DESIGN OF A SOLAR COLD-STORAGE BY AMMONIA-WATER ABSORPTION SYSTEM

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SECTION I

BACKGROUND:

It has been the age-old tragedy that while every year millions of people die of hunger and undernourishment, millions of tons of fresh food are spoiled due to the lack of proper storage facilities. It is even more sad to see this trend continue while the cheap and easy storage technologies are readily available to many. It is in this context that this group has ventured to come up with a simple and easy-to-operate design of a space cooling system.

The bright sun, which could be used as a boon, is viewed as a curse in many tropical countries as it accelerates the rate of food spoilage and decay. But the technology to harness the same temperature of the sun to solve the same problem caused by it is readily available to us. So this group has incorporated the sun as a basic source of energy in its design of a space cooling system.

The technology of harnessing the sun doesn't seem to be very cheap if one looks to the investment cost only. But the negligible cost of operation makes this technology really a cheap and reliable one as compared to the conventional energy based technology. Moreover, in this case the source of energy is eternal! And it can also be hoped that the ongoing research and development activities all over the world will be able to bring down even the investment cost of this technology. Considering these facts this group has come out with a design in which the major source of energy is the sun.

INTRODUCTION:

The designed system is based on the ammonia-water solution. This solution will be heated up by the solar flat collectors. A small electric pump is fitted in the system to pump the basic liquid. The system is designed to be used in food storage rooms. Considering the subsistence type of farming practices prevailing in Nepal, India and Bangladesh, the design is made to operate in small scale to meet the requirements of small farmers and the people from lower or middle income groups.

Though the designed system will not run only on solar energy, the economic operation of this system is made to be less susceptible to the price hike of other sources of energy. It has to be accepted that this system can not work without electricity. But where electricity is available, it will consume really a lesser amount and will thus save conventional energy and consumers' money.

SECTION II

AIR CONDITIONER DESCRIPTION:

The solar-fired air conditioner consists of seven major components: the generator, absorber, condenser, evaporator, intercooler, thermostatic expansion valve, and the solution pump.

THE GENERATOR:

The generator is a heat exchanger which transfers heat from hot water drawn from the storage tank to an ammonia-rich ammonia-water solution. When this solution is heated, ammonia is liberated. This ammonia then flows from the generator to the condenser and evaporator. This ammonia-water solution from which the ammonia was liberated becomes ammonia-poor and is routed to the absorber, through the intercooler, where it is enriched with ammonia.

THE CONDENSER:

The condenser's function is the same in the solar-fired absorption air conditioner as in the vapor-compression air-conditioner; specifically, to cool the superheated refrigerant vapor leaving the generator until it condenses. This condensed liquid thus passes through the termostatic expansion valve to the evaporator.

The heat rejected from ammonia as it cools and condenses is transferred to the cooling water which circulates through the tubes of the condenser.

THE THERMOSTATIC EXPANSION VALVUE:

The thermostatic expansion valve (TXV) has two functions. The TXV must expand the condensed liquid leaving the condenser to a pressure low enough so that the evaporator will function properly and it must regulate the amount of liquid which passes to the evaporator. The pressure and temperature of the vapor leaving the evaporator are sensed by the TXV and used to adjust the orifice through which the liquid expands, thereby regulating both the flow and expansion of the liquid.

THE EVAPORATOR:

The evaporator provides the cooling effect for the house. The liquid which was expanded by the TXV enters the evaporator at a pressure which is much lower than the pressure at which it was condensed in the condenser. Water is chilled to about 50° F in the evaporator by the evaporation of ammonia. The chilled water is then circulated to an air-to-water heat exchanger in the house. Air from the house is forced through the coil where it is cooled by the chilled water in the coil. The heat absorbed by the chilled water is then used to evaporate more ammonia when the chilled water is circulated back to the evaporator. This process occurs continuously as long as the temperature in the house is above the set point of the thermostat.

