

# SOLAR ENERGY REFRIGERATOR

## 日光能冷凍研究

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### INTRODUCTION

The absorption and dispersion of heat, caused by the circulation between gas phase and liquid phase of ammonia, methyl alcohol, acetone or Freon-21 is the fundamental method in refrigerators. The energy required to convert liquid phase into gas phase is supplied by electric power or other sources. In this article, we will describe briefly the application of solar energy for this purpose.

The small-type solar energy refrigeration described here has been designed for field use or rural areas, where electricity is not available.

#### 1. SKETCH OF SOLAR ENERGY REFRIGERATOR

In Fig. 1-a, A, a container, contains 50%  $\text{HN}_3$  solution (meth-

anolsilica gel, acetone-silica gel, or freon 21-tetra-ethylene glycol eimethyl ether may be used also). B is an empty container. Two containers are connected by two pipe sets-distillation pipe and

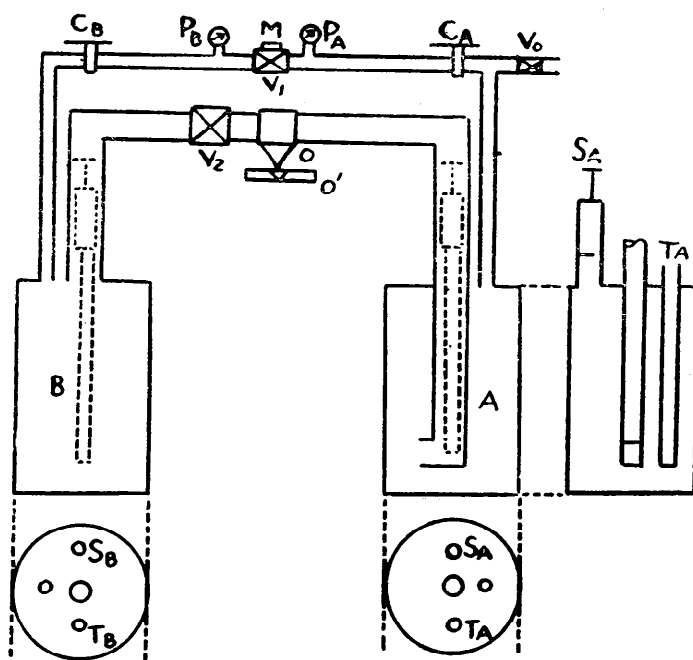


Fig. 1-a

absorption pipe.  $S_A$  and  $S_B$  are safety valves, fixed on the top of the containers A and B separately.  $V_0$  and  $V_1$  are two valves on the distillation pipe.  $V_0$  is used for lowing in  $\text{NH}_3$  gas. Two pressure gauges are mounted on each side of  $V_1$ .  $C_A$  and  $C_B$  are two standard-weight disks on each side. valve  $V_2$  is on the absorption pipe, it is connected to the bottom of container A for absorbing gas easily. A blade  $O'$  is mounted on the middle of absorption pipe. Put the standard weight on the standard-weight disks  $C_A$  and  $C_B$  to keep the whole system is balance (A "horizontal bubble" M is placed on the valve  $V_1$ , it is used for measuring the mass difference of  $\text{NH}_3$  in con-

ainers A and B.  $T_A$  and  $T_B$  are tubes straight to the bottom of A and B. A thermocouple or a thermometer is inserted into the tubes for measuring the temperature).

