Desalination and Water Treatment
www.deswater.com
19 (2010) 249–254
July

doi: 10.5004/dwt.2010.1153

Experimental study of an inverted absorber solar still

Sabah A. Abdul-Wahab[a], Ali M. Al-Damkhi[b], Hilal Al-Hinai[c], Rahul Dev[d]*, G.N. Tiwari[d]

[a]*Mechanical & Industrial Engineering Department, College of Engineering, Sultan Qaboos University, P.O. Box 33, Al Khoud 123, Oman*
[b]*Department of Environmental Sciences,College of Health Sciences, Public Authority for Applied Education and Training (PAAET), Kuwait*
[c]*The Research Council, P.O. Box 1422, Al-Athaiba 130, Oman*
[d]*BAG-Energy Research Society, A-112, Prodhyogiki Apartment, Plot 11, Sector 3, Dwarka, New Delhi-110075, India*
Tel. +91 9968344470; rahuldsurya@yahoo.com, bers2007@gmail.com

Received 2 March 2009; Accepted in revised form 27 December 2009

ABSTRACT

In this communication, an experiment based study of an inverted absorber solar still (IASS) conducted in Muscat, Oman is presented. An IASS is an improved design of a single slope solar still with a curved reflector under the basin. This arrangement helps in more heating of the basin of a solar still from both sides (i.e. top and bottom surfaces) directly and indirectly. The reflector under the basin adds additional heat to increase temperatures of the basin, water and condensing glass cover than that of a conventional single slope solar still. Experimental results show that the productivity of an inverted absorber solar still is more than 3.5 l/m^2 in duration of 12 h, i.e. 7:00 AM–7:00 PM. It is also found that IASS is not capable of holding thermal energy for long duration after 16:00. The thermal storage is lost to ambient through incased air under the basin when the amount of reflected solar radiation reduces. Hence, it is recommended to have an insulation layer under the basin to utilize thermal storage occurred during the day for the evaporation to get more yield per day.

Keywords: Solar distillation; Inverted absorber solar still; Thermal performance; Productivity

1. Introduction

The world is facing a problem of fresh water scarcity. Scarcity of water occurs due to anthropogenic activities which pollute fresh water reserves. Hence, the demand in drinking water is increasing globally. The problem of drinking water becomes a challenge in spite of several methods available for purification of water. It is because most of these water purification methods are highly energy and cost intensive.

Several countries like Kuwait and Oman (Gulf Cooperation Council countries) rely mainly on seawater desalination for fresh and potable water. Al-Mutaz [1] reported that most desalination plants in the Gulf countries are dual-purpose multi-stage flash (MSF) that produce both power and water. It is reported that the reverse osmosis (RO) technology was developed and adapted for the conditions of the Arabian Gulf seawater in 1987 [2]. It is well known that electrical energy based desalination plants has both economical and environmental drawbacks [3] such as these plants have a limited lifetime of 20 years, they are vulnerable to technical faults, and rely on gas and oil (conventional fuels which cause environmental pollution) for power. Negative environmental impacts include the increase of the seawater salinity due to the discharge of brine waste [4] and increased levels of atmo-

* Corresponding author.

spheric carbon dioxide (CO_2) from fuel consumption [5]. Nonetheless, Nairn [5] advocates increasing the production of desalinated water to meet water supply demand. Bremere et al. [6] envisaged that the production of potable water in the desalination market would need to reach 14.8 million m^3/d in water-scarce countries including Kuwait and Oman by 2025.

Solar energy is a form of renewable energy. It can be used for purification of saline and brackish water through solar distillation. Solar distillation is an economical, effective and environment friendly option available to the mankind [7]. It is a method which can be applicable in rural, remote areas of developed and developing countries including the Gulf countries. The Gulf region receives high solar radiation which generates more interest to use solar technologies like solar distillation in these areas. Due to scarcity of fresh water but availability of a long sea shore, solar distillation is a more applicable technology in the Gulf area [8].

