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Evaluation of Thermal Performance of 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. The objective of this project is to establish an alternative eco-friendly refrigeration cycle for producing a temperature usually encountered in a conventional refrigerator. By manufacturing such type of refrigerator adds new dimension to the world of refrigeration. This refrigerator gives some amount of relief to the refrigeration world by making it independent of electric power supply and zero running cost. This system designed by using pair of silica gel as adsorbing material and water as a refrigerant. This system is capable of cooling down a load of 10 litres initially at 35oC; down to 08oC Causing only solar energy produced by a flat plate solar collector.

Test results show that the solar adsorption is capable of cooling down a load of 10 liters initially at 35oC; down to 8oC Causing only solar energy produced by a flat plate solar collector; which was the main objective of this study. Test results show that only chilled water with temperatures between 6 oC and 12oC is produced. Final analysis shows that the process of solar adsorption-assisted cooling could be an alternative for vapour compression system for cold room applications.

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I. INTRODUCTION

The solar adsorption cooling system is similar to the traditional vapour compression refrigeration system with the electricity driven compressor is replaced with a thermal powered one, Figure 1 shows the adsorption container is integrated with a flat plate solar collector and contains a porous adsorbent medium. The solid adsorbent has the affinity to adsorb the refrigerant vapour. Furthermore, the thermodynamic cycle of the adsorption refrigeration system is illustrated on Clapeyron diagram, Figure 2. The cycle consists of four processes; pressurization preheating process at a constant concentration (isosteric heating process 1-2), desorption at constant pressure (isobaric heating process 2-3), depressurization at constant concentration (isosteric cooling process 3-4), and adsorption at constant pressure (isobaric cooling process 4-1).

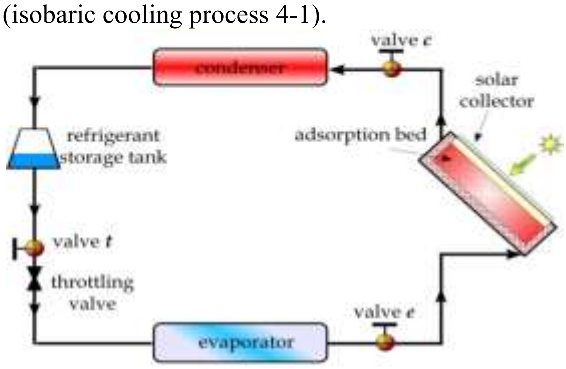

Figure 1. Schematic diagram of the solar adsorption cooling system

The negative environmental consequences related to conventional vapour compression refrigeration machines, have renewed interest in adsorption refrigeration systems whose refrigerants present the advantages of being absolutely benign for the environment, i.e., these refrigerants satisfy the Montreal protocol on ozone layer depletion and the Kyoto protocol on global warming. Additionally, solar adsorption refrigeration systems are attractive, mostly in remote areas without grid-connected electricity, since solar radiation is freely available, and the demand of refrigeration increases particularly in the sunny regions. Some units of solar adsorption refrigerators have been commercialized using activated carbon–methanol system manufactured by BLM Co. of France and zeolite–water system manufactured by Zeopower Co. of USA. These units were technically successful, but their costs are not competitive with the conventional vapour compression system. In addition to their high costs, adsorption systems have some other drawbacks, such low specific cooling power and low coefficient of performance, due to the weak heat transfer within the adsorbers. In order to overcome these disadvantages, several works have been carried out.

The purpose of this study is to design, develop and evaluate environmentally-friendly solar-assisted adsorption refrigerator with composite adsorbent. The aim of the present work is also to explore the benefit of such a system. The study also compares cost effectiveness of the solar powered machine to the conventional vapour compression machine so that the best option can be chosen.

The objectives of the study are

- ❖ To design, develop and evaluate a solar powered Adsorption Refrigeration system with composite adsorbent
- ❖ To assess the cooling capacity of the system.

