The Use of Preheating, Continuos Feeding and Blowing Air to Enhance A Solar Still Productivity

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Abstract A solar still in conjunction with a solar collector and solar cells was used for water desalination. Performance data with design consideration are presented in this study. Numerous investigators have studied the effect of preheating the brine prior to entering the still but their methods were very expensive because they used electricity or gas. In this study the preheating was done by a solar collector and continued feeding (using a pump) by a solar cell. The objective of this study is to enhance a solar still productivity by preheating the brine before entering the still together with blowing air (using a fan operated by a solar cell) on the outer surface of a glass cover. Solar still productivity increased with the greater temperature gradient due to increasing of solar radiation with air velocity blown on the outer surface of the glass cover. Increasing the air velocity by 2.58 m/s, the productivity increased to 1.75 $l/m^2.d$ at low velocities. On the other hand the productivity increased to 0.33 $l/m^2.d$ only with increasing the air velocity by 1.54 m/s at high velocities. This means the effect of air velocity decreases at higher velocities. Preheating also greatly enhanced productivity especially at night. The solar still productivity increased about 4.9 $l/m^2.d$ by increasing the temperature gradient to 14.66 °C with 5 m/s blown air on the outer surface of the glass cover.

1. Introduction

The growth of the world's population and the consequent food shortage, requires the expansion of agriculture especially into arid zones and the greening of the desert.
The famine in the desert and other less publicized regions on the globe provide ample evidence of the necessity of solving this problem by concerted efforts, both national and international. Arid zones constitute about 60% of the earth's land area and are characterized by high levels of solar radiation and shortage of fresh water.
The often possess reservoirs of either brackish or saline water that may be used for both drinking and irrigation after suitable treatment.
Many researches have been done using solar system for water desalination but still the production of fresh water less than requirements.
The objective of this study is to increase the fresh water productivity from a low cost still by the following controlled methods:
1- Pre-heating the brine using a solar collector before entering the still at day time.
2- Operate the system at night using the hot brine to get more fresh water.
3- Blowing cool air on the outer surface of the glass.

2. Materials and Methods

The system operates in a cascading fashion, the brine enters at the top tray and cascades or overflow down, step by step, to the last tray.
The design of the trays in conjunction with the cascading fashion maintains a very shallow water basin depth (5 cm).
Such a design has a definite practical advantage in hilly areas where the still design can be contoured to the landscape.

2.1 Design of solar still

The design of a prototype solar still model proceeded with the aim of achieving four goals: (1) modular construction so that any desired still area can be easily constructed; (2) easy on-site construction, no expensive or difficult site preparation required; (3) minimize construction costs; (4) increasing fresh water productivity.
A schematic diagram of the solar still is shown in Fig. 1. The prototype module of this solar still was constructed and its performance monitored by using personal computer and data logger at Okayama University Lab.

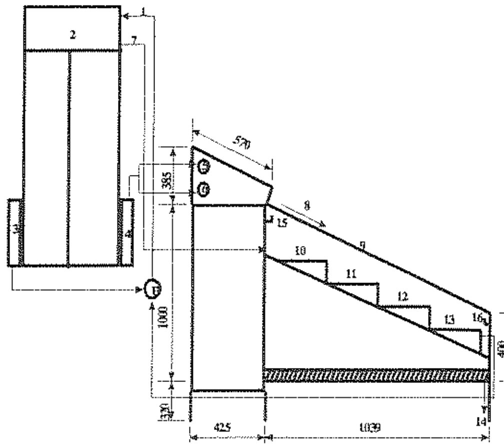

Fig. 1: A combined solar still and solar collector 1 Brine in- 2 Collector- 3,4 Solar cells- 5,6 Fans-7 brine out- 8 Cool air- 9 Glass cover-10,11,12,13 Trays- 14 Fresh water (productivity) - 15,16 Troughs- P Pump.

2.2 Design considerations

2.2.1 Basin water depth

As mentioned by researchers that, the daily productivity of a solar still is weakly dependent upon its basin water depth. The optimum water depth is averaged between 5~30 cm. This is explained by the fact that the water in a shallow basin will reach higher temperatures during the hours of peak insolation due to its smaller thermal mass and its evaporation rate increases exponentially with temperature. Morse and Read (1968) calculated that for an insolation rate of 225 kJ/m^2 h, decreasing the thermal capacity of an insulated still from 1.41 kJ/m^2 °C (7.6 cm) to zero increases productivity by 9%, whereas increasing it from 1.41 kJ/m^2 °C to 5.64 kJ/m^2 °C (30 cm) decreases productivity by 7%.

