

**DESIGN, FABRICATION AND EXPERIMENTAL STUDY OF A MINI SOLAR
COOLING REFRIGERATOR FOR MECHANICAL APPLICATION**

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ABSTRAK

“Solar Cooling Refrigerator” ialah sejenis alat yang dapat menghasilkan penyejukan tanpa penggunaan tenaga elektrik . Selain itu, ia juga tidak menghasilkan bunyi atau pencemaran semasa sistem ini berfungsi. Semua peralatan atau radas yang digunakan dalam projek ini adalah selamat terhadap alam sekitar. Dalam projek ini, mini “Solar Cooling Refrigerator” direka terlebih dahulu, kemudian dibina serta diuji keberkesannya. Objektif utama bagi penyelidikan ini ialah mereka dan membina satu “Solar Cooling Refrigerator” yang dapat menghasilkan kesan penyejukan mula dari asas dalam peti penyejukan. Sistem ini berfungsi secara bersela, iaitu satu kitaran dalam sehari. “Solar Cooling Refrigerator” ini terus menyerap tenaga suria dari pancaran matahari untuk menghasilkan penyejukan, tetapi ia perlu melibatkan beberapa proses seperti proses penyerapan, pengewapan, kondensasi dan pembebasan terlebih dahulu. Dalam sistem ini, kesan penyejukan yang didapatkan dari model ini adalah berkadar langsung dengan pancaran matahari. Misalnya, kesan penyejukan dapat dihasilkan dalam kuantiti yang banyak pada hari yang ber cuaca baik dan cerah sehingga ke tahap tertinggi.

ABSTRACT

Solar Cooling Refrigerator is a device that can be used to produce cooling effect without utilization of electricity. It produces no noise or pollution. All the devices or apparatus that have been used in this project are environmentally friendly. In this project, a mini solar cooling refrigerator has been designed, fabricated and tested. The main aim for this project is to design and fabricate solar absorption cooling refrigerator from scratch for producing small amount of cooling effect in cooling compartment. This system operates intermittently, i.e. perform the cycle per day. This solar cooling refrigerator uses the heat directly radiate from the sun to cause the cooling effect through a few main processes such as adsorption, evaporation, condensation and desorption. In this system, the amount of cooling effect from the prototype is directly proportional to the solar radiation. For example, large amount of cooling effect can be produced in the sunny day until it reaches the maximum limit.

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CHAPTER 1

INTRODUCTION OF SOLAR ICE MAKER OR REFRIGERATOR

1.1 General Introduction

Solar ice makers or refrigerators are devices that used the solar energy directly radiate from the sun or light sources to produce ice or cooling. Nowadays, this device is starting to attract the large amount of public attention. This section will provide an introduction for solar ice maker or refrigerator, what they are, what they can do, why they are important and what are the commercial implications for these devices. 'Isaac' is the acronym for Intermittent Solar Ammonia Absorption Cycle¹. The Isaac uses the Solar Ammonia Absorption Cycle that was discovered in the 1850s, and is still used on a smaller scale by all gas refrigerators. This refrigeration technology fell out of fashion in the 1930s with the arrival of cheap electricity and the discovery of the miracle refrigerant freon. The Isaac uses no electricity, gas or Freon.

During the day, the Isaac stores energy in the receiving tank as high-pressure, distilled, pure ammonia. At night the user checks the sight glass to judge how much ammonia was produced, checked how well the cooling effect in the cooling compartment, and switches the valves from Day to Night positions. The ammonia is allowed to evaporate back into the collector while providing refrigeration for the

cooling compartment. The refrigerant cycle is sealed. In the morning the valves are switched again and the processes start again.

The Isaac is constructed of stainless steel for maintenance-free outdoor installation in Oceanside sites (not to mention some pure industrial beauty). Maintenance consists of re-aiming the collector every four weeks to track the sun, and an occasional bucket of water to wash away any dust.

During the day the solar collector focuses the energy of the sun onto the ammonia generator in the collector trough. Solar heat distils pure ammonia vapour from the water-ammonia solution in the generator. The vapour condenses in the cooling coils and collects as liquid ammonia in the receiving tank in the evaporator.

At the end of the day, the user switches the valves from the Day to Night position to allow the ammonia to evaporate in the cooling coil, providing the cooling in the cooling compartment. The resulting vapour is absorbed back in the generator. Critical to the operation of Isaac is a passive thermosyphon that operates in the Night mode to remove the heat from the generator and allow the ammonia vapour to absorb into the solution at lower pressure and temperature.

