Journal of Advanced Science and Engineering Research Vol 4, No 2 June (2014) 118-126

Impact of Different Configurations on Solar Still Productivity

Article Info

Received: 10/3/2014
Accepted: 25/5/2014

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ISSN 2231-8844

ABSTRACT

Simple solar stills are regarded by many investigators as one of the most promising water purification techniques that have been used effectively to convert sea and brackish water into fresh water. They represent the best solution to supply remote villages and other isolated areas of small communities with fresh water. Due to its low productivity, researchers have put lots of effort to make different design in order to improve its productivity and to identify the effect of different parameters on the stills' production rates. In the present research, a comparison study has been carried out in order to explore and identify configuration effect on solar still productivity. Therefore, three solar stills with identical basin shape and dimensions, but different glass cover configuration have been designed and constructed. The first solar still has a single slope cover, the second solar still has a double slope cover, and the third solar still has a pyramid shaped cover. The experiments have been carried out under the actual outdoor conditions south of Kuwait city from 6:00 am till 7:00 pm during the months of August. It has been found that the single slope solar still produced 3.6 liters/day, the double slope solar still produced 3.95 liters/day (which represents an increase of 9.5% in comparison with the single slope solar still),while the pyramid solar still produced 4.25 liters/day (which represents an increase of 17.5% in comparison with the single slope solar still). The pyramid still has the highest productivity and this was attributed to the fact that it receives extra and more direct sun rays and having smaller space volume..

Keywords: **Desalination; Single solar still; Double solar still; Pyramid solar still**

1. Introduction

Water is the most essential matter in sustaining life. The available fresh water in the earth is limited, but the demand is growing all over the world for various purposes, due to the rapid growth of population and increasing pollution. Water scarcity around the world is increasingly becoming a very serious problem, especially for the developing countries (Rajaseenivasan et al.., 2013). Water and civilization are inseparable. A strong relationship has always linked the availability of fresh water with the population density and the evolution of civilization. Despite the fact that more than three quarters of the planet is covered with water, the available quantity of fresh and drinkable water is not only very limited, but also inappropriately distributed (El-Zahaby et al., 2011). About 97% of the world's water is saline, and more than 2 % of this water is frozen at the polar regions. Hence, less than 1% of the earth's water is available for the needs of the plants, animals and human life in rivers, lakes and ground water (Xiao et al., 2013; Shankar et al., 2012). Even this small fraction of fresh water is believed to be adequate to support life and vegetation on the earth, but unfortunately, it is not evenly distributed. The problem has been aggravated, in many parts of the world, due to pollution and contamination of fresh water resources. In addition; the ground water has been intensively exploited (Agboola and Egelioglu, 2011). Therefore, about 25% of the world populations do not have access to a quantity and quality of fresh water and more than 80 countries are facing severe water problem (Gnanadason et al., 2012). The problem is escalating and many researchers expect that about 40% of the world's population will face a shortage of a fresh water supply by the year 2015 (Ahmed et al., 2012). The present situation represents a big and serious challenge due to the ever-increasing water demand, pollution and salinity. Worldwide drought and desertification are increasing and complicating the problem (Arunkumar et al., 2012).

The situation is more critical in rural and arid areas. Gulf Region and North Africa regions have large coastal locations where seawater is abundant but fresh water is not available. Therefore there is an urgent need for clean and pure drinking water in many of these areas (|Ahmed, 2012a). To overcome these problems, seawater desalination has been shown to be the best alternative to provide fresh water for human consumption for many regions in the world such as the Arabian Gulf, Middle East and Australia (Youssef et al., 2011). Saudi Arabia is now the world's largest producer of desalinated water (about 50% of the world desalinated water) (Alramadan et al., 2012).

