PN-ABD-082
ISN 92559

Intermittent Ammonia-Water Refrigeration System

Training in Alternative Energy Technologies
7th Session
February 17-June 3

by

Mr. Mohammed Sobhi Abd El-Salam (Egypt, Coordinator)
Mr. Matar Toure (Senegal)
Dr. Niyom Bounthanom (Thailand)

INTRODUCTION

One of the main needs for the developing countries is preservation of food, particularly meat, fish, vegetables, and fruits, either in a large scale like a market or in a small scale like a family. This need has to be satisfied by refrigeration to keep the products fresh.

There are two methods of refrigeration. One which is more common, is based on a vapor compression cycle and generally requires electricity. Unfortunately, in most developing countries, electricity is expensive and also not available in rural areas.

The other method, based on ammonia-water cycle requries only heat which can be directly provided by the sun. Since the sun is a free source and also the largest source available, we think that the ammonia-water system, particularly the intermittent system, which is very simple, could be the solution of the developing countries food preservation problems.

The objective:

The objective of this work has been to actually get hands on experience on the operation and testing of the intermittent refrigeration NH_3 and H_2O system.

This report, thus gives the basic activities in the operation.

The construction:

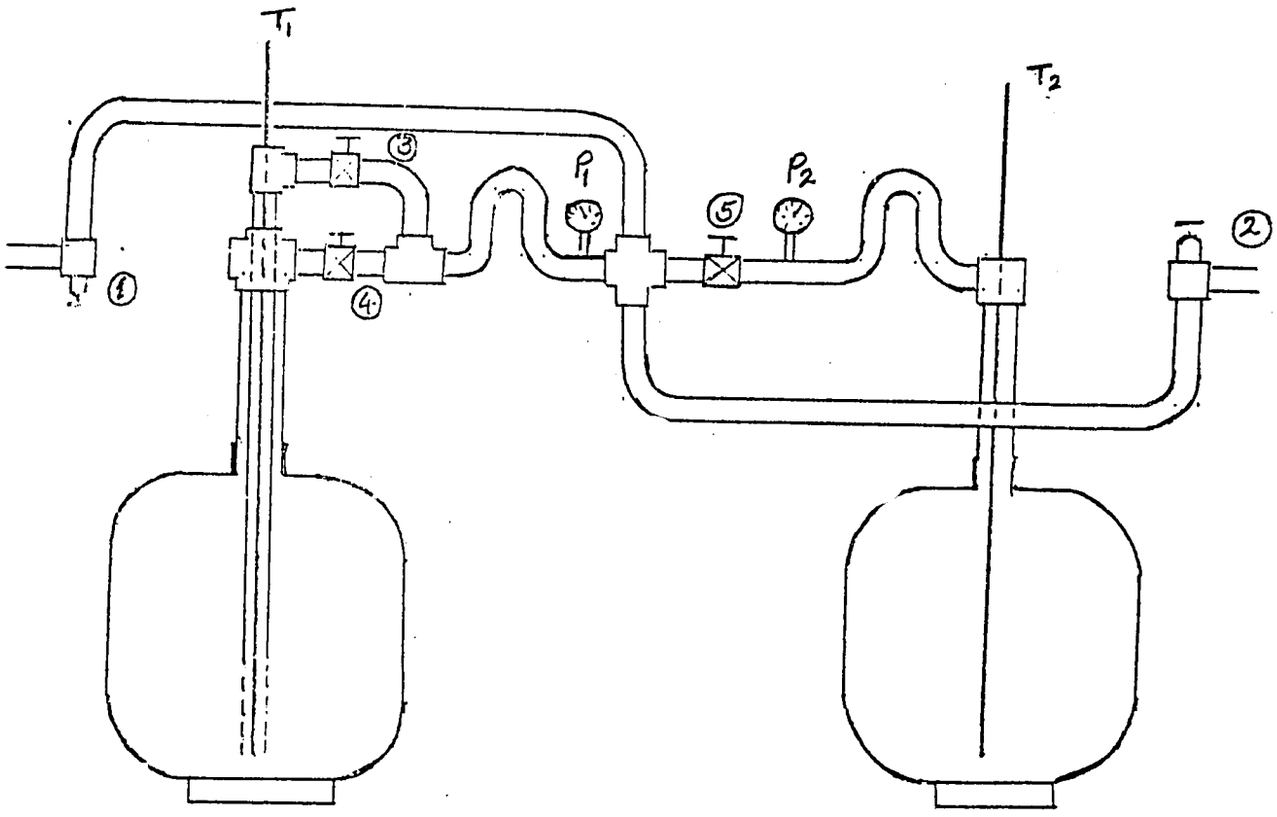

Fig. (1) The Intermittent NH_3/H_2O Refrigeration Unit

The components:

1. Two propane tanks
2. Five stainless steel valves
3. Stainless steel pipe
4. Two ammonia pressure gauges
5. Two type thermal couple probes
6. Stainless steel tees, elbows and crosses

The operation:

1. Pressure testing:

   a. Open valves 1, 3, 4 and 5 and leave 2 closed.

   b. Pump enough water into the system to completely fill the two tanks and the piping arrangements.

   c. The system is now kept under a pressure of approximately 125 to 150 psi for several hours (24 hr).

   d. All leaks discovered during this testing process are tightly closed or sealed by tightening the screws.

   e. Drain the system of all water.

   f. Pull a vacuum on the system by hooking a regular vacuum pump at valve 1 and leaving all the valves open except 2.

