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THE DESIGN AND CONSTRUCTION OF AN ICED BLOCK MAKING MACHINE

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ABSTRACT

In this work, the design and development of an ice block making machine is reported. The average temperature of many tropical parts of Africa like Nigeria is around 35oC which increases the demand for ice block, thus, the need for an ice block making machine. The machine is of external dimensions of 900mm × 600mm × 500mm. It is 20mm thick made up of 1mm of galvanized steel plate (outside), 15mm of polystyrene (an insulating material) and 1mm of aluminum (inside). The cooling load calculation gives a refrigeration capacity of 4.014kW, compressing/condensing unit of 1hp and with 4 evaporator plates each rated hp. The calculated co-efficient of performance (C.O.PR) was 5.65 and the refrigerating efficiency 84.0%. Under test running with 3.85kg of water placed inside the box at an initial temperature of 280 C, there was a gradual reduction in temperature at interval of 30minutes. After a period of 5hrs-30mins, the temperature of the water dropped to 00C. A graph of temperature T (Celsius) against time (min.) indicated that the temperature varied inversely as the time. The implication of this inverse relationship is that the temperature drops with increase in time. From the graph, it was determined that for the water to completely turn to ice block at -40C, it would require a time period of 6hrs, 30mins The outcome of this test shows that the constructed Ice Block Making Machine has been able to produce a cooling effect capable of turning water from room temperature into Ice block.

Keywords: Design, Construction, Iced Block, Machine, Water.

I. INTRODUCTION

Hot weather condition experienced in tropical region like Nigeria as a result of global warming leads to dehydration and excess level of thirst. This can only be overcome by the provision of a very cold water or iced block in order to quench the thirst. Many tropical parts of Africa experience a large amount of bright sunlight every year, this means that for most days of the year, the weather is hot and humid due to the bright shining of the sun for longer hours on most days. According to Iwuoha (2014), the temperatures during the day can rise up to 40°C especially in the northernmost parts of the continent which have a savanna or desert climate. Since the First World War, the rise on the standard of living has become more and more noticeable than any other time in history. One of the greatest technological developments of this remarkable age is the production of "ice" and "preservation" of goods by mechanical means. The statement was confirmed by Osore (2013), where he stated that no other single factor has played a more vital role in the growth and attainment of the present day standard of living than the art of "mechanical refrigeration". Calm and Hourahan (2001) in their study explained that people cooled their food with ice transported from the mountains before the introduction of a mechanical refrigeration, and ice was stored with the aid of snow cellars, pits that were dug into the ground and insulated with wood and straw. Water stored in earthen pot is generally cooler than that which is stored in glass bottles. Hence in time past, cold drinking water was stored in earthen pots in which evaporation took place severally and the water turned to iced block. The formation of ice is as a result of water transformation from the liquid phase by a heat transfer process which is cooling below 0oC, the freezing point of water. A two freezing compartment unit was designed and constructed by Oladunjoye and Omogbemile (2003) while Mohammed et.al (2012) developed and evaluated a prototype refrigerated cooling table for conference services. The study stated that this was imperative for the high demand for cold drinks during meetings and conferences. Nasir et.al (2013) designed and constructed an ice-block making machine using the principle of vapour compression system, the study reported that 1kg of ice block was produced in 70 minutes.

II. METHODOLOGY

Machine Description and Working Principle

The materials selected for the construction of the Ice block making machine equipment was based on strength, and suitability. The ice block making machine consists of the following components; the internal and external

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cabinets were made of aluminum and galvanized plate respectively, the insulator which fills the gap between the inner and outer cabinet was made of polystyrene due to its high thermal insulating properties. The components of the cooling system, that is, compressor, condenser, and evaporator, are made of aluminum and copper. The refrigerant used is R22, this is due to its desirable properties in commercial refrigeration systems.

Design Analysis

The following design parameters are chosen for the Iced Block Making Machine:

External dimensions: 900mm × 600mm × 500mm

Thickness: 20mm made up of 1mm of galvanized steel plate (outside),

15mm of polystyrene (an insulating material) and 1mm of aluminum (inside)

Outside air temperature, To = 350C

Cabinet initial temperature, Ti = 300C

Cabinet final temperature, Tf = -5

0C

Operating time, 8 hours

Refrigerant, R-22

Condensing temperature, Tc = 350C

Evaporating temperature, Te = -5

0C

Degree of subcooling/superheating, 10K

Compressor efficiency = 85%

Enthalpies of R-22 at the various operating states obtained from the Pressure-enthalpy (P-h)

