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Design and Operation of an Intermittent Ammonia-Water Refrigeration Unit

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Abstract

A small solar-powered ammonia-water intermittent absorption refrigeration device has been designed and operated for the production of ice. The system has been found to be simple and interesting. It is concluded that such a system which can be hooked up with any low temperature (160°F - 180°F) heat source will be useful in rural areas where there is no electricity for driving conventional refrigeration units.

1. Introduction

The present energy crisis - The continuous rise of price of oil, has forced the different nations of the world to review the implications of their total commitment to fossil fuels and to go for renewable resources. The renewable energy resources generally come from the sun and hence this concerns direct or indirect uses of solar energy and problems of energy storage. It is true that in order to ensure greater efficiency the most appropriate method of utilizing any form of energy is to transfer it into the usable form through the minimum number of steps. In this respect the use of solar energy for cooling seems most attractive. Moreover, the need for cooling is the greatest when the solar insolation is also the highest. In view of the importance of cooling for the preservation of foods and air-conditioning of buildings, energy requirements for the above have become a significant element in the economic scenarios of any nation.

Most of the developing countries are without indigenous fuel supplies. Ironically enough, these are the countries which could benefit most from refrigeration and air-conditioning. High ambient temperatures combined with high humidity, land

to the spoiling of foods and vegetables by micro-biological actions which could be prevented, so as to lengthen the shelf life of those perishable goods by simple cooling. The bulk of the population in these countries is widely dispersed in rural areas and as such neither transmission of electricity from central generating stations nor the transport of fuels for local use can be economic. Solar energy is, however, available everywhere.

The present project is aimed to study the potential of solar refrigeration. The experience gathered by the participants in designing and operation of an intermittent ammonia-water absorption refrigeration unit for producing ice is meant to be utilised in their respective countries for the preservation of food and other perishable goods. As price structures vary from a country to another no cost analysis of the system has been included in this study.

2. Previous Work

The principles of absorption refrigeration were first used by Faraday in 1824. He vaporized ammonia to produce a refrigerating effect and then adsorbed the refrigerant with silver chloride in a closed system.

The ammonia-water combination was developed by Ferdinand Carre, a Frenchman. An ingenious method of introducing hydrogen gas into the system and using its partial pressure to replace the liquid pump was devised by Baltzar Carl von Platen and Carl George Munters, Students at the Royal Institute of Technology in Sweden. They were granted the United States patent for their system in May 1924 and sold the patent rights to Servel-Electrolux Corporation. The absorption refrigerator then became a common place household item and it was not until the advent of vapour compression refrigerators, the new generation of refrigerants, relatively cheap fossil fuels and easy access to cheap electricity that interest in absorption systems diminished. The use of absorption refrigeration systems fired by oil or gas continued in a small scale to satisfy activities like cold storage for fishing and hunting when

refrigeration was necessary but no electricity was available. Most campers and sailboats are equipped with absorption refrigeration systems and some manufacturers continue to make these models for those markets. The house holders in remote areas and in countries whe the domestic supply of electricity is not yet a reality outside of the city areas are forced to do without a refrigerator even if they can afford one, as they are no longer availabl Brazil is now manufacturing the Electrolux typ absorption refrigerator and some other develop countries also plan to do the same.

The escalation of oil prices since 1973 cau the price of the fuels (gas and oil) used by absorption refrigerator to reach a level which h caused renewed exploration of non-fossil fuels p producing refrigeration.

There are still many places in the world where the refrigerator has never existed. The investigations presently being carried out main address the replacement of the fossil fuels b retains the sophisticated appliance and uses refrigeration.

Most of the so called developing countri

are nonoil producing countries with weak economies. Scarce foreign exchange has to be wisely spent and the problems of purchasing items like refrigerators, materials, tools and technology for manufacturing these refrigerators are considered with the same gravity as the purchase of oil.

