

Review on Solar Adsorption Refrigeration System

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Abstract— The adsorption refrigeration is based on the evaporation and condensation of a refrigerant combined with adsorption. This project will describes the design and fabrication of the experimental chamber, the experimental procedure and its feasibility towards development of an alternative eco-friendly refrigeration cycle for replacement of chlorofluorocarbons. Solar adsorption refrigeration devices are significant to meet the needs for cooling requirements such as air conditioning, ice making and medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. Various solar powered cooling systems have been tested extensively; these systems are not yet ready to compete with the well-known vapour compression systems. For these reasons, research activities in this sector are still on to solve the technical, economical and environmental problems. So, the primary objective of this work is to provide fundamental understandings of the solar adsorption systems and to give useful guidelines regarding the working principles of the various intermittent adsorption systems and their applications in ice making with the aim of improving Coefficient of Performance (COP). Also, in this work, a review of the research state of art of the solar sorption (absorption and adsorption) refrigeration technologies is presented. After an explanation of the systems working principles, recent progress in solar sorption refrigeration technologies are also reported. It shows that solar powered sorption systems refrigeration technologies are attractive alternatives that not only can serve the needs for air conditioning, refrigeration, ice making and cooling purposes, but also can meet demands for energy conservation and environmental protection.

Key words: Adsorption, Solar Adsorption Refrigeration System

I. INTRODUCTION

Cooling is simply the process of reducing the temperature of a space or product for purposes of either comfort or preservation.

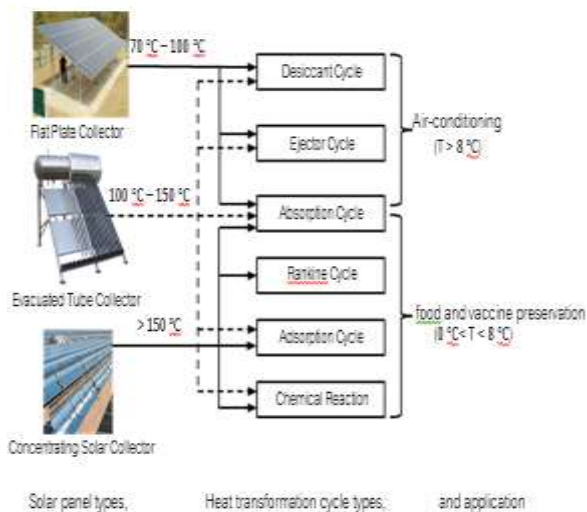


Fig. 1: Solar Cooling Technology

It can be accomplished by various methods, using different types of energy ranging from electrical to mechanical or even purely thermal energy. Thermal energy could be fossil fuel derived, biomass derived or solar radiation. Solar cooling systems have been most commonly employed as the means of extending the vaccine cold chain to rural areas without conventional energy supplies. They may also be used for making ice.

II. ADSORPTION

Adsorption is the general phenomenon resulting from the interaction between a solid (adsorbent) and a gas (refrigerant) based on a physical or chemical reaction process. An adsorption refrigeration machine utilizes the phenomenon of physical adsorption to be fixed at the surface of adsorbent through connections of the Van der Waals forces. Adsorption process can be classified as either physical or chemical, depending on the forces causing the adsorption process. Physical adsorption (physisorption) occurs when Van der Waals forces bind the adsorbing molecules to the solid phase, these intermolecular forces are as same as ones that bond molecules to the surface of a liquid. The chemical adsorption (chemisorption) occurs when covalent or ionic bonds are formed between the adsorbing molecules and the solid substance. Adsorption is an endothermic process accompanied by evolution of heat, the quantity of heat released depends upon the magnitude of the electrostatic forces involved, latent heat, electrostatic and chemical bond energies. The heat of adsorption is usually 30-100% higher than the heat of condensation of the absorbate. In 1972, the theory of adsorption was extensively discussed in New York by Levenspiel. It proffers that during adsorption, a molecular species of a fluid is attached to the surface of a solid, resulting in an increased concentration of the substances at the interface.