THE ABSORBER:

The absorber is needed to recombine the ammonia leaving the evaporator with the weak ammonia-water solution leaving the generator. The absorber operates at approximately the same pressure as the evaporator, which is much lower than the pressure in the generator and the condenser. This pressure difference forces the weak ammonia-water solution to flow from the generator through the intercooler to six nozzles where it is sprayed, in a hollow cone pattern, into the absorber. The heat released during the absorption of the ammonia into the weak ammonia-water tends to slow the process, necessitating cooling the absorber with cooling water. The now strong ammonia-water solution is pumped from the absorber, through the intercooler, back to the generator, which completes the cycle.

THE INTERCOOLER:

The weak ammonia-water solution leaving the generator is at a temperature much higher than the absorber. The strong ammonia-water solution leaving the absorber is at a temperature much lower than the generator. The function of the intercooler is to allow the weak ammonia-water solution before entering the generator. This results in a reduced requirement for hot water to heat the generator and for cold water to cool the absorber. The intercooler is a device which directly improves the overall efficiency of the air conditioner.

THE SOLUTION PUMP:

The solution pump, combined with the generator and absorber, functions as the compressor in a vapor-compression air conditioner in that the combination takes in a low temperature, low pressure vapor and puts out a high temperature, high pressure vapor. The solution pump has the function of pumping the low pressure, strong ammonia-water solution in the absorber through the intercooler and into the generator at a much higher pressure. The solution pump used in the air conditioner is a positive-displacement type pump and a pressure relief valve must be incorporated in the design to prevent dangerous pressure from occuring in case of blockage of the pump output.

SECTION III

Solar System Design

Goal: Design of a solar cold storage by ammonia absorption system.

Purpose: To use the known technology of absorption air conditioning utilizing flat plate collectors for space cooling in a tropical climate.

Reasons for using the ammonia-water systems:

1. The system will function at optimum design conditions with hot water at 140° F.
2. There is no chance of problems with crystallization as is true of the $LiBr/H_2O$ system.
3. Ammonia is relatively easy to obtain in any country.

Reasons for not selecting Lithium Bromide system:

1. Difficult to achieve acceptable cooling effect if water is heated from solar is below 190° F.
2. Without a sophisticated sensor device system the $LiBr/H_2O$ system is subject to "freezing" up and plugging circulation lines with crystallized LiBr.
3. The $LiBr/H_2O$ fluid circulates at pressures less than 1 psia. Higher pressure systems are usually easier to maintain and service.
4. To achieve sufficiently high temperature from a solar collecting system, a fairly costly set up is necessary.

<u>Assumptions</u>

Design conditions:

Outside temperature: 100° F
Inside temperature: 50° F
Average Relative Humidity: 78%

SECTION IV

CONSTRUCTION MATERIALS:

Roof: Asbestos-Cement-Panels will be used to cover the entire roof.

Roof Insulation: Glass fibre insulation, 3.2" per inch of cement asbestos.

Walls: Walls will be built with 8" concrete blocks.

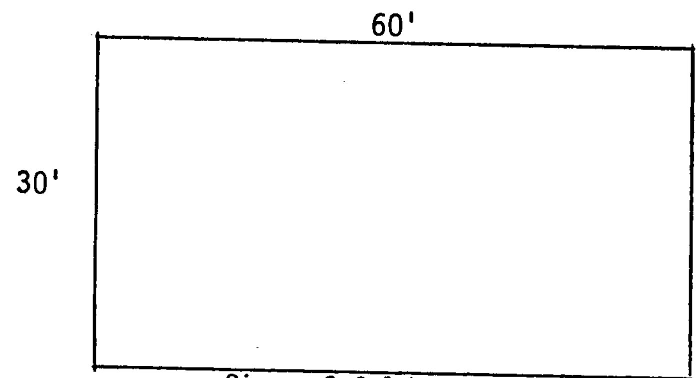
Floor: This will be with concrete slab.

Door: This will be made of wood.

SECTION V

LOAD CALCULATIONS:

Wall Areas



Size of Cold Storage

Room length = 60 ft.
breadth = 30 ft.
height = 15 ft.

