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Design of Ice Manufacturing Plant (2000 lb)

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ABSTRACT

Ice has been used for hundreds of years for short time preservation of food and still it is used to preserve cool drinks and food for short period. There are many types of ice manufacturing plants. They are divided by thickness and shape of ice. The ice plant consists of four main components: condenser, compressor, evaporator and freezing tank containing sodium chloride brine, bring agitator and can with water.

In this paper 2000lb per day block ice manufacturing plant is designed. The temperature of water is 27oC and to reduce it to -7.2oC. Based on this requirement, the design consideration and calculation have done.

Keywords: *Ice plant, condenser, compressor, evaporator and freezing tank*

I. INTRODUCTION

Nowadays, human being is face with global warming effect according to the ozone depletion. So ambient air temperature rises and a result human being suffer from it last summer even some were die. For the rich, they will use freezer or refrigerator but not for lower level people because they will try to fulfill their institution for a day. That's why they need to use ice for their goods or something to be last longer. Myanmar is a developing country so ices are being used in commercially as a result the demand is high.

Ice has been used for hundreds of years for short time preservation of food and still it is used to preserve cold drinks and food for short period. And also prevent from spoil of food. That is one of the methods for food to keep longer in past because there is no refrigerator or freezer. Today, it has been used in same condition. So, the quantity of ice required for different purpose is very large so that manufacturing of ice is one of the principal applications of refrigeration. Ice are also used in medicinal field such as in pharmaceutical, chemical and even in keeping of internal organ of human during replacement cure. The useful of ice is undeniable truth for all. But there is a problem dealing about with ice. The higher the cost of ice production, the more qualified the ice. Higher quality of ice are made from distilled water for upper level of society and low quality of ice are made from raw water that may be contain impurities in last decade.

The main key is that water must be clean and portable and also fit for drinking. However, appreciable number of bacteria can increase in the ice depending on the temperature and length of storage. Nowadays, clean and portable water are available in cheap. The term ice plant is used in this note to mean a complete installation for the production and storage of ice, including the ice manufacturing plant itself that is the unit that converts water into ice together with the associated refrigeration machinery, harvesting and storage equipment, and the building.

Ice plants are usually classified by the type of ice they produce.

Hence there are;
1. Block ice manufacturing plants
2. Flake ice manufacturing plants
3. Tube ice manufacturing plants
4. Slice or Plate ice manufacturing plants and so on.

Ice plants may be further subdivided into those that make dry or wet ice. Dry ice here means ice at a temperature low enough to prevent the particles becoming moist; the term does not refer in this note to solid carbon dioxide. In general, dry sub cooled ice is made in plants that mechanically remove the ice from the cooling surface; most flake ice plants are of this type. When the cooling surface of an icemaker is warmed by a defrost mechanism to release the ice, the surface of the ice is wet and, unless the ice is then sub cooled below 0°C, remains wet in storage; tube ice and plate ice plants are of this type.

In this paper, the proposed concept is to make an ice block. The ice plant is the one that converts water to ice together with associated refrigeration machinery, storage equipment and building. Power and refrigeration requirements are discussed, and the main types of ice manufacturing plants are described.

II. ICE Manufacturing Plant

A. Refrigeration System

All refrigeration systems are based on reversed Carnot cycle. Refrigeration is constructed with four basic components. They are compressor, condenser, expansion device and evaporator

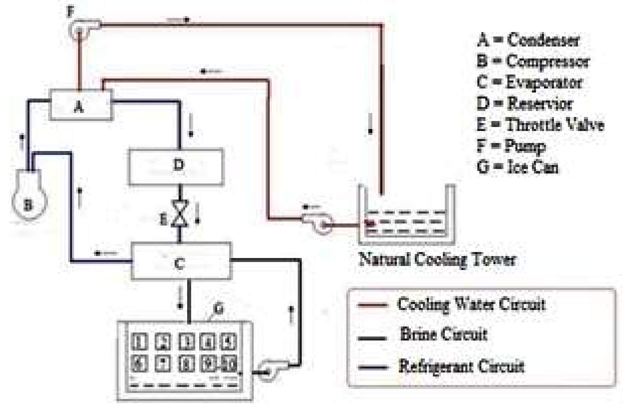

Fig 1: Ice Manufacturing Cycle

The compressor is considered as they are of refrigeration system because it pumps the refrigerant through the system similar to the heart which pumps the blood through the body. Compressing the gas requires that work should be done upon it, it will be clear that compressor must be driven by some form of prime mover. The reciprocating compressor is used in this paper. For a reciprocating compressor the displacement is fixed by the dimensions and the rpm of the compressor. The reciprocating compressor is commonly used in, refrigeration and air conditioning plants.

