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Experimental Studies on Solar Powered Diffusion Absorption Refrigerator

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Abstract: An experimental investigation of solar powered diffusion absorption refrigeration system is presented in this paper. It can be operated without any use of electrical or mechanical energy. The principle behind absorption refrigeration is that it uses three gases to accomplish its cooling effect namely ammonia (refrigerant) water (absorbent) and helium. Ammonia is used as the refrigerant as it is easily available and can produce a better cooling effect. Helium is used to reduce the partial pressure of ammonia vapor in the evaporator chamber so that more ammonia evaporates yielding more cooling effect. Heat input is required at the generator where aqua ammonia is heated to get ammonia vapors. In this project, an experimental setup for absorption refrigeration is made using solar energy to supply input heat. A parabolic dish is used as the solar collector. Solar energy is concentrated to the generator pipes by the solar collector, heating the aqua ammonia solution. This system consists of no moving parts. Circulation of the working fluid is achieved using a bubble-pump. The results show that the system performance is strongly dependent upon the input given by the solar collector, bubble-pump characteristics and the evaporator and absorber mass transfer performance. Cold is produced at temperatures between -5c to -10 C for a driving temperature in the range of 80c –150 C.

Key words: Solar refrigeration · Diffusion absorption · Parabolic solar dish collector

INTRODUCTION

Most conventional refrigeration systems operate with electricity. However, there are regions where it is difficult or not cost efficient to provide electric service. In addition, the cost of generating electricity is high, both economically and ecologically. Therefore, a project was developed to determine a means of providing refrigeration to communities lacking conventional energy sources. The design of an absorption refrigeration system Operating with solar energy was carried out. Solar refrigeration by absorption is considered to be an alternative to substitute conventional refrigeration equipment and a way to save electricity or make Refrigeration possible in areas without electricity.

A diffusion absorption refrigeration (DAR) cycle was first invented around 1920 by Platen and Munters, students at the Royal Institute of Technology, Stockholmin Sweden, [1]. It uses three working fluids, water as an absorbent, ammonia as a refrigerant, and hydrogen as an auxiliary gas. It can operate without any use of electrical and mechanical energy. As there are no moving parts, system maintenance, noise, and vibration are at minimum. This system has been used for more than 70 years [2]. Millions of such refrigerators have been built and used mainly in domestic applications and for use in camping and caravans. The refrigerators can be powered by kerosene or liquid petroleum gas. Electrically powered units are also suitable for where noise can be problematic such as a hotel room.

Working Principle: Fig. 1 shows a schematic view of a DAR designed for domestic use. Within the receiver tank, there is a solution with concentration of 35% (ammonia 35% and water 65% by mass). This solution flows to the generator where it is heated to 80C causing some ammonia to evaporate. The vapor forms bubbles that push columns of liquid solution in the pump-tube up to the liquid–vapor separator in which ammonia vapor is separated out from the solution. Solution with a concentration of 10% is collected at the separator and returns back to the absorber via a solution heat exchanger. At the separator, the vapor leaving the pump-tube usually contains a quantity of

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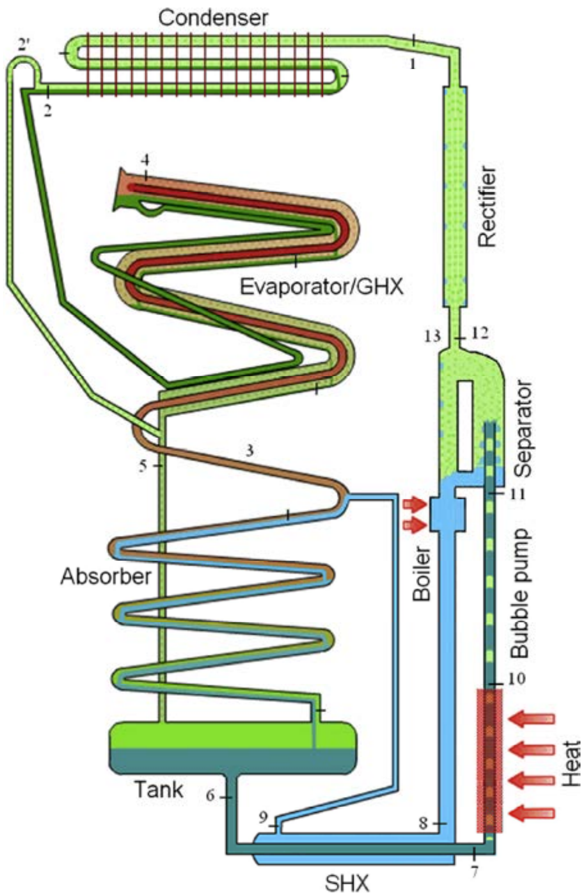