III. PRINCIPLE OF ADSORPTION

Adsorption occurs at the surface interface of two phases, in which cohesive forces including electrostatic forces and hydrogen bonding, act between the molecules of all substances irrespective of their state of aggregation. Unbalanced surface forces at the phase boundary cause changes in the concentration of molecules at the solid/fluid interact. The process of adsorption involves separation of a substance from one phase accompanied by its accumulation or concentration at the surface of another. The adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate.

Adsorption process can be classified as either physical or chemical, depending on the forces causing the adsorption process. Physical adsorption (physisorption) occurs when Van der Waals forces bind the adsorbing molecules to the solid phase, these Intermolecular forces are as same as ones that bond molecules to the surface of a liquid. Molecules that are physically adsorbed to a solid can be released by applying heat; therefore, the process is reversible. Chemical adsorption (chemisorptions) occurs

when covalent or ionic bonds are formed between the adsorbing molecules and the solid substance. The bonding forces of chemical adsorption are much greater than that of physical adsorption. Thus, more heat is liberated. This bonding leads to change in the chemical form of the adsorbed compounds and hence, it is irreversible. For this particular reason, most of the adsorption processes applicable to the thermal system or cooling machine mainly involve physical adsorption. It is the general phenomenon resulting from the interaction between a solid (adsorbent) and a gas (refrigerant), based on a physical or chemical reaction process. An adsorption refrigeration machine utilizes the phenomenon of physical adsorption between the refrigerant and a solid adsorbent; the molecules of the refrigerant come to be fixed at the surface of adsorbent via connections of the type Van der Waals. It is generally consisted of a generator, a condenser, a pressure-relief valve and an evaporator. The generator consists of a solar plate containing the adsorbent, which is heated by the solar radiation, for desorption of refrigerants. A structure example of this kind of system is illustrated in Fig. 2.

When fixed adsorbent beds are employed, which is the common practice, these cycles can be operated without any moving parts. On the one hand, the use of fixed beds results in silence, mechanical simplicity, high reliability and a very long lifetime, on the other hand, it also leads to intermittent cycle operation, with adsorbent beds changing between adsorption and desorption stages, which decreases the COP of the system. Hence, when constant flow of vapour from the evaporator is required in order to provide continuous cooling, two or more adsorbent beds must be operated out of phase.

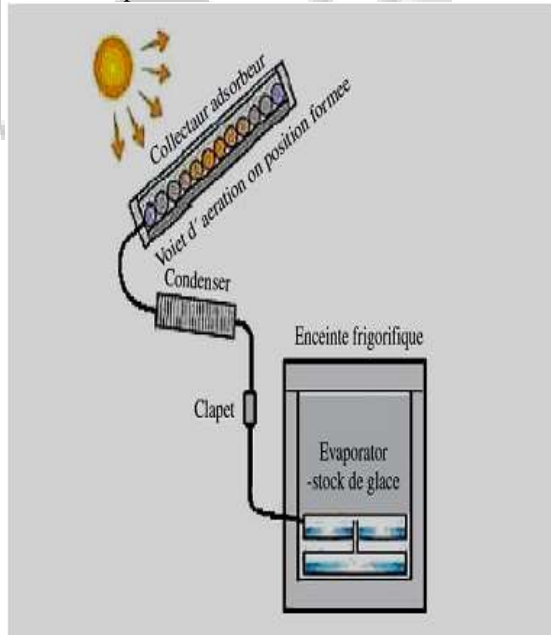


Fig.2 Schematic drawing of a solar adsorption refrigerator (Khattab, 2004)

IV. THE ADSORPTION CYCLE

The solar adsorptive cycle is the succession of two periods, the first period consists of regeneration of the adsorbent by solar energy when the adsorbate is condensed and the second period occurs during the night when the evaporation of the adsorbate and the adsorption take place. Adsorption

