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SOLID ABSORBTION CYCLE SOLAR ENERGY: REFRIGERATORES

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14. Abstract/Notes

There has been recent worldwide interest in the development of solar thermal powered refrigerators utilizing a solid absorber system. Here, we examine three absorber-working fluid combinations that have been proposed: zeolite/water, calcium chloride/ammonia, and activated charcoal/alcohol. Our experiments with the zeolite/water system are also discussed. It is concluded that the proper activation of the solid absorbent, heat transfer in the solar collector, and the circuit design have the greatest influence on the maximum COP obtainable.

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RESUMO

Verificou-se, recentemente, um crescente interesse pelo desenvolvimento de refrigeradores operando com energia térmica solar, utilizando um sistema de absorção sólido. Neste trabalho analisa-se tres combinações propostas de absorvente-fluído de trabalho a saber: zeolito/água, cloreto de cálcio/amônia e carvão ativado/álcool. Nossos experimentos com o sistema zeolito/água também são discutidos. Conclui-se que a ativação correta do absorvente sólido, a transferência de calor no coletor e o projeto do circuito, influenciam significativamente no COP máximo obtido.

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1 - INTRODUCTION

Production of artificial cold in present day refrigeration devices involves expenditure of electrical or thermal power. The sun, through the use of photovoltaic cells or solar thermal collectors, is a viable power source in Brazil for refrigeration due to its year round availability. Here we focus on the use of thermal energy because it implies low technology which is vital for Brazilian rural applications.

In practice, thermal powered refrigerators operate on the absorbtion cycle. This cycle contains an evaporator and condenser which operate exactly the same way as for the more common vapor compression cycle. Heat is taken in at the evaporator, causing the refrigerant to evaporate at low pressure, and heat is released in the condenser at high pressure. In the absorbtion cycle there is no mechanical compressor to raise the refrigerant vapor from low pressure to high pressure, the compression process being realized in one of two ways: a) the use of a liquid absorbent and a pump; b) the use of a cyclical source of heat.

In the first method the refrigerant being evaporated at low pressure is absorbed by a liquid solvent. The mixture is then raised to high pressure by a pump. Heat is added liberating the refrigerant vapor from the solvent and is then condensed by rejecting heat to the atmosphere.

It is not necessary to have a liquid pump if one has access to a cyclical source of heat. An example would be a day and night cycle having the sun as the heat source and the cooler night as the heat dump. During the day the absorbent is heated driving off the refrigerant vapor which is then condensed and stored. During the night the refrigerant is taken up by the cooled absorbent, thus lowering the pressure in the system and driving the evaporation process which extracts heat from the cooling chamber.

This second method does not involve any kind of moving parts and seems to be the optimum way to make use of the solar energy since there is no need for conversion to mechanical energy. However, using a liquid absorbent still requires moving the refrigerant and the absorbent to provide adequate contact. This can be done by natural convection, but it makes the system design complicated and sensitive to environmetal factors such as vibration and motion.

Because of the inherent large surface area, a solid absorbent requires only moving the refrigerant. The solid absorbent can be incorporated directly into a device that functions as a solar collector during the day and as heat radiator during the night. Solid absorbents operate at temperatures around 110^{o}C, while most liquid absorbents need at least 140^{o}C - 150^{o}C for regeneration. The lower temperature of the solid absorbent greatly reduces the complexity of the solar collector as well as the cost, and increases the reliability of the system.

2 - PROPOSED SYSTEMS

The basic design of practically realized system are shown in Figures 1, 2, and 3. These systems look rather simple but have three specific design problems: absorbent/refrigerant combination, valves, and collectors.

