Performance Study of a Solar Powered Ice Maker Operating in Baghdad-City

*Abdual Hadi N. Khalifa
*Ahmed Q. Mohammed
*Asaad T.AL-Omran
**Amar Sadoon Abdul Zahara
*Engineering Technical College- Baghdad Middle Technical University
** University of Technology.

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الخلاصة

يمتاز العراق بوفرة في الطاقة الشمسية، والتي يمكن الاستفادة منها في امداد العديد من المنظومات الشمسية بالطاقة بما ذلك انظمة التبريد والتثليج الامتزازي. تم بناء منظومة تثليج امتزازيه تعمل على الطاقة الشمسية وتستخدم زوج الكاربون المنشط– الميثانول في مدينة بغداد. تتكون المنظومة من مولد ابخار الشمسي بمساحة سطحية تساوي (0.211) م^2 ويحتوي مولد البخار على (3) كغم من حبيبات الكاربون المنشط من النوع (3-NORIT PK 1) وكان قطر الحبيات بحدود (3.15) ملم. يعمل الكاربون المنشط كوسيط ماز لبخار الميثانول . ويضاف الى مولد البخار مكثف مبرد بالهواء الحر لتكثيف بخار الميثانول الخارج من مولد البخار. اما مبخر المنظومة فقد غمر في وعاء بحجم (1) لتر من الماء لغرض تحويل الماء الى ثلج. تم دراسة تأثير تغير النسبة الوزنية للميثانول الى الكاربون و ضغوط المنظومة على اداء منظومة التثليج الشمسية. بينت النتائج ان الانتاج اليومي للثلج بلغ (1) لتر في اليوم الواحد عندما كانت مساحة مولد البخار (0.211) م^2. أي ما يعادل (4.8) كغم ثلج / م^{2}يوم.

الكلمات المفتاحية

الطاقة الشمسية، التثليج الشمسي، منظومة تثليج شمسية امتزازية، التثليج الامتزازي.

Abstract

Iraq is characterized by high abundance of solar energy, which can run many solar energy systems, including adsorption refrigeration systems. A solar-powered adsorption ice maker was built in Baghdad- Iraq. The ice maker works on two adsorption pairs, namely activated carbon and methanol. The unit generator is a flat plate solar collector of (0.211) m^2 filled with a grain activated carbon. The flat plate collector was covered using a glass sheet of 6 mm thickness. A (3) kg of granular activated carbon type (NORIT PK 1-3) of particle size is of (3.15) mm is used as an adsorbent. Methanol is used as a desorbent medium. Different mass of methanol is used to achieve different mass ratios of activated carbon and methanol. A natural air-cooled condenser was used to condense the methanol vapour, while, the evaporator was immersed in a water bath of 1-litre volume, intended to be frozen. The maximum solar coefficient of performance is about 0.36, while the minimum is approximately (0.1). The daily production of ice was (1) litre when the top collector area of (0.211) m^2, which is equivalent to (4.8) kg ice/m^2.day.

Keywords

Solar energy, solar refrigeration, solar ice maker, adsorption refrigerator.

1. Introduction:

Various research and development efforts have been made to predict the performance of the solar-powered ice maker.