cycles are only intermittent in operation, since the adsorbent cannot move through the components, and the cycle comprises two phases: heating–desorption–condensation phase and cooling–adsorption–evaporation phase. When the thermal energy supply is solar energy, the phases correspond to the natural diurnal and nocturnal solar radiation periods, respectively. In this case, the demand for energy is in phase with its supply. Adsorption cycles have been considered for use in heat pump systems, just as many different absorption cycles. Solar powered adsorption refrigeration contains only three major components (container of adsorbents, condenser and evaporator) and functions as follows. The adsorbent is packed in a sealed container painted black for solar radiation absorption. During the day, solar energy heats the high concentration of adsorbent and container to the maximum cycle temperature (Luo, Dye, 2005, P.666). At its condensing pressure corresponding to a particular temperature, the refrigerant starts desorbing from the adsorbent. As the refrigerant vapor is changed to liquid in the condenser, heat is dissipated to the surroundings. The condensate flows by gravity into a liquid receiver or directly into the evaporator. During the night cycle, the adsorbent is cooled to near ambient temperature, thus reducing the pressure of the entire system. When the adsorbent pressure equals the saturated vapor pressure of the refrigerant, the refrigerant boils in the evaporator and causes heat to be absorbed from the immediate environment. The resulting refrigerant vapor is re-adsorbed into the adsorbent, while cooling is produced. The pressure – temperature – concentration (P–T–X) diagram of Fig.3 illustrates the above processes and their typical operating temperatures. Practically realized solar energy powered solid adsorption refrigeration cycles based on the above principles may be classified according to the adsorbent/refrigerant combination used.

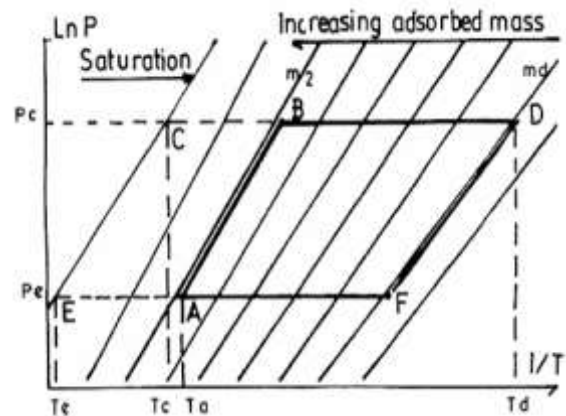


Fig. 3: P-T-X or Clapeyron diagram of adsorption cycle

V. LITERATURE REVIEW

In recent years there has been increasing interest in this technology for many different reasons. The main arguments in favour are that sorption systems are quiet, long lasting, cheap to maintain and environmentally benign. The following studies are tested solar assisted refrigeration machines:

Dupontet al. (1982:193-200) [1], investigated two solar powered solid adsorption refrigerators, one utilizing a water-cooled condenser, while the other used an air-cooled

condenser. The working pair was zeolite 13X–water. Test results showed that in the water-cooled condenser model, the solar COP varied over the range 0.04–0.14 with ice production in the range 3.71–8.14 kg/m² of collector area.

Grenier et al. (1983:4-17) [2], built a large cold store of volume 12 m³ powered by solar energy using a zeolite 13X–water combination. The adsorbent granules were distributed in 24 flat plate type collectors, each of area 0.83 m². The evaporator temperature achieved was a low 2.5 °C, corresponding to a solar COP of 0.086.

Kluppel and Gurgel (1987:2627-2631) [3], built two prototypes of a solar powered solid adsorption cooling system, using a silica gel–water combination. The prototypes used a solar collector in which the adsorbents were packed in the annular space between copper tubes. A solar COP of 0.055 was obtained for the prototype with evaporator temperatures below 4 °C, and a COP of 0.077 for the prototype with evaporator temperature of 4 °C.

Pons and Guillemot (1986:332-337) [4], experimentally investigated a solar adsorption ice maker with 6 m² collector area, which could produce 30–35 kg ice per day under solar radiation of about 22 MJ/m² day.

Mediniet et al. (1991:363-367) [5], studied a non-valve solar adsorption ice maker with a 0.8 m² collection surface area in 1991. The prototype employed an intermittent daily cycle with activated carbon AC35–methanol pair. The results showed that, with a collector efficiency of 0.41 and a thermal COP of 0.40, it is possible to obtain a gross solar COP of 0.15, and to produce 4 kg of ice per day, during summer.

Hajji and Khalloufi et al. (1995:3349-3358) [6], investigated the adsorption kinetics of many adsorbent-adsorbate pair under constant-pressure conditions. They found that the adsorbent thickness and heat transfer coefficient between the adsorbent and the heating/cooling fluid have the strongest influence on sorption kinetics and on the cooling capacity of adsorption systems.