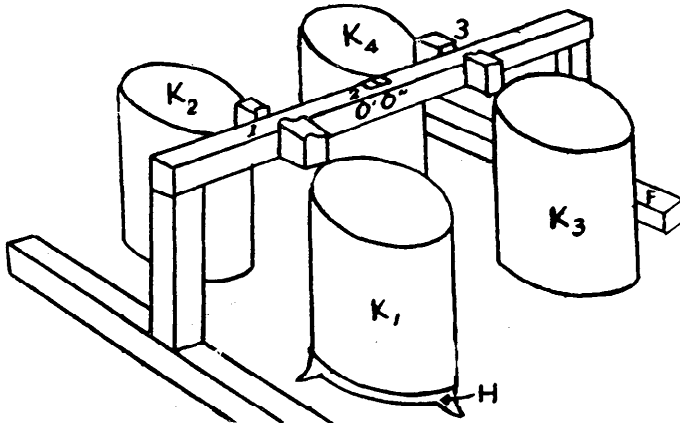


Fig. 1-b

In Fig. 1-b, F is a wooden frame. Blade  $0'$  is fixed on the middle of beam  $0''$ . The blade  $0$  of the refrigerator may be placed at position  $0'$  to measure the mass difference between A and B containers. There are four barrels. The inlet and outlet for water are mounted on  $K_2$  and  $K_4$ .  $K_1$  contains certain liquid, as glycerine and an electric even H is placed under  $K_1$  for heating.  $K_2$  and  $K_3$  contain water.  $K_4$  is a heat-insulated barrel.

## 2. THEORY AND DISCUSSION

A. In practical circulation, two theoretical circulating systems are involved: a. Heat absorption Isobaric Stage (as 2-3-4-5-2 in Fig. 2) and b. Heat Absorption Isothermal Stage (an 1-3-4-6-1 in

Fig. 2).

During the first stage, 2-3 and 3-4 are regeneration phenomena while 4-5 and 5-2 are refrigeration phenomena; 5-2 is the actual-used cooling stage. Let  $t_6$  equal to  $t_1$ ; then 6-1 is the actual-used

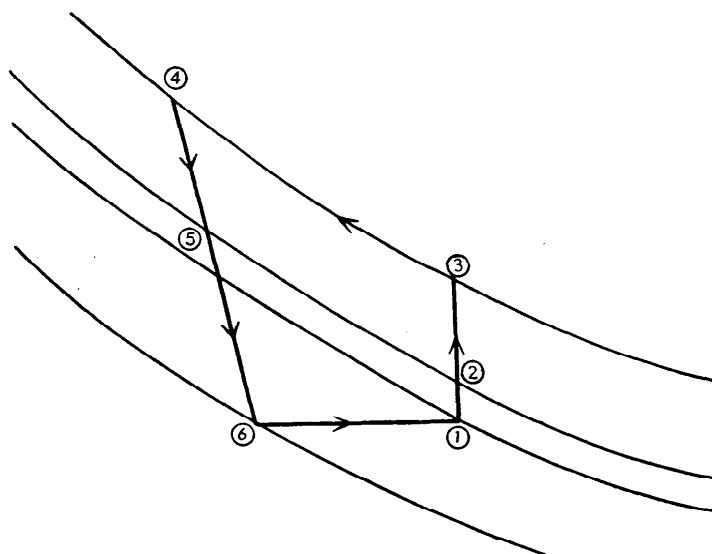


Fig. 2

cooling stage. Because in 4-5 stage, the amount of refrigerant used is less than that used in 4-6 stage, that is the amount of refrigerant left in 5-2 stage is larger than those left in 6-1 stage. Therefore, the cooling efficiency of isobaric stage is large than that of isothermal stage. However, the isobaric stage is not easy for practical use because it is not easy to control the cooling speed of generator-absorber so as to let the refrigerant be at  $t_5$ . The second reason is in the 5-2 stage, we must adjust the isobaric state and at the beginning, the generator-absorber is put in cold water only; the solution is kept at a certain temperature. We may regard it as isothermal stage.

## B. Coefficient of Performance (COP)

$$COP = Q_c / Q_s = W'_5 \times L_5 / (W_4 H_4 - W_2 H_2 + \int_{w_4}^{w_5} H_v dw) \quad (1)$$

$Q_c$  - Effective cooling.

$Q_s$  - Heat, adding to the solution during regeneration.

$W'_5$  - the mass of refrigerant (i.e. the mass of gaseous  $NH_3$ ), at the beginning of 5-2 stage.

$W$  - Mass of solution (i.e. mass of  $NH_3$  aq. s.)

$L_5$  - Latent heat of refrigerant ( $L_5 = L_2$ )

$H$  - Enthalpy of solution ( $NH_3$  aq. solution).

$dw$  - differential mass of vapor, when solution on heating.

$H_v$  - Enthalpy of  $NH_3$  (gaseous refrigerant) at  $dw$  vapor. During 4-5 stage, the following formula is obtained:

$$W'_5 / W'_4 = e(H'_5 - H'_4) / L_m$$

is the mean latent heat of refrigerant ( $NH_3$ ) during 4-5 stage.  $H'_5$  and  $H'_4$  are the enthalpy of refrigerant at 5, 4 positions.