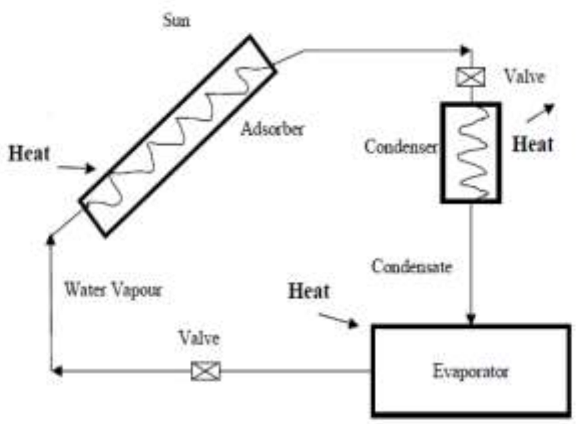

Figure 2: Cycle Flow diagram

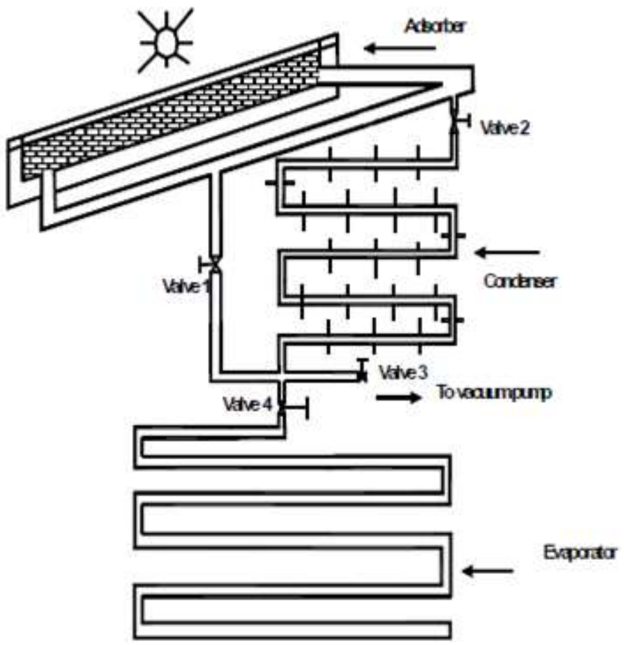

Figure 3: Valve arrangement

The experiment was run according to the procedure as set out in Table 3 and the explanation below:

Table 3 :- Procedure for operating the experimental system

Time	Valve 1	Valve 2	Valve 4	Process
08.00	Close	Close	Close	Heat adsorbent
11.00	Close	Open	Close	Heat adsorbent Condensation
19.00-07.00	Open	Close	Open	Evaporation: Cooling cycle

II. LITERATURE REVIEW

Nanofluids are suspensions of metallic or nonmetallic nanoparticles in a base fluid; this term was introduced by Choi [1]. A substantial increase in liquid thermal conductivity, liquid viscosity, and heat transfer coefficient are the unique characteristics of nanofluids. It is well known that metals in solid phase have higher thermal conductivities than those of fluids [2]. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. The thermal conductivity of metallic liquids is much greater than that of nonmetallic liquids. Thus, fluids containing suspended metal particles are expected apparent enhanced thermal conductivities rather than pure fluids [3]. Masuda et al. [4] dispersed oxide nanoparticles (Al_2O_3 and TiO_2 with 4.3 wt%) in liquid and showed that the thermal conductivity is increased by 32% and 11%, respectively. Grimm [5] dispersed aluminum particles (1–80 nm) in a fluid and claimed a 100% increase in the thermal conductivity of fluid for 0.5–10 wt%. Using the nanofluids in solar collectors has been subjected to a few recent studies.

Yosefi et al. [6] investigated the effect of MWCNT as an absorbing medium on the efficiency of a flat-plate solar collector experimentally and reported 35% enhancement in the collector efficiency for 0.4 wt%. Also the same researchers [7] repeated the experiments with Al2O3–Water nanofluid and reported 28.3% enhancement in the collector efficiency for 0.2 wt%. Chaji et al. [8] used TiO2–Water nanofluid as a working fluid at a small flat plate solar collector and observed 15.7% enhancement in the collector efficiency (compared with pure water). Polvongsri and Kiatsiriroat [9] investigated the thermal enhancement of a flat plate solar collector with silver nanofluid. They concluded that using this nanofluid can improve thermal performance of flat plate collector compared with water especially at high inlet temperature. He et al. [10] investigated the light-heat conversion characteristics of two nanofluids, water–TiO2 and water–carbon nanotube (CNT), in a vacuum tube solar collector under sunny and cloudy weather conditions.