Fig. 1: Schematic assembly diagram of diffusion absorption machine

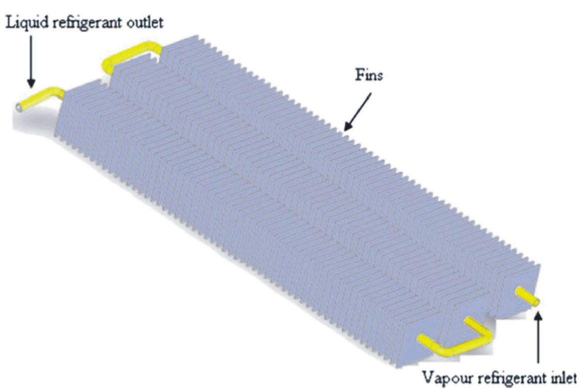

Fig. 2: Condenser design

water. The vapor is then purified at the rectifier where it is cooled down to 50C. The ammonia vapor is then liquefied in the air-cooled condenser. For normal operating conditions, the system pressure is approximately 8 bar. The liquid passes to the evaporator, which is divided into two sections: a freezer and a food chiller. As the evaporator is charged with helium, the partial pressures of ammonia and helium are approximately 1 and 8 bar respectively in the freezer. At this condition, ammonia evaporates between 30 and 18C. Since ammonia continues to evaporate, its partial pressure rises to 3 bar in the food chiller. This pressure corresponds to an evaporating temperature of 5C. The vapor is then absorbed into solution in the air-cooled absorber.

The weak solution is then transferred to the receiver tank to complete the cycle. The density of ammonia is considerably greater than that of helium.

The vapor (ammonia and helium) becomes heavier as ammonia continues to evaporate, therefore it drops from the freezer to the food chiller and enters the absorber. In the absorber, ammonia is absorbed into the solution, the vapor become lighter and thus it rises to the top. This causes a circulation of helium in the evaporator and absorber. The helium circulation has some effect on the evaporation rate in the evaporator and on the absorption rate in the absorber. Not only affecting the mass transfer rate, helium circulation also reduces the cooling capacity as the gas is warm when it leaves the absorber.

Its efficiency is relatively poor. Normally, a refrigerator based on this system provides cooling capacity up to 200 W with COP of 0.2. There have been many attempts to enhance the system performance such as reduction of heat losses from the system by using novel boiler designs [3–5], including an auxiliary gas heat exchanger to reduce the heat load arising from hot auxiliary gas circulation [6]. However, most of the research was carried out with commercially designed refrigerators that have been specifically designed as an air-cooled system. To investigate the system characteristics, variation of some operating parameters should be carried out [7]. Therefore, an experimental refrigerator was designed and fabricated [8].

Experimental Setup and Procedure: For the purposes of the present study, an experimental prototype was built in order to investigate the performance of a bubble pump operated diffusion absorption refrigerator based on solar energy input. The machine is made of stainless steel. Its nominal cooling capacity is 40–47W [9].

The working fluids mixture is composed of ammonia as refrigerant, Water as absorbent and helium as pressure equalizing inert gas [11].

Experimental Set up: A schematic assembly diagram of the experimental set up is given in Fig. 1. The system design allows investigating the bubble pump behavior and the absorber efficiency.