At the beginning of the day, the users operates a drain sequence to remove traces of absorbent from the evaporator, and places the unit back into Day mode to begin the next cycle.

1.1.1 Components of Solar Ice Maker or Refrigerator

There are several main components being used in solar ice makers or refrigerators. Below are some of the main components of solar refrigerators or ice makers³:

a) Adsorbent bed

Adsorbent bed is the most important part of the solar ice maker or refrigerator and hence the performance of this device depends highly on the characteristics of the adsorbent bed. Generally speaking, a good adsorbent bed must have good heat and mass transfer. Recent research showed that the aluminium alloy have a stronger catalytic effect on the decomposition reaction under the solar adsorption refrigeration, therefore stainless steel are used as adsorbent heat transfer metal instead of aluminium alloy although stainless steel has poor heat transfer ability than that of aluminium alloy. The adsorbent bed is made of flat plate stainless steel box, having surface area 1 m², also 19 kg adsorbent is charged and sealed inside the steel plate box, then selective coating is covered on top surface of the steel plate box. Finally the steel plate box is placed behind two sheets of fibre plastic plates in a thermal insulated case. The permeability of the fibre plastic plate for solar radiation is about 0.92, which is higher than that of glass. In order to guarantee better heat transfer between the front side and the adsorbent, many fins (also made of stainless steel) are placed inside the adsorbent bed box in contact with the front side and the activated carbon. The distance between these fins is approximately 0.1 m. The thickness of the adsorbent layer is about 0.04m, the total weight of stainless steel metal is about 20 kg.

In order to improve the transfer of methanol vapour through the activated carbon layer, a false bottom (0.01 m thick in the radial distance) is included in the rear side of the adsorbent bed as mentioned by Pons and Guillemion². As this “false

bottom'' is completely open to the circulation of vapors, it permits an uniform distribution of methanol in the adsorbent.

b) Condenser and evaporator

During the process of desorption of methanol, a well designed condenser is needed to reject the desorption heat. To fulfil this condition, the 18 mm copper tubes with \varnothing 36 mm external aluminium fins are used as condenser, the total heat transfer areas of the condenser is about 4.5 m².

The evaporator must have sufficient volume to collect the entire condensed methanol. In order to enhance the heat transfer effect, the heat exchange surface is designed as a series of four trapezoidal cells, the dimension of the evaporator is 220 mm x 320 mm x 100 mm and the heat exchange area is about 0.28 m².

c) Integration of the subsystems

The adsorbent bed, condenser, evaporator were checked for vacuum proof and then were connected with each other using stainless steel pipe of \varnothing 19 mm. The whole system was mounted on a frame bracket installed with wheels, so that it can be moved easily when necessary. Only one valve is installed beside condenser, which helps to vacuum the whole system as well as to charge the system with refrigerant. A pressure gauge is installed behind adsorbent bed to check for the pressure conditions in the system. Besides, no any other valves or measured instruments are used in the system.

In order to ensure that the system can work normally, it is essential that the whole system should be vacuum proof. After the system was subjected to 72h of

observation and was certain of its intactness, about 500 ml methanol was added into this solar ice maker.

1.2 Objective

The main objective for carrying out this research is to design and fabrication solar cooling refrigerator that can be used to produce cooling for domestic user especially in remote area in stead of electric refrigerator. This technology of solar cooling refrigerator still relatively new in Malaysia and many countries, many people lack of this knowledge and understanding. The objectives of the research can be outlined as follows:

- a. Learning and understanding the fundamental material properties and the history of solar ice maker or refrigerator.
- b. Study some of the literature review related to solar ice maker or refrigerator.
- c. Design the most suitable type of solar ice maker or refrigerator corresponds to our climate.
- d. Construction or fabrication of solar ice maker.
- e. Test the prototype that being built by data collection.
- f. Reporting and documentation..

1.3 Goal of research

In this research, a typical solar cooling refrigerator will be designed and constructed to produce cooling. Since there were not had electricity supplies in the rural or remote areas, thus this device can be widely used to produce the cooling for domestic or commercial purposes instead of electrical ice maker. For example, solar cooling refrigerator can work as medicines storage for preservation purposes. Thus the most suitable type of solar ice maker or cooling refrigerator will be fabricated corresponds to our climate, which will give us reasonably good COP_{solar} .