This investigation looks at the possibility of refrigeration using low temperature heat from a flat plate solar collector. The refrigeration system being investigated was the Intermittent Ammonia-Water Absorption type. (Icy Ball as marketted by Crosley Bros of England.)

Most of the studies of solar powered absorption refrigeration systems did not investigate the use of the ammonia-water combination and used generator temperatures that were higher than that attainable by conventional flat plate collectors and hence used concentrating devices to achieve the higher temperatures necessary.

The University of Florida started investigations into solar heating and cooling systems since 1936 (Bibliography 1)

Since then many studies have been done

which showed that ammonia-water combination is best for solar heated system although the commercial applications of solar heated cooling systems tended to use a lithium bromid-water combination because of the availability of these from the gas and oil fired cooling units. Bibliography shows a list of studies that were perused for this investigation.

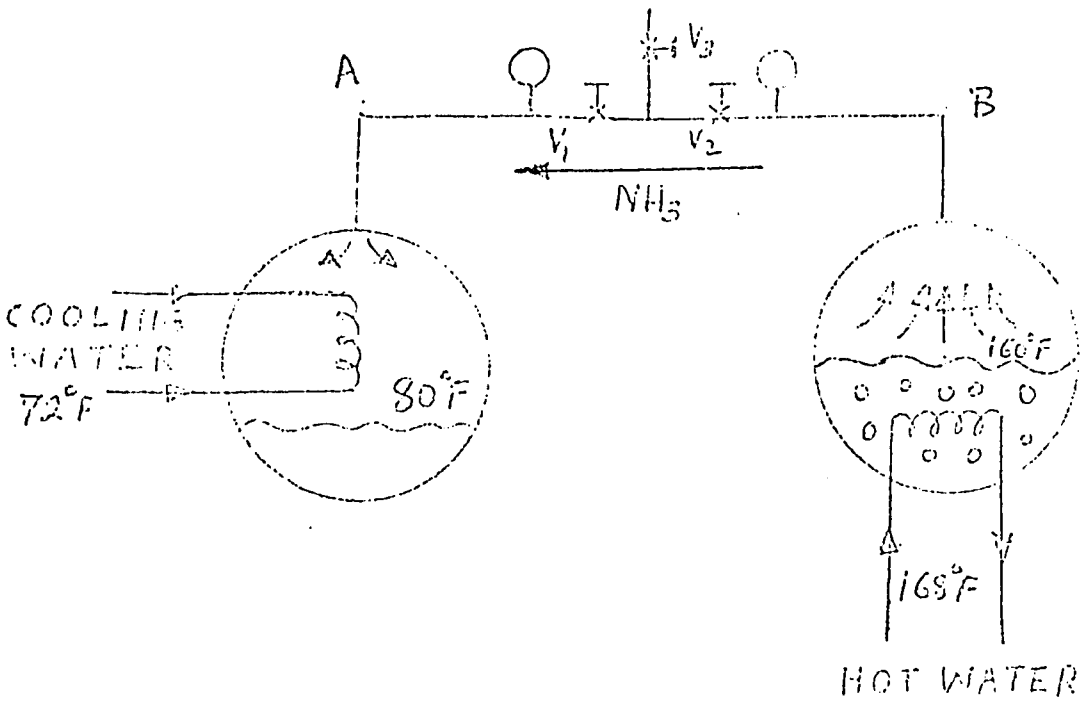
In lithium bromide-water combination, water is used as a refrigerant and as such this combination is not suitable for the production of ice. Moreover in order to operate this combination very low vacuum compared to ammonia-water is to be maintain Table 1. shows the comparison of pressure range of the two systems for the same ranges of temperatures.