In 1987, Pons and Guilleminot, 1986 [1] had designed a solar-powered ice maker, with 6 m^2 top collector area. The collector containing about (130) kg of active carbon, the net production of ice was (30-35) kg per day. The net COP was about (0.12). Some of the specific aspect of such machines, like heat transfer within collector, the delayed of adsorption end and the chimney effect between collectors were introduced. Lemmini and Meunier, 1990 [2] have presented a numerical simulation of one-year around the operation of a solar adsorption refrigerator operated with active carbon and methanol, the highest efficiency was obtained in winter and the average solar COP was (0.14). The solar ice maker adsorptive model was studied by Boubakri et al., 2000 [3] the identification procedure is carried out employing an experimental data base obtained from tests carried out on two adsorptive solar-powered ice-makers using a methanol/carbon pair. The packaged component, the collector–condenser, represents the main new feature of these units. The prediction is compared with results of correlations. This allows a comparison of the collector–condenser behavior in the two units since the collector–condenser of one of these units is equipped with a radiation shield. The model is then used to study daily ice production sensitivity vis-à-vis critical physical parameters of the unit and to estimate the limits of the collector–condenser technology with flat plate collectors.","DOI":"10.1016/S0038-092X(00, A two solar ice makers were tested, each cycle operating on methanol/carbon pair. The experimental data was as input to theoretical model. The results of the theoretical model were, the rear and front side heat transfer coefficient of the generator and condenser were obtained. Y. and Wang, 2007 [4] have reported a survey of novel technology to improve adsorption system and make it become a realistic alternative; more than (100) patients were classified into four main groups. Leite et al., 2007 [5], presented the thermodynamic processes of the adsorption cycle and the experimental results of a solar icemaker use activated-carbon methanol pair. The collector-generator consists of multi-tubular with an opaque black radiation-absorbing surface. The maximum ice production was (6.05)kg, per meter square of collector area, when the generator temperature was (100) °C. The results of an adsorptive system driven by solar energy were simulated by Freni et al. 2008 [6]. The unit was used for freezing and cold storage. The generator that contained the activated carbon was connected to a solar collector and an evaporator. The production of the unit was (5) kg of ice/day, The simulation of a solar ice maker working on the active carbon/methanol pair was introduced by Vasta et al., 2008 [7]adsorbent bed, condenser and cold chamber (evaporator and water to be frozen. The adsorption/ desorption processes through the condenser and the generator cycle were described, the experimental test was carried out in north Mediterranean climate. A heat and mass recovery adsorption chiller has been designed and tested by Luo et al., 2010 [8]. The chiller under study consist of a two adsorption units, cooling tower, two stages evaporator and a fan coil unit. The adsorption pair was activated carbon- methanol. The key variables under study were temperature of hot water, chilled water temperature, time of heating and cooling processes. A two bed (1.5) adsorption chiller with mass recovery was studied by Khalifa et al., 2013 [9], the authors mentioned that a semi continuous chiller was produce when using two generators with the chiller. Simple manual valves were used to switch between the two generators. The adsorption pair was activated carbon-methanol. M.A et al., 2015 [10] has presented a tubular solar collector/adsorber intended for the adsorption refrigeration unit. Activated carbon–methanol was used as an adsorption pair. Heat and mass transfer in adsorbent bed and energy balance in the solar collector/adsorber was solved using Dubinin–Astakhov equation. Effect of some parameters, such as adsorption pair, the size of adsorber tube, the tube material and collector glazing cover, on the system performances, were investigated A two beds car adsorption chiller was introduced by Khalifa et al., 2015 [11], a two copper tube were installed concentrically to form the unit generator. Two activated carbon layers were used to line the inner surface inner copper tube, the two layered were spaced by (5) cm. the exhaust gas was simulated using propane burner to produce a hot gases in the temperature range of (80 to 140) °C. The tubular adsorber of solar adsorption cooling system was presented by Chekirou et al., 2016[12]. The unit was driven by a flat-type solar collector. Three different configurations of glazes were studied, namely; single glazed cover, double glazed cover and, transparent insulation material cover. The modelling and the analysis of the adsorber were the key points of the study. Solar energy was used to heat adsorber. The unit generator contains a porous activated carbon with methanol. Cherrad et al., 2018 [13]a transient numerical model, referred as CBSR model, was developed for determining the operating temperatures and its corresponding times of the solar adsorption refrigeration cycle with activated carbon AC35-methanol pair for unsteady solar irradiation. The operating temperatures and its corresponding times obtained by the present model compared with those of the literature showed an acceptable difference, whereas the study introduced most factors which can affect the performance of the machine. The presenting of the operating temperatures of the solar adsorption refrigeration cycle as a function of solar cold generation energy allowed to sweep the interval of cycle temperatures of functioning of the machine according to climatic conditions (solar irradiation and ambient temperature, has used a transient numerical model to determine the operating temperatures and the corresponding times of the activated carbon AC35-methanol solar adsorption refrigeration cycle. The temperatures and its corresponding times, which obtained from the presented model, were compared with those of the literature showed an acceptable difference.