For many decades scientists all over the world have been trying to improve the performance of solar stills. Various designs of solar stills have been developed over the past several years such as double slope solar still, multi-wick solar still, etc. [9,10]. A most conventional design of the solar still is a single slope solar still. The main disadvantage of the conventional single slope solar still is low amount of distilled water produced per unit area because of lower water temperature [10]. There are several methods to increase the water temperature such as: (a) active solar distillation, i.e. addition of heated water into the solar still in natural or forced mode [11,12]; (b) decreasing the water depth [13]; (c) increasing the basin temperature by reflectors [14]; (d) addition of dye in the feed water [15,16], etc.

An inverted absorber solar still (IASS) is a combined system of a conventional single slope solar still and a curved reflector under the basin. An improved design of an IASS has the advantage of double sided heating of the basin, i.e. from top as well as from bottom. This results in increasing the temperature of the basin and water. An inverted absorber solar still also has high absorptivity and a low bottom heat loss coefficient of the absorbing plate in comparison with the conventional single slope solar still. Tiwari and Suneja [17] presented a thermal model and theoretical analysis of an IASS in terms of climatic, design and operational parameters. It is reported that an optimum water depth of 10 cm in the basin resulted in 11% more yield when the water flows over the condensing surface to cool it [17]. The effect of water flow on the internal heat transfer of a solar still is analyzed and it is shown that convective and radiative heat transfer coefficients do not vary much except the evaporative heat transfer coefficient with water depth variation [18]. The effect of a double basin and triple basin for an IASS was also presented by Suneja and Tiwari [19]. A parametric study on an inverted absorber asymmetric line-axis solar compound parabolic concentrator (CPC) is studied as high temperature solar distillation option and explicit expressions for temperature of water, glass-cover, distillate output and efficiency are given by Yadav and Yadav [20]. Effects of several parameters such as the amount of water, absorptivity and concentration ratio are observed. It is shown that these parameters increase with the decrease in the amount of water mass. Yadav et al. [21] presented modified designs of the inverted absorber asymmetric line axis CPC. An experimental study of the inverted absorber asymmetric line axis CPC conducted in Bihar, India is reported with the yield of 3.04 l/m^2 for 6 h test period [22]. In another experiment on a double exposure single basin solar still with the basin area 0.2 m × 1 m and 3 l of water in the basin conducted in Bihar, India, Yadav et al. [23] reported the yield up to 0.7 l and maximum water temperature 64.8°C between 12:00–13:00 PM. Similarly, maximum temperatures of the basin, inner surface and outer surface of the glass cover are found 69°C, 61°C and 53°C respectively between 12:00–13:00 PM in the experimental period of 5 h (i.e. from 10:03 to 15:23) for a typical day in March 1997. This design of IASS is proposed for high temperature distillation similar to a solar still connected with a flat plate collector (FPC) in a passive mode to avoid thermal losses occurred in pipes used to connect the solar still and FPC [23]. Yadav et al. [24,25] reported various measured temperatures and used the ray trace method for solar flux calculation and finite element method (FEM) for isothermal contour plot inside the lower chamber. It is observed through simulation that suppression of solar radiation decreases the reflector and aperture cover temperature. It is also reported that increased concentration ratio from 1 to 3 increases the water temperature and yield.

In the present work, an experiment based study of an IASS conducted in Muscat, Oman is given. This experimental study consists of measurements of various temperatures and productivity of IASS. The experiment was performed on a day (clear sky condition) of September 2008.

2. Working principle

An inverted absorber solar still (Fig. 1) works on the mechanism of double sided heating of the basin from top and bottom. Solar radiation passes through the glass to incident directly on the top surface of the basin whereas indirectly on the bottom surface (i.e. after reflection from the inner surface of the reflector). This results in more heat transfer to the basin plate. This absorbed heat is then transferred to the water mass over the top surface of the basin. It helps in increasing the temperature of the water. Due to additional heat transfer to the water mass in comparison to the conventional solar still, high temperature difference occurs between the water and the condensing glass cover in an IASS. The hot water releases its heat to the glass cover through evaporation, convection and radiation and to ambient through the side walls of the solar still. Water vapor leaves impurities such as salt, dissolved matter and microbes etc. behind to come in contact with the inner surface of the glass cover. The water vapor condenses there after releasing the latent heat, due to which a phase change phenomenon occurs, i.e. from the vapor phase to water. An ambient air flowing over the glass surface dissipates the heat to cool down the glass. The condensed water trickles down in the form of a water film into the trough due to the slope of the condensing glass cover under gravity. The trough guides the condensate to the collecting jar through plastic tubes [19,20].