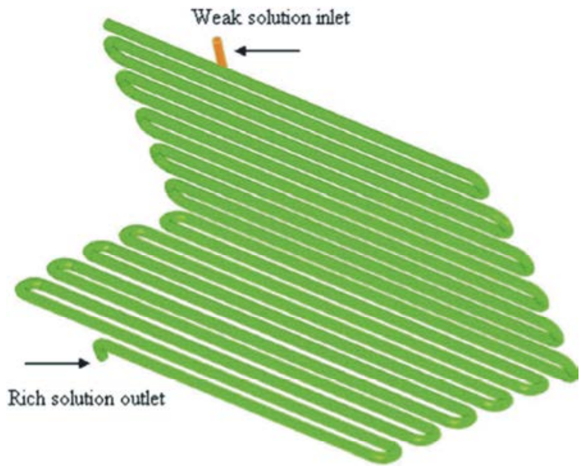

Fig. 3: Absorber

The design of the main components is as follows:

Generator: As shown in Fig. 1, the boiler and the bubble pump are not combined in one unit as in a classical DAR but separated in order to investigate each of both machine components independently from one another [10].

Therefore the generator consists of:

- A single vertical tube (height: 800 mm, diameter: 8/10 mm) to which the heat input is restricted to a small zone in the bottom,
- A vapor-liquid separator connected to the tube and
- A boiler [12].

Condenser: As the machine is intended to be powered with thermal solar heat the condenser is air-cooled. 58 fins enhance the heat transfer process.

Absorber: For the same reason, the absorber is also air-cooled. It is constituted of a folded tube (120 mm in length and 10 mm in diameter) which forms two planes with a variable angle between them. The absorber efficiency is a function of the residence times of the gas and the liquid which them selves depend on the opening between the planes. Fig. 3 shows the absorber design [13].

Evaporator-Gas Heat Exchanger: As illustrated in Fig. 1, the evaporator/gas heat exchanger is a shell and tube HX, to which the condensate refrigerant tube is attached in order to provide some sub-cooling of the liquid refrigerant before it gets in the evaporator [14].

Procedure: First, the whole machine is evacuated using a rotary vacuum pump. The reservoir is thereafter charged with aqua ammonia solution. Finally, helium (inert gas) is added until a pressure of 4 bars is reached corresponding to the total required system pressure. Fifteen calibrated K-type thermocouples are used to measure the temperatures at different locations of the apparatus. The temperatures are monitored and stored for further treatment [15]. When the steady state is established (constant evaporator temperature), a fixed amount of water (four liters) is poured in the water tank that surrounds the evaporator [16].

Experimental Setup of Solar Dish

Reflector: The reflector of our experimental device consists of a parabolic concentrator of 202mm opening diameter. Its interior surface is covered with a reflecting layer. Which reflect solar rays on the face of a receiver placed at the focal position of the concentrator. The concentrator is posed on a directional support according to two axes to ensure the follow-up of the sun [17].

The equation for the parabola in cylindrical coordinates is:

$$z = \frac{r^2}{4f}$$

The surface of a paraboloid of diameter of opening d whose focal distance f is given by:

$$S = \frac{8\pi}{3} f \left\{ \left[1 + \left(\frac{d}{f4} \right)^2 \right]^{3/2} - 1 \right\}$$

The surface of opening of a paraboloid is:

$$S_0 = \frac{\pi d^2}{4}$$

The focal distance is given by the following expression:

$$f = \frac{d^2}{16\,h}$$

h is the depth of the dish.