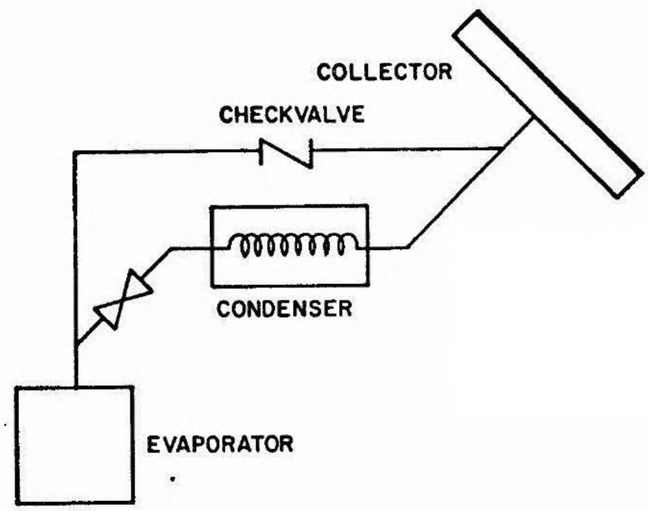

Fig. 1 - Zeolite-water cycle.

c) The absorbent should be stable and its properties should not degrade with time.

d) It should have a desorbtion temperature compatible with flat plate solar collectors.

e) It should be reasonably cheap.

It is not possible for any one material to satisfy all these requirements, so some sort of compromise is necessary in the selection of absorbent/refrigerant combinations. In the past several combinations of solid absorbents with different refrigerants have been already investigated. Among others the following three combinations have found special interest of the researchers:

a) zeolite/water (Tchernev, 1982; Ragot and Rouyer, 1983);

b) calcium chloride/ammonia (Iloeje, 1985);

c) activated charcoal/alcohol (Delegado, 1982).

In Table 1 some properties of each combination are summarized, which may be helpful for the design of a specific refrigeration system. Although we could not find the useful factor of absorbtion in the temperature range of interest for all three combinations, we note that a and c involve only physical, while b involves both physical and chemical absorbtion. Given that physical absorbtion typically occurs at much lower temperatures (Kittsley, 1969), we feel that combination b will have a lower factor of absorbtion than a and c in this respect. Furthermore the toxicity of ammonia, the high system pressure, and a rather complicated control system make that system not very atractive. The data show that the charcoal/alcohol cycle has some advantages which count especially for Brazil, where both materials are available in abundance, although no experiments have been carried out with ethanol.

TABLE I

PROPERTIES OF SELECTED SOLID ABSORBENT / REFRIGERANT COMBINATIONS

PROPERTY	ZEOLITE/ WATER	CALCIUM-CLORIDE/ AMMONIA	ACTIVATED ETHANOL	CHARCOAL/ METHANOL
Theoretical minimum evaporation conditions (°C / mbar)	0/6	-33/500	-31/100	-44/100
Evaporation temperature reached in practice (°C)	3	-12	?	-10
Condensation conditions at ambient temperature (°C/mbar)	35/60	35/13,3 x 10^3	35/131	35/262
Latent heat of coolant at minimum evaporation conditions (kcal / kg)	Solid /liquid 80 Liquid/gas 539	330	220	260
Thermal conductivity of dry absorbent (kcal / mh°C)	~0.1	~0.7	~0.05	~0.05
Factor of aborbtion (kg / kg)	0.3	0.6	0.5	0.5
Useful factor of absorbtion between 25°C/110°C	0.08	?	?	?
Corrosiveness of absorbent/coolant	nil/nil	nil/high	nil/low	nil/low
Toxicity of absorbent/coolant	nil/nil	nil/high	nil/low	nil/medium
Degradation of absorbent (years)	5 to 20	4	?	?
COP Reached in pratice cycle/overall	0.34/0.13	0.3/0.07	-	0.4/0.15
Ice production obtained in practice (kg / m^2 / day)	3 to 4	1	-	6

2.2 - VALVES

For a remotely installed solar powered refrigerator it is a must that it works fully automatic. To operate one valve with some kind of pressure, temperature, or sunlight sensor seems to be feasible, but to operate several valves in a specified sequence may turn out to be a nightmare of control system (Figure 2).

2.3 - SOLAR COLLECTOR

The collector should heat the solid absorbent over day to a maximum achievable temperature and cool it at night as low as possible. These requirements are completely contrary, leading to a compromise in the construction of a collector-cooling unit which may not perform well. The heat transfer from the heating (cooling) surfaces to the absorbent and also in the absorbtion material itself should be high. Closely associated with heat transfer problem in the transport mechanism of the refrigerant vapor through the absorbent.