Total area of the walls including door
= 60 x 15 x 2 + 30 x 15 x 2
= 1800 + 900
= 2700 sq. ft.

Door

~~(height)~~
Length = 10 ft.
Breadth = 12 ft.

Area of door = 12 x 10 = 120 sq. ft.

Area of wall excluding door = 2700 - 120 = 2580 sq. ft.

and area of roof = 60 x 30 = 1800 sq. ft.

Let us consider thickness of concrete wall is 8".

From ASHRE Standard, Thermal conductivity for brick wall with 8" concrete block = 0.279, (glass fibre insulation = 3.2"/inch of cement asbestos.)

Cement asbestos thickness = 2"

Thermal conductivity for glass fibre = 0.05

Thermal conductivity for cement asbestos = 1.2

Thermal conductivity of wood (2") = 0.1

h_1 = 2, air to glass fibre

K_1 = cement asbestos

K_2 = glass fibre.

$$\text{"U" for roof} = \frac{1}{\frac{1}{2} + \frac{3.2 \times 2}{12 \times 12} + \frac{2}{12 \times 0.05} + \frac{1}{4}2}$$

$$= \frac{1}{0.5 + 0.44 + 3.33 + 0.50}$$

$$= \frac{1}{4.52} = \frac{1}{4.77}$$

$$= 0.22$$

"U" for wall $\simeq$ 0.276

$$\text{"U" for door} = \frac{1}{\frac{1}{h_1} + \frac{2"}{12 \times K} + \frac{1}{h_2}}$$

$$= \frac{1}{\frac{1}{2} + \frac{2}{12 \times .10} + \frac{1}{2}}$$

$$= \frac{1}{0.5 + 1.66 + 0.5}$$

$$= \frac{1}{2.66} = 0.37$$

(1) Heat Load for Roof

$$= U_R A_R \Delta T_R$$

$$= 0.22 \times 1800 \times (100-50)$$

$$= 0.22 \times 1800 \times 50 \qquad = 19800 \frac{Btu}{hr.}$$

(2) Heat Load for Wall

$$= U_W \times A_W \times \Delta T_W$$

$$= 0.274 \times 2580 \times 50 \qquad = 35346 \frac{Btu}{hr.}$$

(3) Heat Load for Door

$$= U_D A_D \Delta T_D$$

$$= 0.37 \times 120 \times 50 \qquad = 2220 \frac{Btu}{hr.}$$

(4) Sensible Load

$$= 19800 + 35346 + 2220 = 57336 \frac{Btu}{hr.}$$

(5) Let us assume the latent heat is 2% of the sensible heat load

$$\text{Latent heat} = 57336 \times 0.02 = 1147 \frac{Btu}{hr.}$$

(6) Total ~~Sensible~~ Load

$$= 57336 + 1147$$

$$= 58513 \frac{Btu}{hr.}$$

(7) Load for Appliances $= 200 \frac{Btu}{hr.}$

Total Load = ~~$58713 \frac{Btu}{hr.}$~~

58513 + 200

$$= 58713 \frac{Btu}{hr.}$$

Now 1 ton $= 12{,}000 \frac{Btu}{hr.}$

Total heat load $= \frac{58713}{12000} = 4.89 \approx 5$ ton

COLLECTOR NOS

Collector capacity assuming

$$1000 \ \text{Btu/Ft}^2 \ \ \text{day}$$

Let us consider A/C unit operates 10 hrs. per day.