3. Experimental setup and observations

A photograph of the experimental setup of an inverted absorber solar still is shown in Fig. 1, and the schematic diagram of an IASS with dimensions is also shown in Fig. 2. The setup is installed at Sultan Qaboos University, Muscat, Oman (23°37´N latitude, 58°35´E longitude). The setup is a combination of a conventional solar still and a curved reflector under the basin of the solar still. The basin of the solar still (area = 1 m^2, i.e. length = 1 m, width = 1 m) is fabricated using galvanized iron sheet of 1.5 mm thickness. To increase the absorption of solar radiation, the basin liner is blackened on both sides. The sides of the solar still are insulated by a 5 cm thick layer of Styrofoam to reduce heat losses to ambient. A reflector with the radius of curvature of 1 m, as shown in Fig. 1, is used to heat the basin from the bottom. This reflector is also made of galvanized iron sheet of 1.5 mm thickness with aluminum foil on its inner surface used to increase the reflectance.

The whole assembly is mounted on an iron stand with the length 1.5 m of a larger leg. Two iron rod of the length 0.38 m is provided to support the reflector. The glass cover of the still is made of 4 mm thick simple window glass inclined at an angle of 23.4° with horizontal optimized for 23.37°N latitude of Muscat to receive maximum solar radiation. Another glass cover with the same inclination angle on the reflector is used to transmit the solar radiation on the inner surface of the reflector and to avoid the convection heat loss from the bottom of the solar still. The glass covers are sealed with a black rubber tape (Aero tape) and an adhesive plastic tape with plastic clips for efficient operation as the rubber support allows the expansion and contraction between dissimilar materials on heating and cooling, remains elastic for a quite longer time and prevents air leakage also as shown in Fig. 1. A plastic tube is used to collect the distillate into a collecting jar. The orientation of the whole assembly is kept towards the south direction. Table 1 shows various dimensions and materials of different components of the inverted absorber solar still.

Fig. 1. A photograph of an inverted absorber solar still.

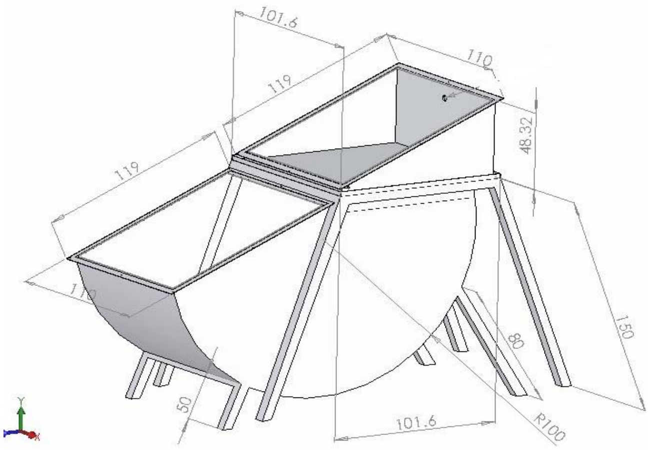

Fig. 2. Schematic diagram of an inverted absorber solar still (all dimensions are in cm.).

The experiment was carried out in the day time duration of 12 h (7:00 AM–7:00 PM) on a day in September 2008. Table 2 shows the various parameters taken into account. A thermometer having least count 0.1°C is used to measure the ambient temperature. Other temperatures are recorded by using a multi point data recorder (thermocouples reader). A measuring jar with the least count 10 ml was used for measuring the yield.

3. Results and discussion

The experiment based results for the inverted absorber solar still with water depth 0.01 m for a day of September 2008 are analyzed. Water depth 0.01 m was considered because Dev and Tiwari [13] proved that 0.01 m water

Table 1
Various dimensions and materials of different components of the inverted absorber solar still

Parameter	Quantity
Single slope solar still: Material – metal (GI sheet)	
Length, m	1
Width, m	1
Inclination angle (ø), °	23.4
Thickness of metal sheet, mm	1.5
Height at lower side (H), cm	5
Cover on the solar still walls: Material – glass	
Length, m	1.15
Width, m	1.06
Thickness, mm	4
Reflector: Material – metal (GI sheet), cylindrical shape	
Radius, m	1
Thickness of metal sheet, mm	1.5
Stand: Material – metal (GI), L-shaped angle	
Length, cm	3
Width, cm	3
Thickness, mm	3
Cover on the opening of the reflector: Material – glass	
Length, m	1.6
Width, m	1.6
Thickness of glass, mm	4

depth is optimal in 0.01, 0.02 and 0.03 m of water depths and low distillate production by most of passive solar stills, i.e. below 10 ls. Water depth 0.1 m [17] is not considered because the condensing cover is not cooled by water flow over it. At water depth 0.1 m, i.e. solar still is filled with 100 l of water which is higher water mass than 10 l.