Temperature °F	Pressure (PSIA)	
	Li Bromide-Water	Ammonia-Water
160	0.51	154.7
80	0.51	154.7
40	0.12	74.7
20	—	48.2

Table 1. Working pressures for Lithium Bromide-Water against Ammonia-Water

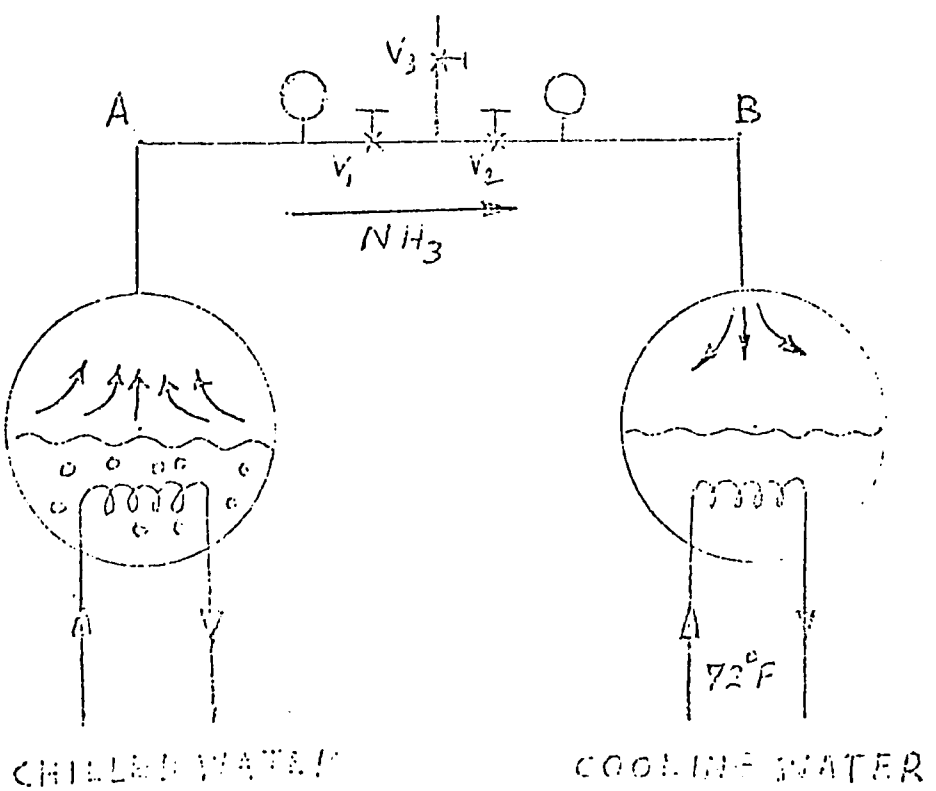
3. Intermittent Absorption Refrigeration

The system as its name implies is not a continuous process, but works intermittently. An intermittent absorption system consists of two tanks each of which is meant to serve double functions. During charging mode one of them acts as generator driving out the refrigerant from the solution when heated and the other as condenser of the refrigerant. charging usually takes a short time compared to the cooling mode during which cycle the previous generator tank becomes the absorber and the condenser tank becomes the evaporator where the required refrigeration is attained. Fig 1. explains the operating principle of both charging and cooling modes. During charging mode heat is applied in the generator while the condenser is cooled. Ammonia will evaporate from high concentration ammonia-water solution in the generator and the resulting vapour will go to the condenser where it will be cooled and condensed. This condensation will continue as long as the temperature of saturation of the ammonia at the corresponding system pressure is higher than that of the cooling water of the condenser. During this mode, the concentration of ammonia in



Valves :
V_1 and V_2 open
V_3 closed.

GENERATION (CHARGING) MODE (a)



Valves :
V_1 and V_2 open.
V_3 closed.