2.2.2 Vapor tightness

All solar stills should be designed to be completely vapor tight. In practice cracks and holes especially at junctions of dissimilar materials. Maximum effort must be expended to reduce these to a minimum by use of proper sealant.

2.2.3 Distillate leakage

The troughs for distillate collection should be designed so as to prevent the possible leakage of distillate, either internally or externally. In this study product was well covered by aluminum sheet to prevent re-evaporation of distillate.

2.2.4 Glazing material

The preferred glass thickness as mentioned by Sodha and et al, 1981 is 2~3 mm depending upon the expected stress load. The properties of glass are (1) high transmittivity for solar radiation (about 88%), (2) opaqueness to infrared radiation, (3) wettability with respect to water (formation of liquid film rather than droplets on the glass surface), (4) resistance to ultraviolet degradation and (5) relative strength. The disadvantage of most transparent plastics is that, in general, they lack one or more of the five properties listed above. In this study a 3 mm glass thickness with 48 $\times$120 cm^2 was used.

2.2.5 Glazing slope and shape

Aderibigbe, 1985 has attempted to determine by means of a coupled heat and mass transfer analysis the optimal glazing inclination for maximum yearly average productivity in basin type solar stills as a function of site latitude. He has found that the optimal glazing slope is 14° for latitudes less than 14° north or south. The range of glazing slopes used in practice varies between 10° and 30°. It is desirable to minimize the slope angle in order to minimize the fraction of solar radiation reflected from the glazing. In this study the still was tilted at 30° on the horizontal.

2.2.6 Glazing cleaning

The productivity of the still will be decreased if the transmittance of the glazing is reduced. The glazing can be coated by dust, dirt and salt deposits. In general, glass requires minimal cleaning than plastic because the plastic is usually electrostatic and thereby attract dust. In this study the glass was washed periodically.

2.3 Solar still

The still having a net basin area of 0.3 m^2 (which is four containers with 0.25$\times$0.30 m^2 area for each one. Each container has a 3.75 liter capacity (15 liter brine water capacity as a total).
The still walls were fabricated from 0.5 mm venial chloride sheets and the containers were made from black plastic. The upper glazing was from a 3 mm glass with 0.576 m^2 area (0.48$\times$1.2 m^2).
Two solar cells (12 V and 2 A each) were using for generating the power at day time One for operating two fans (12 V, 1.2 A and 170 mm diameter each) together to blow a cool air on the upper surface of the glass cover during the experiment. The other solar cell was for operating a water pump (12 V

and 0.9 A) to recycle the brine from the still to the collector.
The glass and cool air (blowing by fans) were tilted at 30° on the horizontal. It should be noted that, rate of dust and dirt covering on the external side of the glazing will increase as the slope decreases and the rate and extent of natural cleaning by wind and rain will decrease.

2.4 Preheating of feedstock

Numerous investigators have studied the effect of preheating the feedstock prior to entering the still. Kudish and et al. (1996) used an external thermal energy input to preheat the feedstock before entering the still because most energy is needed for evaporation. Their research was succeeded but was very expensive. In this study, the feedstock was preheated by using a flat plate solar collector before entering the still and the pump was operated by solar cell.

2.5 Measurements

Solar collector and solar cells performances have been done for almost more than two years (Elbatawi and et al. 1997). The solar collector was filled by the feedstock at early morning (before sunrise) and the hot brine was interring the solar still by gravity and return to the collector by pump. The fans (operated by a solar cell) start to blow the air on the outer surface of the glass just before the hot brine interring the solar still. The product of fresh water was collected and measured every hour through a data logger and personal computer. The water temperatures, solar radiation, solar cell's voltage, ampere and ambient temperature were measured every two minutes using data logger and personal computer.

2.5.1 Productivity rate

Cooper, 1973 determined the productivity rate of a solar still The following empirical equation was used as a linear correlation between the productivity rate and solar radiation:

$$m_w = AH_h + B \qquad (1)$$

Where m_w is productivity rate ($l/m^2.s$), H_h is solar radiation incident on a horizontal surface (kW/m^2), A and B are constants determined by least square regression analysis of the measured data. So, with a reasonable degree of confidence, the equation can be used to predict the production rate of a particular type of solar still as a function of solar radiation.