      Run the vacuum pump until a lowest possible pressure is obtained as indicated by the pressure gauges, P_1, P_2. In ideal laboratory conditions a vacuum pressure of as low as 30 psi can be obtained.

   g. Before removing the vacuum pump all valves are closed and then the pump is removed. The unit is now ready for charging.

Charging the system:

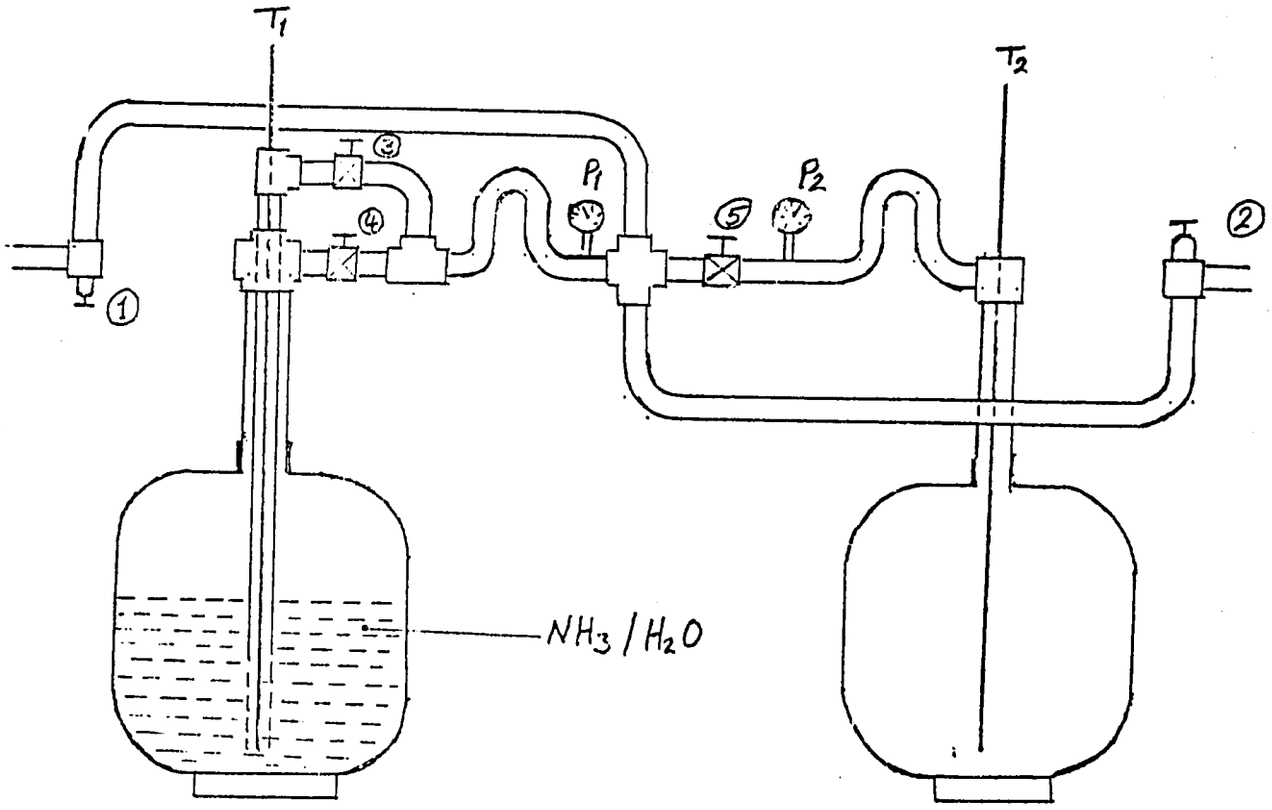

Fig. (2) The unit after charging

1. A weighed quantity (8.5 lb) is put in a tank.
2. Tightening the system completely and evacuated again for a few hours.
3. The valves are all closed and the vacuum pump removed.
4. Charging ammonia to the system by absorbing it into the water.
   The amount of ammonia is 8.5 lb in the first stage and 12.75 lb in the second stage.
5. During the charging, the valves 2 and 5 are closed, and the valves 1, 3 and 4 are opened.
6. After the charging, the valve 1 is closed.

The generation and condensation of NH_3:

