Development and Experimentation of a Mobile Mini Ice-tube Making Machine

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Abstract—This project entails the design and fabrication of mini ice-tube making machines, which made use of food flask (cooler) as the cooling compartment which was installed inside a lagged stand made of galvanized iron, and two trays of ice-tube which was arranged vertically inside the cooling compartment after the installation of all refrigeration components. The mobile machine is designed to produce 50 pieces of ice-tube which is 25 pieces per tray, and the mass of water to produce this quantity of ice-tube was 2.5135 kg of water in 5 hours 51 minutes. The results revealed that the machine is sustainable in terms of material availability, lightweight, mobility, cost economy and performance.

Keywords—Ice-tube making machine, experimental, mobility, lightweight, effectiveness

INTRODUCTION
Refrigeration may be defined as lowering the temperature of an enclosed space by removing the heat elsewhere (Ajeet and Salem, 2016). When food items are stored inside a refrigerator at temperatures below the freezing point, the process of growth of microorganisms is greatly impaired. According to Abubakar et. al. (2012) in developing tropical countries like Nigeria domestic use of refrigeration is the most prevalent due to very high temperatures. Akinola et. al. (2015) stated that the non-availability or epileptic supply of electricity is not making the use of refrigerators effective. Poor supply of electricity and the warm climate in Nigeria today are responsible for the large demand for ice because of the need to locally refrigerate drinks and perishable food items. The development of a mini ice-tube making machine arrangement was borne out of this need. Golob et al. (2002) discovered that ice has been used to cool down the crops after harvest and to maintain the temperature low during shipping since ancient time. Ice is added crushed inside the produce container. This crushed ice takes out the heat from the commodity, causing it to melt while ensuring high relative humidity surrounding the produce (Sargent et al., 1988). This method is suitable for produce that can tolerate the contact with ice and water. Liquid ice or slurry of ice (ice and water) can enhance produce cooling by filling all of the void volume of the container. Ice cooling is considered as a fairly quick and simple method since it can be done directly in the field and within few minutes (Kader, 2002).

Ice is water in the solid state which may be any one of the 15 known crystalline phases of water. Its solid phases include snowflakes, hail, icicles, glaciers, pack ice and entire polar ice caps (Lemboye et. al., 2015). Ice is produced mechanically for domestic, leisure (for sports and recreation activities), commercial and industrial purposes (ASHRAE, 2006).

Dickson et. al. (1984) designed an ice making machine comprising of a plurality of ice forming moulds, a rotatable water spray bar for communicating make-up water from a water sump toward the moulds during a freezing cycle, a refrigerating system which includes a compressor, condenser and an evaporator for freezing water sprayed into the moulds; a water holding tank or plate for retaining water in heat transfer relationship to the ice moulds to aid the release of the ice formed during the harvest cycle. He achieved the reduction in cycle time due to the fact that the temperature of the refrigerator was minimized during the harvest cycle, hence, reducing the freezing cycle time.

Meier (1992) developed totally automatic machine for making the harvest blocks of ice. The machine has an ice chamber having four sidewalls and a bottom wall, the sidewalls has flange extending outward from the bottom edge, refrigerant lines were arranged in serpentine design on the sidewalls for providing refrigerant to the sidewalls and flange to increase the freezing rate, thereby giving rise to an energy cost effective machine.

Schlosser et. al. (1996) made improvements in the ice making machine in their invention by greatly curtailing...
the necessity for downtime, cleaning and sterilization of the machine, thereby enchanting the continuity and efficiency of operation of ice making machine. These were achieved by designing an automatic self-cleaning ice making machine having a freeze cycle and a harvest cycle.

