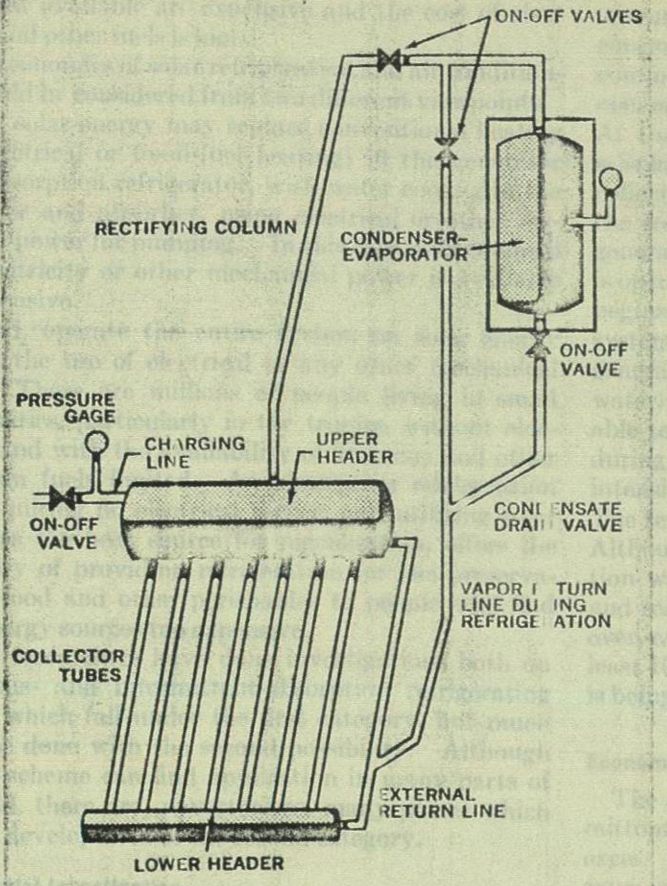

Fig. 1 Schematic representation of intermittent-absorption refrigeration system.

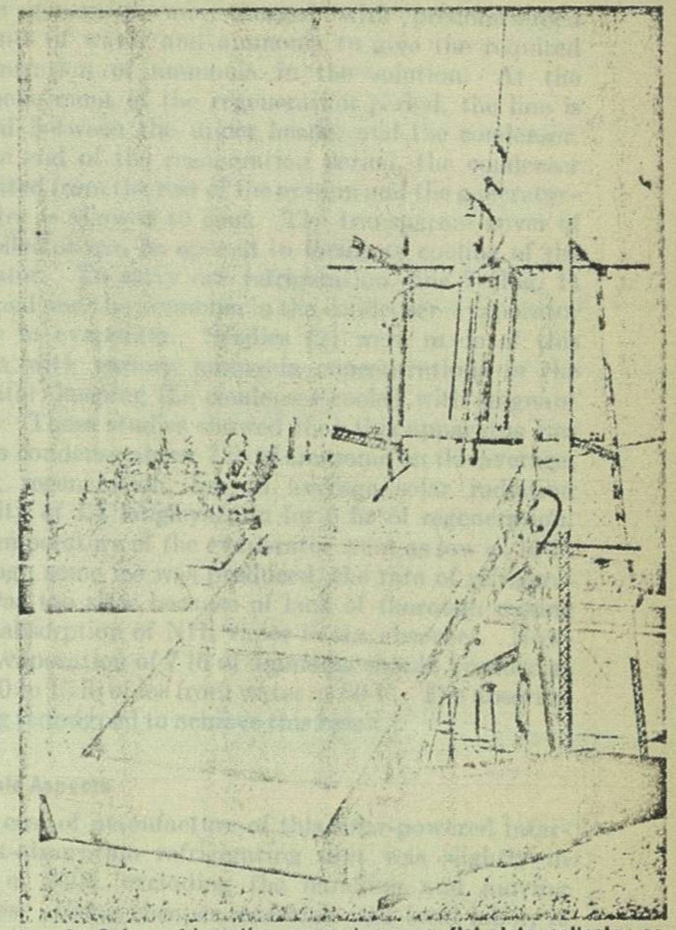

Fig. 2 Solar refrigeration apparatus uses flat-plate collector as the generator and absorber.

solar-powered refrigeration

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Solar refrigeration is attractive in parts of the world where electric power is not readily available and fossil fuels are expensive. Most work on solar refrigeration has been done on continuous-absorption refrigeration systems which cannot serve the purpose if the pumps require power. Furthermore, a continuous system becomes too complex to be handled by the local people. Here's a description, including the economic aspects, of a solar-powered intermittent-absorption refrigeration system that operates without electricity.