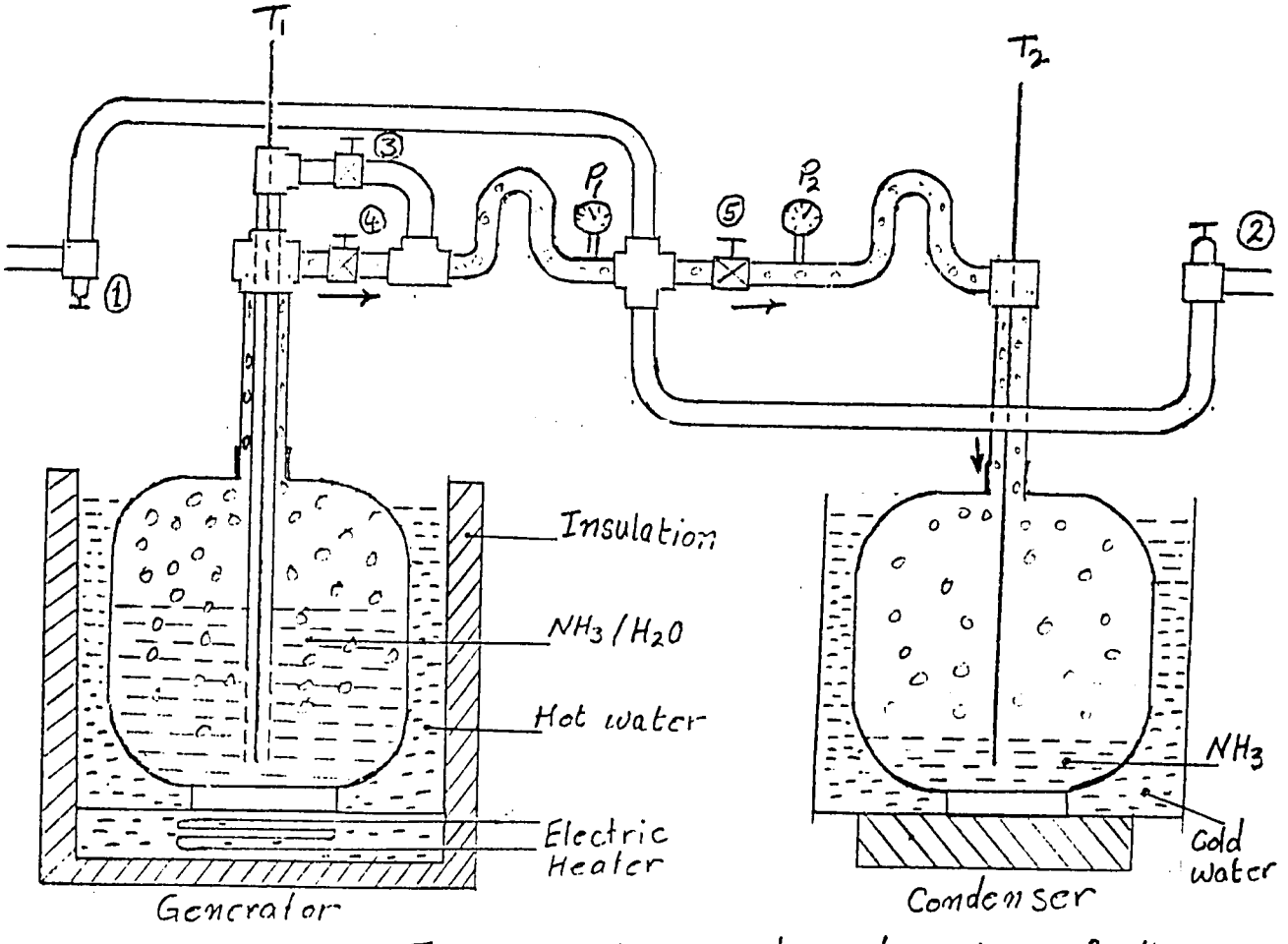

Fig. (3) The generation and condensation of NH_3

1. To operate the system, heat is added to the tank of NH_3/H_2O now referred to as the generator. The valves 1, 2, 3 and 5 are kept closed and valve 4 is opened. This will permit initial pressure to build up in the generator.
2. Next, the valve 5 is opened to flow NH_3 into the condenser which is kept at ambient temperature. During the generation process heat is added to NH_3/H_2O and heat is removed from the NH_3 tank.
3. The generation is stopped when the pressure in the two tanks is the same. At the end of the generation all the valves are closed.

The evaporation and absorption of NH_3:
(Cooling process)