2.5.2 Productivity

The productivity of a solar still is defined as the cumulative amount of distillate obtained over any time period θ_1 to θ_2. It is usually reported on a daily basis ($kg/m^2.d$ or $l/m^2.d$) and is given as:

$$\Phi = 3.6 \times 10^3 \sum(m_w \times \Delta\theta) \qquad (2)$$

Where Φ is solar still productivity ($l/m^2.d$), $\Delta\theta$ is time from sunrise (h) and mw is the mass transfer rate($l/m^2.s$) .
On the other hand Duffie and Beckman, 1990 provides some equation to calculate the productivity as follows:

$$m_D = 9.15 \times 10^{-7} h_c (P_{wb} - P_{wg}) \qquad (3)$$

Where:

$$h_c = 0.884((T_b - T_g) + ((P_{wb} - P_{wg}) \times T_b/(2016 - P_{wb})))^{1/3} \qquad (4)$$

$$P_{b,g} = 293.3 T_{b,g} - 84026.4 \qquad (5)$$

T = absolute temperature (K).
m_D = mass transfer rate ($l/m^2.s$).
h_c = convection coefficient.
P_{wb} = vapor pressure of water in the basin (mmHg).
P_{wg} = vapor pressure of water in the glass (mmHg).
T_b = temperature of water in the basin (K).
T_g = temperature of water in the glass (K).

2.5.3 Efficiency

The overall efficiency of a solar still is defined as the productivity ratio multiplied by an average value for the latent heat of vaporization (the thermal energy required to raise the water to the evaporation temperature).to to the cumulative solar radiation incident during the time period. Efficiency can be calculated from the following equation:

$$\eta = (\lambda \times \Phi) / (3.6 \times 10^3 \sum(H_h \times \Delta\theta)) \qquad (6)$$

Where η is solar still efficiency (dimensionless) and λ is latent heat of vaporization of water (J/kg). The latent heat of vaporization of water can be determined from the following equation (ASAE Standards 1993):

$$\lambda = 2502535.259 - 2385.76424(T - 273.16) \qquad (7)$$
where; $273.16 \leq T \leq 338.72$

3. Results and Discussions

In operation, solar radiation is transmitted through the cover and absorbed by the brine and the basin. The brine is heated, water evaporates, and vapor rises to the cover by convection where it is condensed on the underside of the cover. Condensate flows by gravity into the collection trough at the lower edges of the cover; the cover had a sufficient slope that surface tension of the water caused it to flow into the trough without dropping back into the basin. The trough is constructed with enough pitch along its length so that condensate flows to the lower end of the still, where it drains into a product water collection container.

3.1 Effect of solar radiation

Solar radiation is the most important parameter affecting still productivity. It is the driving force in the distillation process. In Fig. 2, the results plotted in a curve showing the still productivity as a function of solar radiation by using the least square analysis. The functional relation was :

$$\Phi=3.7789H+0.0741 \quad (8)$$

The solar still productivity increasing with increasing of solar radiation, for example, when the solar radiation was 0.49 kW/m^2 the productivity was 1.7 $l/m^2.d$ with no blowing air and 2.7 $l/m^2.d$ with blowing air on the outer surface of the glass cover. When the radiation was 0.19 kW/m^2, the productivity was 1.1 $l/m^2.d$ with no blowing air and 1.5 $l/m^2.d.$ with blowing air On the other hand the solar still productivity decreased with decreasing of solar radiation, for example, the productivity decreased from 2.5 $l/m^2.d$ to 1.0 $l/m^2.d$ when the radiation decreased from 0.53 kW/m^2 to 0.15 kW/m^2 respectively.

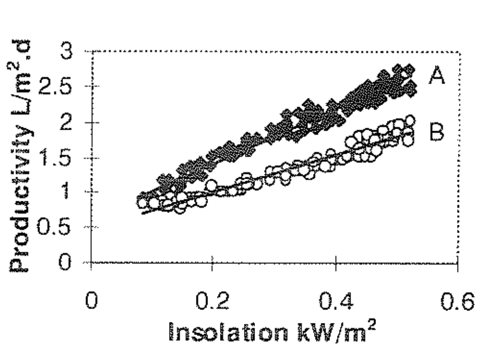

Fig. 2: Effect of daily insolation on productivity A is the effect of insolation and blowing air by fan on the outer surface of the glass cover and B is the effect of insolation only.

