Journal of Scientific and Industrial Studies, Volume 4, Number 4, 2006
ISSN 1117 – 1693

DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A COMMERCIAL ICE-MAKER

Odesola, Isaac Folorunso, Nwaneto Franklin Nwaneka and Adeyemo, Adekunle Saheed
Department of Mechanical Engineering
University of Ibadan, Ibadan, Nigeria

ABSTRACT

The ice-maker (freezer) was designed, constructed and tested. The ice-making machine is to freeze 27kg of water in 9 different compartments in 12 hrs. The quantity of heat to be removed in order to achieve freezing is 12556.89 kJ, and this is used to determine the refrigeration tonnage of the machine (0.124 ton). Polyurethane and Galvanized steel sheets have been selected for insulation and cabinet materials respectively due to their low thermal conductivities and high corrosion resistant properties. The performance tests show that the ice-maker is capable of producing 9 ice cubes (10 cm x 10 cm x 30 cm) in 12 hrs; while the economic analysis indicate that the project is economically viable. The cost of the ice-maker is N 51,650.00 and the investment payback is estimated to be 74 days with regular supply of electricity.

Keywords: Ice, Heat Removal Rate, Insulation, Freezing, Compressor, Condenser

NOMENCLATURE

δ = Surface tension
P_r, 1 = prandtl no. for saturated liquid
T_w _t_{sat} = Excess temperature in Kelvin
C_p, f = specific heat of saturated liquid in J/kg.K
C_{sf}= An empirical constant 0.015 for combination of copper tube

INTRODUCTION

The need for preservation of food and space cooling for comfort and other uses has from time immemorial attracted the invention of series of appliances and methods for achieving these human needs. Efforts made so far have yielded a lot of achievements in this area and this has led to the invention of refrigeration and air-conditioning systems. Both systems involve cyclic process by which natural heat transfer down a temperature gradient through the external supply of energy to the systems. By definition, refrigeration is the transfer of thermal energy from a region of lower temperature to a region of higher temperature. In the past it was on record that cooling was achieved by the use of ice, but in these modern times, refrigeration involves cyclic processes. Refrigeration therefore is the production and utilization of below atmospheric temperature for cooling purpose. To achieve cooling, the system extracts heat from the space to be cooled and since a statement of the First Law of Thermodynamics is that energy can neither be created nor destroyed, the temperature of the space falls by an amount equivalent to the quantity of heat absorbed. The ice-making machine is a refrigerator that is used in the production of ice of different shapes and sizes: blocks, cubes, flakes and so on. The design of this freezer is based on the principle of reversed Carnot cycle in which heat is removed from a region of lower temperature to a region at higher temperature and the empirical correlation in boiling and condensation heat transfer.

RESEARCH METHODOLOGY

DESIGN CONSIDERATION AND CALCULATION.

Cooling Load Calculation.

Dimension of ice to be produced: 10cm x 10cm x 30cm.
Volume of ice = (10 x 10 x 30) cm = 3000cm^3
No. of ice-block = 9

$$Q_1 = MC\Delta T \quad (1)$$

$$Q_2 = ML \quad (2)$$

$$\text{Heat removal rate} = \frac{quantity..of..heat..removed}{Total..time} = \frac{Q}{t} \quad (3)$$

RATING OF THE ICE-MAKER

The refrigeration capacity, which is the rate of heat removed in the evaporator, is expressed in terms of tons of refrigeration. A ton of refrigeration (TR) is the amount of refrigeration effects produced by the uniform melting of I ton (1000kg) of ice at 0°C in 24 hrs.

EFFECTIVE DISPLACEMENT/VOLUME FLOW RATE

The volume flow rate of the refrigerant at the compressor inlet gives the effective displacement of the compressor required for the freezer. This determines the stroke, revolution per minute and bore of the compressor to be used.

Therefore,

Volume flow rate (V_0) = Mass flow rate x specific volume

$$V_0 = M_0 v_1 \quad \ldots\ldots\ldots\ldots \quad (4)$$

v_1 = Specific volume of the refrigerant.

POWER INPUT TO THE COMPRESSOR.

The power input to the compressor for the ice-maker is expressed as;

Power = Mass flow rate x energy required per kilogram of refrigerant

The power required by the compressor is 136W, but to allow for factor of safety, 200W compressor will be used.