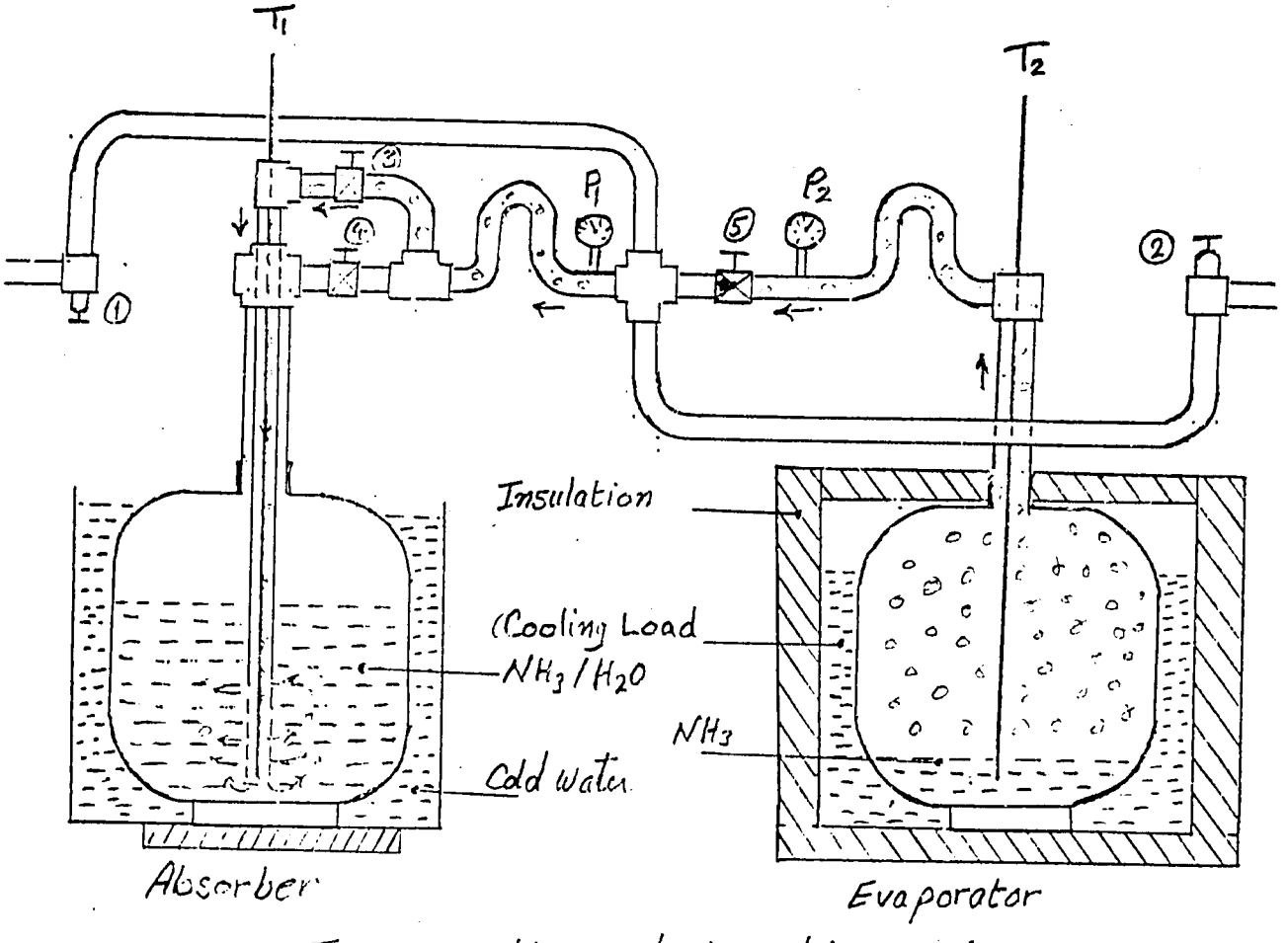

Fig.(4) The evaporation and absorption of NH_3

1. The NH_3 tank is put in the cooling load insulated box.
2. During the evaporation, the valves 1, 2 and 4 are closed and the valves 3 and 5 are opened.
3. The NH_3/H_2O tank is put in the cold water at ambient temperature.
4. At the end of evaporation, all valves are closed.