Of all the potential uses of solar energy, the most attractive is solar cooling. The possibility of providing a refrigerator or cooling unit to people living where conventional cooling units operated by electricity or fossil fuels are scarce or unavailable would be a tremendous boon to the world.

In tropical countries, there is great interest in solar

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cooling because everyone desires cooling, but the devices now available are expensive and the cost of electricity and other fuels is high.

The economics of solar refrigeration and air conditioning should be considered from two different viewpoints.

First, solar energy may replace conventional heating (i.e., electrical or fossil-fuel heating) in the generator of an absorption refrigerator, with water cooling in the condenser and absorber, using electrical or other mechanical power for pumping. In this case, it is assumed that electricity or other mechanical power is available but expensive.

Second, operate the entire system on solar energy without the use of electrical or any other mechanical power. There are millions of people living in small communities, particularly in the tropics, without electricity, and with the availability of kerosene and other petroleum fuels limited. An absorption refrigeration cycle requiring no electrical power, and utilizing solar energy as the heat source for regeneration, offers the possibility of providing refrigeration for the preservation of food and other perishables to people who find other energy sources too expensive.

Many researchers have done investigations both on continuous- and intermittent-absorption refrigerating systems which fall under the first category, but much has to be done with the second possibility. Although the first scheme can find application in many parts of the world, there are, nevertheless, many places which need the development of the second category.

Experimental Investigation

Much of the work in solar cooling has been in continuous-absorption systems and less in intermittent-absorption refrigeration systems. Therefore, an intermittent-absorption refrigerating unit was designed, built, and tested [1].[3] A schematic diagram of the apparatus is shown in Fig. 1 and a photo of the system in Fig. 2.

This system used the flat-plate collector as the generator and absorber. The collector–generator apparatus consisted of ½-in. steel pipes connecting a 2-in. feeder and 6-in. header. Thin copper sheets were soldered to the tubes and the whole collector–generator apparatus enclosed in an insulated wooden box. The collector was covered with a transparent double glazing with an area of about 18 sq ft. This system was tested with an ammonia–water solution at different concentrations. The pressure in the system is controlled by the condensing temperature. In the tropics, the daytime temperature is usually high during summer, which increases the pressure of the system to a high level when the condenser is air cooled. The difficulty of high pressure can be obviated by using an ammonia–sodium–thiocyanate combination instead of ammonia–water. Usually, ground water is much cooler than the ambient temperature. Well water could be used as a bath for condensing the ammonia vapor at a much reduced pressure. This, in turn, would increase the quantity of ammonia condensed for useful refrigeration. Hence, cooling the condenser with stagnant water, and the absorber with ambient air, is an ideal combination for locations having high daytime temperatures.

The generator was charged with predetermined amounts of water and ammonia to give the required concentration of ammonia in the solution. At the commencement of the regeneration period, the line is opened between the upper header and the condenser. At the end of the regeneration period, the condenser is isolated from the rest of the system and the generator–collector is allowed to cool. The transparent cover of the collector can be opened to facilitate cooling of the generator. To carry out refrigeration, line 7 (Fig. 1) is opened and the ammonia in the condenser–evaporator begins to evaporate. Studies [2] were made of this system with various ammonia concentrations in the generator, keeping the condenser cooled with stagnant water. These studies showed that this apparatus was able to condense about 7 lb of ammonia on the average, during regeneration, for an average solar radiation intensity of 1.1 langleys/min for 6 hr of regeneration. The temperature of the evaporator went as low as 10 F. Although some ice was produced, the rate of refrigeration was too slow because of lack of thorough mixing and reabsorption of NH_3 vapor in the absorber. However, evaporation of 7 lb of ammonia should produce at least 10 to 15 lb of ice from water at 80 F. The absorber is being redesigned to achieve this result.

Economic Aspects

The cost of manufacture of this solar-powered intermittent-absorption refrigerating unit was slightly in excess of $400, excluding the handling and moving expenses. Using cheaper materials and local labor, it should be possible to reduce this cost. The annual depreciation and maintenance of the unit, assuming 10 percent of the initial cost, is thus of the order of $40. The annual output of ice would be in the range of 3600 lb, assuming 12 lb of ice per day for 300 days of sunshine or 3000 lb of ice for 250 days of sunshine. Since this system utilizing no electrical or other energy than solar is intended for places where there is abundant sunshine, it is reasonable to assume that sunshine would be available for more than 250 days per year. Therefore, the the cost of ice would be of the order of 1.3 cents per lb.