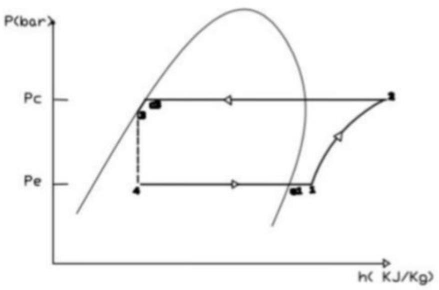

Fig. 1: Pressure-enthalpy (P-h) diagram of the refrigeration cycle

INPUT DATA	ANALYSIS	DECISION
Length, L = 900mm Width, W = 600mm Height, H = 450mm Density of water, ρ = 1000kg/m^3	Mass m, of water Volume, V = Area × Height Area = Length × Width Mass, m = ρ × V	m = 243kg
STAGES OF HEAT REMOVED		
Specific heat of water, C_p = 4.187KJ/KgK T_i = 30°C, T_s = 0°C, m =243Kg	**STAGE 1**: Sensible heat, Q_{s1}, from 30°C to 0°C Qs = m C_p($T_i - T_s$)	Q_{s1} = 30523.2KJ
m = 243kg Latent heat of fusion, h_{fg} = 335KJ/kg	**STAGE 2**: Latent heat , Q_L, at 0°C Q_L= m x h_{fg}	Q_L = 81405KJ
m = 243kg, T_s = 0°C, T_f = -5°C Specific heat of Ice, C_p = 2.11KJ/Kg	**STAGE 3**: Sensible heat, Q_{s2}, from 0°C to -5°C Q_{s2} = m C_p(T_s-T_f)	Q_{s2} =2563.6KJ
Q_{s1} = 30523.2KJ, Q_L = 81405KJ, Q_{s2} =2563.6KJ	**TOTAL HEAT REMOVED, Q_p** $Q_p = Q_{s1} + Q_L + Q_{s2}$	Q_p =114491.85KJ
Q_p =114491.85KJ, t = 8 hr = 8 ×3600 = 28800s	**TOTAL HEAT REMOVED/Unit time, Q_T** $Q_T = \frac{Q_p}{t}$.	Q_T = 3.975 KJ/s = 3975W

WALL GAIN LOAD, $\dot{Q}_W$		
K_1 = Conductivity of Aluminum = 205W/mK K_2= Conductivity of Polystyrene =0.033W/mK K_3 = Conductivity of mild steel = 54W/mK x_1 = Thickness of polystyrene = 15mm = 0.015m x_3 = Thickness of mild steel = 1mm = 0.001m	**U = overall heat transfer coefficient** $\frac{1}{U} = \frac{x1}{k1} + \frac{x2}{k2} + \frac{x3}{k3}$ (Osore, 2018)	U = 2.199W/mK
U = 2.199W/mK $T_o = 35^0C$ $T_i = 30^0C$	**Wall Gain Load, $\dot{Q}_{W1}$ (2 of sides of cabinet)** Area, $A_1 = L \times B$ $\dot{Q}_{W1}$= 2 x UA_1 [To - Ti] (Osore, 2018)	$A_1 = 0.3m^2$ $\dot{Q}_{W1}$ = 6.597W
	Wall Gain Load, $\dot{Q}_{W2}$ (Front & Back of cabinet) Area, $A_2 = L \times H$ $\dot{Q}_{W2}$ = 2 x UA_2 $[T_o - T_i]$	$A_2 = 0.45m^2$ $\dot{Q}_{W2}$ = 9.896W
	Wall Gain Load, $\dot{Q}_{W3}$ (Top & Base of cabinet) Area, $A_3 = L \times W$ $\dot{Q}_{W3}$ = $2UA_3$ $[T_o - T_i]$	$A_3 = 0.54m^2$ $\dot{Q}_{W3}$ = 11.875W
$\dot{Q}_{W1}$ = 6.597W, $\dot{Q}_{W2}$ = 9.896W, $\dot{Q}_{W3}$ = 11.875W	**TOTAL WALL LAOD, $\dot{Q}_W$**	$\dot{Q}_W$ = 28.368W