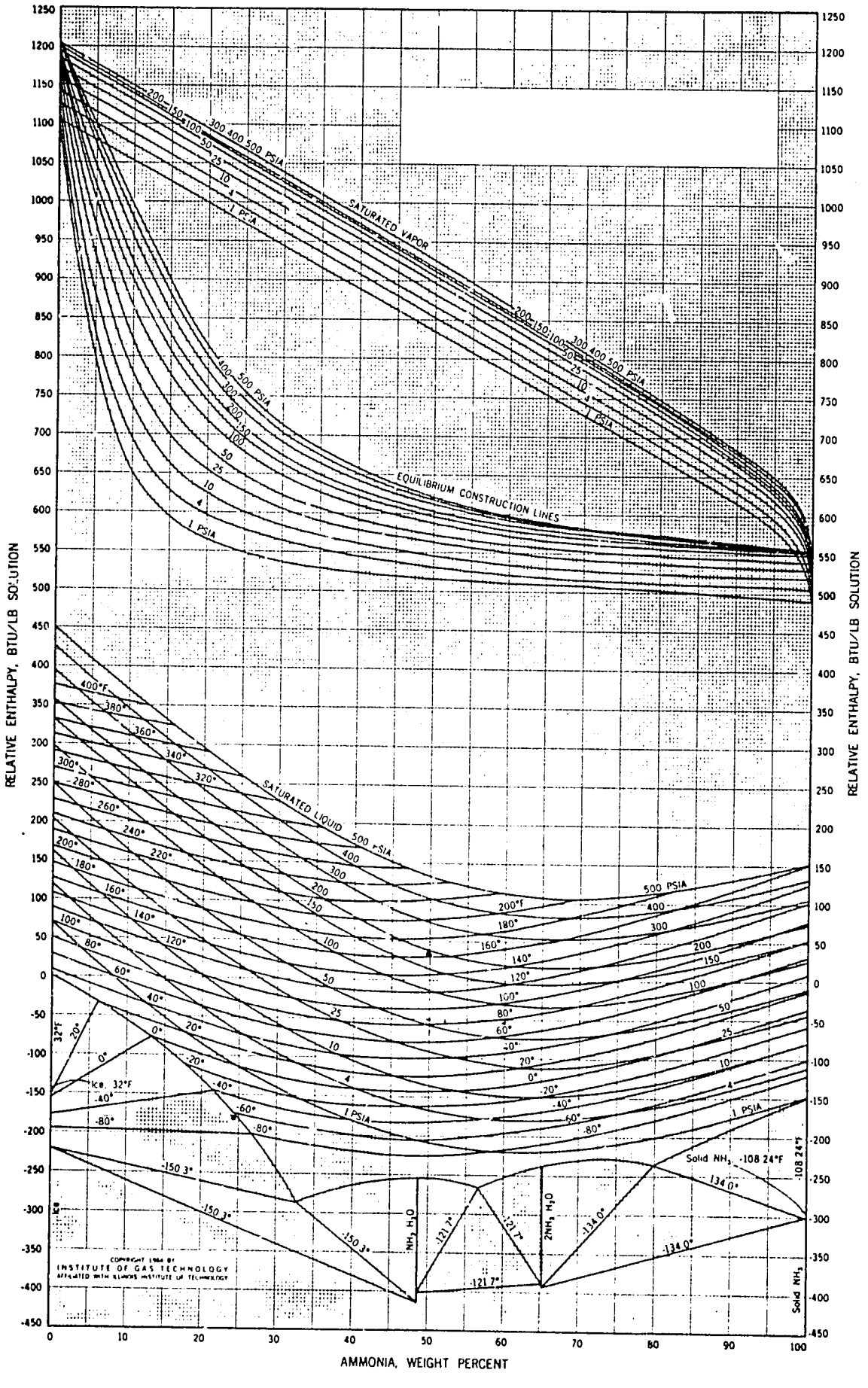

Fig. 32 Equilibrium and Thermodynamic Properties of Ammonia-Water Solutions[a]

[a]Prepared by Heilpump Corp., Cleveland, Ohio, under ASHRAE RP 271 from IGT Research Bulletin #34, with revised vapor enthalpy data.

Table 15 Refrigerant 717 (Ammonia) Properties of Liquid and Saturated Vapor[a]

Temp F	Pressure psia	Pressure psig	Volume cu ft/lb Vapor v_g	Density lb/cu ft Liquid $1/v_f$	Enthalpy** Btu/lb Liquid h_f	Enthalpy** Btu/lb Vapor h_g	Entropy** Btu/lb · R Liquid s_f	Entropy** Btu/lb · R Vapor s_g
-105	0.996	27.9*	223.2	45.71	-68.5	570.3	-0.1774	1.6243
-100	1.24	27.4*	182.4	45.52	-63.3	572.5	-0.1626	1.6055
-90	1.86	26.1*	124.1	45.12	-52.8	576.9	-0.1338	1.5699
-80	2.74	24.3*	86.50	44.73	-42.2	581.2	-0.1057	1.5368
-70	3.94	21.9*	61.60	44.32	-31.7	585.5	-0.0784	1.5059
-60	5.55	18.6*	44.73	43.91	-21.2	589.6	-0.0517	1.4769
-50	7.67	14.3*	33.08	43.49	-10.6	593.7	-0.0256	1.4497
-40	10.41	8.7*	24.86	43.08	0.0	597.6	0.0000	1.4242
-38	11.04	7.4*	23.53	42.99	2.1	598.3	0.0051	1.4193
-36	11.71	6.1*	22.27	42.90	4.3	599.1	0.0101	1.4144
-34	12.41	4.7*	21.10	42.82	6.4	599.9	0.0151	1.4096
-32	13.14	3.2*	20.00	42.73	8.5	600.6	0.0201	1.4048
-30	13.90	1.6*	18.97	42.65	10.7	601.4	0.0250	1.4001
-28	14.71	0.0	18.00	42.57	12.8	602.1	0.0300	1.3955
-26	15.55	0.8	17.09	42.48	14.9	602.8	0.0350	1.3909
-24	16.24	1.7	16.24	42.40	17.1	603.6	0.0399	1.3863
-22	17.34	2.6	15.43	42.31	19.2	604.3	0.0448	1.3818
-20	18.30	3.6	14.68	42.22	21.4	605.0	0.0497	1.3774
-18	19.30	4.6	13.97	42.13	23.5	605.7	0.0545	1.3729
-16	20.34	5.6	13.29	42.04	25.6	606.4	0.0594	1.3686
-14	21.43	6.7	12.66	41.96	27.8	607.1	0.0642	1.3643
-12	22.56	7.9	12.06	41.87	30.0	607.8	0.0690	1.3600
-10	23.74	9.0	11.50	41.78	32.1	608.5	0.0738	1.3558
-8	24.97	10.3	10.97	41.69	34.3	609.2	0.0786	1.3516
-6	26.26	11.6	10.47	41.60	36.4	609.8	0.0833	1.3474
-4	27.59	12.9	9.991	41.52	38.6	610.5	0.0880	1.3433
-2	28.98	14.3	9.541	41.43	40.7	611.1	0.0928	1.3393
0	30.42	15.7	9.116	41.34	42.9	611.8	0.0975	1.3352
2	31.92	17.2	8.714	41.25	45.1	612.4	0.1022	1.3312
4	33.47	18.8	8.333	41.16	47.2	613.0	0.1069	1.3273
6	35.09	20.4	7.971	41.07	49.4	613.6	0.1115	1.3234
8	36.77	22.1	7.629	40.98	51.6	614.3	0.1162	1.3195
10	38.51	23.8	7.304	40.89	53.8	614.9	0.1208	1.3157
12	40.31	25.6	6.996	40.80	56.0	615.5	0.1254	1.3118
14	42.18	27.5	6.703	40.71	58.2	616.1	0.1300	1.3081
16	44.12	29.4	6.425	40.61	60.3	616.6	0.1346	1.3043
18	46.13	31.4	6.161	40.52	62.5	617.2	0.1392	1.3006
20	48.21	33.5	5.910	40.43	64.7	617.8	0.1437	1.2969
22	50.36	35.7	5.671	40.34	66.9	618.3	0.1483	1.2933
24	52.59	37.9	5.443	40.25	69.1	618.9	0.1528	1.2897
26	54.90	40.2	5.227	40.15	71.3	619.4	0.1573	1.2861
28	57.28	42.6	5.021	40.06	73.5	619.9	0.1618	1.2825
30	59.74	45.0	4.825	39.96	75.7	620.5	0.1663	1.2790
34	64.91	50.2	4.459	39.77	80.1	621.5	0.1753	1.2721
38	70.43	55.7	4.126	39.58	84.6	622.5	0.1841	1.2652
42	76.31	61.6	3.823	39.39	89.0	623.4	0.1930	1.2585
46	82.55	67.9	3.547	39.19	93.5	624.4	0.2018	1.2519
50	89.19	74.5	3.294	39.00	97.9	625.2	0.2105	1.2453
54	96.23	81.5	3.063	38.80	102.4	626.1	0.2192	1.2389
58	103.7	89.0	2.851	38.60	106.9	626.9	0.2279	1.2325
62	111.6	96.9	2.656	38.40	111.5	627.7	0.2365	1.2262
66	120.0	105.3	2.477	38.20	116.0	628.4	0.2451	1.2201
70	128.8	114.1	2.312	38.00	120.5	629.1	0.2537	1.2140
72	133.4	118.7	2.235	37.90	122.8	629.4	0.2579	1.2110
74	138.1	123.4	2.161	37.79	125.1	629.8	0.2622	1.2080
76	143.0	128.3	2.089	37.69	127.4	630.1	0.2664	1.2050
78	147.9	133.2	2.021	37.58	129.7	630.4	0.2706	1.2020
80	153.0	138.3	1.955	37.48	132.0	630.7	0.2749	1.1991
82	158.3	143.6	1.892	37.37	134.3	631.0	0.2791	1.1962
84	163.7	149.0	1.831	37.26	136.6	631.3	0.2833	1.1933
†86	169.2	154.5	1.772	37.16	138.9	631.5	0.2875	1.1904
88	174.8	160.1	1.716	37.05	141.2	631.8	0.2917	1.1875
90	180.6	165.9	1.661	36.95	143.5	632.0	0.2958	1.1846
92	186.6	171.9	1.609	36.84	145.8	632.2	0.3000	1.1818
94	192.7	178.0	1.559	36.73	148.2	632.5	0.3041	1.1789
96	198.9	184.2	1.510	36.62	150.5	632.6	0.3083	1.1761
98	205.3	190.6	1.464	36.51	152.9	632.9	0.3125	1.1733
100	211.9	197.2	1.419	36.40	155.2	633.0	0.3166	1.1705
110	247.0	232.3	1.217	35.84	167.0	633.7	0.3372	1.1566
120	286.4	271.7	1.047	25.26	179.0	634.0	0.3576	1.1427
125	307.8	293.1	0.973	34.96	185.1	634.0	0.3679	1.1358