The condenser is a heat exchange device similar to the evaporator; it rejects the heat from the system absorbed by the evaporator. This heat is rejected from a hot superheated vapor in the first passes of the condenser. The middle of the condenser rejects latent heat from the saturated vapor, which is in the process of phase changing to a saturated liquid. The last passes of the condenser reject heat from sub-cooled liquid. This further sub-cools the liquid to below its condensing temperature. In fact, the three functions of a normal condenser are to de-superheat, condense, and sub-cool the refrigerant. When heat is being absorbed into the system, it is at the point of change of state (liquid to a vapor) of the refrigerant where the greatest amount of heat is absorbed. The same thing, in reverse, is true in the condenser. The point where the change of state (vapor to a liquid) occurs is where the greatest amount of heat is rejected. The condenser is operated at higher pressures and temperatures than the evaporator and is often located outside. The same principles apply to heat exchange in the condenser as in the evaporator. The materials a condenser is made of and the medium used to transfer heat make a difference in the efficiency of the heat exchanger.

The evaporator in a refrigeration system is responsible for absorbing heat into the system from whatever medium is to be cooled. This heat-absorbing process is accomplished by maintaining the evaporator coil at a lower temperature than the medium to be cooled.

The expansion device, often called the metering device, is the fourth component necessary for the compression refrigeration cycle to function. The expansion device is not as visible as the evaporator, the condenser, or the compressor. Generally, the device is concealed inside the evaporator cabinet and not obvious to the casual observer. It can be either a valve or a fixed-bore device.

B. Refrigerant R22

Refrigerant R22 is a (HCFC) has less effect on ozone layer**.** It has one hydrogen atom in its compound and not all the hydrogen atoms from it are replaced by the halocarbons as it happens in chlorofluorohydrocarbons (CFCs). The halocarbons have high detrimental effect to the ozone layer of environment. Since R22 is HCFC it has lesser ozone destruction capability. The ozone destruction potential of R22 is only 5% of refrigerant R11, which has the highest ozone destruction potential. Greater water absorbing capacity:

Refrigerant R22 has greater water absorbing capacity than R12. This is very important in low temperature applications since the water in refrigerant R22 would have less troubling effects on the refrigeration system. Anyways, even minor amount of water in the refrigeration system is undesirable. In developed countries R22 is being replaced in the phase manner. No new equipment using Refrigerant R22 would be available from January 2010. Thereafter R22 would be available only for servicing the old systems. By the year 2021, complete production of refrigerant R22 would stop. Some of the available alternatives for R22 are: R-134a, R-507, and R-407c.

III. Design Theory

A. Determination of Cooling Capacity of Evaporator

Before starting the design of compressor, heat rejected from water to make ice is firstly considered. In this ice manufacturing plant, temperature of water to make ice is 27℃. Cooling capacity of evaporator must also be known. Operating condition such as evaporating temperature and condensing temperature must also be known.

Heat rejected from water can be calculated by following equation.

$$Q_{ice} = (m_{ice}C_p\Delta t)_{water} + m_{ice}h_w + (m_{ice}C_p\Delta t)_{ice}$$

Where,

Q_{ice} = Heat rejected from water, kW
m_{ice} = Total weight of ice , kg/day
C_p = Specific heat of water, 4.187 kJ/kg
Δt = Temperature difference, K
H = Latent heat of fusion of ice, 335 kJ/kg

B. Determination of Compressor size

The speed of rotation of crankshaft is one of the factors of compressor displacement. In an effect to reduce the size and weight of the compressor, the compressor design is towards higher speeds. Rotational speeds are between 50 to 55 rpm (for slow speed compressor) and between 250 to 3400 rpm (for modern compressor). In this paper, the motor with 2850 rpm, 220 volt and frequency of 50 Hertz is used.