The experimental results show very good light heat conversion characteristics of the CNT–H2O nanofluid with the weight concentration of 0.5%. Because of the better light-heat conversion characteristics of the CNT–H2O nanofluid compared to the TiO2–H2O nanofluid, the temperature of the CNT–H2O nanofluid is higher than that of the TiO2–H2O one. Lue et al. [11] examined thermal performance of an open thermo-siphon which uses Cuo–Water nanofluid for high-temperature evacuated tubular solar collectors. They showed that with optimal filling ratio 60% and optimal mass concentration 1.2%, evaporating heat transfer coefficients may increase by about 30% compared with those of pure water.

Keshavarz and Razvarz [12] experimentally studied the effect of Al2O3/Water nanofluid on the efficiency enhancement of a heat pipe at different operating conditions. They concluded that the thermal efficiency of a heat pipe charged with nanofluids is higher than that of pure water as working fluid. Saidur et al. [13] also theoretically investigated the effect of using Al2O3/Water nanofluid on the performance of direct solar collector. They showed that using nanofluids within 1.0% volume fraction gave a promising improvement on the direct solar collector performance. Sani et al. [14] introduced a new nanofluid, made from dispersing carbon nanohorn in ethylene glycol, for solar energy applications. Their results show that this nanofluid is useful for increasing the efficiency of solar thermal devices and costs reduction (in comparison with carbon-black nanofluid). Natarjan [15] investigated the thermal conductivity enhancement of a base fluid using carbon nanotube (CNT). According to their results, if these fluids are used as heat transport media, the efficiency of the conventional solar water heater will be increased.

Tyagi et al. [16] studied the capability of using a non-concentrating direct absorption solar collector (DAC) theoretically and compared its performance with a conventional flat-plate collector. In their research, a nanofluid composed of water and aluminum nanoparticles, was used as the absorbing medium. According to their results, the efficiency of a DAC with nanofluid is up to 10% higher than that of a flat-plate collector. Otanicar [17] studied environmental and economical effects of using nanofluids to enhance the solar collector efficiency compared with conventional solar collectors.

III. DESIGN OF SYSTEM

Figure 3.1 shows schematic layout of a adsorption refrigeration system running on solar energy. The solar refrigerator consists of an adsorbent bed (2), a condenser (5), an evaporator (7), water tank (8), insulation box (9) as well as connecting pipes. For this system, there are no any reservoirs, connecting valves and throttling valve, the structure of the system is very simple. The working principle of this no valve solar refrigerator is described as follows. On a sunny day, the adsorbent bed absorbs solar radiation energy, which raises the temperature of adsorbent bed as well as the pressure of refrigerant in adsorbent bed. When the temperature of adsorbent reaches the desorption temperature, the refrigerant begins to evaporate and desorb from the bed. The desorbed refrigerant vapor will be condensed into liquid via the condenser and flows into the evaporator directly; this desorption process lasts until the temperature of adsorbent reaches the maximum desorption temperature. During night, when the temperature of the adsorbent bed reduces, the refrigerant vapor from the evaporator gets adsorbent back in the bed. During this adsorption process, the cooling effect isreleased from refrigerant evaporation, and the ice is formed in the water tank placed inside thermal insulated water box. Likely in a vapour compression system the adsorption refrigeration system also consists of a compressor, a condenser, and an evaporator but no throttle valve is used. However, in this system the compressor is replaced by a thermal compressor which is operated by heat instead of a mechanical energy. The vaporized refrigerant is adsorbed in the pores of the adsorbent in the reaction chamber i.e. adsorbent bed. Thus the operation of the adsorption cooling system depends on adsorption/desorption characteristics of the particular adsorbent/refrigerant pair. Due to the loading of the adsorbent, the thermal compressor is operated intermittently.