Table 2
Variable parameters considered for the experiment

Parameter	Specification
Date	25/09/2008
Depth of water, cm	1
Shade on solar still	No
Charcoal addition	No
Dye addition	No
Insulation on the solar still walls	Yes
TDS in feed water, g/l	38

It is obvious that 100 l of water require more amounts of solar energy and time to raise the water temperature in comparison to that of 10 l. One more reason for taking 0.01 m water depth is that 100 l of water would have a higher amount of thermal storage than 10 l which can be lost through the metallic basin of IASS with lesser distillate production than that of 10 l. Hence at a low water depth (0.01 m), the water temperature increases at a faster rate.

Fig. 3 shows an hourly variation of temperatures of ambient, basin, water and condensing glass cover for IASS taken on 25/09/08. Maximum temperatures of the ambient air, water and condensing cover were found 34.1, 70.5 and 70.3°C respectively at 12:00 PM. The basin temperature was found maximum 83.6°C at 13:00 PM because of heating of the basin from both sides. It was observed that the water temperature was lower than the glass temperature in the morning between 7:00 AM–9:00 AM. It happened because glass absorbed heat and got heated more than the water. Water got heated up slowly and achieved a higher temperature than the condensing glass cover after 9:00 AM. This effect is the result of thermal capacity of the water mass in the basin which raised the water tem-

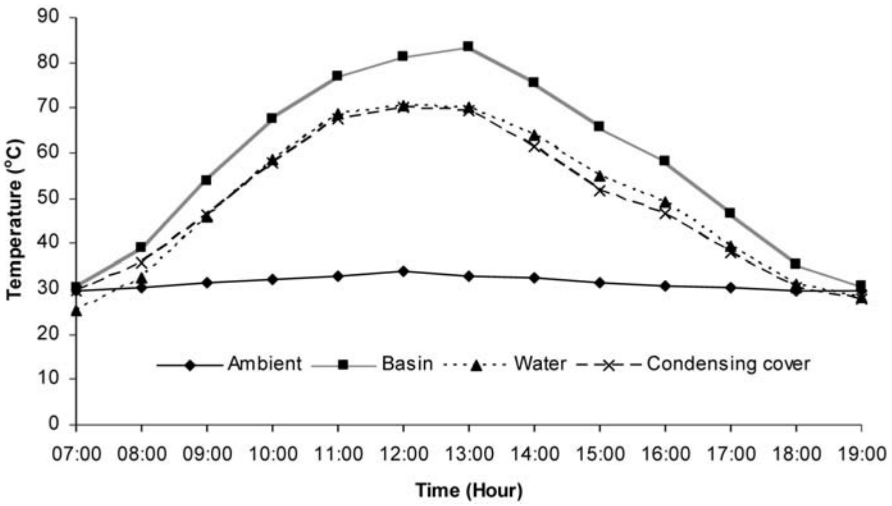

Fig. 3. Hourly variation of various temperatures for an inverted absorber solar still on a day of September 2008.