[a]From National Bureau of Standards *Circular* No. 142 (1945) and *Circular* No. 472 (1948).
*Inches of mercury below one standard atmosphere. **Based on 0 for the saturated liquid at −40 F. †Standard cycle temperatures.

Temp, F	Viscosity, $lb_m/ft \cdot h$: Sat. Liquid	Sat. Vapor	Gas, $P = 1$ atm $\times 10^{-2}$‡	Thermal Conductivity, Btu/h · ft · F: Sat. Liquid	Sat. Vapor	Gas, $P = 1$ atm $\times 10^{-3}$‡	Specific Heat, c_p, Btu/lb_m · F: Sat. Liquid	Sat. Vapor	Gas $(c_p)_{0\ atm}$	Gas $(c_p)_{1\ atm}$	Temp, F
-100				0.410			1.030				-100
-80				0.395			1.044				-80
-60				0.380			1.056	0.523	0.477		-60
-40				0.365			1.066	0.543	0.480		-40
-20	0.629	0.022	2.02	0.350	0.011	11.1	1.075	0.565	0.483	0.547	-20
0	0.558	0.0237	2.11	0.335	0.012	11.7	1.083	0.590	0.486	0.536	0
20	0.494	0.0246	2.20	0.321	0.012	12.2	1.092	0.620	0.489	0.528	20
40	0.437	0.0256	2.29	0.306	0.013	12.9	1.103	0.655	0.493	0.522	40
60	0.386	0.0266	2.39	0.291	0.015	13.5	1.118	0.698	0.496	0.519	60
80	0.341	0.0277	2.48	0.276	0.016	14.2	1.135	0.750	0.500	0.517	80
100	0.301	0.0288	2.58	0.261	0.018	14.9	1.158	0.814	0.504	0.517	100
120	0.268	0.0299	2.67	0.246	0.020	15.6	1.187	0.866	0.508	0.518	120
140	0.238	0.0312	2.77	0.231	0.022	16.3	1.222		0.512	0.520	140
160	0.213	0.0325	2.87	0.216	0.025	17.1	1.265		0.517	0.523	160
180	0.190	0.0340	2.97	0.201	0.029	17.8	1.317		0.521	0.527	180
200	0.171	0.0358	3.06	0.186	0.034	18.6	1.379		0.526	0.532	200
220	0.154	0.0380	3.16	0.169	0.039	19.4	1.452		0.530	0.536	220
240	0.124	0.0411	3.26	0.149	0.044	20.2	1.536		0.535	0.542	240
250	0.110	0.043	3.31	0.137	0.049	20.7	1.59		0.537	0.544	250
260	0.094	0.046	3.36	0.120	0.060	21.1	1.65		0.540	0.547	260
270			3.41	0.102	0.081	21.5			0.542	0.550	270
271*	0.060	0.060	3.42	0.087	0.087	21.5			0.542	0.550	271*
280			3.46			21.9			0.544	0.552	280
290			3.51			22.3			0.547	0.555	290
300			3.56			22.8			0.549	0.557	300
320			3.66			23.7			0.554	0.562	320
360			3.86			25.4			0.564	0.572	360
400			4.06			27.3			0.574	0.581	400
440			4.27			29.1			0.584	0.590	440
500			4.57			32.0			0.599	0.602	500