SWEPT VOLUME OF THE COMPRESSOR.

For reciprocating compressor with volumetric efficiency η_c of between (65 and 85) %, rotating at a speed of (between 200 and 600 rev/min), the swept volume is given as; Holman J.P., (1997)

$$V_s = \frac{V_0}{nN\eta_v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where V_0 = volume flow rate of refrigerant (m^3/min).

n = number of cylinders

N = rotational speed (rev/min).

η_v = Volumetric efficiency. (%)

EVAPORATOR THERMAL DESIGN.

In the thermal design of the evaporator for the freezer, empirical correlations in boiling heat transfer were used. From Rohsennow and Griffith equations we have:

$$[q/A]_{total} = [q/A]_{boiling} + [q/A]_{forced-convection} \ldots\ldots\ldots\ldots \quad (6)$$

$$[q/A]_{boiling} = \mu_L h_{fg}\left(\frac{g(e_l - e_v)}{\delta}\right)^{1/2}\left[\frac{C_{p.l}(T_w - T_{sat})}{Pr^s_l\, C_{sf}\, h_{fg}}\right]^3 \quad (7)$$

From Dittus-Bolter relation

$$[q/A]_{forced-convection} = 0.023\,[eVD]^{0.8}\left[\frac{C_p\,\mu}{\mu}\right]^n \frac{k(T_w - T_{sat})}{k}\,\frac{}{d} \ldots\ldots (8)$$

Nusselt no. $N_{ud} = 0.023\,Re^{0.8}\,Pr^n = hd/k \quad \ldots\ldots\ldots\ldots \quad (9)$

Also

$$[q/A]_{boiling} = \mu_l h_{fg}\left(\frac{\rho_l - \rho_v}{\delta}\right)^{1/2}\left(\frac{C_{p.l}(T_w - T_{sat})}{Pr^s C_{sf} h_{fg}}\right)^3 \quad \ldots\ldots (10)$$

δ = surface tension

Pr, l = prandtl no. for saturated liquid

$T_w - T_{sat}$ = Excess temperature in Kelvin

$C_{p.l}$ = specific heat of saturated liquid in J/kg.K

C_{sf} = An empirical constant 0.015 for combination of copper tube

CONDENSER RATING

Condenser requirement are specified using data issued by equipment manufacturers or regulating bodies like ASHRAE.

INSULATION THICKNESS

The insulator thickness of ice-making machine is given by the American Refrigeration Institute (ARI) design and data books as (0.03m)

REFRIGERANT SELECTION

Refrigerant (R-134a) has been selected based on its physical, chemical and thermodynamic properties.

RESULTS AND DISCUSSION

Energy Analysis of the Ice-Maker

The working drawings for the fabrication of the ice maker are shown in Figures 1-8 Energy consumed by the ice-maker for the freezing duration is analysed below. With power supply from the Power Holding Company (PHCN) NEPA (Tariff) 1kWh = N4.00 Power consumed by the ice-maker = Compressor power + Cooling fan power = (200W +30W) =230W

Energy consumed by the ice-maker for 12hrs = (230W x 12hrs)/1000 = 2.76 kWh

Amount charged for 12hrs = 2.76 x 4.00 = N11.04

Also, using alternative power supply that is a 4KVA generator will be appropriate for the ice- maker.

Fuel consumption;

10 litres of diesel will be consumed in 12hrs.

1 litre = N80.00

10litres of diesel = N800.00

Using 4KVA generator which is appropriate for the ice-maker, 7litres of diesel will be consumed in 8hrs.

1litre of diesel = N80.00

7litres of diesel = N560.00

ECONOMIC ANALYSIS

Tables 1-3 below illustrate the cost samples of ice of various sizes obtained from some ice producers.

Total monthly yield = 720 x 30

= N 21600.00

Cost of energy consumed daily=N22.08

Cost of energy consumed monthly = N662.40

Cost of the ice- maker =N51, 650

From the above analysis, it is therefore established that the designed ice-maker will perform very well when compared with existing commercial ice-makers.

However, the investment payback on the ice-making machine is approximately 74 days.

