

one of the major engineering tasks of our time. It is to find out what air transportation is carrying people and what it is carrying. The latest published figures (for 1967) show that the airlines used about 8.5 percent of the national total. If one considers the amount of fuel consumed per mile per passenger, the average jet plane which only half-occupied seats 14 passengers miles per gal. The average U.S. auto also gets about 14 miles per gal. It is clear that the fuel consumption per passenger mile in each can be about the same.

It may turn out that short-range aircraft are attractive for transportation means for short trips between cities, especially in congested areas such as along the coast. Short takeoff (STOL) and vertical takeoff aircraft may become important commuter transports of the future. They could reduce the use of the automobile as a commuter carrier.

At a time when mechanical engineers are taking a serious look at how they can continue contributing to the well-being of mankind, energy production and conservation is one of the major questions. Whatever steps are taken and whatever priorities are suggested by mechanical engineers, they must be responsive to:

1. Ways to reduce the accelerating depletion of fossil fuels, primarily petroleum and natural gas.
2. New processes and restrictions for handling atmospheric pollutants.
3. Introduction of new means for energy production and their combination of fossil fuels.
4. Introduction of energy-storage systems of massive capacity.
5. Fundamental revision of the design (and marketing) concepts for the automobile as a transportation medium.
6. The role of mass transportation in the conservation of energy, and in reducing urban pollution as well as transporting people effectively.

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A revolution in new design and marketing viewpoint for the automobile needs to be promulgated. The automobile industry is being looked upon as a transportation machine and not as an artifact of affluence or an "occupational" machine. It is extravagant and wasteful to consider that a vehicle is long 8 ft wide, weighing over 3 tons, and equipped with an engine delivering over 200 hp. It often needs to transport only 1 person.

Besides the efforts to remove or reduce undesirable exhaust products, the new automobile needs to be greatly reduced in size and engine power. This can be done without sacrificing comfort or safety. A significant savings in total national fuel consumption would be realized if every manufacturer would reduce the horsepower and size of the new auto designs.

It is the view of the engineering community's responsibility to support a major change in design philosophy and to inform the driving public about the consequences of indiscriminate use of the automobile. If the average driver could be made sensitive to an effort to reduce unnecessary auto travel, this too would aid in reducing air pollution.

Beyond these recommendations are the efforts to find a cleaner substitute for the internal combustion engine. This far, the pressure to bring about a revolution in this direction has not been too great. But the pressure is mounting and so some serious developments may soon be in the making. For example, a short-range electric car would be suitable for commuting to work and for a great deal of the errand-running done in suburban communities.

Methods for mass transportation are evolving rapidly. Attention after a long period in which existing systems (primarily rail) have been allowed to decay and pass out of existence. In part, the neglect of mass transportation systems is due to the fact that urban areas have been due to a decentralization of commercial offices, plants, and stores from the heart of the city to highly dispersed locations in the suburbs in areas such as the western part of the city.

In most major American cities, the population in the city proper has been going down. For example, in Detroit, Mich., the city population decreased an average of approximately 1 percent per year during the 1960s while the suburban population increased at about 0 percent per year. In metropolitan areas where new centralized transportation systems are being constructed, it is recognized that these will not cause a substantial shift in the commuter auto traffic in these areas. One of the most serious and costly new transportation systems is being built in San Francisco. It is estimated that when in operation, it could reduce auto traffic in the city by 2 percent (13).

One of the great challenges for the metropolitan transport system is to transport the city dwellers to jobs in the suburban areas. For this function, the flow of people is reversed from earlier concepts of mass transportation which were designed to take automobiles into the city. Rail systems linked with suburban transportation could contribute to reductions in atmospheric pollutants and would help in the conservation of fossil fuels. The imaginative innovation of subway and surface mass transportation systems in populated areas should be