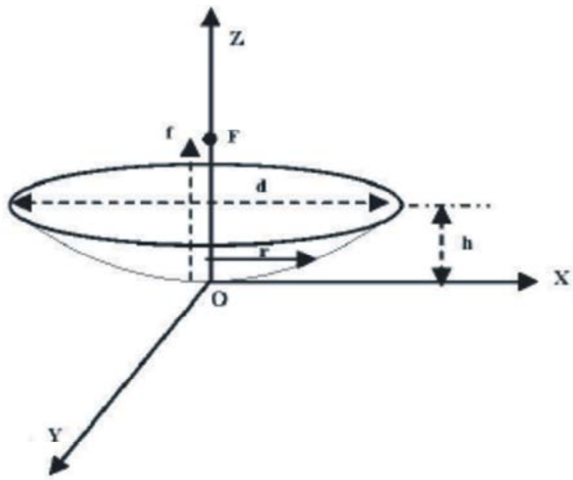

Fig. 4: Geometrical parameters

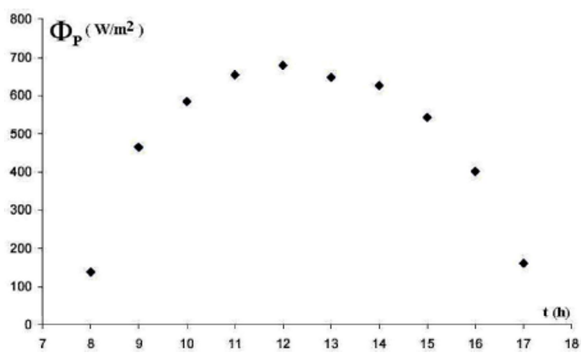

Fig. 5: Solar flux density received by the concentrator

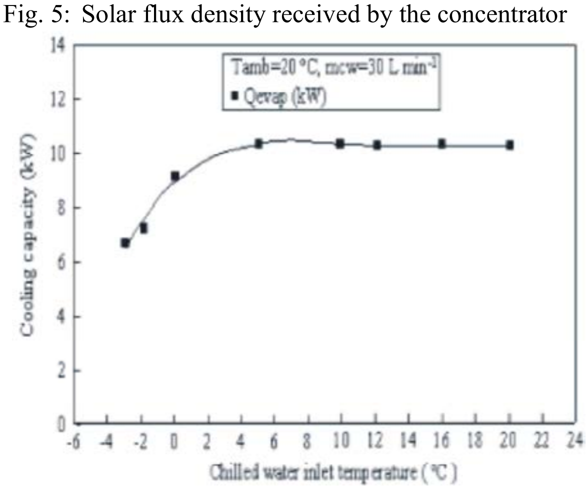

Fig. 6: VAR system with air-cooled absorber and condenser

Characteristics of the Solar Concentrator:

Diameter of opening of the parabola 202 mm
Surface collecting of the parabola 2.1 m2
Depth of the parabola 254 mm
Focal distance 11 mm

The reflecting layer covering the surface of the parabola is based on steel with a reflecting coefficient near 0.85.

Receiver: The receiver is a stainless steel disk. This receiver is with a diameter of 120 mm, (thickness 20 mm) and is covered with a thin coat of black paint to decrease the reflex ion of the solar rays and it is located in the focal zone of the parabola [18].

The absorption coefficient of the absorber is 0,9.
The geometrical concentration of this model is

$$C_g = \frac{S_0}{S_a}$$

Sa is the lighted area of the absorber

Characteristics of Receiver:

Receiver diameter 120m m
Surface receiving 0.19mm2
Geometrical concentration factor f = 11
Thermal conductivity λ= 2 W/mK

Experiment Results: units: cooling capacity against chilled water inlet temperature.

CONCLUSION

A low capacity thermal driven diffusion absorption machine based on solar power input is designed, constructed and tested for various heat power inputs [19]. The experimental results show that the bubble pump exiting temperature as well as those of the major components of the machine but the absorber is very sensitive to the heat power inputs to the bubble pump [20] . For bubble pump heat inputs from 120 to 170w, the driving temperature varies in the range of 80–150 C. The lowest temperature reached at the evaporator entrance is -5 C provided by a driving temperature 120 C and a power inlet Qbp ¼60W. The COP of the machine has reached a maximum of 0.14 for Twater ¼ 30c and Qbp ¼60W.

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