*Critical Temperature. Tabulated properties ignore critical region effects.
‡Actual value = (Table value) × (Indicated multiplier).

The first stage:

Theoretical analysis and expectation:

a. Generation of NH_3

- The concentration of NH_3 50% before the generation.
- Temperature of solution is 160°F.
- Corresponding pressure is 180 psi at the beginning.
- Temeprature of NH_3 inside the condenser is 76°F.
- Corresponding pressure is 143 psi.

∴ Minimum pressure of the solution is 143 psia, at this pressure and temperature 160°F, the concentration of NH_3 becomes 44% (from Fig. 32 ASHRAE Handbook of Fundamentals.)

The total weight of the solution is 17 lb (8.5 H_2O and 8.5 NH_3) at concentration 50% when the concentration of NH_3 becomes 44% the amount of NH_3 generated = $8.5 - \frac{0.44 \times 8.5}{0.56} = 1.82$ lb

∴ The amount of heat required to generate 1.82 lb NH_3 = 1.82 X latent heat + 17X sensible heat + losses. (From Fig. 32 ASHRAE Fundamentals.)

At concentartion 50%, ambient 76F, max. temp. 160°F

∴ Sensible heat = 85 BTU/lb

Latent heat = 570 BTU/lb

At concentration 44%, temp. 160°F

Latent heat = 585 BTU/lb

∴ The average latent heat = $\frac{570 + 585}{2}$ = 577.5 BTU/LB

∴ The amount of heat required to generate 1.82 lb

NH_3 = 1.82 X 577.5 + 17 X 85 + Losses

Q_G = 1051.05 + 1445 + Losses (Losses = 5%)

Q_G = 2496.05 X 1.05 = 2620.8 BTU

$= U \times A_S \times \Delta t \times T$

$= 50 \times 2.5 \times 10 \times T$

$\therefore T = \frac{2620.8}{50 \times 2.5 \times 10} = \underline{2.09}$ hrs (Time required)

b. <u>The evaporation of NH3</u>:

The amount of NH_3 is 1.82 liquid at ambient temperature 76°F. The corresponding pressure is 143 psia

∴ The latent heat = 503 BTU/LB

The minimum pressure inside the absorber is 48 psia corresponding to ambient temperature 76°F and concentration 50%.

∴ The latent heat = 490 BTU/LB

The average latent heat = $\frac{503 + 490}{2}$ = 496.5 BTU/LB

∴ The cooling load = 1.82 X 496.5 = <u>818.33</u> BTU

Q_G = 818.33 BTU

$\therefore$ C.O.P. = $\frac{Q_E}{Q_G} = \frac{818.33}{2620.8} = \underline{0.312}$

= <u>31.2%</u>

Minimum temperature can be obtained inside the evaporator is 20°F after complete evaporation and absorption of NH_3.

<u>First stage results</u>:

Temperature (T_2) inside the condenser	75°F
Temperature (T_1) inside the generator	165°F
Generating time	2.5 hr
Amount of NH_3 generated	1.8 lb
Temperature (T_1) of NH_3/H_2O inside the absorber	75°F
Minimum temperature (T_2) after complete evaporation	25°F
Cooling time	2 hr
Quantity of water inside the system	8.5 lb
Quantity of NH_3 inside the system	8.5 lb
Concentration of NH_3	50%

The second stage:

Theoretical analysis and expectation:

a. The generation of NH_3 process:

- The concentration of NH_3 60% before the generation.
- Temperature of solution is 185°F.
- Corresponding pressure is 350 psia at the beginning.
- Temperature of NH_3 inside the condenser is 79°F.
- Corresponding pressure is 147.9 psia

∴ Minimum pressure of the solution is 147.9 psia. At this pressure and temperature 185°F the concentration of NH_3 is 37% (From Fig. 32 ASHRAE.)

- The total weight of the solution is 21.75 lb

(8.5 H_2O and 12.75 NH_3)

When the concentration becomes 37%

∴ The amount of NH_3 generated = $12.75 - \frac{0.37 \times 8.5}{0.63}$

= 7.76 lb.

The amount of heat required to generate 7.76 lb NH_3 = 7.76 X Latent heat + 21.75 X Sensible heat + Losses. (From Fig. 32 ASHRAE.)