These aspects which highly influence the efficiency of the whole system have never been widely discussed in the literature. It is interesting to show (Table 1) that the high COP of the charcoal/alcohol system was probably related to a good overall heat transfer in the collector. The low COP of the calcium chloride/ammonia system stems from low temperatures in the core of the collector, thus not permiting the full chemical reaction (Iloeje, 1985).

3 - OUR EXPERIMENTS

3.1 - APPARATUS

Our first prototype (Figure 4) was of the zeolite/water type and had the following design parameters:

- condensing temperature: 35^{o}C;

- collector temperature: $100^{o}C$;
- evaporator temperature: $> 0^{o}C > 5^{o}C$;
- mass of Zeolite - 13X: 5kg;
- cooling chamber: 7 litres.

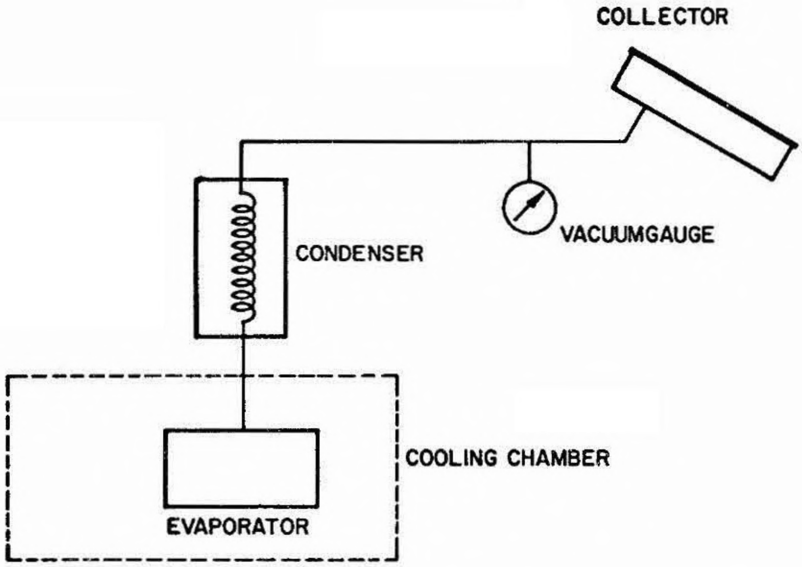

Fig. 4 - Basic design of prototype refrigerator.

The condenser was an aircooled fin tube unit. The collector consisted of a solar absorber made out of 0.5mm coppersheet painted black with a removable double glass cover, and glass wool thermal insulation. Fins soldered to the coppersheet inside the solar abaorber provided a good heat contact to the zeolite. Some perforated tubes placed inside the zeolite facilitated bulk vapor motion into and out of the collector during the desorbtion/absorbtion process. The evaporator consisted of a 15cm by 12cm diameter vessel installed in a plastic foam insulated cooling chamber. The components were connected through ordinary copper pipes. It should be noted that there was no valve installed in the circuit. The components were mounted in a frame for easy outdoor installation. A vacuum gauge allowed the measurement of the system pressure and throughout the apparatus temperature sensors were installed. The radiation level was measured by a pyranometer. All data were recorded by a data acquisition system.

3.2 - TEST

After drying and activating the zeolite, the evaporator was filled with water which had been first outgassed by boiling and then freezing. The system was closed, pumped down to approximately 6 mbar and then sealed off. The refrigerator was placed outdoors facing north with a collector inclination of 35^{o}. During several days the following parameters were monitored:

- radiation level of the sun;
- absorber temperature;
- collector temperature in the middle of the zeolite;
- condenser temperature;
- evaporator temperature;
- ambient temperature.

The removable glass cover of the collector was lifted at night in order to allow the air to pass over the solar absorber, thus increasing the cooling effect.