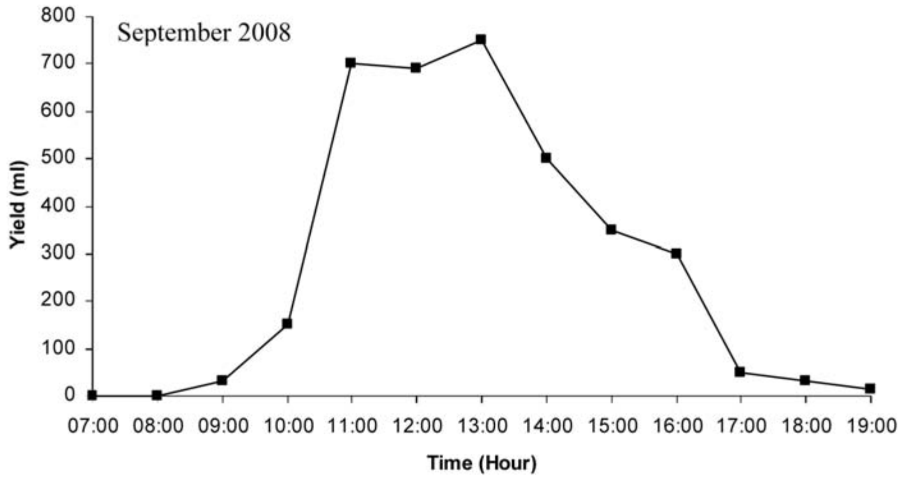

Fig. 4. Hourly variation of yield for an inverted absorber solar still on a day of September 2008.

perature. As solar intensity, i.e. heat input, increased the water temperature started increasing and vice a versa.

One can also observe that the inverted absorber solar still does not hold high water temperature for longer time. Water and basin temperature started decreasing after 13:00 PM as the heat input into the basin decreased due to the change in the direction of solar radiation. Due to the sun position in the west direction at 16:00 PM, only a small part of solar radiation, i.e. diffused radiation, was passed through both glasses and it was not as effective as direct solar radiation. The water temperature became almost equal to glass temperature after 17:00 PM as shown in Fig. 3. It happened because the basin of the inverted absorber solar still started losing its heat to air incased in the reflector assembly, i.e. the lower chamber of the solar still. From Fig. 4 it is clear that after 16:00 PM, the hourly yield decreased drastically from 300 ml to 50 ml at 17:00 PM. This particular time changes with season due to varying sun position and trajectory. Hence, it is a drawback of an inverted absorber solar still due to which water looses its heat accumulated in daytime in spite of the high thermal heat capacity. From the observed data it is concluded that after 16:00 PM a movable insulation plate under the bottom surface of the basin should be inserted to increase the hourly yield during evening and night hours by reducing the bottom heat loss. Putting an insulation plate after 16:00 PM can prevent heat loss to ambient and enhance utilization of heat in evaporation. The insulation plate under the basin can be inserted by making a provision from the back of the reflector. With the increase in nocturnal production the net amount of the distillate would increase by IASS unit.

Fig. 4 shows an hourly variation of the yield produced by the inverted absorber solar still at a water depth of 1 cm. In Muscat, the solar intensity comes to the maximum value between 12:00 to 13:00 PM but because of thermal storage, the yield is maximum during 13:00–14:00 PM due to the phase difference between the solar intensity and evaporation. One can observe that the daily yield was found more than 3.5 l/m^2 in duration of 12 h of the day. It is known that a conventional solar still produces distillate 1.5–2.0 l/m^2 in 24 h [9]. Hence, one can conclude that the IASS produces more yield in comparison to the conventional solar still and can be used as a better passive solar distillation system.

4. Conclusion

On the basis of the present study the following conclusions are drawn:

1. The experimental study suggests a new and improved design of the single slope solar still by using a reflector under the basin, i.e. an inverted absorber solar still (IASS).
2. Water temperature increases due to modification in the design of the conventional solar still with the use of the reflector under the basin.
3. The yield is found more than 3.5 l/m^2 in daytime duration of 12 h which is more than the yield of the conventional solar still, i.e. 1.5–2 l/m^2 in 24 h.
4. The results suggest that putting insulation after 16:00 PM under the basin can prevent downward heat loss to the incased air inside the reflector assembly. This modification can enhance nocturnal production of the yield which will further improve the performance of IASS.

Acknowledgement

The financial support provided by the Sultan Qaboos University, Muscat, Oman (Grant No. IG/ENG/MIED/08/05) to carry out this research work in collaboration with IIT Delhi, India and BAG Energy Research Society (BERS), Varanasi, India is gratefully acknowledged.

References

[1] I.S. Al-Mutaz, Potential of nuclear desalination in the Arabian Gulf countries, Desalination, 135 (2001) 187–194.

[2] MEW, Statistical Year Book: Water 2006. Ministry of Electricity and Water, Kuwait, 2007.