COOLING MODE (b)

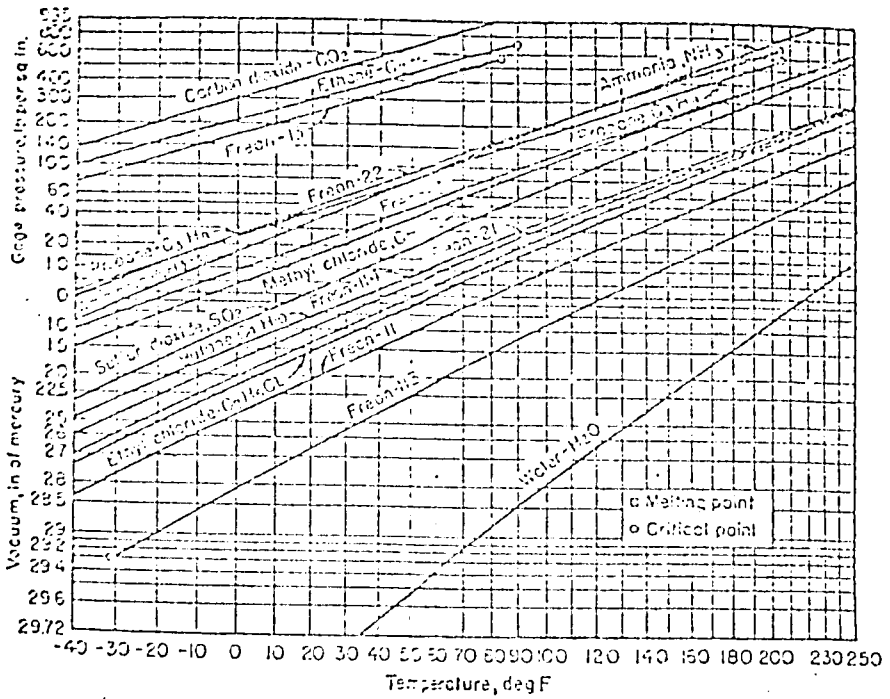


Fig. 2. Pressure-temperature relations of saturated vapors of refrigerants.

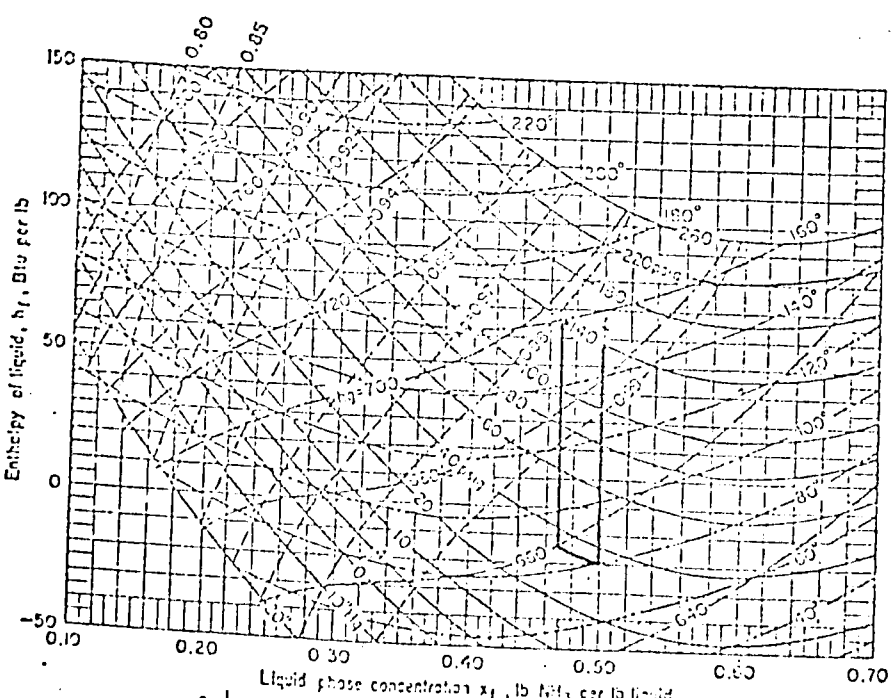


Fig. 3. Physical properties of ammonia-water solutions.