On heating, the refrigerant is evaporated from solution but a part of the solvent, evaporated from solution but a part of the solvent, evaporated also.

For convenience in calculation, we assume that no solvent is evaporated in the above theory. Thus.

$$dw = [(1 - X_R) / (X_R - X_R')] dw'$$

$dw'$  - mass of refrigerant ( $NH_3$ ) at temperature  $t$ , evaporated from solution to container B.

$X_R, X_R'$  - the conc. of solution (containing refrigerant) and the conc. of steam (containing refrigerant).

$dw$  - the mass of gas (including refrigerant and solvent) evaporated from solution into container B at temperature  $t$ .

The above mentioned is Heat Absorption Isothermal Circulating System, but in fact involves also a part of isobaric circulation. Therefore, the actual cooling amount  $Q_c$  is  $W'_6 \times L_m$

where  $L_m$  - the average latent heat during 1-6 stage.

$W'_6$  - Mass of refrigerant ( $NH_3$ ) at 6 position.

$$\text{So, } COP = W'_6 \times L_m / (W_4 H_4 - W_2 H_2 + \int_{w_4}^{w_2} H_v dw)$$

We may also use a simple method to obtain COP theoretically.

A. During isobaric absorption stage: If  $X_{R2}, t_2, t'_3, t_4$  are known,

$$\text{then, } W_4 = \frac{1 - X_{R2}}{1 - X_{R4}}$$

$$COP = \frac{270(1 - W_4)}{W_4 H_4 - H_2 - 384(1 - W_4)}$$

B. During isothermic absorption stage: If  $X_{R1}, t (= t'^3), t_4$  are known,

$$W_4 = \frac{1 - X_{R1}}{1 - X_{R4}}$$

then,

$$COP = \frac{256(1 - W_4)}{W_4 H_4 - H_1 + 384(1 - W_4)}$$

The above calculated approximate values apply only for solutions with concentration at 0.4-0.5, and  $t_1, t_2, t'_3$  at  $26^\circ\text{C}$ - $38^\circ\text{C}$ ,  $t'_4 = 130^\circ\text{C}$  (with error: 2%) In Fig. 3-b, 1-3-4-6 is theoretical circulating 1-7-8-9 is practical circulating. It is clear that the actual pressure is greater than the theoretical pressure. The difference in temperature between containers and barrels is the heat that flows from high to low. Although a portion of solvent is evaporated from

container A to B on heating, yet because the tubes and the outlet and inlet of valves are small, it has little effect on experiment.

Calculating COP by experimental result:

$Q_c$  - From energy, we added subtracting the energy absorbed by surroundings.

$$Q_s = W_8 H_3 - W_1 H_4 + \sum_{w_8}^{w_1} H_v dw$$

$W_8, W_1$  may be obtained by experiment.

$H_1, H_8, H_v$  may be found from tables, and  $\sum_{w_8}^{w_1} H_v dw$  may be calculated by plotting a diagram (with pressure and temperature of solutions VS the mass of solvent).

### 3. OPERATION

#### I. Volatile stage (See Fig. 1-a and b)

- (1) Put the blade 0 of Fig. 1-a refrigerator at position 2 to let 0 contact 0' in Fig. 1-b. Adjust the standard weight on  $C_A$  and  $C_B$  to keep it in balance.
- (2) Put the refrigerator at position 3 and immerse container A into barrel (containing glycerine). Immerse container B into barrel (containing  $H_2O$ ). Then open  $V_1$  and close  $V_2$ . Heat  $K_1$  with electric oven H to raise the temperature of glycerine (solar energy may be used instead of electric oven). At certain intervals (e.g. 10 or 20 min), measure the temperature and weigh the mass difference between container A and B. At this time, some  $NH_3$  is evaporated from A and enters into B, where it liquified, continue until the concentration of  $NH_3$  in container A decreases 20%. Close  $V_1$  and determine

again the total mass of  $\text{NH}_3$  evaporated from A to B.

## II. Cooling stage

Put refrigerator at position 1 so as to put container A in  $K_3$  barrel and container B is  $K_4$  barrel (containing  $\text{H}_2\text{O}$ ). At certain intervals, measure the temperature and weigh the amount of  $\text{NH}_3$  evaporated from container B into container A. Thus, the temperature within  $K_3$  barrel decreased.