[3] J.G. Kuwait Pike, Groundwater resources development and the environment in the central region of the Arabian Gulf. Int. J. Water Resource Develop., 1 (1983) 115–132.

[4] A. Purnama, H.H. Al-Barwani and R. Smith, Calculating the environmental cost of seawater desalination in the Arabian marginal seas, Desalination, 185 (2005) 79–86.

[5] A.E. Nairn, Water management in the Arabian Gulf region and a partial solution to water shortages, Dev. Water Sci., 50 (2003) 183–189.

[6] I. Bremere, M. Kennedy, A. Stikker and J. Schippers, How water scarcity will effect the growth in the desalination market in the coming 25 years, Desalination, 138 (2001) 7–15.

[7] G.N. Tiwari, Solar Energy — Fundamentals, Design, Modeling and Applications, Narosa Publishing House, New Delhi, India, 2005.

[8] H. Al-Hinai, M.S. Al-Nassri and B.A. Jurban, Effect of climatic, design and operational parameters on the yield of a simple solar still, Energy Convers. Mgmt., 43 (2002) 1639–1650.

[9] G.N. Tiwari and A. Tiwari, Solar Distillation Practice for Water Desalination Systems, Anamaya, New Delhi, India, 2007.

[10] M.A.S. Malik, G.N. Tiwari, A. Kumar and M.S. Sodha, Solar Distillation, Pergamon Press, Oxford, UK, 1982.

[11] O.O. Badran and H.A. Al-Tahaineh, The effect of coupling flate-plate collector on the solar still productivity, Desalination, 183 (2005) 137–142.

[12] H. Tanaka, Y. Nakatake and M. Tanaka, Indoor experiments of the vertical multiple-effect diffusion type solar still coupled with a heat-pipe solar collector, Desalination, 177 (2005) 291–302.

[13] R. Dev and G.N. Tiwari, Characteristic equation of a passive solar still. Desalination, 245 (2009) 246–265.

[14] H. Tanaka and Y. Nakatake, Numerical analysis of the vertical multiple-effect diffusion solar still coupled with a flat plate collector: optimum reflector angle and optimum orientation of the still at various seasons and locations, Desalination, 207 (2007) 167–178.

[15] O.O. Badran, Experimental study of the enhancement parameters on a single slope solar still productivity, Desalination, 209 (2007) 136–143.

[16] A. Tamimi, Performance of a solar still with reflectors and black dyes, Solar Wind Technol., 4 (1987) 443–446.

[17] G.N. Tiwari and S. Suneja, Thermal analysis of an inverted absorber solar still for high yield, Int. J. Solar Energy, 20 (1999) 111–127.

[18] S. Suneja and G.N. Tiwari, Effect of water flow on internal heat transfer solar distillation, Energy Convers. Mgmt., 40 (1999) 509–518.

[19] S. Suneja and G.N. Tiwari, Effect of water depth on the performance of an inverted absorber double basin solar still, Energy Convers. Mgmt., 40 (1999) 1885–1897.

[20] Y.P. Yadav and S.K. Yadav, Parametric studies on the transient performance of a high-temperature solar distillation system, Desalination, 170 (2004) 251–262.

[21] G.N. Tiwari, Y.P. Yadav, P.C. Eames and B. Norton, Solar distillation systems: the state-of-the-art in design development and performance analysis, Renewable Energy, 5(1) (1994) 509–516.

[22] Y.P. Yadav, A.K. Yadav, N. Anwar, P.C. Eames and B. Norton, An asymmetric line-axis compound parabolic concentrating single basin solar still, WREC, (1996) 737–740.

[23] Y.P. Yadav, P.C. Eames and B. Norton, A double exposure single basin solar still for high temperature solar distillation, WREC, (1998) 2376–2379.

[24] Y.P Yadav, Reflector augmented solar heat collectors, Proc. 3rd Int. Conference on Solar Radiation and Daylighting (SOLARIS 2007), Vol. I, Anamaya Publishers, India, 2007.

[25] J. Narayan and Y.P. Yadav, Metallic condensing surface solar still augmented by asymmetric CPC, Proc. 3rd Int. Conference on Solar Radiation and Daylighting (SOLARIS 2007), Vol. II, Anamaya Publishers, India, 2007.