	$\dot{Q}_W = \dot{Q}_{W1} + \dot{Q}_{W2} + \dot{Q}_{W3}$	
AIR CHANGE LOAD, $\dot{Q}_A$		
L = 0.9m H_1 = 0.5m W = 0.6m	Inside Volume of cabinet $V_1 = L \times H_1 \times W$ **Note** : If $V_1 < 100m^3$, then $\dot{Q}_A$= $[0.7V_1+2]\Delta T$, (Osore, 2013) $\Delta T = [T_o - T_i]$	$V_1 = 0.27m^3$ $\dot{Q}_A$ = 10.945 W
TOTAL REFRIGERATION LOAD, $\dot{Q}_R$ [or REFRIGERATION CAPACITY, Ref. Cap.]		
$\dot{Q}_W$ = 28.368W, $\dot{Q}_A$ = 10.945 W, $\dot{Q}_T$ = 3975W	$\dot{Q}_R$ = $\dot{Q}_W + \dot{Q}_A + \dot{Q}_T$ = **Ref Cap**	$\dot{Q}_R$ = 4014.3W
COMPRESSOR POWER		

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Assumption Sub-cooling is assumed to take place along the saturated liquid line so that $h_3 = h_{f3}$ at T_3 $T_c = 35°C$ $T_i = 30°C$ Degree of subcooling = $T_c - T_3 = 10K$ Ref. Cap = 4.014KW Refrigerant: R – 22 $T_c = 35°C$ $T_e = -5°C$ At $P_1 = P_4 = 4.25$ bar $P_c = P_2 = 14.0$ bar Degree of sub cooling/super heating = 10K Compressor efficiency, η = 85 % $h_{e1} = h_{g1}$ at P_1 =4.25 barh$_{e1}$ = 404 KJ/Kg h_1 = 412 KJ/Kg h_2 =442.5 KJ Kg h_3=h_4 = 232 KJ/ Kg Fig. 1 & Lemmon *et.al* (2007). h_{e3} = 244 KJ/Kg Compressor efficiency, η = 85 %	@ $T_c = 35^0C$, P_c = 14.0 bar $T_3 = T_c - 10K$ Compressor Power, $P_o = \dot{m}(h_2 - h_1)$ Ref. eff. = $h_{e1} - h_4$ Mass flow rate, $\dot{m}$ $\dot{m} = \frac{\text{Ref. Cap.}}{\text{Ref. eff}}$ $P_o = = \dot{m}(h_2 - h_1)$ Input power to compressor, P_i $P_i = \frac{P_o}{\eta}$ Conversion to hp 746W = 1hp	$T_3 = 25°C$ $\dot{m}$= 0.0233kg/s P_o = 0.714 KW P_i = 835 W
$T_L = -5 + 273 = 268k$ $T_H = 35 + 273 = 308k$, $COP_R = 5.65$	$\eta_{RE} = \frac{COP_R}{COP_{CR}}$	η_{RE} = 84.0 %

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	Horse power rating $= \frac{P_i}{746}$	Compressor size $\approx$ 1 hp
RATE OF HEAT REJECTION BY THE CONDENSER, Q_c		
	$Q_c = \dot{m}\,[h_2 - h_{c3}]$	Q_c = 4.625 KW
RATE OF HEAT ABSORTION BY THE EVAPORATOR, Q_e		
	$Q_e = \dot{m}\,[h_{e1} - h_4]$	Q_e = 4.019 KW
COEFFICIENT OF PERFORMANCE, COP_R		
	$COP_R = \frac{he1-h4}{h2-h1}$	COP_R = 5.65
REFRIGERATING EFFICIENCY, η_{RE}		
	$C.O.P_{CR} = \frac{T_L}{T_H - T_C}$	$C.O.P_{CR}$ = 6.7

III. MODELING AND ANALYSIS

Materials and Fabrication of Components

Apart from the design analysis required for the determination of the various sizes and ratings of components used, a good knowledge of the physical, chemical and mechanical properties of materials for materials selection and various joining methods are critical for the fabrication of components.

The iced block making machine is of a simple configuration and very rigid to withstand the operating conditions and effect of the cooling unit. The unit consists of the evaporator, compressor, condensing, capillary tube, filter drier, insulator rubber with polystyrene which prevents heat loss in the cabinet in order to increase the cooling efficiency. The interior cabinet is made up of aluminum sheet in order to avoid corrosion, reduce its weight, increase its strength and have a good thermal conductivity. The exterior cabinet is made up of galvanized plate.

The fabrication of the relevant components, assembling of component parts, charging and testing of the iced block making machine were all carried out in the Welding and Fabrication, Refrigeration and Air Conditioning, Machine Shop and Bench-Fitting workshops of the Department of Technical Education, The College of Education (Technical) Kabba. Kogi State. The materials for the fabrication were cut as indicated in Fig . 2 (Working Drawing) while the various component parts were put together as shown in Fig. 3 (Exploded Drawing) and Fig. 4 (Assembly Drawing.). The constructed Iced Block Machine is shown in Fig. 5 **Figure 1:** 3D view of building.