Basically solar cooling refrigerator consists of several main components and each of them will perform they own tasks. The main components of this device are vacuum tube type solar collector, condenser, evaporator and insulated cooling box. In my prototype, the copper pipe in loop form inside the solar collector will be used as absorbent bed. Adsorbent bed is the most important part and has played an important role in the cooling performance. The performance of this device depends on the characteristics of solar ice maker or refrigerator such as heat and mass transfer.

The working pair used in this system is activated carbon and methanol. The activated carbon will work as adsorbent to adsorb the liquid of refrigerant. This adsorbent will pack inside the solar collector. There have two copper pipes between the solar collector and refrigerator to link each at inlet and outlet of the solar ice maker or refrigerator. This type of solar ice maker or refrigerator worked intermittent, only one cycle per day.

During the daytime, the sunshine irradiates to solar collector, so the collector is heated up and desorbed from the activated carbon. In desorption, the liquid methanol adsorbed in activated is heated up and vaporizes. Then the vapor of methanol condensed at condenser and stored in evaporator. At night, it will work

reversible, once the collector temperature drop to ambient temperature. The adsorbent will adsorb back the methanol from evaporator or cooling coil. The liquid in the evaporator will vaporizes and adsorb the heat from cooling compartment and then cooling effect occurred there.

1.4 Methodology of Research

Below are some methods that have been carried out during conducting this project:

a) Preliminary study and literature review.

- To know and understand working principle of a solar ice maker.
- To learn various types of working pairs and the elements used in a solar ice maker.
- To calculate the efficiency of a solar ice maker.
- To find out the most suitable type of solar ice maker that can be used in our climate.

b) Experiments

- To find out the parameters that influenced the efficiency of the system.

c) Calculations

- Calculate the COP of the system

The work chart for this research is given at Appendix A

1.5 Problem Statement

- 1 **Cost** – The high capital cost for solar ice maker or refrigerator is the main problem that contributed to the development of this technology in Malaysia. In order to compete practically with electric ice maker, solar type ice maker or cooling refrigerator must become more competitive from the standpoint of both capital cost and efficiency. For our project to design and fabricate solar ice maker, the cost is a major problem to purchase the solar vacuum tube and fabricate the complicated adsorbent bed.
- 2 **Solar radiation inconsistency**- Since our country has received the solar radiation whole the year, but this solar energy is not consistently radiated to our country like raining and cloudy day. If the raining day or cloudy day, the availability of the solar energy to the earth is limited, the solar power can not drive the solar cooling refrigerator to work. Thus the backup system, solar energy storage is needed in order to operate the solar ice maker or cooling refrigerator during insufficient solar radiation period.
- 3 **Lack of information**- In Malaysia, it is difficult to find any information that related to this field, solar cooling refrigerator. All the information that had been taken from reference books and website are from the foreign countries which is not completed and still in fundamental research. They did the researches in the different climate and it gives us the different result and limitations for fabricating the solar refrigerator. Further more, there are no related consultancies that can guide and assist us when doing this project.
- 4 **Technology and facility**- This newer technology had came across a problem with lack of facilities that enable to produce solar vacuum tube and adsorbent bed for high performance of heat transfer.

CHAPTER 2

LITERATURE REVIEW

2.1 Research Paper 1

R.Z.WANG et al.⁴ from Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200030, People's Republic of China have fabricated and tested an energy efficient hybrid system of solar powered water heater and solar adsorption ice maker.

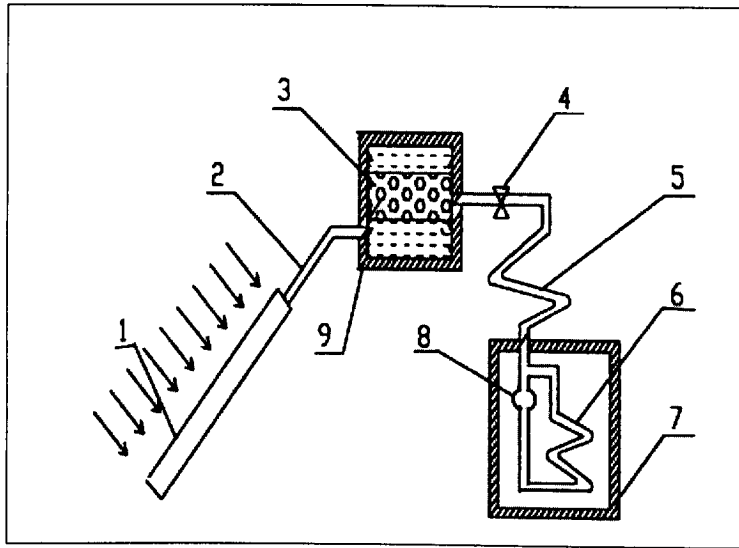


Figure 2.1 Schematic of the solar water heater and adsorption ice maker.

