Experimental Study on a Novel Solar Watering Tube for Producing Water from the Air

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Abstract. In this paper, one novel solar adsorption watering tube was designed. Solar watering tube (SWT) is an independent unit producing water from air, which uses solar energy to drive the production process. Compared with the traditional methods of producing water, the production process of SWT bases on adsorption/desorption theory. The influence of operating conditions on the SWT was investigated. Under the typical weather conditions, as follows, the ambient temperature was about 20°C~35°C, ambient relative humidity was about 44%~74%, and the solar radiation was about 22MJ.d-1m-2, the adsorbent bed temperature could reach 222°C in the day and cooled down to about 40°C in the night. A single SWT could produce about 90ml water one day.

Introduction

Solar energy is the source of energy for people and modern society. Solar energy is one of the best renewable sources, it is clean and environment friendly. The earth is covered by large volumes of water; however, there are lots of dry regions lacks of water. The problem of providing dry areas with fresh water can be solved by the following methods [1]:

1. Transportation of water from other locations;
2. Desalination of saline water;
3. Extraction of water from atmospheric air.

Transportation of water to these regions is usually very expensive, and desalination depends on the presence of saline water resources which are usually rare in dry regions. It is well-known that the global air is a huge and renewable water source which contains about 14,000 km^3 [2] of water vapor. Many regions are deficient in fresh water, so the extraction of water from the air may be a novel way of producing fresh water in dry areas.

The use of solar energy for adsorption refrigeration and producing fresh water is one of the hot issues in research in recent years, and scholars from all countries are studying deeply about it. N. Audah studied the feasibility of using a solar-powered liquid desiccant system to meet both building cooling and fresh water needs in Beirut's humid climate, using parabolic solar concentrators as a heat source for regenerating the liquid desiccant. In the Lebanon coastal climate with conditioned area of 80 m^2, the objective was to produce 15L of fresh drinking water a day and meet air conditioning need of residence at minimum energy cost [3]. Efat Chafik presented a new water desalination process. The basic unit operation in this process was to use solar energy for heating an air stream, and seawater was added into the hot air in order to humidify it. On the base of this solar desalination process, a desalination plant was predicted to provide 10 m^3 of potable water daily [4]. Ahmed Sultan suggested a non-conventional method for water production from atmospheric air on a 24-h basis, using a compact system. They concluded that the maximum efficiency increased with the initial concentration and decreased with the increase of the regeneration air stream velocity and absorption temperature [5]. H.I. Abualhamayel used a suitable liquid desiccant to extract fresh water from the humid atmosphere in Dhahran, Saudi Arabia, and they showed that for given operating

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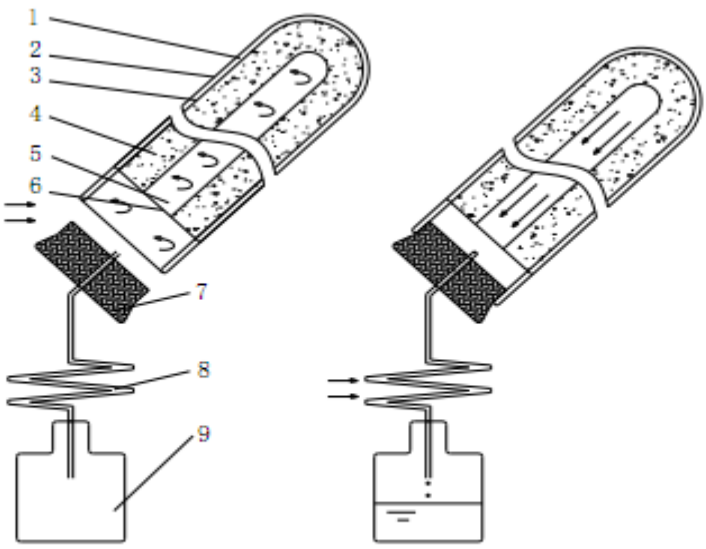
conditions it was possible to obtain about 1.92 kg of water per m^2 of the unit [6]. Chou analyzed thermal characteristics of the apparatus for producing drinking water from air using both adsorbents and beat pump by solar energy and calculated the efficiencies of producing drinking water [7-9]. Liu proposed a new composite adsorbent $Si0_2 \cdot xH_2O \cdot yCaC1_2$ and made a portable unit for extracting water from air. The experimental results showed that the equilibrium adsorbent uptake was 1.9 times that of synthetic zeolite 13X (13X zeolite molecular sieves). The water adsorbed in the adsorbent bed could be desorbed at 60-80 °C, and it could be driven by solar energy [10, 11].