Schlosser et. al. (2004) designed an ice making machine which comprises of a refrigeration system, water system having a fresh water inlet, water circulation mechanisms, an ice-forming device in thermal contact with the evaporator and interconnecting water lines. Further work was done by adding a control system which has a temperature sensing device in thermal contact with the outlet of the condenser, a microprocessor programmed to use input from the temperature sensing device either at a predetermined time after initiation of freeze cycle to determine the desired duration of the freeze cycle or at a predetermined time prior to the end of the freeze cycle to determine the desired duration of harvest cycle.

The above ice making machines are expensive and not readily available for local use. Hence, this work aims to design and fabricate a mini-ice tube making machine using locally available materials. The specific objectives are to design a portable mobile ice-tube making machine; fabricate the portable mobile ice-tube making machine using locally available materials; and evaluate the performance of the ice-tube making machine.

RESEARCH ELABORATION

The proposed ice-tube making machine is designed based on the vapour compression refrigeration system, using a plastic vacuum flask (cooler) as the refrigeration compartment and the tube plate that will accommodate the ice-tubes will be installed inside the cooler compartment. Due to the fact that cooler is to be used as the cooling medium, for the cooler to get to the freezing point of water it was investigated that heat will be gained by the cooler body due to temperature difference, therefore to overcome this challenge and to increase the freezing efficiency, the cooling medium will be installed inside a lagging compartment making the lagging for the whole system to be sufficient.

Tube Calculation

\[ \text{tube volume} = \pi r^2 h \]

where \( r \) is the radius of the tube cylinder base circle, \( h \) is the height of the tube cylinder

Surface area of tube = Area of top and bottom circle + area of the side

\[ = 2\pi r^2 + 2\pi rh \]

The height \( h \) of the tube to be produced in this project will be 4cm and the diameter as 4cm

Tube volume per ice tube = 50.27 cm³

Tube surface area = 75.40 cm²

Volume of water to be freeze to produce 50 ice-tubes

\[ = 2513.5 \text{ cm}^3 \]

Volume of water to produce 50 ice-tubes

\[ = 2513.5 \text{ cm}^3 \times 0.0025135 \text{ m}^3 \]

From the calculation above

2.5135 litters of water will be used to produce 50 ice-tubes of radius 2.5cm and tube height of 4cm.

\[ \text{Mass} = \text{density} \times \text{volume} \]

(1)

Density of water = 1000 kg/m³

Mass \( m \) = 2.5135 kg

Design Calculation

For any product to be frozen and stored at some temperature below its freezing temperature, the heat involved is calculated in three parts, (Dossat, 2010).

i. The quantity of heat given off by the product in cooling from the entering temperature to its freezing temperature.

\[ Q_1 = ml \]

(3)

\[ Q_1 = 842.0225 \text{ KJ} \]

The amount of energy needed to change the water to ice at 0°C

\[ Q_2 = ml \]

\[ Q_2 = 842.0225 \text{ KJ} \]

The amount of energy needed to cool the ice from 0°C to -10°C

\[ Q_3 = 105.240 \text{ KJ} \]

The total heat \( Q_t \) to be removed in the freezer is

\[ Q_t = Q_1 + Q_2 + Q_3 = 1231.4125 \text{ KJ} \]

Total compartment area = 5766 cm²

Components installation compartment height = 28 cm

Total cooler area = 2400 cm²

Thickness before re-lagging = 15 mm

The cooler will be installed on the already fabricated stand, and the space available between the stand and the cooler is the area to be lagged.

Cooler installation area on stand = 5766 cm²

Lagging area = compartment area on stand – cooler area

Lagging area = (5766 – 2400) cm² = 3366 cm²

Heat flow equation through the walls by conduction is given in equation 7.

\[ Q_A - T_{hf} - T_{cl} = Q \left( \frac{1}{A_{hf}} + \frac{1}{A_{KA}} + \frac{1}{A_{KB}} + \frac{1}{A_{KC}} \right) + LDA \text{ KD} + 1A_{hf} \]