encouraged. 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

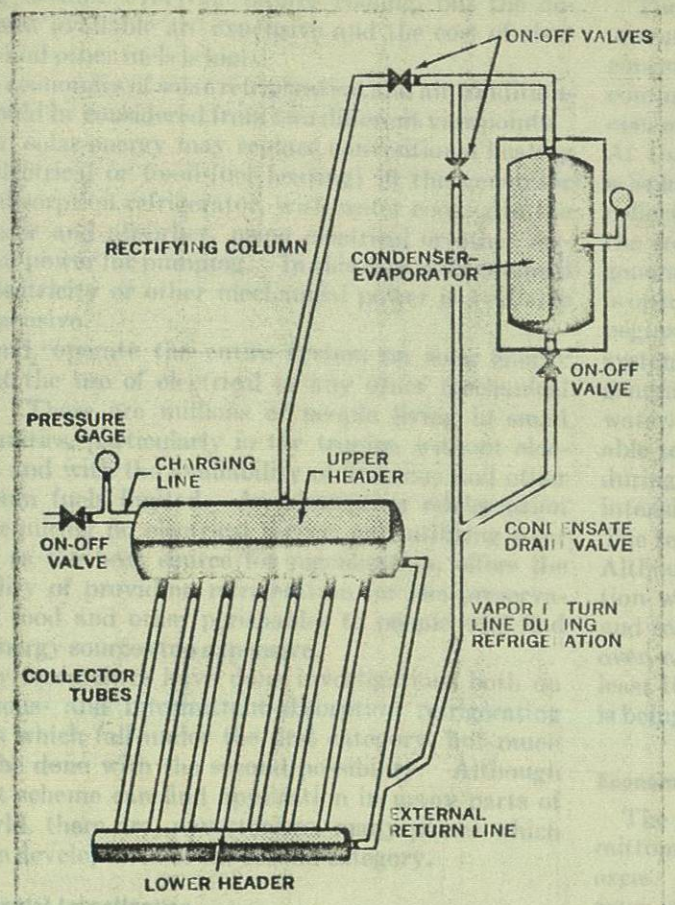


Fig. 1 Schematic representation of intermittent-absorption refrigeration system.

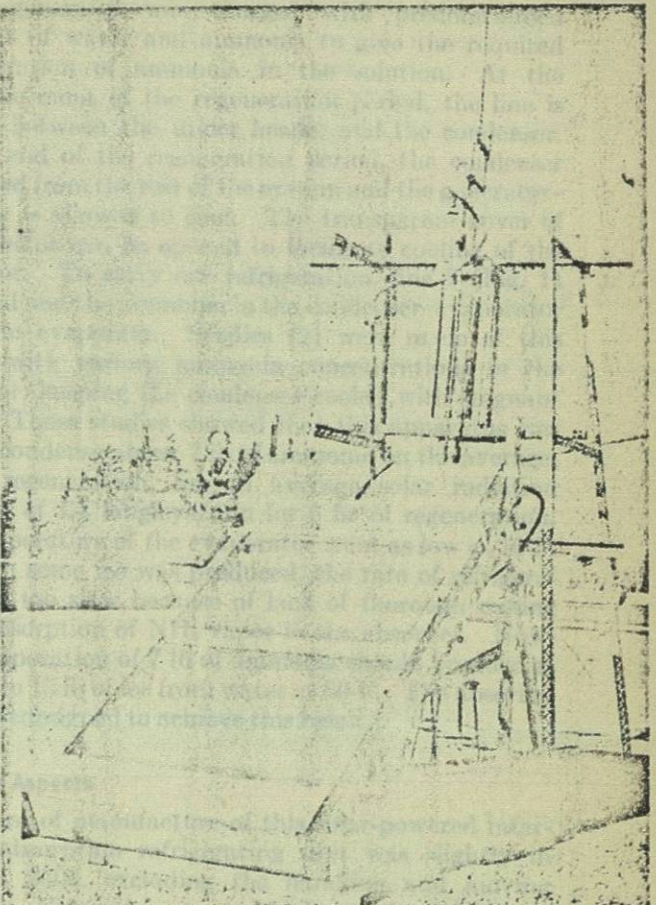


Fig. 2 Solar refrigeration apparatus uses flat-plate collector as the generator and absorber.

Solar-powered refrigeration

ROBERT K. SWARTMAN¹ and C. SWAMINATHAN²

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.

¹ Associate Professor, Faculty of Engineering Science, University of Western Ontario, London, Ontario, Canada. Mem. ASME.
² Heat Balance Engineer, Ontario Hydro, Toronto, Ontario, Canada; formerly Research Assistant, Faculty of Engineering Science, University of Western Ontario, London, Ontario, Canada.
 Based on a paper contributed by the ASME Solar Energy Applications Group.

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

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 1/2-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.

³ Number in brackets designate References at end of article.