The bore and stroke are two fundamental parts of a compressing unit required for determination of the capacity of the compressor. The relationship between bore and stroke differs somewhat with the individual compressor. The dimension of bore may be less than that of the stroke. The general trend in high speed compressor is towards a large bore and short stroke. The piston velocity (m/sec) that is a function of compressor speed limits the length of stroke.

$$\text{Piston Speed} = \frac{2 \times L \times rpm}{60}$$

Where, L = Length of stroke (m)

The maximum relative speed of crankshaft (r.p.m) and the maximum piston speed give the approximately value of length of stroke by using equation. Then length of stroke can be obtained. Most of hermetic type reciprocating compressors are produced by various manufacturers provide the stroke about 0.8 times the bore (D). Therefore this paper also assumed the stroke as (L = 0.8 D).

The quantity of heat that each unit mass of refrigerant absorbs from the refrigerated is known as refrigerating effect.

Refrigerating Effect (R.E) = $h_1 - h_4$ kJ/kg

The refrigerant flow to the evaporator is regulated with a hand expansion valve on the suction line after the evaporator.

$Q_{evap} = m_R°(h_1 - h_4)$

The volume of vapor that must be remove each minute can be calculated per minute by the specific volume (v_1) that can be found in the saturated table after vaporizing temperature is known.

$v°_R = m°_R \times v_1$

The piston displacement of a compressor is the volume displaced by the piston as it moves from one end of its stroke to the other, multiplied by the number of cylinder.

$$\text{Piston displacement} = \frac{\pi}{4} \text{ x } D^2 \text{ x L x N x n}$$

Where,

N = number of revolution per minute (rpm)

n = number of cylinder

The actual volume of suction vapor removed from the suction line per unit time is the actual displacement of the compressor. The ratio of the actual displacement of the compressor to its piston displacement is known as the total or real volumetric efficiency of the compressor.

$$\text{Volumetric efficiency} = \frac{\text{actual intake volume}}{\text{theoretical piston displacemnt}}$$

Where $v_{suction}$ is the specific volume of vapor entering the compressor and $v_{discharge}$ is the specific volume of the vapor after isentropic compression to P_d. The values of specific volumes can be read of the p-h chart from the table.

$$\eta_{cv} = 1 + c - c\left(\frac{V_{suction}}{V_{discharge}}\right)$$

This clearance volumetric efficiency has a maker effect upon the compressor piston displacement required per ton of refrigeration developed. The effect becomes more marked as the compression ratio or the spread between condenser and evaporator pressure increases.

C. Determination of Evaporator Tube Length

In this ice making plant, bar-tube coil type evaporator is used. Before starting the design of evaporator, cooling capacity, evaporating temperature, initial temperature of brine, Final temperature of brine must be known. To determine evaporator tube length, the following equation is used.

$Q_{evp} = U\ A\ \Delta t$

Where, Q_{evp} = Heat absorbed by evaporator coil, kW

U = Heat transfer coefficient, W/m²K

A_e = Effective surface area of evaporator coil, m²

Δt = Log mean temperature of difference, K

$$\Delta t = \frac{GTD_e - LTD_e}{Ln\frac{GTD_e}{LTD_e}}$$

(3.3)

Where,

GTD_e = Greater temperature difference evaporator, K or ºF

LTD_e = Lower temperature difference evaporator, K or ºF

A_e = $\pi\ D_e\ L_e$

Where,

D_e = Diameter of the evaporator coil

L_e = Length of the evaporator coil

To obtain the effective surface area, heat transfer coefficient should be known.

For sodium chloride brine, U can be obtained from chart. If calcium chloride brine is used, U can used obtained chart.

To calculation U, many effects may be considered to get value of U.

$$COP_{(theo)} = \frac{h_1 - h_4}{h_2 - h_1}$$

Where,

$COP_{(theo)}$ = Coefficient of performance theoretical

h = enthalpy

$$COP_{(act)} = \frac{\text{Reffrigeration effect}}{\text{Energy input}}$$

Where, $COP_{(act)}$ = Coefficient of performance actual

Energy input = Motor Power, P_{motor}, kW

$$P_{motor} = \frac{W_{comp}}{\eta_m \times \eta_e}$$

Where,

W_{comp} = Compressor work done, kW

η_m = Mechanical efficiency

η_e = Electrical efficiency

D. Determination of Condenser Tube Length

To calculate condenser tube length, required surface area of condenser coil is firstly considered. The surface area of condenser coil is calculated by the following equation.