generator becomes 0.47 (Design calculations)

At the end of charging mode the weak ammonia - water solution (concentration of 0.47 of NH_3) in the generator is cooled. As the temperature of the solution is lowered, the weak solution starts to absorb the ammonia vapour which was not condensed and thus the system pressure is decreased. As a result, liquid ammonia of the previous condenser will evaporate and thus will extract heat from the surroundings. Hence, in cooling mode the condenser becomes the evaporator and produces refrigeration. Cooling mode will continue till the concentration of ammonia in the absorber reaches the initial concentration of 0.5. At this point generation mode can be initiated for the repetition of the cycle. Although generation time is relatively short, the cooling time can be varied according to the requirement by controlling the connecting valve between the absorber and the evaporator or heat addition.

4 Design Calculations

Initial design parameters are the following:

1. a. Cooling water available at 72°F to be used for the condenser during generation mode and the absorber during the cooling mode.
   b. Assuming a temperature difference of 8°F between the cooling water and inside of the vessels, the water available for cooling will be at 80°F.
2. Temperature of heating water = 168°F.
3. Temperature at which ammonia evaporates in the evaporator vessel = 20°F.
4. One pound of ice is to be produced using this unit.

Charging Mode

In the charging mode (generation mode) the saturated vapour pressure is equal to the saturated vapour pressure of ammonia at 80°F. Referring to the pressure-temperature chart of Fig. 2 the corresponding pressure is found to be equal to 140 psig.

charging is completed.

Therefore $\frac{NH_3}{NH_3+1} = 0.47$

$NH = 0.47(NH_3+1)$

$NH_3 = \frac{0.47}{0.53}$

$= 0.89$

The amount of ammonia which is generated after charging is completed is

$1.0 - 0.89 = 0.11$ lb.

<u>Total Refrigeration Load</u>

Refrigeration load required to cool the evaporator vessel $= M_E \times C_p \times \Delta T$ (where, M_E = weight of evaporator)

Assume evaporator vessel is made of steel which has a specific heat of 0.11. Take the evaporator weight to be = 30 lb.

∴ refrigeration load to cool evaporator

$= 30 \times 0.11 \times (80-20)$

$= 198$ Btu

Refrigeration load required to cool ammonia from 80°F to 20°F

$$= (h_{at\,80^\circ F} - h_{at\,20^\circ F}) \times M_{NH_3}$$
$$= (132 - 64.7) \times M_{NH_3}$$
$$= 67.3\ M_{NH_3} \quad \text{Btu}$$

Where M_{NH_3} is the required lb. of NH_3 to be evaporated.

To cool 1 lb. of water from 80°F to 32°F requires

$$1 \times (80 - 32) = 48 \quad \text{Btu}$$

To make 1 lb of ice from water at 32°F requires 144 lb.

∴ Total refrigeration load

$$= 198 + 67.3\ M_{NH_3} + 48 + 144$$
$$= (390 + 67.3\ M_{NH_3}) \quad \text{Btu}$$

Refrigeration effect of 1 lb. of NH_3

$$= 500 \quad \text{Btu}$$

Therefore if the amount of ammonia to be evaporated is M_{NH_3}, then

$$\frac{390 + 67.3\ M_{NH_3}}{500} = M_{NH_3}$$

$$M_{NH_3} = \frac{390}{432.7}$$

$$= 0.90 \quad \text{lb.}$$

$$\text{Amount of solution} = \frac{2 \times 0.90}{0.11}$$
$$= 16.36$$

Since the ratio of NH_3 to H_2O in strong solution is 1:1, initially the amount of water and ammonia should be 8.18 lb. each in order to generate 0.90 lb. of NH_3.

