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Irrigation Water Production via a System of Solar Stills-cum-Greenhouse Evaporative Cooler

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Abstract: This study aims at investigating the productivity and efficiency of a new system combining solar stills (SS) and a greenhouse evaporative-cooler to provide irrigation water demand for greenhouses in seawater-intruded areas. Galvanized-steel sheets were used to fabricate four solar stills with 1 m^2 floor area and 23^o inclined glass cover. Brackish water (EC = 4 dS m^{-1}) was placed inside each SS. Water productivity is potentially enhanced by increasing evaporation, increasing condensation or both. In this study, evaporation was increased by black painting the bottom surface of SS or by using small pieces of locally available black granite as heat absorbers. Also, to increase evaporation, conductive heat loss through the sidewalls of SS was curbed using 5 cm-thick thermal insulation (K=0.03 W m^{-1} K^{-1}). In order to increase condensation, cold brackish water flowing down the greenhouse evaporative cooler was pumped to the surface of the glass cover at high and low water flowrates.
Results showed that thermal insulation alone increased the solar still effectiveness (SSE) from 31.2 to 47.0% (control) and increased the amount of condensate from 2.9 to 4.3 L m^{-2} day^{-1}. Henceforward, the conventional (insulated and non-cooled) SS was used as a control. When cover-cooling was used, SSE increased by 4.9 and 9.5% than the control and the amount of condensate reached 4.6 and 4.9 L m^{-2} day^{-1} at low and high water flowrates, respectively. Heat absorbers (granite) increased SSE by 7.2 and 10.8% higher than the control at low and high water flowrates, respectively. Heat absorbers alone (without cooling) increased SSE by 7.5%. The maximum amount of condensate (5.0 L m^{-2} day^{-1}) was obtained when heat absorbers were used at high flowrate. Calculations showed that for every cucumber-grown greenhouse, a total number of 23 solar stills could provide the water necessary for irrigation in places lacking freshwater sources.
Key words: Solar desalination, solar stills, greenhouse, evaporative cooler, irrigation water

INTRODUCTION

Seawater intrusion problem is negatively affecting the agricultural production in the Sultanate of Oman particularly in Al-Batinah Coastal Plains which is considered the most agricultural area in Oman (Stanger, 1985; Ahmed et al., 2001). This problem was caused by the chronic water scarcity (annual rainfall is nearly 100 mm) coupled with aggressive water-pumping from coastal groundwater aquifers (Abdel-Rahman, 1996; FAO, 1997). Due to this problem, almost 52% of the agricultural land is abandoned (Al-Ajmi and Abdel-Rahman, 2001; Al-Khamisi et al., 2012). Tremendous efforts have been done to combat and revert this situation but still the intrusion keeps on creeping inland. Therefore, adaptation strategies could be one vital solution to live with the seawater intrusion and try to benefit from its existence. In this direction, two possible techniques have been explored which are; growing salt-tolerant crops (e.g. Pearl Millet and Jatropha) and shifting from open-field cultivation to controlled-environment agriculture (mainly greenhouses). The latter was found to save almost two-thirds of the greenhouse freshwater requirement when saline groundwater was used to moisten the evaporative cooler of the greenhouse (Sablani *et al.*, 2006). This leaves only the provision of one-third of greenhouse water requirement that goes for irrigation.

Solar desalination techniques present a promising source of freshwater to meet the ever-increasing demand for freshwater caused by the continuous increase in population and industrialization (Goosen et al., 2000a). Several designs and techniques of solar desalination units/plants are available in literature. A thorough technical and historical overview on the development of solar desalination techniques is provided by several authors (e.g. Delyannis and Delyannis, 1973; Malik et al., 1982; Fath, 1998; Tiwari, 1992; Chaibi, 2000; Delyannis and Belessiotis, 2000; Farid, 2000; Tiwari et al., 2003; Tiwari and Tiwari, 2008, Kabeel and El-Agouz, 2011). One of the earliest designs is the so called "conventional" solar still that is a single basin and a single effect type (i.e. does not benefit from latent heat of condensation). This version of solar stills has undergone a serious of changes aiming at technical and economic enhancements.

Since solar desalination techniques mainly rely on the two processes of humidification (evaporation) and dehumidification (condensation), then their productivity can be augmented through the optimization of these two processes (Goosen et al., 2000b). Evaporation is potentially increased by blackening the bottom surface of the solar still basin, using heat absorbers such as charcoal, sponge cubes or metallic pieces, using wick-type materials, using reflecting mirrors, or by using black dyes (Lawrence et al., 1988; Minasian and Al-Karaghouli, 1995; Nafey et al., 2001 and 2002; Naim and Abd-El Kawi, 2002a and b; Abdel-Rehim and Lasheen, 2005). Condensation, on the other hand, can be enhanced by reducing thickness of glass covers, spraying the condensing surface with a surfactant material, placing the condensing surface in the shade, or cooling the condensing surface with a flow of water (Abu-Hijleh, 1996; Abu-Hijleh and Mousa, 1997).

This study investigates the potential of improving the productivity and effectiveness of conventional solar stills when humidification is increased with granite pieces (heat absorbers) placed in water and when dehumidification is improved by cooling the glass cover with water that is flowing out of a greenhouse evaporative cooler in order to produce the irrigation water demand of greenhouses in seawater-intruded areas.

EXPERIMENTS

These experiments are designed to achieve two objectives; to study influence of evaporation and condensation enhancements on solar still productivity and effectiveness and to determine the number of solar stills required to provide the greenhouse irrigation demand.