Therefore, this work presents a novel unit of SWT. Different from the Solar Cooling Tube (SCT) [12-15] which uses solar energy for adsorption refrigeration and getting cooling capacity, the SWT can produce liquid H_2O from air using solar energy as power. In this paper, the SWT was experimentally studied, and the apparatus consists of an adsorbent bed, a condenser, a water collector and a hard borosilicate glass tube.

Principle

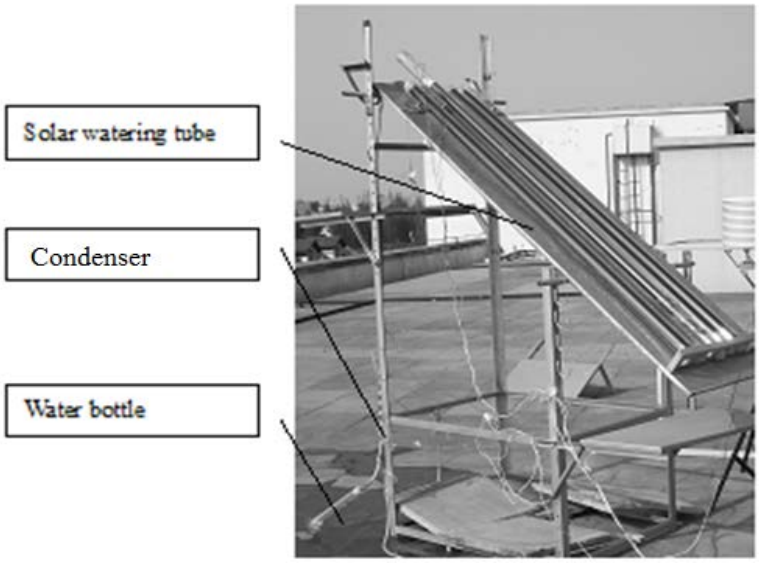
Based on the adsorption/desorption theory, the SWT adsorbs vapour from air in the night and uses solar energy to heat adsorbent bed which desorbs vapour in the day. Using the compound adsorbent bed, the temperature difference between day and night corresponds to the adsorption capability difference of adsorbent bed. The SWT produces fresh water from air.

The sketch and the photograph of adsorption and desorption process of the SWT is shown in Fig. 1. The length of the solar watering tube is 1800 mm. the Diameter of the outer tube and inner tube is 58mm and 47mm respectively, and the effective surface area is about 0.0846 m^2. This SWT is mainly composed with these parts: vacuum tube, adsorbent bed, condenser, H_2O vapors channel, airproof plug, and water bottle. The vacuum tube is made of hard borosilicate glass and has high transmission of sunlight, and it also can sustain high degree of vacuum (lower than 5×10^{-3}Pa).



1、adsorption process in the nighttime

2、desorption process in the daytime



1. outer glass, 2. inner glass, 3. vacuums layer, 4. adsorbent bed, 5. H2O vapors channel, 6 filter net, 7. airproof plug, 8. condenser, 9. water bottle

Fig.1 Sketch and photograph of adsorption and desorption process of the SWT

The process of producing water from air by SWT is as following:

In the night, the moist atmosphere flows through the adsorbent bed. When the temperature drops low enough, the adsorbent bed begins to adsorb vapour from the moist atmosphere. The adsorption process lasts about 12 hours and ends in the next morning.

In the morning, the airproof plug is sealed to the vacuum tube. The adsorbent bed begins to receive solar energy, and the adsorbent temperature rises up rapidly, because the vacuum tube helps to gather solar energy with little loss. When the temperature of adsorbent bed rises high enough, the vapour desorbs from the adsorbent bed. The steam releases the latent heat during condensation, and the water is stored in the water bottle because of gravity. In the whole day, the SWT can receive solar radiation while vapour keeps desorbing from the adsorbent bed, so fresh water is produced continuously in the daytime until the solar radiation is too weak for desorption.