$$\text{Total load/day} = 58713 \times 10 = 587130 \ \frac{\text{Btu}}{\text{Day}}$$

$$\text{Collector Area} = \frac{587130}{1000} = 587.13$$

$$\simeq 588 \ \text{sq. ft.}$$

Size of Collector =

8'' Length
4' Breadth

Area of collector =

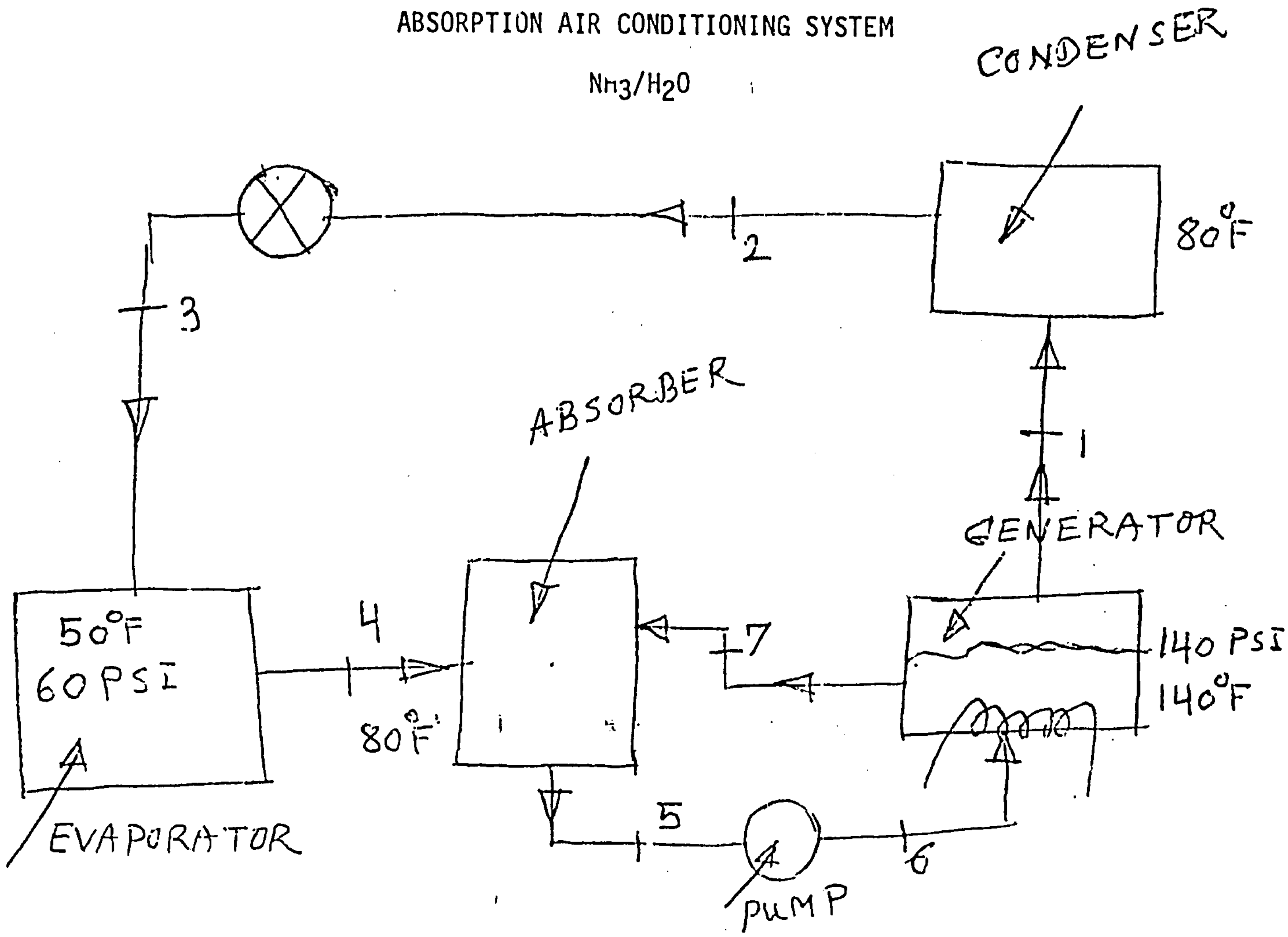
8' x 4' = 32 sq. ft.