$Q_{air} = h_{wet} \times C_f \times A_o \times (T_{ab} - T_{sb})$

Where,

Q_{air} = amount of heat rejected by air, Btu/hr

h_{wet} = Heat transfer coefficient of wet surface, Btu/hr-ft²-F

C_f =Coil surface efficiency or contact factor of coil surface

A_o =Effective surface area of condenser coil, ft²

T_{ab} =Entering temperature of air or DB, °F

T_{sb} =Dew point temperature of entering air, °F

In evaporative condenser, there must be combination type of heat disposing into air and water. So, the amount of heat removed by water must be firstly considered in order to determine the amount of heat removed by air.

$Q_{bleed\ water} = \rho V_f° C_p (T_1 - T_2)$

Where,
$Q_{bleed\ water}$ = Heat removal load due to cooling water, kW
ρ = Density of water, kg/m^3
$v^{\bullet}_f$ = Volume flow rate of cooling water, m^3/sec
C_p = Specific heat capacity of water, 4.187 kJ/kg
T_2 = after passing through the water temperature of condenser, ^oC
T_1 = before passing through the water temperature of condenser, ^oC

$Q_{cond} = m_f^{\circ}(h_2 - h_3)$

Where,
Q_{cond} = Amount of heat rejected by condenser coil, kW
m^o_r = Mass flow rate of refrigerant, kg/sec
h_2 = Enthalpy of refrigerant at entrance of condenser, kJ/kg
h_3 = Enthalpy of refrigerant at leaving of condenser, kJ/kg

According to the cooling tower evaporation rule of Thumb, the seasonal average in your area may be 75% of evaporative cooling.

$V_f^{\circ} = 0.75 \times Q_{cond}$

In this condenser, the amount of heat removed by air can be determined by summing of sensible heat and latent heat of air. Entering air temperature and leaving temperature must be known.

Sensible heat can be calculated by this equation,

$Q_{sensible} = 1.1 \times cfm \times (T_2 - T_1)$

Latent heat can be found out by following equation,

$Q_{latent} = 0.68 \times cfm \times (W_2 - W_1)$

Where,
$Q_{sensible}$ = Sensible Heat transfer, Btu/hr
Q_{latent} = Latent Heat transfer, Btu/hr
T_2 = Leaving temperature of air, ^oC
T_1 = Entering temperature of air, ^oC
W_2 = Specific humidity of leaving, grain/lb
W_1 = Specific humidity of entering, grain/lb

$Q_{air} = Q_{sensible} + Q_{latent}$

Where,
Q_{air} = Heat removal load due to air, Btu/hr

From this, volume flow rate of air (cfm) passing through the condenser can be calculated.

Following equation can compute fan break horse power,

$$\text{Fan BHP} = \frac{\text{cfm} \times \text{pressure drop in inch of water}}{6346 \times \text{fan efficiency}}$$

And

$$\text{Fan motor} = \frac{\text{Fan BHP}}{\text{electrical efficiency}}$$

And the velocity of fan is given by,

$$v = \sqrt{\frac{BHP \times \eta_m \times 550 \times g}{m_a^{\cdot}}}$$

Where,
V = fan flow velocity, ft/sec
g = Gravitational acceleration, 32.2 ft/sec^2
m°_a = mass flow rate of air, lb/sec
η_m = Mechanical Efficiency

E. Input Data

In this thesis, required data are as follow;

Hermetic type reciprocating compressor

Condensing temperature	= 54.4^oC	
Evaporating temperature	= -7.2^oC	
Outside diameter of condenser coil	= 3/4 inch	
Mass flow rate of refrigerant	= 0.0346 kg/sec	
Evaporating temperature	= -7ºC	
Type of refrigerant	= R 22	
Type of material	= Bar-tube Evaporator	
Diameter of coil tube	= 0.0254 m	= 1in
Initial temperature of Brine	= -3º C	= 26.6 ºF
Final temperature of Brine	= -5º C	= 23 ºF