Four identical solar stills were constructed in the Agricultural Experiment Station (AES) of Sultan Qaboos University, Oman (Fig. 1). Each solar still was made from galvanized-steel having a floor area of 1 m^2 and 23^o inclined glass cover (3 mm thick). The bottom surface of the basin of all solar stills was painted black to increase the absorptivity of solar radiation. 55 liters of brackish water (EC = 4 dS m^{-1}) was placed inside each solar still. The brackish water evaporated due to solar heat gain and then condensed on the undersurface of the glass cover. Conductive heat loss through the sides of solar stills was curbed using 5 cm thick thermal insulation (thermal conductivity is 0.03 W m^{-1} K^{-1}). To enhance condensation, cold brackish water flowing down from the evaporative cooler of one greenhouse at AES was pumped to the upper surface of the glass cover. Two water flowrates (high and Low) over 24-hr cooling intervals were investigated. Further evaporation enhancement was done through the use of small granite pieces (locally available) in the basin of one solar still. Therefore, three cover-cooling treatments were obtained (no-cooling, low-cooling and high-cooling) and two extra-heating treatments (with and without granite pieces).

Figure 1. Four solar stills at the Experimental Station of Sultan Qaboos University.

RESULTS and DISCUSSION

From the experiments conducted during September 9 – October 1, 2013, results showed that the thermal insulation used on the sidewalls of solar stills increased the solar still effectiveness from 31.2% for the conventional solar still (non-insulated and non-cooled) to 47.0% (on average) for the insulated non-cooled solar still and increased the amount of condensate from 2.9 to 4.3 L m^{-2} day^{-1}. When the effectiveness of insulated non-cooled conventional solar still, 47%, (as a control) was compared to the effectiveness of cover-cooled stills, it was found that cover-cooling at low and high water flowrates increased the still effectiveness by 4.9 and 9.5%, respectively. Similarly, the amount of condensate increased to 4.6 and 4.9 L m^{-2} day^{-1} at low and high water flowrates, respectively. Furthermore, results indicated that the use of granite pieces as heat absorbers increased the still effectiveness by 7.2 and 10.8% at low and high water flowrates, respectively as compared to the effectiveness of the control. The use of granite pieces alone (without cooling) resulted in an increase in still effectiveness by 7.5%. It was also found that the use of granite pieces and cover cooling at high flowrate produced the highest amount of condensed water which was 5.0 L m^{-2} day^{-1}. All of these findings are illustrated graphically in Figure 2.

The condensed water had a quality similar to that of distilled water (0.008 dS m^{-1}). This means that the condensed water can be mixed with raw brackish water prior to using it in irrigation. This would increase the volume of irrigation yet it deteriorates the quality. More than 90% of greenhouses in Oman are used to grow cucumber which has a threshold salinity value of 2.5 dS m^{-1}. Thus, every 5 L of water could be added to another 8.3 L of brackish water without exceeding the cucumber threshold value. If the total wetted area in cucumber greenhouses is 74 m^2 and crop evapotranspiration is 4 mm day^{-1} (during hottest months) then a total number of 23 solar stills would be sufficient to provide the water necessary for irrigation.

CONCLUSIONS

In conclusion, solar desalination seems to be an appealing technique to provide irrigation water demand in places having brackish ground water. It was found that solar still productivity and effectiveness were significantly improved when the glass of cover was cooled using the greenhouse evaporatively-cooled water. Another significant improvement was also attained when locally-available granite pieces were used to augment water evaporation. The use of granite pieces and cover cooling at high flowrate produced the highest amount of condensed water. It was also found that 23 solar stills cooled with evaporatively-cooled brackish ground water are sufficient to provide the irrigation water demand for one cucumber-cultivated greenhouse.

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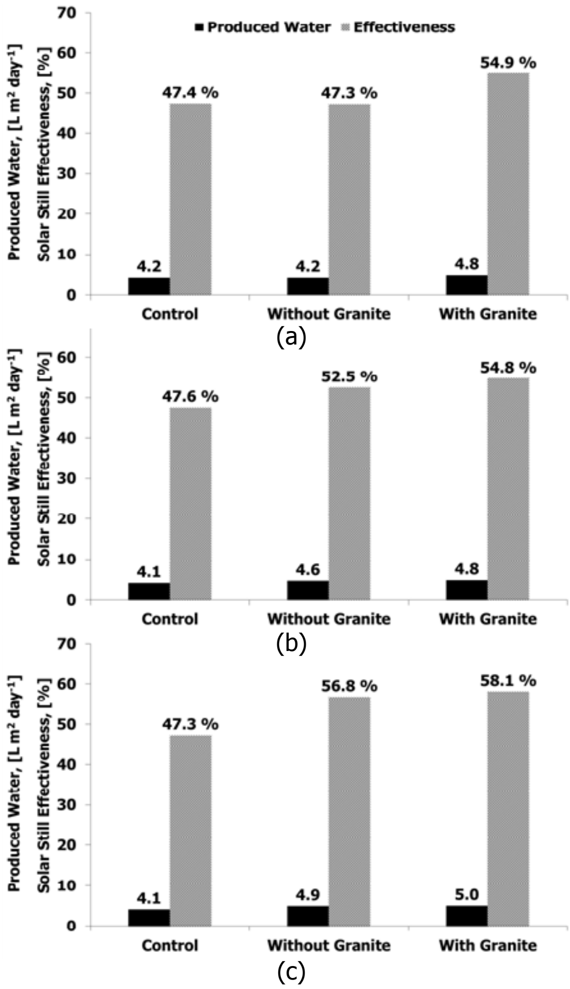

Figure 2. Water production and solar still effectiveness of three solar stills; conventional (control), without and with granite solar absorbers under three treatments; (a) no cover cooling, (b) low flowrate and (c) high flowrate of cold water cooling.

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