In this work, a solar adsorption ice maker was designed and built to produce (1) litre of ice. The unit performance is studied under the variation of working pressure and the mass ratio of activated carbon to methanol.

2. Principles of adsorption cycle

The adsorption refrigerator is constructed out from two containers, the first one represent the evaporator, while the second one is adsorber. The two containers, condenser and valves were connected together using copper tubes. Four processes can be recognized for the typical adsorption refrigeration cycle as shown in Fig. (1). Starting with the Isosteric heating process (1-2), in this process the system temperature and pressure increases due to solar radiation incidence on the flat plate solar collector that contains active carbon and methanol. The second process is the desorption and condensation process (2-3), desorption of methanol included in the active carbon and condensation of vapour in the air-cooled condenser. The third process isosteric cooling (3-4), during the period when solar radiation is at its lower value, active carbon cools through removing of back insulation from a collector, so that, both pressure and temperature of desorber decreases due to rejection of sensible heat. The fourth process is Isobaric (4-1), refrigeration process occurs, where both sensible and latent heat is extracted from the adsorber. The coefficient of performance (COP) is the measure of cycle performance and can be calculated as follows:

$$COP = \frac{\frac{m_w c_w (T_i - T_f)}{\Delta t_c} + \frac{m_{ice} h_f}{\Delta t_f}}{I.\tau.\alpha.A}$$

Where:

m_w and m_{ice}: Mass of water and ice respectively (kg).

c_w: Specific heat of water (kJ/kg K).

T_i and T_f: Initial and final temperatures of water (°C).

h_f: Latent heat of water fusion (kJ/kg).

Δt_c: Time required to cool water from initial to final temperature (s).

Δt_f: Time required to freeze the water (s).

I: Solar radiation falls on tilt surface (kW/m2).

τ and α: Transmissivity and absorptivity of glass cover.

A: Collector area m2.

3. Construction of the solar refrigerator

To find out the best mass ratio of active carbon to the methanol, working pressure and working temperatures, an experimental pilot device made of a small glass ice maker was built firstly. The glass ice maker that is shown in Fig. (2) was built from around bottom, three necks glass flask of (1) litre volume, which acts as vapour generator, a glass condenser, and a round bottom glass flask, which serves as an evaporator. The generator is heated by a hot water bath, while, the evaporator is immersed in another water bath at ambient temperature. Different experiments were achieved; the key variables are the mass ratio of activated carbon to the methanol. After finding the suitable mass ratio of active carbon to methanol, working pressure and temperatures, the solar-powered ice maker was built as shown in Fig. (3).

This solar-powered ice maker aims to produce about (1) kg of ice per day, so, the components of the system should be specified and designed to meet this objective.

The components of the solar powered ice maker are flat plate solar collector of dimensions of (460×46050 ×) mm .The collector was made from a copper plate of 1 mm thickness, and contain about (3) kg of active carbon. The cooling of the collector during the night is improved by using air dampers within the collector.