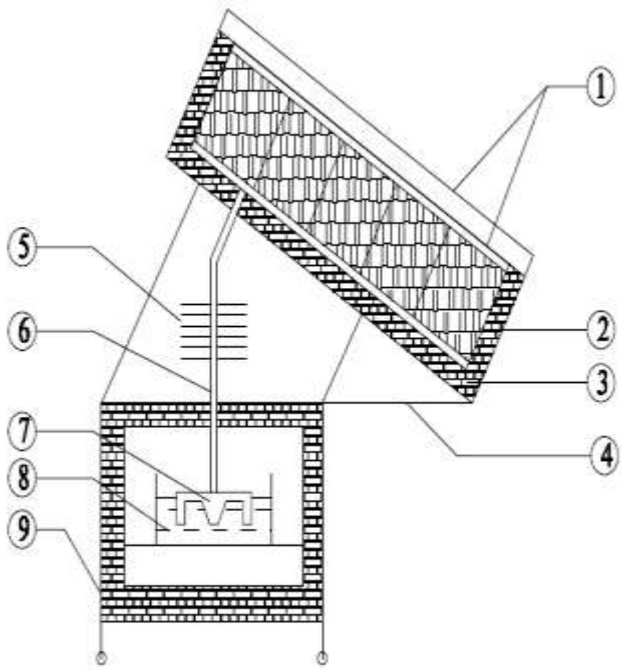

Fig 4: Structure of the no valve Solar Ice maker

1. Cover Plate, 2.Adsorbant Bed, 3.Insulation Materials, 4.Frame, 5.Condenser, 6.Connecting Pipe, 7.Evaporator, 8.Water Tank, 9.Insulation Box.

IV. RESULTS AND DISCUSSION

4.1 Analysis of the evaporator temperature

In figure 4.1 below, analysis of the evaporator temperature versus time over day/night period is presented.

The evaporator temperature decreased gradually until it reached a minimum value of 12^{o}C. The load of 10 litres of water, initially at a temperature of 35^{o}C was cooled down to 12^{o}C.

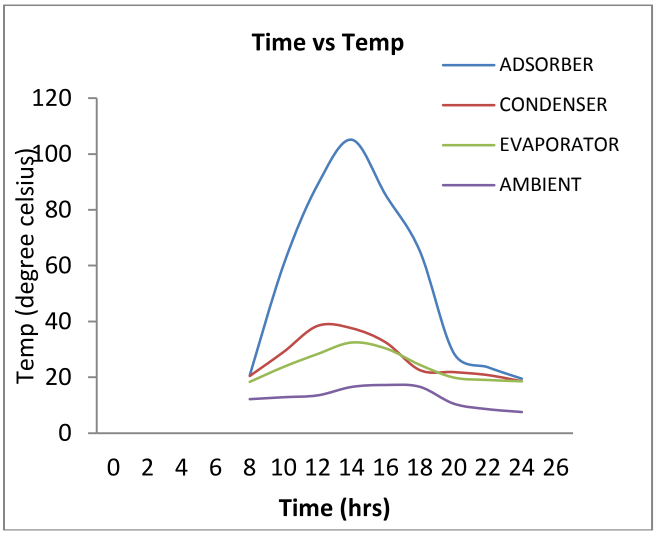

Figure 4.1: System temperature versus time

Figure 4.2 below represents working pressures and temperatures, for the tested Calcium Chloride/water pair.

