materials used for this research is given in Table 2.

8. Operational and Performance Testing Procedure

The operational procedure of the table-type refrigerator; is to start the compressor, that compresses or pumps the refrigerant, all through the refrigerating cycle, compressor, evaporator, dryer, capillary tube, etc are all connected together electrically and mechanically). This is facilitated by connecting the plug to an electric source after which the control switch is turned on for the compressor to start working.

Table 2: Bill of Engineering Measurement and Evaluation

S/N	Items	COST (₦)
1	Compressor	7500
2	Condenser	4500
3	Evaporator	3500
4	Capillary Tube	2000
5	Dryer	1800
6	Relay	1600
7	Overload	2600
8	Cooler	3500
9	Frame	8500
10	Hinges	750
11	Screw	500
12	Wire	1100
13	Transportation	7000
14	Miscellaneous	5000
	Total	**49850**

The process of testing the table-type refrigerator after it had been fully constructed, with all the deferent conponents that will make it function at its optimal best was the basic step of pluging to the electric source since the refrigerator was built to be powered electrically. The first observation was huming of the compressor, becoming hot as a result of its pumping duty,thereby giving off heat. Gradually the conderser become hot as the hot refrigerant pass through it then the dryer becomes hot too, as a result of the passage of hot gas passing through it while it filters the refrigerant, when the capillary tube become hot too and closs to the end, the effect of cooling was noticed.

As it was about going into the evaporator, then it left the refrigerator cover for about 2-3 minutes, so as to allow the circulation of the cooling effect around the evaporator. After the door was opened up it was observed to be cold. In order to confirmed; the efficiency of the constructed refrigerator some canned drinks were put inside and left for about 15 minutes after which the drinks were observed to be already cold and chilled for consumption, thereby confirming the constructed table-type refrigerator to be functioning properly.

9. Safety Precaution for Safe Use of the Constructed Table-Type Refrigerator

i. Never put a damaged or faulty appliance into operation in order to avoid shock.
ii. Ensure that the electrical cable does not have dent or damage.
iii. Never attempt to move or left the refrigerator by pulling the door or source.
iv. Never leave the refrigerator open when there is no need to open.
v. Never place the refrigerator under direct sunlight.
vi. Never place the refrigerator near any heat source.
vii. Always clean the inner cabinet of the refrigerator to avoid odors.
viii. Do not use sharp object on the refrigerator so as to avoid puncturing the gas tubes which could result to leakages.

10. Conclusion

The refrigerator is said to be one of human's greatest discovery, due to its importance in every sector of human endeavours. refrigerator is one of the very first set of applianes every home in the world, would like to have in their possession, not just for its ability to cool drinks, preserve food, but also to store perishable food for future use. Refrigerator is also used in offices, confectionaries and even in ice producing plants (ice block making).

Finally, in relation to the marine field; refrigerator is the main storage and preserving facility on onboard a vessel, so as to keep them food fresh. Refrigerator is also used during a voyage on fishing trawler to preserve fish before they are processed, therefore, the need for a refrigerating system, in this present world of ours cannot be over emphasized.

11. Recommendation

Having successfully designed, constructed and tested the table-type refrigerator, it is therefore recommended that the details of this research be used to enlighten the populace, on the procedures of construction, operation of the refrigerator, cooling effect and the importance of the refrigerator in human day-to-day activities. The commercial making of the table-type refrigerator is also recommended.

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