3.3 - RESULTS

Figure 5 shows the temperature curves during three consecutive days. The zeolite temperature is coupled with the daytime sunshine and with the heat rejection at nighttime. The condenser temperature (not shown for clearness of the figure) was always some $5^{o}C$ higher than the plotted ambient temperature. The evaporator temperature fell to 3^{o}C during the night, increased rapidly to 15^{o}C in the morning, and in the late afternoon reached the ambient temperature before falling rapidly down again. Corresponding zeolite temperatures at the points of the rapid slope change were in the range of 70^{o}C to 75^{o}C. The average pressure in the system increased slightly from the early beginning of operation.

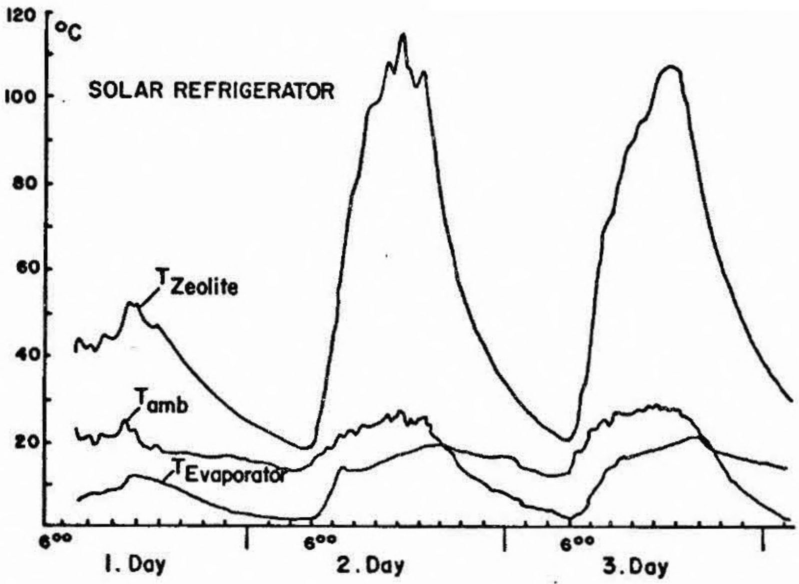

Fig. 5 - Temperature curves of the solar refrigerator.

3.4 - DISCUSSION OF RESULTS

The temperature curve of the evaporator showed clearly that the efficiency of the refrigerator is practically zero, because at the end of each cycle no net cooling effect could be observed. This undesirable behavior resulted from two reasons:

a) there are no valves in the system;

b) the zeolite was not properly activated.

Since there is no valve to block the way from the collector directly to the evaporator, the liquification of the water vapor took place in the evaporator instead in the condenser, because there was found the lowest temperature. Therefore the evaporator temperature raised quickly in the morning hours when the zeolite started to desorb water vapor. A checkvalve in the circuit (see Figure 1) between the condenser and the evaporator is necessary. The second valve could be a capillary tube which does not permit the flow of vapor through the condenser during the evaporation process.

From a certain point (change of slope of the evaporator temperature) the zeolite no longer desorbed water because it was already completely dry. Therefore the heat delivered from the sun beyond that point was lost. The slight increase in evaporator temperature afterwards is due to the heat loss through the thermal insulation of the cooling chamber. In the late afternoon, when the zeolite fell back to the limiting absorbtion temperature (app. $80^{o}C$), it started to absorb the water from the evaporator, thus cooling down the chamber again. The refrigerator was dismantled in order to examine the zeolite. It was found dry, but not activated as a later measurement of the absorber surface of the material showed. Our apparently dry zeolite ($120^{o}C$, 3 days) had an absorber surface area of $9,68m^2/gr$, and after reactivation ($390^{o}C$, 3 hours), $258m^2/gr$.

4 - CONCLUSION

From the review of three different types of solar powered solid absorbent refrigerator systems we conclude that the zeolite/water or the charcoal/alcohol cycle are best adapted to Brazil. It is also clear that the heat transfer in the solar collector-absorber unit is of major importance. Our experiments with a zeolite/water cycle pointed out the necessity of properly activating the absorbent. It is also obvious that a valving system is needed and we propose a checkvalve between the condenser and evaporator with a capillary tube in parallel (Figure 1).

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