$$\text{No. of collectors} = \frac{588}{32} = 19$$

SECTION VI

ABSORPTION AIR CONDITIONING SYSTEM

NH_3/H_2O



	Temp. (T)	Pressure (P)	Conc. (X)	Flow Rate (W)	Enthalpy (h)	NH_3 lb/hr (A)
1.	140	140	1.0	1.0	665	119.0
2.	80	140	1.0	1.0	132	119.0
3.	50	60	1.0	1.0	132	119.0
4.	50	60	1.0	1.0	625	119.0
5.	80	60	0.6	4.2	-4.0	499.8
6.	80	140	0.6	4.2	-3.7	499.8
7.	140	140	0.53	3.2	52.0	380.0

Symbols

T = Temperature °F
P = Pressure, PSIG
X = Concentration, in terms of NH_3
W = Flow rate
h = Enthalpy, Btu/lb.

For 1 lb. H_2O flow

$$X_5 = X_6 = 0.6 = \frac{NH_3}{NH_3 + H_2O} = \frac{NH_3}{NH_3 + 1}$$

$$0.6\ NH_3 + 0.6 = NH_3$$

or $NH_3 = \frac{0.6}{0.4} = 1.5$ lb.

solution = 1.5 + 1 = 2.5 lbs.

$$X_7 = 0.53 = \frac{NH_3}{NH_3 + 1}$$

or $0.53\ NH_3 + 0.53 = NH_3$ $\quad = 1.12 + 1.0$

$NH_3 = \frac{0.53}{0.47} = 1.12$ $\quad = 2.12$

W_6/For 0.6 NH_3 flow necessary is 2.5 lb.

1 NH_3 flow necessary is $\frac{2.5}{0.6} \times 1 = 4.2$ lb.

Mass balance in generator

$$W_6 = W_1 + W_7$$

$$W_7 = W_6 - W_1$$

$$= 4.2 - 1 = 3.2 \text{ lb.}$$

Total mixture flow at 7 23.2 lbs.

$$h_6 = h_5 + \frac{V_5}{J}(P_6 - P_5)$$

For H_2O, $V_5 = 0.016$

NH_3, $V_6 = 0.027$

$$V_5 = \frac{0.016 + 1.5 \times 0.027}{1.5 + 1}$$

$$\doteq 0.0226$$

$X_5 = 0.6$

1 lb. H_2O

1.5 lb. NH_3

$$h_6 = -4 + \frac{0.02}{778} \times 1.44\ (140-60)$$

$$= -3.7$$

For 1 lb. NH_3 flow

<u>CONDENSER</u> (1-2)

$$\cancel{PE_1} + \cancel{KE_1} + U_1 + P_1V_1 + {}_1Q_2 = \cancel{PE_2} + \cancel{KE_2} + U_2 + P_2V_2 + \cancel{W_{12}}$$

$$Q_{1.2} = h_2 - h_1 = 132 - 665 = -533 \frac{Btu}{\#NH_3}$$

<u>EVAPORATOR</u>

$$\cancel{PE_3} + \cancel{KE_3} + U_3 + P_3V_3 + {}_3Q_4 = \cancel{PE_4} = \cancel{KE_4} + U_4 + P_4V_4 + \cancel{W_{34}}$$

$${}_3Q_4 = h_4 = h_3 = 625 - 132 = 493 \frac{Btu}{\#NH_3}$$

<u>THROTTLING</u>

$$\cancel{PE_2} + \cancel{KE_2} + U_2 + P_2V_2 + \cancel{Q_{23}} = \cancel{PE_3} + \cancel{KE_3} + U_3 + P_3V_3 + \cancel{W_{2-3}}$$

$$h_3 = h_2$$

ABSORBER

$$W_4h_4 + W_7h_7 + Q_{4,5,7} = W_5h_5$$

or, $1 \times 625 + 3.2 \times 52 + Q_{4,5,7} = 4.2 \times -6$

or, $Q_{4,5,7} = -16.8 - 625 - 166.4 = -808.2 \frac{Btu}{\#NH_3}$

GENERATOR

$$W_1h_1 + W_7h_7 = W_6h_6 + Q_{6,7,1}$$

or, $1 \times 665 + 3.2 \times 52 = 4.2 \times (-3.7) + Q_{6,7,1}$

or, $Q_{6,7,1} = -15.54 + 665 + 166.4$

$= 846.94 \frac{Btu}{\#NH_3}$

Total NH_3 requirement:

Q_{3-4} for evaporator $= 493 \frac{Btu}{\#NH_3}$

Total load $= 58713 \frac{Btu}{hr.}$

NH_3 req. is $= \frac{58713}{493} = 119$ lb.

coefficient of performance (COP)

$$= \frac{\text{cooling effect}}{\text{heat supplied from the generator}}$$

$$= \frac{493}{846.94} = 0.58$$

Power for pump (W_p)

$$h_5 + W_p = h_6$$

$$\text{or,} \quad W_p = h_6 - h_5 = -3.7 - (-4)$$

$$= -3.7 + 4$$

$$= 0.3 \frac{\text{Btu}}{\text{hr.}}$$

$$\text{Power } (W_p) = \frac{0.3 \times 499.8}{2545} = 0.058 \text{ h.p.}$$

$$Q_{GEN} = 846.94 \frac{\text{Btu}}{\text{lb.}} \times \frac{119 \text{ lb.}}{\text{hr.}} = 100{,}786 \frac{\text{Btu}}{\text{hr.}}$$

$$Q_{COND} = -533 \times 119 = -63{,}427 \frac{\text{Btu}}{\text{hr.}}$$

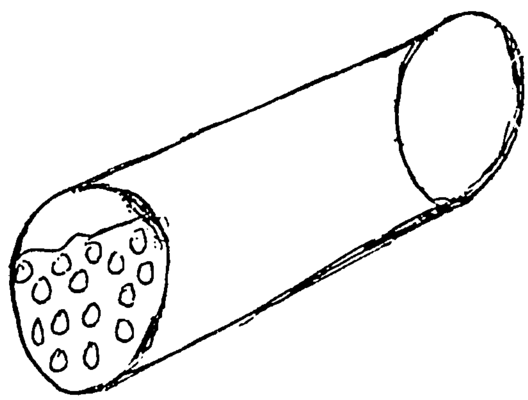
$$Q_{EVAP} = 493 \times 119 = 58667 \frac{\text{Btu}}{\text{hr.}}$$

$$Q_{ABSOR} = 808.2 \times 119 = -96{,}176 \frac{\text{Btu}}{\text{hr.}}$$

SECTION VII

DESIGN OF GENERATOR, CONDENSER, EVAPORATOR, ABSORBER

Design of Generator



length = 3.5 ft.

tube dia. = 0.5"

$$Q_{GEN} = U_g \times A_G \times \Delta T_G$$

$$100{,}786 = 100 \times A_G \times 10$$

$$A_G = \frac{100786}{1000} = 100.786 \text{ ft}^2$$

$$\text{Area of tube} = \pi DL$$

$$= 3.14 \times \frac{.5}{12} \times 3.5$$

$$\text{No. of tubes} = \frac{100{,}786 \times 12}{3.14 \times 0.5 \times 3.5} = 220$$

Cross-sectional area of tube

$$= \frac{\pi \times 0.5^2}{4 \times 144} = \frac{\pi \times 0.25}{4 \times 144} = 0.00136 \text{ ft}^2$$