(4)
Q_a = 54.6816 W
For 6hrs of operation,
\[ Q_{total} = Q_{product} + Q_{conduction} \]  \hspace{1cm} (5)
\[ Q_{total} = 2412.54 \text{ KJ} \]
Assuming infiltration load is 10% of \( Q_{total} \)
Infiltration load = 241.254 KJ
Hence,
\[ Q_{final} = Q_{total} + \text{ infiltration load} \]  \hspace{1cm} (6)
\[ Q_{final} = 2653.80 \text{ KJ} \]

**Compressor Design**

This is the capacity of the compressor required to produce the required refrigeration for the system and to remove the required amount of heat

From Converting \( Q_{final} \) of (2653.80 KJ) to kilowatts, we have:
\[ Q_{final} = \frac{6 \times 3600}{h} \]  \hspace{1cm} (7)

Cooling load = 0.12286 kW
Since 1 hp = 0.746 kW
While a \( \frac{1}{6} \) (0.167) hp compressor was selected.
Compressor power = 0.1647 hp.

The compressors capacity required to produce the refrigeration load of (0.1647 KW) in working for 6 hours per day is \( \frac{1}{6} \) (0.167) hp.

**Mass flow rate of the refrigerant**

Mass flow rate \( (m) = \frac{\text{cooling load}}{h_1 - h_4} \)\]
\[
M = 0.0007914 \text{ Kg/s} \hspace{1cm} (8)
\]

**Fabrication of freezer compartment**

The following processes were carried out in the fabrication of the freezer compartment. The material used in the fabrication of the freezer compartment is galvanized iron sheet for the freezer body and angle iron for the stands. The galvanized iron sheet is measured and marked out with the measurement specification required for the body. The angle iron is measured and marked out. All materials been marked out are cut out with electric cutting machine. The angle iron for the stand are arranged and welded together using electric welding machine. The galvanized iron sheets for the body are welded to the stand configuration.

After the fabrication of the freezer compartment, the cooler that is to be used for the inner compartment of the freezer is inserted into the fabricated body, the cooler is lagged with the freezing compartment using fibre glass as lagging material. A hole for copper tube passage between the compartment and the cooler is drilled out. The opened area of the compartment after lagging is covered with galvanized sheet. The freezer compartment is sprayed with silver paint to prevent future corrosion.

The refrigerating unit which comprises of the condenser, compressor and evaporator and AC cooler fan are installed as follows: Two pairs of tyres are fixed to the stands. The evaporator is bolted inside the inner cooler in a way that will cover almost the entire inner surface of the cooler. The copper tube is joined to the suction and discharge port of the evaporator, and the copper tube is passed down through the drilled hole in the compartment body. The condenser, cooler fan, and compressor are bolted down inside the created compartment area.

Copper pipes were cut using a tube cutter, and also flared using flaring tools, the copper pipe from the low side of the compressor was connected and joined to the pipe from the evaporator, while the copper pipe from the high side of the compressor was connected and joined to the pipe from the condenser. The copper pipes were welded and joined together using brazing equipment which consists of an oxy-acetylene, regulators and gauges, hose, and torch.

The filter drier was welded and joined to the capillary tube, and it was mounted in the suction line to prevent particles from entering the compressor. The system was tested for leakages before it was charged with refrigerator.

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**Plate 1: Ice-tube tray**

**Plate 2: Ice-tube interior**

**Plate 3: Component installation**
RESULTS AND DISCUSSIONS
The mini ice-tube making machine was designed to make use of water which was introduced into the tube tray to be loaded into the freezing compartment of the ice-tube making machine. The temperature was taken with thermometer at three stages with interval of 30 minutes and the readings were recorded.

The tube tray consist of 25 pieces of cylindrical cups per tray which each can be removed separately and it is arranged inside the tube tray, the tube was loaded by pouring water into the cup after the water has been weighed with weighing balance to know the weight of the water to be used, for the purpose of the design 2.5135kg of water were loaded into the two trays of the ice-tube to produce the required number of ice-tube which was weighed by weighing balance.