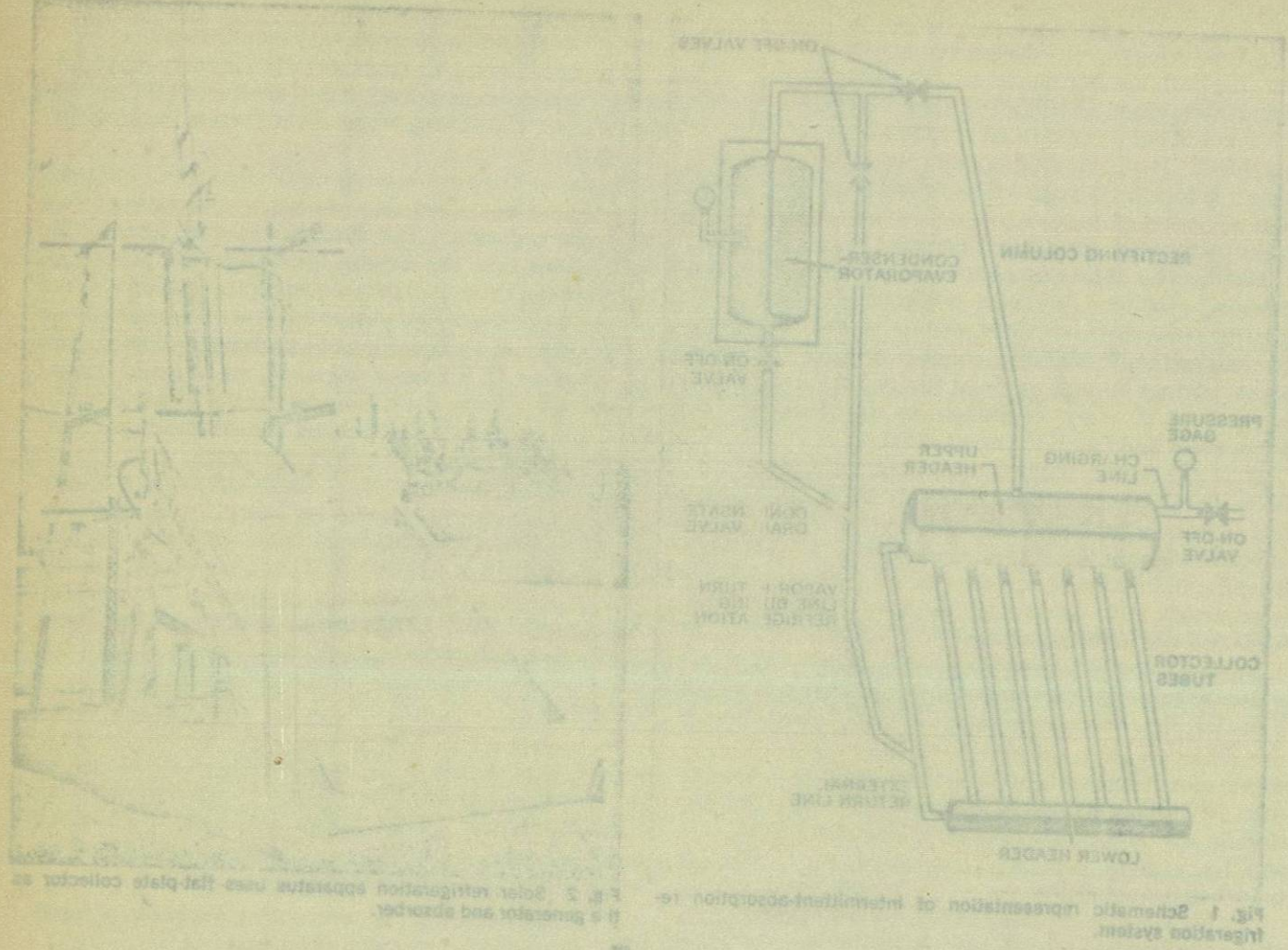
The generator was charged with predetermined amounts of water and ammonia to give the required concentration of ammonia in the solution. At the commencement of the regeneration period, the line is opened between the upper header and the condenser. At the end of the regeneration period, the condenser 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 langley/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 NH₃ 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 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.



ROBERT K. SWARTMAN and C. SWAMINATHAN
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In tropical countries, there is great interest in solar refrigeration. 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.

TABLE 1. Comparative Costs of Refrigeration

Vapor Compression Refrigeration
Assume capital cost of \$180.00 for 10-cu-ft cabinet, 1/8-hp motor, COP = 4, efficiency of motor = 0.8, and cooling load = 7450 Btu/day

Table with 5 columns: Energy Source, Energy Cost, Capital Charges, Operating Charges, Cost of Ice. Rows include electricity at 3¢/kwh and 5¢/kwh.

Absorption Refrigeration
Assume capital cost of \$700.00 for NH3-H2O unit, 9-cu-ft cabinet, COP = 0.5, efficiency of heating value to generator = 0.7, cooling load = 6000 Btu/day

Table with 5 columns: Energy Source, Energy Cost, Capital Charges, Operating Charges, Cost of Ice. Rows include natural gas, kerosene, propane, and electricity.

Solar-Powered Absorption Refrigeration

Table with 5 columns: Unit, Capital Cost, Capacity of Ice Production, Capital Charges and maintenance, Cost of Ice. Rows include UWO (NH3-H2O), Farber, Chung & Duffie, Trombe & Föex.

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.

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.

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.

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

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 flow 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 regeneration, the condenser is opened and the ammonia in the condenser- evaporator is allowed to evaporate. Studies [2] were made of the 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 langley/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 NH3 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.

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Using lightweight 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. The problems associated with the system could be overcome.