Total cross-sectional area

$$= n \times a = 220 \times 0.00136 = 0.299$$
$$\simeq 0.3 \text{ ft}^2$$

Total cross-sectional area including space between the tubes (excluding 25% vacancy)

$$= 0.3 \times 2 = 0.6 \text{ ft}^2$$

Including 25% $= \frac{0.6}{0.75} = 0.8 \text{ ft}^2$

ie, cross-sectional area of generator $= 0.8 \text{ ft}^2$

Now, $\frac{\pi D^2}{4} = 0.8$

or, $D^2 = \frac{0.8 \times 4}{3.14} = 1.019 \text{ ft}^2$

$D = 1.0095 = 1$ ft. diameter of generator

generator = 3.5' L x 1'D

CONDENSER

$$Q_c = U_c A_c \Delta T_c$$

or, $63,427 = 100 \times A_c \times 10$

$$A_c = \frac{63427}{1000} = 63,427 \simeq 64 \text{ ft}^2$$

No. of tubes in condenser $= \dfrac{64}{\frac{17 \times .5 \times 3.5}{12}} = \dfrac{64}{0.131 \times 3.5} = 140$

Total cross-sectional area of tubes $= n \times a = 140 \times 0.00136$
$= 0.19$

Area of condenser $= \dfrac{\pi D^2}{4} = 0.19 \times 2$

$= 0.38 \text{ ft}^2$ without vacant 25%

Total area of condenser $= \dfrac{0.38}{0.75} = \dfrac{\pi D^2}{4}$

or, $d^2 = \dfrac{0.38 \times 4 \times \text{3.14}}{0.74 \times 3.14} = 0.64 \text{ ft}^2$

$D = 0.8 \text{ ft}^2$

Condenser size = 3.5' L x 0.8' D

EVAPORATOR

$$Q_{EVAP} = U_E A_E \Delta T_E$$

$$\text{or,} \quad A_E = \frac{58667}{100 \times 10} = 58.667 = 59 \text{ ft}^2$$

$$n = \frac{59}{0.131 \times 135} = 129$$

$$na = 129 \times 0.00136$$

$$= 0.175 \text{ ft}^2$$

$$\frac{\pi D^2}{4} = \frac{2 \times 0.175}{0.75} \qquad \text{or,} \quad D^2 = \frac{2 \times 0.175 \times 4}{3.14 \times 0.75} = 0.594$$

$$D = 0.77 \text{ ft}$$

Evaporator size = 3.5' L x 0.77' D

ABSORBER

$$A_{ABS} = \frac{96,176}{1000} = 96,176 = 97 \text{ ft}^2$$

$$n = \frac{97}{0.131 \times 3.5} = 212$$

$$na = 212 \times 0.00136 = 0.288 \text{ ft}^2$$

$$\frac{\pi D^2}{4} = \frac{2 \times 0.288}{0.75} \quad \text{or,} \quad D^2 = \frac{2 \times 0.288}{3.14 \times 0.75} = 0.97$$

$D = 0.99$ or 1 ft. Size = 3.5' L x 1' D

WATER FLOW RATES

Generator:

$$Q = W\,Cp\,\Delta T \qquad\qquad 1 \text{ gal.} = 8.36 \text{ lb.}$$

$$W = \frac{Q}{Cp \times \Delta T} = \frac{100786}{1 \times 10 \times 8.36 \times 60} = 20.1 \text{ GPM}$$

Condenser:

$$W = \frac{63.427}{100786} \times 20.1 = 12.6 \text{ GPM}$$

Evaporator:

$$W = \frac{58667}{100{,}786} \times 20.1 = 11.7 \text{ GPM}$$

Absorber:

$$\frac{96176}{100786} \times 10.1 = 19.18 \text{ GPM}$$

HEAT BALANCE

$$\Sigma Q = \Sigma W$$

or, $-533 + \sout{493} - 808 + 847 + 493$

or, $1340 - 1341 = -1$

SECTION VIII

ECONOMIC FEASIBILITY

The capital cost for the set up of the ammonia/water absorption system will be higher in comparison to an air cooled conventional system. Since an ammonia/water absorption system needs less maintenance cost, there is a good possibility of decreasing the overall cost if this system is used for a period of 15 years. This design is done specifically for tropical countries like India, Bangladesh and Nepal. Unfortunately, the costs of an ammonia/water absorption system and an air cooled conventional system for India, Nepal and Bangladesh are not known at this moment, the details of economic analysis cannot be done.

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