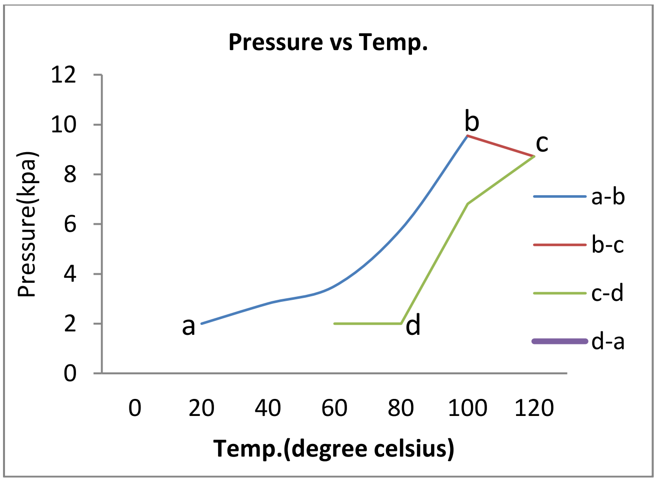

Figure 4.2: Measured temperature–pressure of adsorber

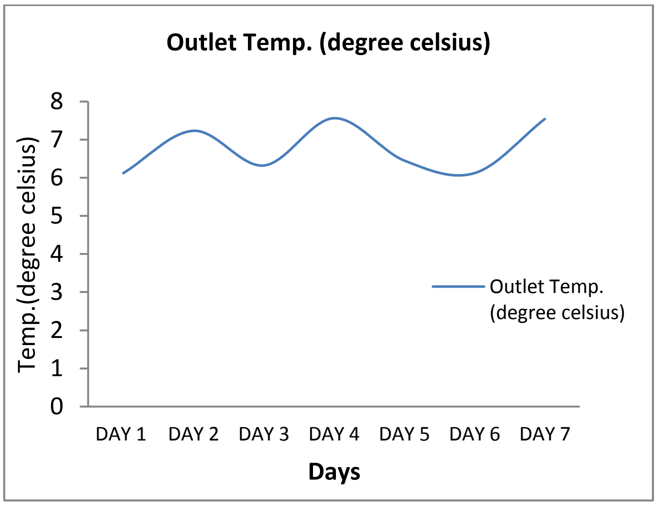

Figure 4.3: Measured temperature–pressure of adsorber

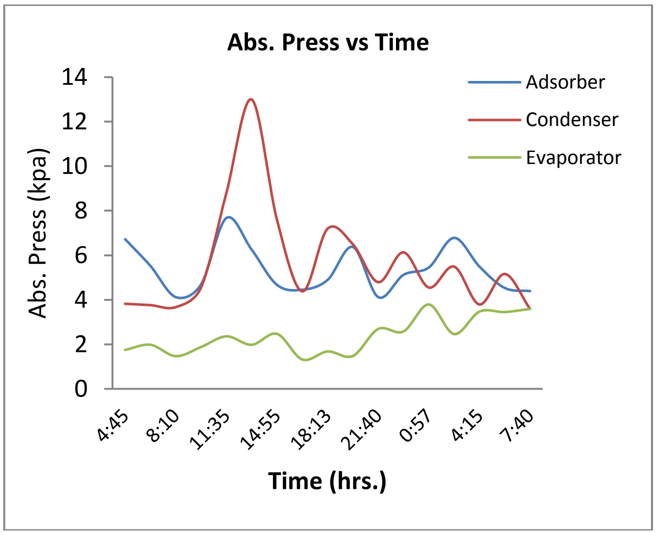

Figure 4.4: Measured temperature–pressure of adsorber

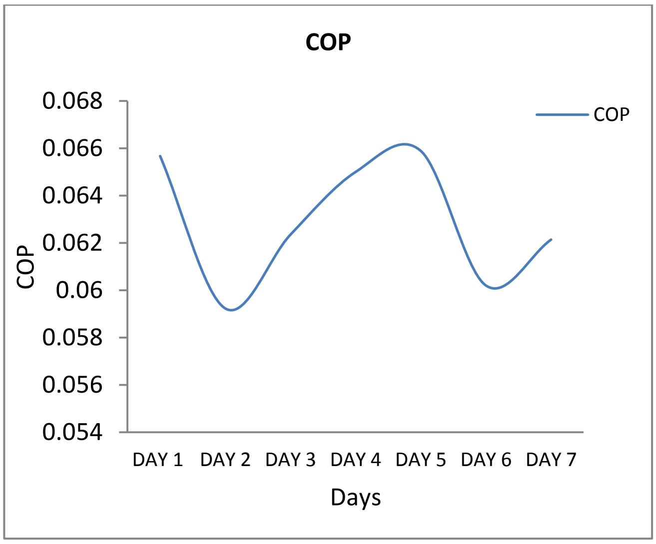

Figure 4.5: Variation in System COP

Figure 4.5 Represents variations in system COP. Maximum COP of system is achieved up to 0.066. Variation in system COP depends on the solar intensity.

V. CONCLUSION

- Test results show that the fridge is capable of cooling down a load of 10 liters initially at 35^{o}C; down to 06^{o} C Causing only solar energy produced by a flat plate solar collector; which was the main objective of this study.
- Test results show that only chilled water with temperatures between 6 ^{o}C and 10^{o}C is produced.
- Final analysis shows that the process of solar adsorption-assisted cooling could be an alternative for vapour compression system for cold room applications.

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