3.2 Effect of fan air velocity on productivity

Increasing air velocity reduces the glazing temperature, which in turn increases the rate of condensation due to the greater temperature gradient. The lower glazing temperature also increases the rate of condensation and radiation. As shown in Fig. 3, when the fan air velocity increased from 1.13 m/s to 3.71 m/s, the productivity increased from 0.42 $l/m^2.d$ to 2.17 $l/m^2.d$. On the other hand when the air velocity was increased from 3.69 m/s to 5.23 m/s ,the productivity increased from 2.91 $l/m^2.d$ to 3.24 $l/m^2.d$ only. This indicated that the effect of air velocity decreases at higher velocities.

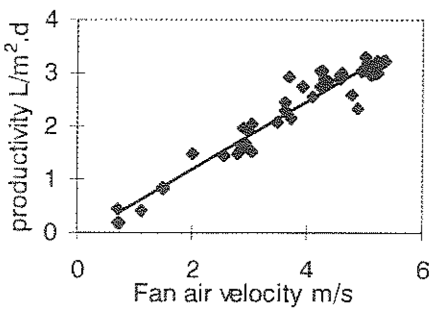

Fig. 3: Effect of daily fan air velocity on productivity

3.3 Effect of preheating

The preheating of feedstock was done by circulating it prior to entering the still basin through an array of flat plate solar collector. A small pump was used for circulating the brine at night time with 3.5 l/min flow rate. The use of preheating was greatly enhance productivity during the night as shown in Fig. 4. For example, the increase of temperature gradient from 2.1 °C to 16.76 °C showed an increase of productivity from 0.38 $l/m^2.d$ to 5.23 $l/m^2.d$. It was concluded that at high water temperature, the increase in temperature gradient between the water surface and the glazing caused by increasing air velocity results in an increased the rate of evaporation.

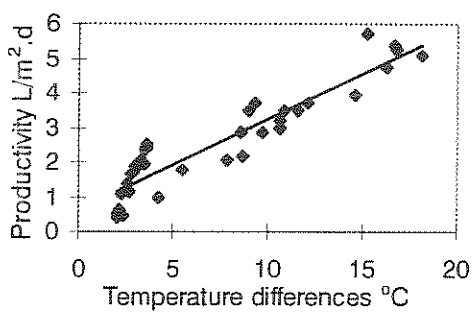

Fig. 4: Effect of daily preheating on productivity

4. Conclusions

Numerous performance correlations have been determined for a solar still with preheating. The results concluded that;

1- Solar still productivity increased with the greater temperature gradient due to increasing of solar radiation with air velocity blown on the outer surface of the glass cover. Increasing the air velocity by 2.58 m/s, the productivity increased to 1.75 l/m^2.d at low velocities. On the other hand the productivity increased to 0.33 l/m^2.d only with increasing the air velocity by 1.54 m/s at high velocities.

2- The use of preheating was greatly enhance productivity especially at night. The solar still productivity increased about 4.9 l/m^2.d by increasing the temperature gradient to 14.66 °C with 5 m/s blown air on the outer surface of glass cover.

References

Aderibigbe, D.A., Optimal cover inclination for maximum yearly average productivity in roof-type solar still, *Water Desalination*, Elsevier Science, 255 pp., Amsterdam, 1985.

American Society of Agricultural Engineering Standards, 40th Ed., st Joseph, MI, ASAE, 1993.

Cooper, P.I., Digital simulation of experimental solar still data, *Solar Energy*, 14:451, 1973.

Duffie, J.A. and W.A. Beckman, *Solar Engineering of Thermal Process*, John Wiely, 657 pp., New York, 1990.

Elbatawi, I.E.A., K. Mohri, and K. Namba, Simulation of incident solar radiation at Okayama city, 56th Japanese society annual meeting of agricultural machinery, Mie University, Japan, pp 237-238, 1997.

Kudish, A.I., M.M. Aboabboud, L. Horvath, G. Mink, and M. Yasin, An energy saving atmospheric evaporator utilizing low grade thermal or waste energy, *Energy, 21*(12), 1107-1117, 1996.

Morse, R.N. and W.R.W. Read, A rational basis for the engineering development of a solar still, *Solar Energy*, 12:5, 1968.

Sodha, M.S., A. Kumar, G.N. Tiwari, and R.C. Tyagi, Simple multiple-wick solar still, *Solar Energy*, 26:127, 1981.