The majority of areas that have deficiencies in fresh water supply have huge amounts of solar energy freely available (Ahmed, 2012b). In recent years producing pure water by using solar energy has gained momentum, and solar stills are regarded by many researchers to be one of the most promising solutions to solve the water scarcity problem, mainly in remote arid areas (Aburideh et al., 2011; Murugavel and Srithar, 2012). Solar stills represent the foremost attractive and simple technique among all the distillation processes. It is particularly suited for production on a small scale, where the intensity of solar energy is considerable. It is easy to set up and needs little and cheap maintenance with low skilled labors (Rajamanickam and Ragupathym, 2012). A number of solar still units are installed for domestic utilities in West-Indian Islands, Australia and the US/Mexico border (Patel et al 2011; Foster et al 2005). The basic concept of the solar still's system operation is a direct simulation of the greenhouse effect (Panchalm et al., 2011). Because of its low productivity, solar stills are not so popular; therefore, researches have focused on studying various parameters affecting the productivity by adopting different techniques and exploring new designs to improve the still's performances and increase productivity (Dev et al., 2011). Despite all these attempts and proposed ideas by many researchers in the past three decades, the solar stills performance is still limited (Ahmed et al., 2009).

Many researchers investigated the solar stills basin water depth. Almost all researchers agreed that, the basin water depth is considered the main parameter that affects the still performance and it is inversely proportional to the productivity of still (Ahsan et al., 2014). Other researchers investigated the effect of cover inclination angle on stills productivity. Khalifa (2011) performed an extensive survey of the literature about this effect. The author concluded that the cover inclination angle is a seasonal dependent value, and it should be large in winter and small in summer. The trend obtained suggested an optimum cover inclination angle that is close to the latitude angle of the operational site. Kabeel and ElAgouz (2011) performed a review on developments on solar stills. They concluded that the still basin material plays an important role in improving the productivity of the still. The rubber basin was considered the best used material in improving the absorption, the storage and the evaporation effects. They also found that using, ink, dye, asphalt coating, sponge, fins and stepped also improve the productivity. The coupling of stills with solar collector, hot water tank, external reflector, internal and external condenser also increased the still productivity. Abdallah and Badran (2008) concluded that using sun tracking system is more effective and capable in enhancing productivity than fixed system. Al-Hinai et al, (2002) and Panchal (2008) individually performed parametric studies on conventional single slope and conventional double slope solar stills. They reported that distilled output of double slope solar still is higher compared with single slope. Fath et al. (2003) presented an analytical study as well as thermal and economic comparisons between pyramid and single slope solar still configurations. They reported that the single slope still was found to be slightly more efficient and economical than the pyramidal one.

Despite the presents of many extensive literature reviews and surveyings performed on the climatic, parameters, design, and types of solar stills no comparison has been reported linking the three configurations of simple slope, double slope, and pyramid solar stills together (Rajaseenivasan et al., 2013; Xiao et al., 201; Khalifa, 2011; Kabeel and El-Agouz, 2011; Sampathkumar et al., 2010; Varun, 2010; Aybar, 2007). The majority of the investigations tackle the effects of different parameters on specific configuration. Therefore the aim of present work is to study experimentally the performance of three different still configurations by comparing the productivity and other parameters of simple slope, double slope, and pyramid stills under the actual outdoor environment.

2. Experimental facilities

Three different configurations of solar stills have been designed and fabricated in order to experimentally evaluate and compare the parameters affecting the operation and production of single slope, double slope, and pyramid solar stills. Figure (1) shows the cross sectional diagram of the three configurations. All three stills have identical basin of 1 m^2 as shown in Figure (2). The slope of the glass cover for the three stills was 32.5° refer to the horizontal and the glass thickness was 4 mm. The single slope still shown in Figure 3 has a flat (square) glass sheet with total area of 1.2 m^2.The cover of double slope still shown in figure 4 was manufactured using two glasses (oblong) each one with area 0.593 m^2. The pyramid type cover was manufactured using four (triangle) glasses each one with area 0.296 m^2 as shown in Figure 5. The covers were attached directly to each other and on the basin and sealed using silicon sealant material. The sealant is important for efficient operation.