Total monthly yield –Cost of Energy consumed = (N21600-662.4)

=N20, 937.60

$$\text{Payback} = \frac{\text{Price of ice-maker} \times 30}{20{,}937.60} = 74 \text{ days}$$

Table 1: Samples of ice of various sizes

Size (cm)	Cost(N)	Freezing time (hrs)	No produced per day	Estimated yield (N)
10cm x 10cm x 10cm	15	12	18	270
20cm x 20cm x 20m	30	12	12	360
30cm x 30cm x 30cm	50	12	8	400
50cm x 50cm x 50cm	70	12	4	280

Table 2: Production analysis of the designed ice-maker

Size (cm)	cost(N)	Freezing time (hrs)	No produced per day	Estimated yield (N)
10cm x 10cmx30cm	40	12	18	720

Table 3: Samples of condenser rating

Hermetic compressor suction temperature	Air cooled or evaporative condensing Temperature				
0°C	30°C	35°C	40°C	45°C	50°C
-18	0.77	0.74	0.72	0.72	0.69
-16	0.81	0.78	0.75	0.73	0.70
-12	0.82	0.79	0.77	0.75	0.72
-10	0.85	0.82	0.80	0.78	0.75
-8	0.87	0.84	0.82	0.79	0.76

Source: ASHRAE Design and Data Guide (2000)

BILL OF QUANTITIES

The cost implication of the ice-maker has been determined and presented below as bill of quantities

Table 4: Bill of quantities

	DESCRIPTION	QUANTITY	RATE (N)	TOTAL COST (N)
1	Galvanized steel sheet 8ft x 4ft	1 sheet	3,800	3,800
2	Galvanized steel sheet 8ft x 4ft	1 sheet	4,200	4,200
3	Copper tube coil	1 roll	2,000	2,000
4	Polyurethane or Polystyrene insulation sheet (8ft x 4ft)	1 sheet	3,500	3,500
5	Angle iron (mild steel) 40mm x 40mm x 6m	2 lengths	950	1,900
6	Danfoss Reciprocating Compressor 1/5hp, Single-phase 220v. (Hermatic)	1	14,000	14,000
7	Condenser coil with fan 3/4hp, double circuit, staggered	1	4,500	4,500
8	Thermostatic expansion valve	1	1,500	1,500
9	Driver	1	500	500
10	Rivet (2.5mm)	1pkt	200	200
11	Receiver (1.5 litres)	1	1,000	1,000
12	Accumulator (1.5 litres)	1	2,500	2,500
13	Sight glass	1	300	300
15	Needle valve (15mm O.D)	3	250	750
16	Labour			11,000
	Total			**51,650**

CONCLUSION

From the results obtained, the following conclusions are drawn:

i 85% volumetric efficiency of the compressor will produce efficient ice-making

ii the ice-maker will produce 27 cubes in 24hrs with maximum efficiency. From the different analysis of energy consumed using the two basic energy sources, it is more effective to use power supplied form NEPA. However, with the current power outage being experienced in the country, it is advised that alternative power supply, i.e. generator, should be on standby to compliment the supply from the National Grid.

REFERENCES

1. Bejan, Adrian. (1993): Heat Transfer, Josh Wiley and Sons, Inc, New York
2. Eastop, T.D and McConkey.(1993): Applied Thermodynamics for Engineering Technologists, 5th edition, Longman Singapore Publisher.
3. Holman J.P.(1980): Thermodynamics, 3rd edition, McGraw Hill New York.
4. Holman J.P., 1997 Heat Transfer, 8th edition, McGraw Hill New York

5. Incropera, F.P. and Dewitt, D.P.(1995): Fundamentals of Heat and Mass Transfer; 3rd edition, John Wiley and Sons, Inc. New York.
6. Perry, Robert, H., and Green, Don W. Perry, 1998; Chemical Engineers Handbook, 7th Edition, McGraw Hill Book Co. Singapore, International Edition.
7. Whitman, William C. and Johnson, William. M, (1995): Refrigeration and Air-Conditioning Technology, 3rd Edition, Delmar Publishers. New York.
8. Odesola, I.F., and Sefiu, Y.B., (2006): Computerised Approach to Cooling Load Estimates for air-Conditioning Design, Nigerian Journal of Engineering Management, Vol.7, No.1, 2006, 46-49