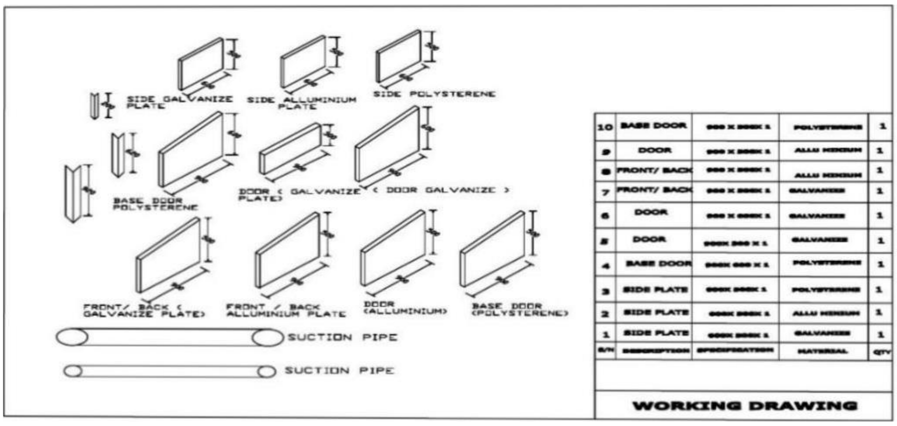

Fig. 2: Working Drawing

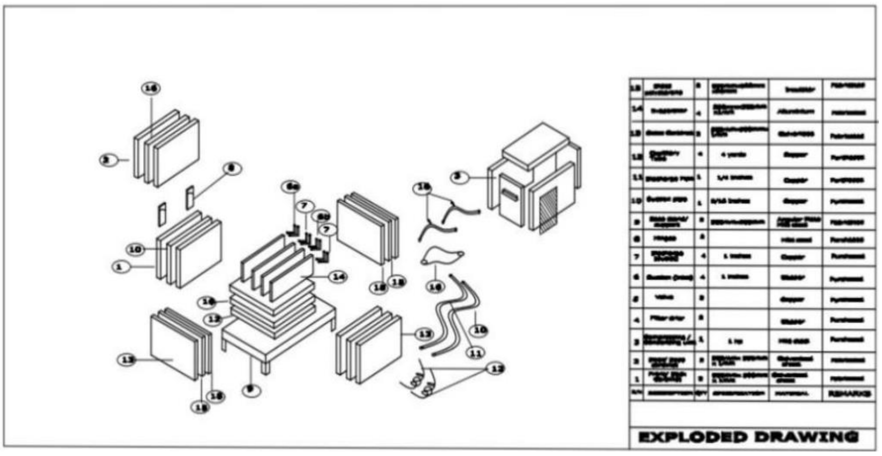

Fig. 3: Exploded Drawing

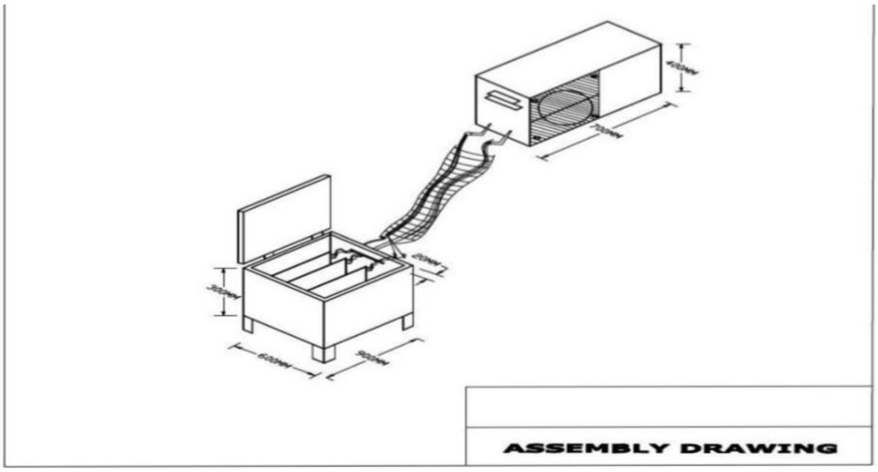

Fig. 4: Assembly Drawing

The polystyrene was fitted to the bent galvanized sheet which made up the cabinet. The aluminum sheet was used to cover the inner part of the cabinet by fitting and riveting it to the polystyrene after which the edges of the cabinet were covered and smoothened with a filler. The evaporator plates were fitted into the compartment using rivet and the compressing/condensing unit was mounted afterwards. The capillary tube was welded to the inlet of the evaporator through the discharge of the compressor and from the discharge of the evaporator to the suction of the unit. The compressor was flushed with NIDO gas and then charged with R-22 refrigerant to operating conditions thus providing the desired cooling effect. The mild steel angle iron used for the base stand was profiled to a specification of 920mm × 620mm × 200mm.