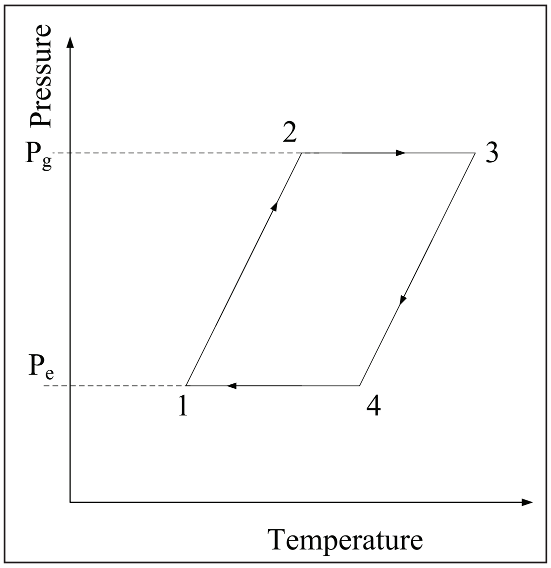

Fig. (1): Adsorption refrigeration cycle

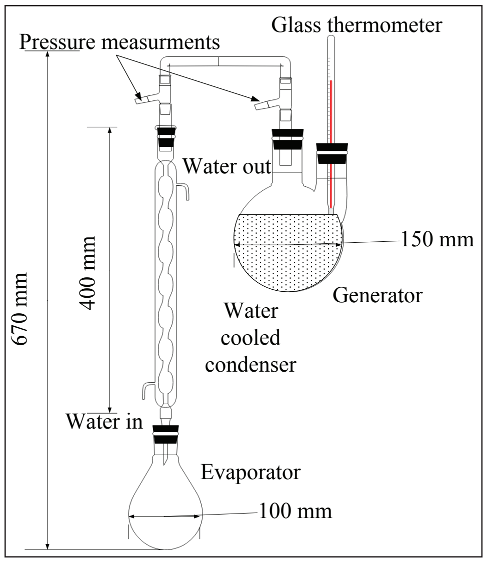

Fig. (2): The pilot adsorption refrigeration unit

To enhance the heat, transfer between the top side of collector and adsorbent, four copper fines are placed inside the collector in contact with top side and adsorbent, as shown in Fig. (3). The air-cooled condenser was made of finned copper tubes. A glass flask of (0.5) litre volume was used as a receiver and equipped by a valve, as shown in Fig. (3a). The glass flask was used to measure the volume of condensate methanol. Finally, an evaporator of dimensions of (26026 ×260 ×) mm, made from a copper plate of (1) mm thickness. The evaporator was immersed in a water bath of (1) litre volume at ambient temperature. The receiver, evaporator and water bath are placed in an insulated container. The temperature were measure at (18) points, two pints at the condenser surface, (6) points at the collector surface, another (6) point through the collector, the remaining thermocouples are used to measure the evaporator, water around the evaporator, receiver and ambient temperatures. All thermo couples were inserted in copper tubes of (5) mm in diameter, then the copper tube were installed through the unite generator, as shown in Fig.(3b).