Tangkengsirisin et al. (1998:347-353) [7], studied the parameters influencing the desorption rate in order to improve the efficiency of the solar collector. They verified that blue silica gel had better absorptivity in the near – infrared region than white silica gel and that the addition of activated carbon to the silica gel improves the desorption rate and regeneration temperature of the packed bed.

Sumathy and Zhongfu et al. (1999:704-707) [8], tested a solar powered icemaker with the solid adsorption pair activated carbon and methanol. The icemaker consisted of a flat plate collector with an exposed area of 0.92 m², and produced ice at a rate of 4 to 5 kg/day. Test results showed that both the condensing and adsorption bed temperature had significant influence on the performance of the system. The COP obtained ranged from 0.1 – 0.12.

Buchter, Dind, and Pons et al. (2003:79-88) [9], tested an adsorptive solar fridge in Ouagadougou, Burkina-Faso. The adsorption pair was activated carbon/methanol. The adsorber area was 2 m², single glazed. The condenser was air-cooled (natural convection) and the evaporator contained 40 liters of water that could freeze into ice. This amount of ice acts as a cold storage for the cold cabinet (available volume of 440 liters). Experimental performance was presented in terms of the gross solar COP. During the test period, irradiance was between 19 and 25MJ m⁻², the

ambient temperature was average at 27.4°C at sunrise and 37.4°C at mid-afternoon. The solar COP lay between 0.09 and 0.13.

Boubakri, Guillemont, and Meunier et al. (2000:249-263) [10], presented a solar adsorptive ice maker model and validated it experimentally. The Adsorbent - adsorbate pair used was active carbon–methanol. The collector area used was 1 m², 90 mm thick, 20° tilted and made of two identical stainless steel shells. A grid held 20 kg of activated carbon. Daily ice production was 11.5 kg per m² of collector, with a COP of 0.19.

Wang et al. (2000:189-195) [11], introduced a hybrid system of solar powered water heater and adsorption ice maker. Experiments were performed in a developed prototype hybrid system. It was verified that the hybrid system is capable of heating 60 kg of water to 90°C as well as producing ice at 10 kg per day with a 2 m² solar collector.

Khattab et al. (2004 : 2747- 2760) [12], developed a solar-powered adsorption refrigeration module with the solid adsorption pair of charcoal and methanol. Test results show that, the daily ice production is 6.9 and 9.4 kg/m² and net solar COP is 0.136 and 0.159 for cold and hot climate, respectively.

VI. CONCLUSION

In this work, the review on several research works done by different people has been presented. It also contains the categorization of different adsorbate/adsorbent pairs; stating some specific requirements in the choice of the various pairs. Theoretical adsorption equilibrium models have also been outlined. These are related equations governing the solar adsorption technologies focused on in this work. They enhance the understanding of the physics of the adsorption process applicable to refrigeration. The empirical equations of D–R or D–A, which separate adsorbate and adsorbent properties are generally preferred. Also, adsorption cycle is presented; which is the succession of two periods. The first period consisting of regeneration of the adsorbent by solar energy, when the adsorbate is condensed, and the second periods occurs during the night when the evaporation of the adsorbate and the adsorption takes place. The cycles are only intermittent in operation, since the adsorbent cannot move through the components, and the cycle comprises two cycles. Adsorption cycles have been considered for use in heat pump systems, just as many different absorption cycles. The working principles of four intermittent adsorption systems are reviewed; which are silica gel – water system, zeolite – water system, activated carbon –methanol system and activated carbon – ammonia system. The unique advantages of using an environmentally friendly refrigerant, chemically stable working pair and inexpensive construction materials locally available in developing countries, like Nigeria make solid adsorption solar refrigeration attractive for further developments, but however, a lot of research works still needs to be done for enhancing the heat and mass transfer to improve performances of solar sorption refrigeration systems. More modern solar energy collecting and transferring technologies, and more advanced optimization and models are also being anticipated. In addition, combined systems and domestic equipments using

advanced micro – exchangers are also the trend of development.

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