The main apparatuses used in the experiment of SWT performance were as following: a 2700 Multimeter / Data Acquisition system of Keithley Co. was used for collecting the data of temperature measurement, T-type thermo-couples and K-type thermo-couples were used as the temperature sensors for the lower and higher temperature testing respectively, a model TRM-123 Temperature & Radiation Instrument produced by Jinzhou was used for measuring the solar radiation density, and a model RYQ-1 automatic surface meteorological station was used for measuring the environmental temperature and relative humidity of the air. The intervals between measuring of the temperature and solar radiation were 5 minutes, and the data could be shown instantaneously in the computer and stored in the appointed document.

Results and Discussion

Ambient Temperature and Relative Humidity Variation

The trends of ambient temperature and relative humidity variation are shown in Fig.2. The maximum and minimum ambient temperatures were about 35.2°C and 20.3°C respectively. The average ambient temperature was 25.7°C. The ambient relative humidity fluctuates between 44% and 74% during the experimental time.

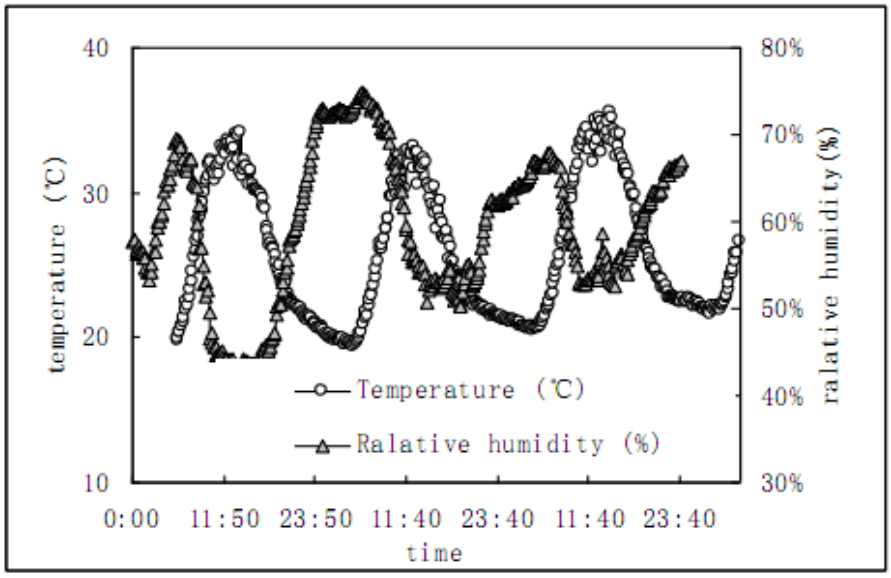


Fig.2 The ambient temperature and relative humidity

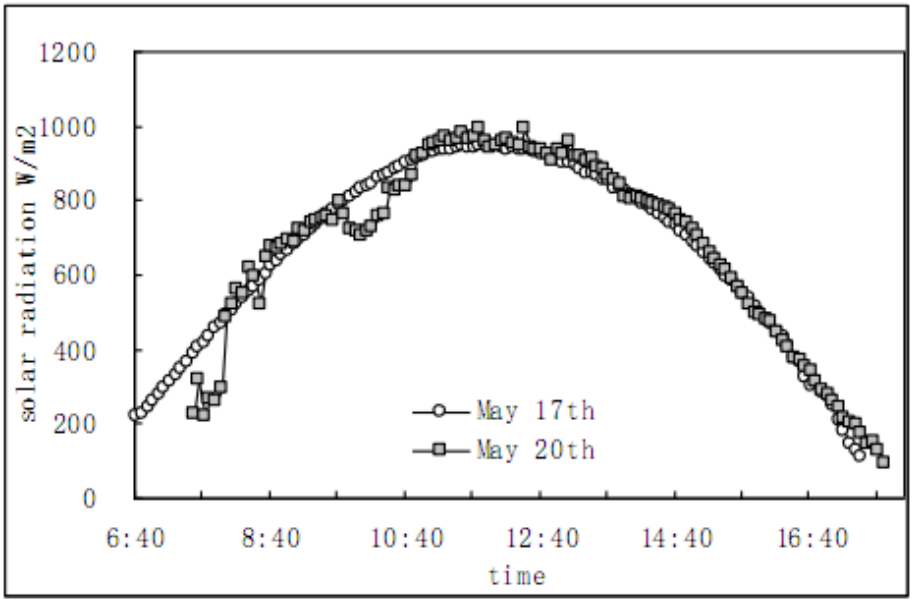


Fig. 3 Variation of solar radiation

Solar Radiation Variation

During the experimental period, the weather was sunny and a little cloudy. The solar radiation variation is shown in Fig.3. The max solar radiation was about 1000W/m^2 and the minimum was about 200 W/m^2. The daily solar radiation from the two experiments were about 21.51 MJ·d^{-1}m^{-2} and 21.87 MJ·d^{-1}m^{-2} respectively.