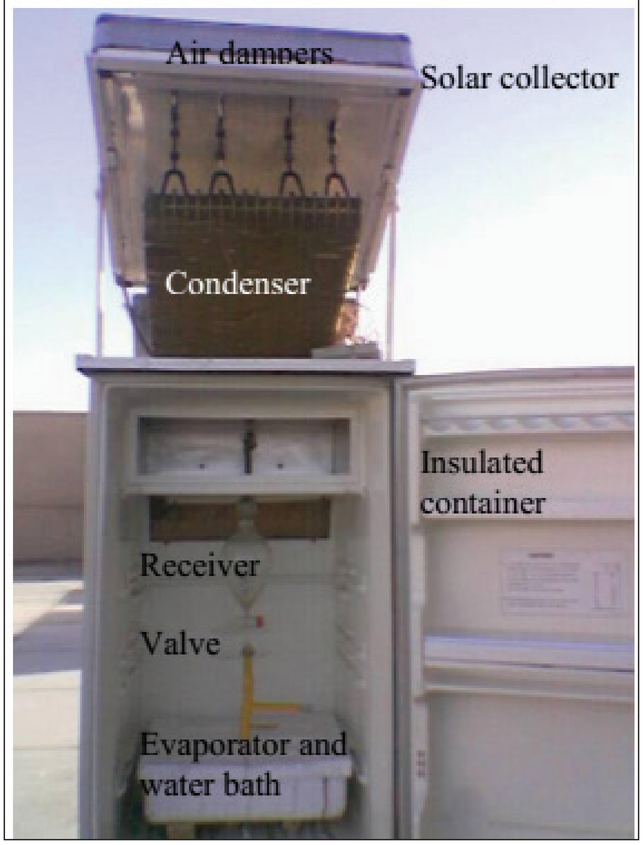

Fig. (3a): the solar adsorption ice maker

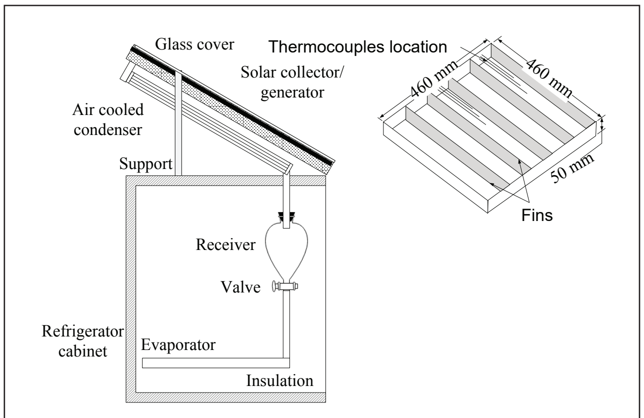

Fig. (3b): The solar adsorption ice maker, showing the solar collector

The solar-powered ice maker is built in Baghdad, Iraq to undergo the first cycle in middle August. The key variables to be examined are working pressure; namely; (3, 3.5, 4 and 5) kPa. and the under study mass ratios were (3.8:1, 3.2:1 and 2.56:1).

4. Results and discussion

Fig. (4) shows the variation of the temperature of unit components with the time, when the mass ratio (MR) of activated carbon to the methanol of (3.8:1) and the working pressure is (5) kPa. It can be seen from the figure that, the maximum mass of condensate methanol is about (275) grams, while the minimum temperature of the evaporator is about (5) °C, and it remains constant for about (2) hours. It can be seen from the figure that the activated carbon temperature follows the collector outer surface temperature. It can be seen that the mass of liberated methanol starts from (10) hr due to the opening the valve separated generator. As the solar radiation increases, the mass of liberated methanol increases rapidly tell (16) hr, then the mass of methanol kept constant 16 to (24) hr. due to constant pressure of generator during the period of time mentioned above.

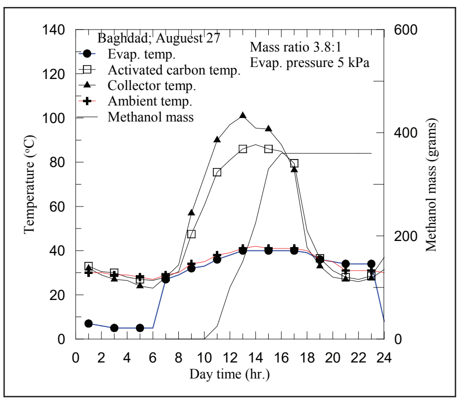

Fig.(4): The variation of condensate methanol mass and cycle components temperatures with the day time, mass ratio is 3.8:1 and evap. Pressure is (5) kPa.

Fig. (5) shows the variation of the temperature of unit components with the time, when the MR is held constant at (3.8:1), but the working pressure reduces to (4) kPa. It can be seen from the figure that, due to the reduction in working pressure, the mass of condensate methanol increases to (315) grams, while the evaporator temperature reduces to (0)°C, for about (2.5) hours. The maximum collector temperature follows the solar radiation.