IV. Result Data

Table1. Design Result Data for Ice Manufacturing Plant (Compressor)

No	Description	Symbol	Result Data	Unit
1	Refrigerant flow rate	m^o_R	0.0364	kg/s
2	Actual intake volume	v^o_R	2.2938 x 10^{-3}	m^3/s
3	bore	D	43	mm
4	length	L	34	mm
5	Volumetric efficiency	η_v	98	%
6	Compressor work done	W_{comp}	1712	W
7	Coefficient of performance	COP_R	2.978	
8	Compressor motor power	P_{motor}	2377	W

Table2. Design Result Data for Ice Manufacturing Plant (Condenser)

No	Description	Symbol	Result	Unit
1	Mass flow rate of refrigerant	m^o_r	0.0364	kg/sec
2	Amount of heat rejected by condenser coil	Q_{cond}	6.8	kW
3	volume flow rate of cooling water	V_f	1.42 x 10^{-6}	m^3/sec
4	Heat removal load due to cooling water	$Q_{bleed\ water}$	0.01189	kW
5	Amount of heat rejected by air	Q_{air}	23161.98	Btu/hr
6	Amount of heat rejected by fan air	Cfm	849.67	Ft^3/min
7	Fan break horse power	BHP	0.0984	hp
8	Fan motor break horse power	BHP	0.1231	hp
9	Mass flow rate of air	m	0.9699	lb/sec
10	Fan air flow velocity	V	11.56	m/sec

11	Slope of air enthalpy saturation curve	M	1.14	kJ/kg-K
12	Outside diameter of condenser coil	D	0.0127	m
13	Reynolds Number	Re	7783.45	-
14	Heat transfer coefficient of air	h_o	33.92	Btu/hr-ft^2-ºF
15	Heat transfer coefficient of wet surface	h_{wet}	158.74	Btu/hr-ft^2-ºF
16	Effective surface area of condenser coil	A_o	11.84	ft^2
17	length of condenser coil	L	90	ft

Table3. Design Result Data for Ice Manufacturing Plant (Evaporator)

No	Description	Symbol	Results	Units
1	Greater Temperature Diff	GTD_e	4 , 7.2	ºC , ºF
2	Lower Temperature Diff	LTD_e	2 , 3.6	ºC , ºF
3	Log mean Temperature Diff	Δt_m	2.88 , 5.19	ºC , ºF
4	Heat transfer coefficient	U	95 , 540	btu/hrft^2ºF, Wm^2k
5	Heat transfer coefficient in brine	$U_{(brine)}$	99 ,562.249	btu/hrft2ºF, W/m2k
6	Effective surface area evp; coil	A_e	3.35	m^2
7	(Brine) Effective surface area evp; coil	$A_{e(brine)}$	3.217	m^2
8	Length of evaporator coil	L_e	137.72	ft
9	Length of evaporator coil (brine)	$L_{e(brine)}$	132.25	ft
10	Energy Input, Motor power	P_{motor}	2.71	kW
11	Theoretical Coefficient of performance	COP_{theo}	2.97	_
12	Actual Coefficient of performance	COP_{act}	1.29	_

V. Conclusion

Firstly, it is important to understand concept of refrigeration which is related with Carnot cycle, Thermodynamic heat transfer and energy conservation when study the refrigeration system.

In this paper, hermetic type of single cylinder reciprocating refrigeration compressor is designed. The compressor work done from calculation is 1712 Watts and bore and stroke is 43mm and 34mm respectively. The compressor motor is 2377 Watts. The motor with 2850 rpm, 220 volt, and a frequency of 50 Hertz is used. Volumetric efficiency is 98%. Coefficient of performance is 2.978. This design based on refrigeration load 5100 Watt. Refrigerant flow rate is 0.0346 kg/sec is used in evaporative condenser. The condenser must reject amount of heat 6.8 kW. So the area might be 16.48 ft^2 and length be 84ft^2. If vertical type of shell and tube condenser is used, we will need 20 tubes that might be 1inch diameter, 45 ft. should be long and shell diameter 28 inches. In the evaporator coil of diameters are 0.0127m^2 and 0.01905m^2.

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