The Adsorbent Bed Temperature Variation

The adsorbent bed temperature variation of the SWT in two cycles of adsorption is shown in Fig.4. In the day, the adsorbent bed received the solar energy. The adsorbent temperature rose up rapidly to 222°C, and the water was desorbed from the 13X zeolite adsorbent bed. The vapour released the latent heat during condensation and became liquid, then stored in water bottle because of gravity.

When the adsorbent temperature dropped low enough at night, the adsorbent bed began to adsorb the water vapour from the air. In the adsorption process, the fresh air which contained water vapour flowed though the adsorbent bed and the adsorbent bed adsorbed vapour from atmosphere. The

adsorbent bed temperature variation in the nighttime is shown in Fig.4. The adsorbent bed temperature cooled down from about 110°C to the minimum of about 40°C. At this temperature the adsorbent bed can adsorb water from atmosphere.

The Condensation Temperature Variation

The condensation temperatures of the SWT were tested in this experiment. There were two temperature test positions near the inlet and outlet of the condenser. In the desorption process from 7:30 to 17:30 in the daytime, the desorbed water vapour was condensed in the condenser. In this experiment, the temperature was measured near the inlet of the condenser. The variation of the condensation temperature can be seen in Fig.5. The temperature of inlet position varied from 22.9 °C at 7:30 am to about 32.2 °C at 13:45 pm, while the outlet position varied from 22.8 °C at 7:30 am to about 29.3 °C at 13:45 pm.