Dimensions of Evaporator

Assuming diameter of evaporator = 3"

$\therefore$ Volume of NH_3 in evaporator $= \frac{\pi}{4} D^2 L$

Where L is the length of evaporator
D is the diameter

Volume of saturated NH_3 liquid at 80°F

$$= M_{NH_3} \times V_{at\ 80°F}$$

$$= 0.90 \times 0.0247$$

$$= 0.0222 \quad ft^3$$

$$\therefore \quad L = \frac{4 \times 0.0222}{\pi \times (3/12)^2}$$

$$= 0.45 \quad ft.$$

Taking evaporator length to be 1 ft. to allow for vapour evaporation.

The minimum thickness of the evaporator vessel is determined by assuming that twice the maximum working pressure (280 psi) is acting on both ends of the vessel. Thus

$$P \times D \times L = 2 \times t \times L \times E_s$$

where

P = twice maximum working pressure, psig
D = diameter of vessel, inch
L = length of vessel, inch
t = thickness of vessel material, inch
E_s = tensile strength of steel (40,000 lb/in^2)

$$\therefore \quad t = \frac{P \times D \times L}{2 \times L \times E_s} = \frac{PD}{2E_s}$$

$$= \frac{280 \times 3}{2 \times 40{,}000} = 0.0105 \quad \text{inches}$$

<u>Dimensions of Generator</u>

Specific volume of solution

$$V = V_{NH_3} \times X_{NH_3} + V_{H_2O} \times X_{H_2O} = 0.0267 \times 0.5 + 0.016 \times 0.5$$

$$= 0.0214 \quad ft^3/lb.$$

$\therefore$ Volume of solution $= 0.0214 \times 16.36$

$$= 0.35 \quad ft^3$$

Choose the generator diameter at 8 inches

$$\frac{\pi}{4} \times \left(\frac{8}{12}\right)^2 \times L = 0.35$$

$$L = 0.47 \quad ft$$

Take L = 2 ft to allow for vapour space.

Using same method as above calculated thickness = 0.025 inches.

Because of unexpected misuse, if the device is left unattended in the sun, for example, the pressure in the system may rise beyond the maximum design pressure of 140 psig. Moreover, in order to take care of the combined stress of bending and simple compression or shear the thicknesses are taken as 0.125 inches for both condenser and generator...

<u>Heat Transfer</u>

Volume of generator material

$$= 2 \times \frac{\pi}{4} \times \left(\frac{8}{12}\right)^2 \times \frac{0.125}{12} + \pi \times \frac{8.125}{12} \times 2 \times \frac{0.125}{12}$$

$$= 0.0073 + 0.0443$$

$$= 0.0516 \quad ft^3$$

Weight of generator $= \rho_{steel} \times V_{generator}$

$$= 490 \times 0.0516$$

$$= 25.28 \quad lbs.$$

Heat required to raise temperature of solution to 160°F

$$Q = M_G \times C_{p_G}(160-80) + M_S \times (h_{fs} - h_{is}) + M_{NH_3} \times 500$$

where

M_G = mass of generator
C_{pG} = specific heat of generator
M_S = weight of solution
h_{fs} = final enthalpy of solution
h_{fi} = initial enthalpy of solution
W_{NH_3} = weight of evaporated ammonia

$$Q = 25.28 \times 0.11 \times 80 + 16.36 \times (58 - (-20)) + 0.94 \times 500$$
$$= 222.46 + 1276.08 + 450$$
$$= 1,948 \quad \text{Btu.}$$
$$= U \times A \times \Delta T \times \text{time}$$

where U = overall heat transfer coefficient
A = surface area of generator
ΔT = temperature difference between heating water and ammonia/water solution

$$A = 2 \times \frac{\pi}{4} D^2 + \pi (D + 2t) \times L$$

$$= 2 \times \frac{\pi}{4} \times \left(\frac{8}{12}\right)^2 + \pi \times \frac{8.25}{12} \times 2$$

$$= 0.698 + 4.32$$
$$= 5.0 \quad ft^2$$

take U = 100 Btu/hr. ft^2 °F . . . ref. (22)

∴ Charging Time

$$= \frac{1948}{100 \times 5 \times 8} = 0.49 \text{ hrs.}$$

22.