At concentration 60%, ambient 79°F, max. temp. 185°F

∴ Sensible heat = 125 BTU/LB

at pressure 350 psia ∴ Latent heat = 520 BTU/LB

At concentratiohn 37%, temperature 185°F and pressure 147.9 psia.

Latent heat = 560 BTU/LB

∴ The average latent heat = $\frac{520 + 560}{2}$ = 540 BTU/LB

∴ The amount of heat required to generate 7.76 lb of NH_3

$Q_G = 7.76 \times 540 + 21.75 \times 125 + (\text{Losses} \simeq 10\% \text{ of total})$

$= 4190.4 + 2718.75 + (\text{Losses})$

$Q_G = 7600 \text{ BTU}$

$= U \times A_S \times \Delta T \times \tau$

$= 50 \times 2.5 \times 10 \times \tau$

$$\tau = \frac{7600}{50 \times 2.5 \times 10} = 6.08 \text{ hrs (time required)}$$

b. <u>The evaporation of NH_3 process</u>:

The amount of NH_3 is 7.76 lb liquid at ambient temperature 80°F. The corresponding pressures is 153 psia.

∴ The latent heat = 498.7 BTU/LB

Minimum pressure inside the absorber is 80 psia corresponding to ambient temp. 80°F and 60% NH_3

∴ The latent heat = 492 BTU/LB

$$\therefore \text{ The average latent heat} = \frac{498.7 + 492}{2} = 495.35 \text{ BTU/LB}$$

The cooling load = 7.76 X 495.35

$Q_E = 3843.9$ BTU

$$\text{C.O.P.} = \frac{Q_E}{Q_G} = \frac{3843.9}{7600} = 0.506$$

$$= \underline{50.6\%}$$

Minimum temperature that can be obtained inside the evaporator is 44.5°F after complete evaporation and absorption of NH_3 to be 60% concentration.

Second stage results:

Quantity of water inside the system	8.5 lb
Quantity of NH_3 inside the system	12.75 lb
Concentration of NH_3	60%
Maximum temperature (T_1) of solution during generation	185°F
Minimum temperature (T_2) of NH_3 during condensation	78°F
Amount of NH_3 generated	8.48 lb
Generating time	5 hrs
Temperature (T_1) during absorption	79°F
Minimum temperature (T_2) during evaporation	28°F
Cooling time	7 hrs
Amount of cooling load water	15 lb
Amount of NH_3 evaporated	5.8 lb
Amount of NH_3 is still liquid	2.68 lb

At the end of cooling, we get amount of ice about 4 lb as a layer surrounding the tank. One bound of ice needs 250 BTU.

The third stage:

Theoretical analysis and expectations:

a. Generation of NH_3:

- The concentration of NH_3 60% before the generation.
- Temperature of the solution is 160°F.
- Corresponding pressure is 260 psia at the beginning.
- Temperature of NH_3 inside the condenser is 76°F.
- Corresponding pressures is 143 psia

∴ Minimum pressure of the solution is 143 psia, at this pressure and temperature 160°F, the concentration of NH_3 44%.

The total weight of the solution is 21.25 lb. (8.5 lb H_2O and 12.75 lb NH_3) at concentration 60% when the concentration of NH_3 becomes 44%, the amount of NH_3 generated = 12.75 -

The amount of heat required to generate 6.07 lb NH_3

= 6.07 X Latent heat + 21.25 X Sensible heat + Losses

At concentration 60%, ambient 76°F, max. temp. 160°F

∴ Sensible heat = 95 BTU/LB

Latent heat = 540 BTU/LB

At concentration 44%, temp. 160°F

Latent heat = 585 BTU/LB

∴ The average latent heat = $\frac{540 + 585}{2}$ = 562.5 BTU/LB

The amount of heat required to generate 6.07 lb

NH_3 = 6.07 X 562.5 + 21.25 X 95 + (Losss ≃ 5%)

Q_G = 5433.125 X 1.05 = 5704.78 BTU

= 50 X 2.5 X 10 X T

∴ $T = \frac{5704.78}{50 \times 2.5 \times 10}$ = 1251.05 BTU/HR

g xG =

If we use solar water heater with efficiency 40% and the average insolation 300 BTU/FT_2/hr.

∴ g_S = 300 X 0.4 = 120 BTU/FT_2/hr

The area of solar water heater required

$$= \frac{q_g}{q_s} = \frac{1251.05}{120} = 10.4 \text{ ft}^2$$

$$\simeq 11 \text{ ft}^2$$

b. The evaporation of NH_3:

The amount of NH_3 is 6.07 lb liquid at ambient temperature 76°F and pressure 143 psia.

Latent heat = 623 - 127 = 496 BTU/LB

∴ The average latent heat =

The cooling load = 6.07 X 599.5 = 3638.96 BTU

$$C.O.P. = \frac{Q_E}{Q_G} = \frac{3638.96}{5704.78} = 0.6378$$
$$= 63.78\%$$

Minimum temp. can be obtained inside the evaporator is 41°F at ambient temp. 76°F.

The observations:

1. In order to accelerate the condensation and absorption processes of ammonia, it is necessary to have a continuous flow in the vessel from the supply.

2. In order to accelerate the generation and evaporation of this system, it should increase the surface area of heat transfer by building heat exchanger inside the propane tank.

3. The main problem to produce ice is the insulating layer of ice surrounding the tank. This layer decreases the cooling effect.