## 4. EXPERIMENTAL RESULTS (see Fig. 3-a)

The author and his co-workers have conducted such an experiment five times. The highest temperatures of  $\text{HN}_3$  (aqueous solution) are  $98^\circ\text{C}$ ,  $105^\circ\text{C}$ ,  $114^\circ\text{C}$ ,  $124^\circ\text{C}$  and  $134^\circ\text{C}$ , respectively. During volatile and cooling stages, the temperature of cooling water is approximately  $27^\circ\text{C}$ .

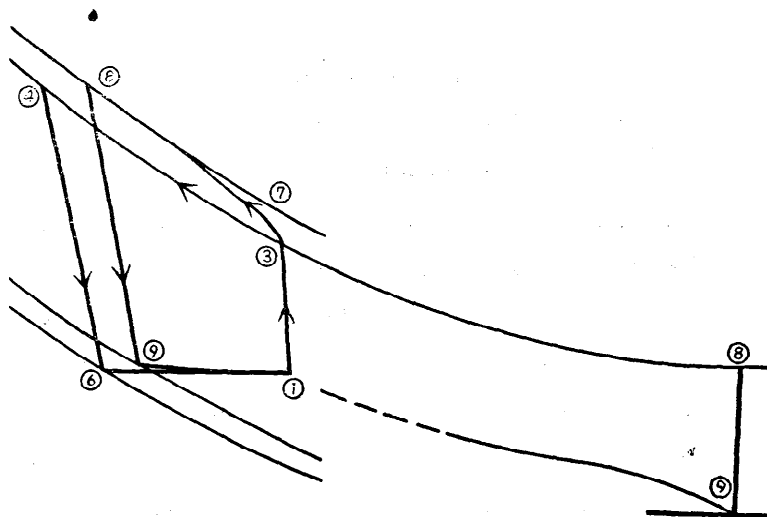


Fig. 3-a



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Fig. 3-a

Times	Max. Temp. of Sol. $\text{NH}_3$ $t_8$ $^{\circ}\text{C}$	Regeneration Stage					Refrigeration Stage			Actual Results		Theoretical Results		
		Max. Pressure $\text{kg/cm}^2$	Final Conc. of Sol. $\text{NH}_3$ XR8	Temp. of Con-tainer B $^{\circ}\text{C}$	Mass of $\text{NH}_3$ Evap- orated g	Water in Con-denser as Per-centage of $\text{NH}_3$ %	Heat to Solution Q Cal $(10^2)$	Average Temp. of Con-tainer B $^{\circ}\text{C}$	Mass of $\text{NH}_3$ Evap- orated g	Mn. Temp. of $\text{NH}_3$ in Con-tainer B $^{\circ}\text{C}$	Total Cooling Below $0^{\circ}\text{C}$ Cal $(10^4)$	Average Eff. Cooling Value Cal/g	COP	Heat Absorption Isobaric Stage
												Average Eff. Cooling Value Cal/g	COP	Average Eff. Cooling Value Cal/g
1	93	12.9	0.385	25.9-26.4	386	0	3,200	23.9	386	-12.8	1,020	41.6	0.322	54.5
2	105	12.95	0.335	27.1-28.2	557	2	4,250	26.1	557	-15.8	1,420	58.0	0.352	70
3	114	13.35	0.296	25.2-27.2	662	1.4	4,650	25.8	662	-22.2	1,730	70	0.374	81.6
4	124	14.3	0.270	27.2-24.2	728	2.6	5,100	26.7	728	-18.3	1,785	72.7	0.352	91.6
5	134	14.15	0.223	26.4-28	820	2.2	5,750	27.2	820	-21.1	2,010	83	0.356	100.5
														52.5
														67.5
														76
														86.5
														95
														0.397
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														0.369
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														0.360

## 5. CONCLUSION

- (1) In  $\text{NH}_3\text{-H}_2\text{O}$  refrigerating circulating system, the COP value calculated theoretically is very near to the COP value, obtained from the experiment, while the effective cooling value is less 5-15% than the theoretical value.
- (2) During every stage the container, itself may absorb or liberate heat. Therefore, larger container contains larger amount of refrigerant. When in operation, better result is often obtained.

## 6. REFERENCE

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