(1) Solar collector; (2) water pipe; (3) absorber; (4) valve; (5) condenser; (6) evaporator;

(7) refrigerator (with cold storage); (8) receiver; (9) hot water container.

A hybrid system of solar water heater and absorption ice maker consists of solar collector, water tank, absorber/ generator, condenser, evaporator, receiver and

ice box. The hybrid system did not prove successful before because the heat transfer in the activated carbon bed is very poor and causes a big problem to the cooling and heating of absorbent. Thus they solve this problem by compressing the absorbent bed to enhance heat transfer and use much thinner absorber in the adsorbent bed, thus there will be good for heat transfer.

The features of the hybrid system are:

- It has two main purposes, which are water heater and refrigeration with one solar collector. This system suitable for household application.
- From the figure above, the absorber/ generator is separated from collector, hence a high efficiency vacuum collector can be used for heating water purpose and at the same time the absorber will heat up. High efficiency heating does not mean the absorber cooling during night is bad.
- Energy efficiency is high with using the total solar energy that has been collected.
- Methanol is safely to be used as refrigerant because its dissolution in the activated carbon- fiber absorber is not exceed 100°C due to water tank.

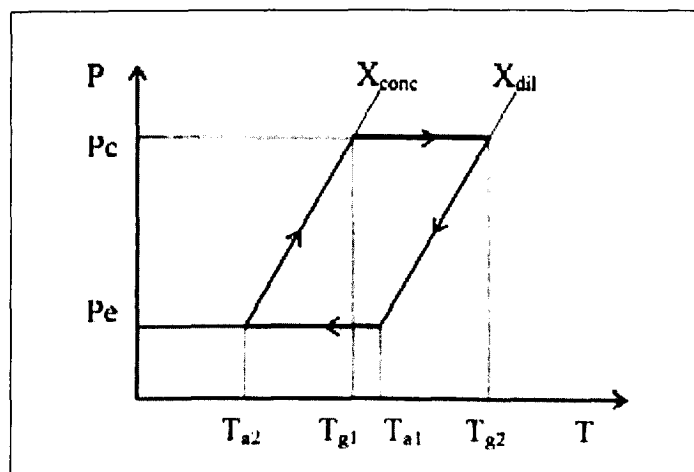


Figure 2.2 Adsorption refrigeration cycle

After did the modification for hybrid system of solar water heating and ice-making, the absorber having the dimension of 28 Ø 50 × 1 × 750 mm stainless steel tubes, in which 22 kg activated carbon was filled, the absorber mass is about 25 kg. The water tank is filled with 120- 150 kg water. The electric heater 1500 W is used to simulate a 3m² vacuum heat pipe type solar collector.

The experiment were conducted to test the feasibility of the working pair that been used in the system based on the efficiency of the hybrid system.

Experimental date	Energy accepted (MJ)	Hot water output		Ice output		COP _{system}	COP _{cycle}	η_{system}
		°C	kg	°C	kg			
Dec. 9–10, 1998	54	98	150	– 2.5	10.5	0.067	0.386	0.906
March 10–11, 1999	49	91.3	112	– 1.8	10	0.064	0.431	0.758

Table 2.1 The experimental results of the hybrid system

Experimental date	Energy accepted (MJ)	Hot water output		Ice output		COP _{system}	COP _{cycle}	η_{system}
		°C	kg	°C	kg			
Dec. 9–10, 1998	24.6	98	60	– 2.5	10.5	0.143	0.386	0.795
March 10–11, 1999	22	91.3	60	– 1.8	10	0.144	0.431	0.797

Table 2.2 Calculated performance of the hybrid system based on experimental results

The coefficient of performance and efficiency are calculated by the following relation:

$$COP_{solar} = \frac{Q_{ref} - Q_{cc}}{\int G(t) dt}$$

$$\eta_{solar} = \frac{Q_{water}}{\int G(t) dt}$$