Fig. 5 & 6: The Constructed Iced Block Machine

IV. RESULTS AND DISCUSSION

An ice making machine has been designed and constructed with several tests performed based on the objectives of this study. The unit was test-run in order to evaluate its performance. It was connected to a 15Amp, 240V outlet. The unit was observed to run continuously for five hours thirty minutes (5hrs-30mins) at an interval of 30 minutes for each recording of temperature drop in water. The initial temperature of the water was recorded to be 280C with the aid of a thermometer before it was placed in the unit. The temperature drop in water with time was observed by recording the water temperature at 30 minutes interval until the final product of an ice was achieved. The test was repeated eleven times and values obtained were recorded in all cases as illustrated in the table and graph below.

Table 1: Temperature variation of water with time in the machine

Readings	Temperature (^{0}C)	Time(min)
1st	20	30
2nd	18	60
3rd	16	90
4th	14	120
5th	12	150
6th	10	180
7th	8	210
8th	6	240
9th	4	270
10th	2	300
11th	0	330

(Water at room temperature 280 C, Cabinet inner temperature 200 C).

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Table 1 shows that the average drop in temperature at 30minutes time interval was 2oC. After running the machine for 5hrs 30minutes continuously, the temperature dropped to 0oC, the freezing temperature of water. At this temperature, there was formation of ice flakes. Figure 6 gives a graph of temperature T (oC) variation of water with time t (min). The result indicated that the temperature of the water varies inversely with time. The implication of this inverse relationship is that the temperature drops with increase in time. It was observed that for the water to completely turn to ice block at -40C, it would require a time period of (6hrs-30mins).

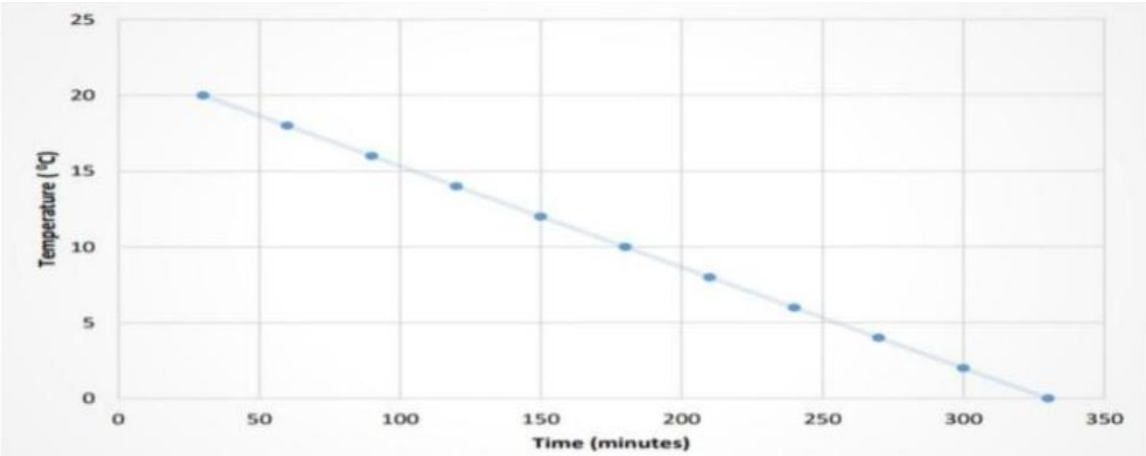

Fig. 7: Graph of Temperature T (oC) variation of water against time t (min)

V. CONCLUSION

The Iced Block Making Machine with overall external dimensions of 900mm × 600mm × 500mm, powered by a compressing/condensing unit of 1hp and with 4 evaporator plates each rated hp was successfully designed and constructed. The outcome of the test run conducted on it indicated that the machine is capable of turning an average of 3.85kg of water at 280C to Ice-block at temperature of -40C in a period of 6hrs, 30minutes. All the materials and component parts used in the development of the machine were locally sourced.

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