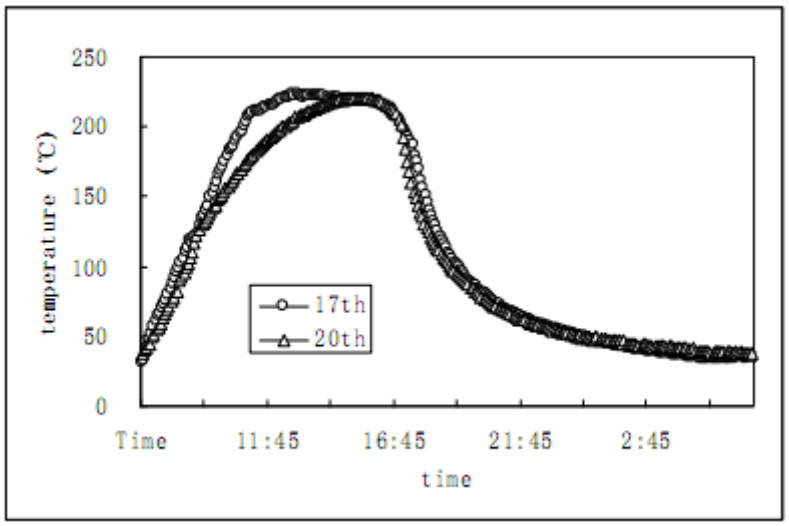


Fig.4 The adsorbent bed temperature variation of the SWT

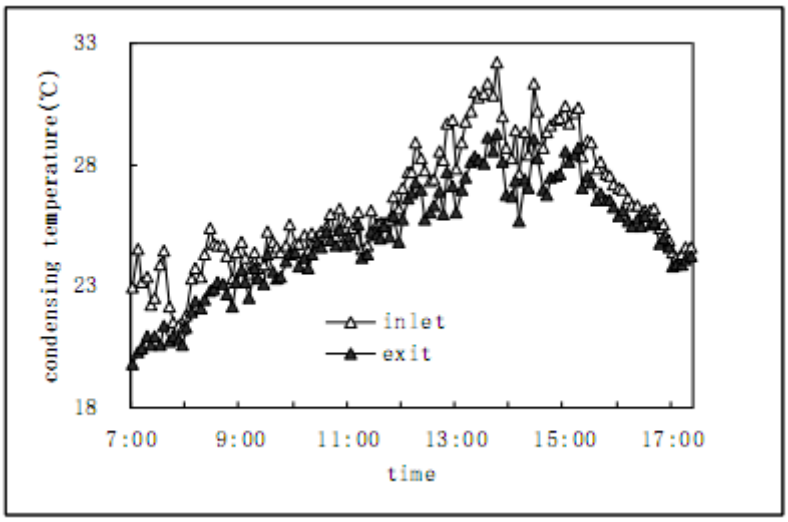


Fig.5 The inlet and exit condensation temperature variation

The Fresh Water Yield of a Single SWT

The fresh water yield of a single SWT is the characteristics to evaluate the ability of the SWT. It can be seen in Fig.6. During this experiment, fresh water yield was tested about every 30 minutes. From Fig.6 the rate of fresh water yield during 8:00-14:00 was high and became low after 14:00. The experimental results indicate that the daily fresh water yield of a single SWT was 93ml and 89 ml

respectively. In terms of per square meter, the daily fresh water output of the system was 1099 ml/m^2 and 1052 ml/m^2 respectively.

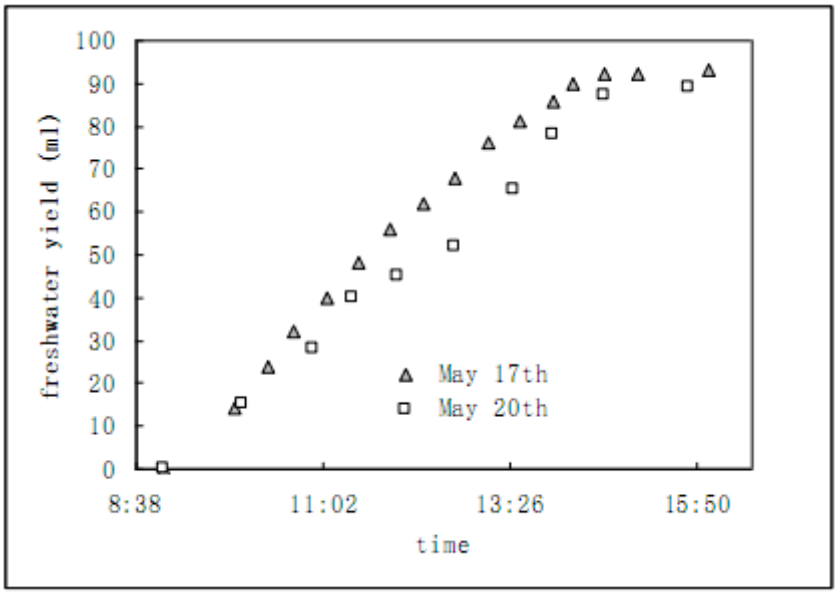


Fig.6 the fresh water yield of a single SWT

Conclusions

The SWT uses solar energy as heating resource to acquire fresh water. The performance of the SWT was experimentally studied in this research and the following conclusions could be drawn:

1. On an average day, when the ambient temperature was about 20°C- 35°C, the ambient relative humidity was about 44% - 74% and the solar radiation was about 22 MJ·d^{-1}m^{-2}, the adsorbent bed temperature of the SWT could reach to 222°C, and this temperature can reach to the standard of desorption.

2 In the night, the adsorbent bed temperature dropped from 110°C to the minimum of about 40°C. 40°C can reach to the standard of the adsorbent bed to adsorb vapour from air.

3. The condensation temperature of the SWT varied from 22 °C to 32°C during the day.

4. The daily fresh water yield of a single SWT was about 90 ml a day. In terms of per square meter, the daily fresh water output of the system was 1050 ml/m^2.

Acknowledgements

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