Ice at this price would be a boon to people living in areas where electricity and other conventional energy sources either are not available or are expensive. Comparing this cost to the usual cost of ice in the range of 2 to 4 cents per lb in tropical countries such as India, intermittent solar refrigeration is attractive. The cost of ice from solar-powered intermittent-absorption refrigeration greatly depends on the cost of the generator–absorber and condenser–evaporator units. Since the generator and absorber are combined with the flat-plate collector in the system investigated by the authors, the cost of ice produced by this unit would be reduced by a reduction in the overall cost of the unit.

Using indigenous materials and local labor in India, one of the authors designed and built a flat-plate collector, covered with two layers of glass, for a solar air conditioner [3], at $2.50 (18 rupees) per sq ft. This cost would be quite reasonable in most tropical countries. Therefore, ice could be produced at low cost by a solar-powered intermittent-absorption system like the one tested by the authors, provided several major problems associated with the system could be overcome.

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[3] Numbers in brackets designate References at end of article.

TABLE 1. Comparative Costs of Refrigeration

Vapor Compression Refrigeration

Assume capital cost of \$180.00 for 10-cu-ft cabinet, ⅛-hp motor, COP = 4, efficiency of motor = 0.8, and cooling load = 7450 Btu/day

Energy Source	Energy Cost	Capital Charges	Operating Charges	Cost of Ice
electricity	3¢/kwh	5¢/day	4.2¢/day	0.25¢/lb
electricity	5¢/kwh	5¢/day	7.0¢/day	0.32¢/lb

Absorption Refrigeration

Assume capital cost of \$700.00 for NH_3—H_2O unit, 9-cu-ft cabinet, COP = 0.5, efficiency of heating value to generator = 0.7, cooling load = 6000 Btu/day

Energy Source	Energy Cost	Capital Charges	Operating Charges	Cost of Ice
natural gas	\$1.05/10⁶ cu ft	19¢/day	2.52¢/day	0.72¢/lb
kerosene	20¢/U.S. gal	19¢/day	2.32¢/day	0.71¢/lb
kerosene (in India)	35¢/U.S. gal	19¢/day	4.08¢/day	0.77¢/lb
propane	\$10.00/100 lb	19¢/day	8.64¢/day	0.92¢/lb
electricity	3¢/kwh	19¢/day	15.00¢/day	1.13¢/lb
electricity (in India and Burma)	5¢/kwh	19¢/day	25.00¢/day	1.46¢/lb

Solar-Powered Absorption Refrigeration

Unit	Capital Cost	Capacity of Ice Production	Capital Charges and maintenance	Cost of Ice
UWO (NH_3—H_2O)	\$400.00	3000 lb/year	\$40.00/year	1.33¢/lb
Farber		41 lb/day		not known
Chung & Duffie				\$4.00/ton
Trombe & Föex				0.9-1.4¢/lb

Note: Assume amortization of 10% of capital cost per annum; cooling required to freeze water from 85 F to ice at 30 F is 200 Btu/lb; for commercial absorption and vapor compression units, use factor is 40% and losses are 40%.

The major problem is the performance of the flat-plate collector as an efficient absorber. The flat-plate collector as a heat dissipator is an area where nothing has been done so far. Plans are underway to investigate this area and to design an efficient absorber suitable for intermittent-absorption refrigeration.

Little information is available on the exact cost and economics of solar refrigeration. Chung and Duffie [4] estimated that an intermittent-absorption food cooler having a capacity of 1000 Btu/cycle would cost \$50, a continuous-absorption ice machine \$300, and \$150 for a solar heat exchanger, so the cost of ice production would be of the order of \$4.00 per ton. Trombe and Föex [5] estimated the cost of ice per kilogram to be of the order of 7 to 10.5 old francs (0.9 to 1.4 cents per lb) by solar refrigeration. Tabor [6] has derived the economics of solar refrigerators from thermodynamic considerations and concludes that solar refrigerating systems with storage facilities will not compete with kerosene-operated units unless the local price is several times the "fair" price of \$60 per ton (19 cents per U. S. gal). These figures might not be accurate today because of the increase in the cost of materials and labor. However, the paper by Ba Hli et al. [7] suggests that ice at 1 cent per lb from a unit producing 50 lb per day should cost not more than \$500. The recent investigation by Farber [8] on a compact solar refrigerating system seems to be encouraging, although the cost analysis of ice production in this system is not available.

The approximate costs for various systems proposed by different investigators are summarized in Table 1.

Conclusion

Indications are that a solar-powered intermittent-absorption refrigeration system has an important role. It can compete favorably with conventional systems and, in fact, can be superior in many parts of the world.

Acknowledgment

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