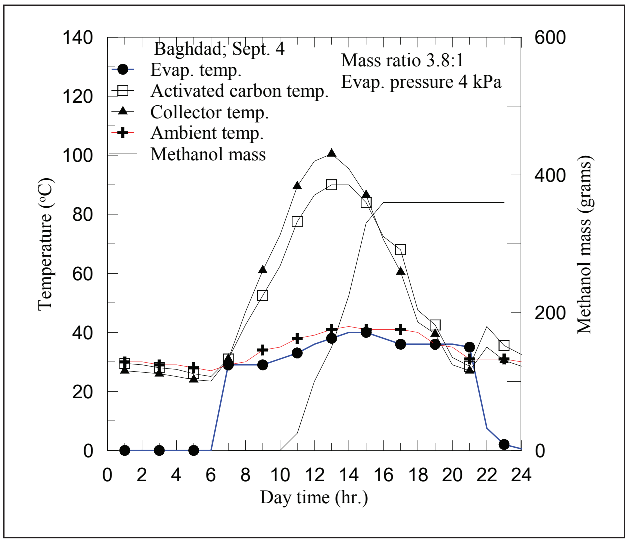

Fig. (5): The variation of condensate methanol mass and cycle components temperatures with the day time, mass ratio is 3.8:1 and evap. Pressure is (4) kPa.

Fig. (6) shows the variation of the temperature of unit components with the time when the working pressure is (3) kPa, while the MR is the same as in above. It can be seen from the figure that, there is insignificant effect on the performance of the machine as a result of the reduction in working pressure below (4) kPa. But, it can be seen that the evaporator temperature is slightly below (0)°C, which means the formation of ice. The reduction in evaporator temperature is due to the low saturation temperature that corresponding to the saturation pressure.

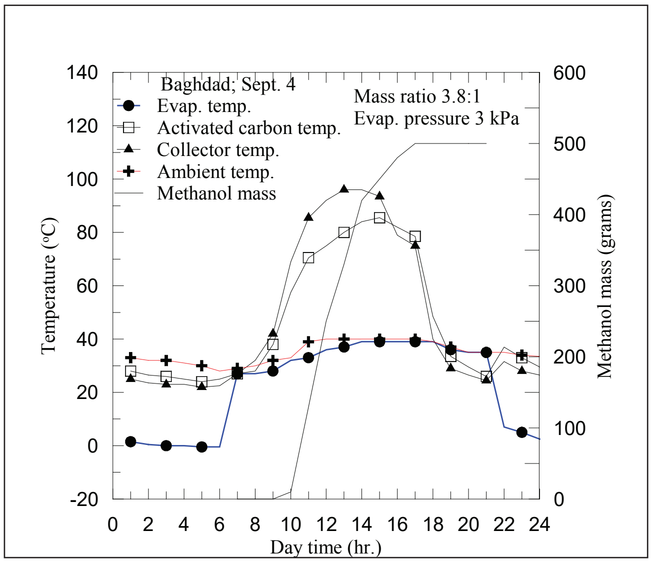

Fig. (6): The variation of condensate methanol mass and cycle components temperatures with the day time, mass ratio is 3.8:1 and evap. Pressure is (3) kPa.

Fig. (7) shows the variation of variables mentioned above when the MR reduces to (3.2:1), and the working pressure is (3.5) kPa. It can be seen from the figure that the mass of condensate methanol is about (395) grams, which offers more heat of evaporation that must be delivered from evaporator water bath, and also it can be seen that the evaporator temperature bellows (0) °C, which means freezing of water in the evaporator water bath.

5. Conclusions

The feasibility of ice production or even cooling using solar energy was studied; it was found that from the study:

1. it is possible to produce about (1) kg of ice per day when the collector area is (0.221) m^2, which is equivalent to about (4.5) kg ice/m^2.day.
2. The solar COP of the machine ranged from (0.1 to 0.36).
3. Working pressure and mass ratio of active carbon to methanol have a significant effect on the performance of the machine. The best mass ratio of active carbon to methanol is about (3.8:1), when the working pressure is (4) kPa.

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