The initial temperature of the water to be frozen was taken by the use of thermometer before it was loaded into the evaporator compartment and temperatures were recorded at every 30 minutes during the working cycle of the ice-tube making machine. The results obtained are shown in the Figure 2.

From Figure 2, we can derive the heat removed within an interval of 30 minutes in order to calculate the actual C.O.P of the system and the refrigeration efficiency of the system.

Table 1: Dissolve time comparisons between trays used.

<table>
<thead>
<tr>
<th>Position of ice-tube</th>
<th>Top tray dissolve time (minute)</th>
<th>Bottom tray dissolve time (minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge 1</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>Edge 2</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>Edge 3</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Edge 4</td>
<td>32</td>
<td>33</td>
</tr>
<tr>
<td>Middle</td>
<td>34</td>
<td>35</td>
</tr>
</tbody>
</table>

Averages dissolve time for tray used

Average dissolve time for top tray = \[\frac{32+36+30+32+34}{5} = 32.8 \pm 33 \text{ Minutes}\]

Average dissolve time for bottom tray = \[\frac{34+29+31+33+35}{5} = 32.4 \pm 32 \text{ Minutes}\]
Results discussion
From Table 1 comparing the average dissolve time for both trays, it is seen from the above calculation that the top tray has the highest dissolve time of 33 minutes and the bottom tray of 32 minutes, the difference in time of dissolve is due to the time of unloading each tray from the system since the time difference is some seconds interval.

From Figure 2 at 90 minutes of continuous system running, the water reached temperature of 0 °C and after 90 minutes the temperature of the system reduced by 1 °C interval for each minutes, this is as a reason that the system is doing much work to transform the water to ice at those temperatures. The temperature remains constant at -3 °C from 180 to 210 minutes; this might be as a result that the ice formed is trying to harden changing from ice slurries to ice-tube.

After 360 minutes of continuous operation of the system it was noticed that the inside temperature of the system did not change from -10 °C, from this observation, it can be said that the system has reach its constant enthalpy; therefore the system can continue to run for various hours with constant temperature of -10 °C.

Coefficient of performance (C.O.P)
The coefficient of performance is the ratio of the cooling load to the compressor power; the C.O.P is mainly affected by the change in evaporating and condensing temperature.
Compressor power = 0.1647 hp
Ambient temperature = 27 °C, Temperature after 30 minutes = 11 °C
Heat removed per 30 minute (q) = \( \frac{0.5 \times 4.2 \times (27 - 11)}{30 \times 60} \) = 0.01867 kW
Heat removed per 30 minute (q) = 0.01867 kW
Actual C.O.P = \( \frac{Q_c}{q} \) (Rajput 2016) \( (9) \)
\( Q_c \) is cooling load, and it is as calculated as 0.122865 kW
From (equation 18) Actual C.O.P =6.581
COP\(_{\text{theoretical}}\) = \( \frac{T_2 - T_1}{T_2 - T_1} \)
COP\(_{\text{theoretical}}\) = 7.108
Refrigerating efficiency = 92.60 %
Time taken to freeze 1kg of water = 2.15 hours
Time taken to produce ice-tube of 2.5135kg of water (50 ice-tubes) = 5.51 hours

Plate 4: Ice-Tube Produced

CONCLUSION
A portable/mobile ice-tube making machine was developed and evaluated. The machine ran for 5 hours 51 minutes to produce 50 pieces of ice-tube with 2.5135 kg of water using two ice-tube tray 25 pieces per tray, and all part used for fabrication were selected to reduce weight of the machine, reduce cost of production and also increase the efficiency of the machine.

REFERENCES


Biography of Author(s)

CALEB, O. O. (B. Eng. Mechanical Engineering, M. Eng. Building Services Engineering) is a lecturer at the Department of Mechanical Engineering Federal University of Technology Akure, Ondo State, Nigeria.

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