5. Construction and Operation

The generator - absorber and condenser - evap evaporator, pipe and pressure gauges are connected as shown in Fig 1. When connecting the pipes and pressure gauges, care must be taken so that there will not be any leakage.

Before the generator is charged with ammonia the whole system is pressure tested with water to one and a half times the highest operating pressu at which generation of ammonia will take place. Only when the pressure gauge does not show any decrease in pressure, the whole system is put unde vacuum and then the generator is charged with water and ammonia in right proportion.

The required amount of water is measured and put into the generator. The whole system is then weighed. Liquid ammonia is then charg in while the whole system is kept on a scale. While charging ammonia into the generator the point of charging and the generator is sprayed with water, the generator is kept cool so that the water inside it stays cool and that increas the absorption of ammonia in water.

When the required amount of ammonia is obtained inside the generator, charging of ammoni

is stopped and the whole system is ready for operation.

For rural areas where there is no electricity, generation mode and cooling mode will have to be done manually. For small scale refrigeration and cooling, the design of the generator-absorber and condenser-evaporator can be limited to the size where heating and cooling of the generator and condenser will require less effort and less fuel consumption.

In the generation mode, the generator [Fig 1(a)] can be heated by hot water from solar collectors or by boiling water which is obtained by others means, while the condenser is cooled by immersing it in cold water. Ammonia in the generator will evaporate and this vapour flows to the condenser where it is cooled down and condensed. Actual generation time will depend on the design of the system. In the present case it was half an hour. By weighing condenser while generation of ammonia takes place, the difference of the initial and the final weights of the condenser will give the amount of ammonia generated. When this difference in weight is constant, the generation

of ammonia may be considered to have been completed.

In the cooling mode of operation [Fig 1(b)] the evaporator is placed in the insulated area where refrigeration is required to take place, while the absorber is kept immersed in cold water. Since ammonia boils at a temperature lower than the temperature at which refrigeration is needed, ammonia in the evaporator will evaporate and flow back to the absorber where it is absorbed by the weak solution. While ammonia evaporates and flows to the absorber, it takes away the heat from the refrigerated space and thereby produces the cooling effect.

6. Conclusion and Recommendation

The present effort has proved that intermittent absorption refrigeration system with water and ammonia is feasible for the production of ice and at the same time very simple to operate as it does not have any moving parts. Proper design and the combination of right materials are very important for any system. During the visits to many solar energy establishments in the USA it has been found that sophisticated designs and wrong combination of materials for the systems meant to utilize solar energy led to many undesirable results. Such failures costing large sums of money are often attributed to the solar energy itself. Publicity of this type of undue accusation is detrimental to the development or exploitation of solar energy for wider use.

The exercise of design, fabrication and the ultimate operation of an intermittent ammonia-water absorption refrigeration unit for the production of ice has been found to be simple and interesting. The participants of this group are now confident to take up such design

according to the specific needs. It is hoped that some of them will actually make their own device when they return home and thus try to popularize the system in rural areas where there is no electricity.

It is recommended that intermittent ammonia-water absorption refrigeration units be manufactured in large numbers for the rural population of the developing countries so that technical expertise is developed locally. Once the general public is familiarized with the system, commercial interest is likely to grow eventually. Large scale manufacture will initially be not possible unless financed by some international agencies. This is because of the fact that as there is no market for such units in any developed society, no manufacturer is interested in the venture. The vicious circle of demand and supply has to be broken by an international agency dedicated to the development of rural population of the developing countries. As a matter of fact, several such countries have already stated that small solar-driven refrigeration units are urgently needed for the preservation of food

in rural areas where no electricity is available. Once the vicious circle as referred to above is broken, an accelerated progress in the application of small solar-driven refrigeration units can be expected.

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