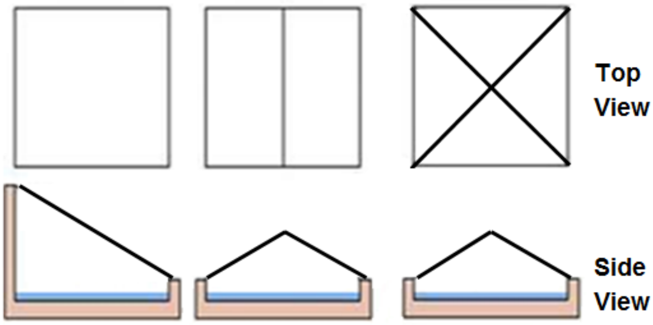

Fig.1 Solar still Cross Sectional diagram (A) Single Slope (B) Double Slope, and (C) pyramid

Fig.2. Still Basin for the three configurations

Fig.3. Single Slope Cover Arrangements.

Fig.4. Double Slope Cover Arrangements.

Fig.5. Pyramid Cover Arrangements

The basin consists of galvanized steel tank (GI gauge 20 sheet) lining by 2.54 cm insulation material (fiber glass) then supported by wooden frame using 2.54 cm wooden sheets. The inside galvanized steel is coated by powder coating black paint.

At the lower edge of all glass covers, trough were designed and fabricated to collect condensate water running down the inside surface of the glass covers. The trough is fixed with a little slope to ensure that the flow of water is towards the outlet pipe. A schematic diagram of the trough cross section is shown in Figure 6.

K-type thermocouples were used in all solar stills to measure the temperatures at seven critical locations: Basin temperature, water basin temperature, space (vapor) temperature, glass cover inside temperatures, glass cover outside temperature, collected water temperatures, and storage water in feeder temperatures. All thermocouples were calibrated. A digital thermometer was used to measure the ambient temperature.

All thermocouples for each solar still were connected to a selector switch, the selector switch connected to Humidity/Temperature Meter device.

Leveling sensors made of high quality stainless steel were used to control and maintain the water level in the basin to the required value. Each level sensor was connected to solenoid valve. The leveling sensor and the solenoid valve are operated using 240V AC. A plastic tank with capacity of 5 US Gallons was used as a water supply to each solar still.

The Daystar solar meter with a reading with accuracy of ±1 W/m^2 was used to measure the solar intensity with a maximum display reading of 1999W/m^2.

A digital anemometer was used to measure the wind speed at a position of the same of the solar stills height.

All three types of stills were positioned close to each other facing south as shown in Fig. 7.

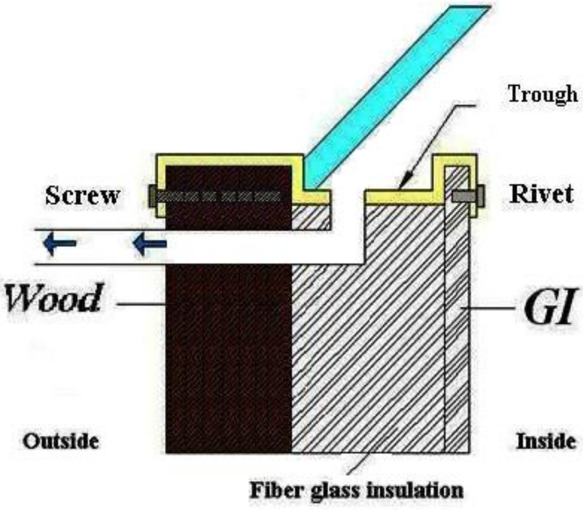

Fig. 6. Trough schematic Diagram.

Fig.7. The three stills configurations in situ

3. Results and Analysis

The experimental tests of this research has been carried out, from 6:00 am till 7:00 pm during the month of August, at Alwafra farms located in the south of Kuwait city with coordinate (Nº 28. 564549/ Eº 48.200884) and Elevation 9 m. The average wind speed was around 7.5 km/hr, the average humidity was around 10% and the peak solar intensity obtained was 998 W/m² at about 12:00 noon.

A graphic plot of the measured temperatures obtained in single slope still, double slope still, and pyramid solar still experiments are shown in Figs 8, 9 and 10 respectively. In all these figures, the highest average temperature was the basin temperature and the lowest temperature was the glass outer side temperature. The outside glass temperature is the lowest temperature due to the effect of direct wind and ambient temperature. The basin temperature is directly heated up by sun radiation.

The three solar stills accumulated production rate are shown in Figure 11. The total production for the single slope solar still was 3.613L/day, for double slope solar still was 3.957L/day, and for the pyramid solar still was 4.245L/day. The percentage increase in water production based on the single slope solar still is 9.5% for the double slope solar still and 17.5% for the pyramid slope solar still. Figure 12 shows the stills production rate on hourly basis. The highest production rate produced by the pyramid solar still may attributed to the fact that the pyramid solar still has four sides which allow more solar radiation to be trapped inside the still all day round. It may also be due to the fact that the pyramid solar still has the lowest space volume. This agrees with the finding of Alfaylakawi (2012) which stated that reducing stills space volumes increasing the stills productivity. The pyramid space volume was calculated to be 0.123 m^3 which is 33.3% lower than the space volume of the double slope solar still (0.1845 m^3) and is 66.7% lower than the space volume of the ingle slope solar still (0,369 m^3). It can be seen that after the 17:00 hour, the pyramid still production decrease in comparison to the other two still. At this time, the sun decline in such a way that it does not have a direct effect on the production rate.

To demonstrate the previous results obtained for the three different configurations, the variation of temperature difference between the basin water temperature and the glass cover inside surface Temperature (Tw-Tgi) with time is presented in Figure 13 for the three different configurations. This temperature difference may be regarded as the driving force for condensation. As can be seen from Figure 13, the pyramid solar still mostly has had the highest temperatures differences which may explain the highest productivity rate in comparison to the other two solar stills.

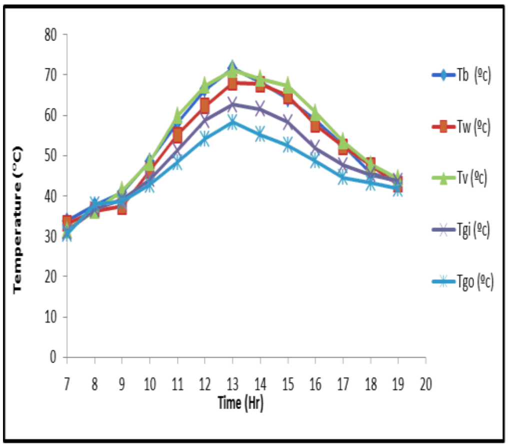

Fig.8. Measured temperatures for single slope solar still

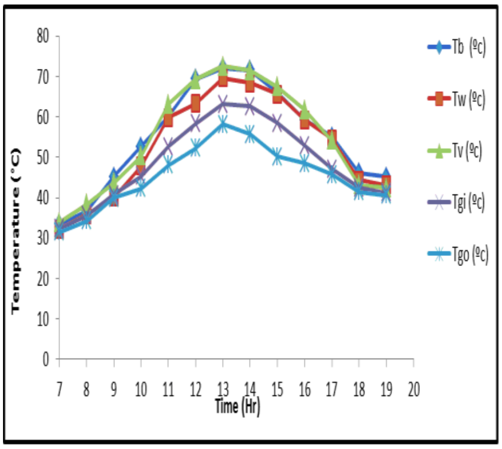

Fig.9. Measured temperatures for double slope solar still

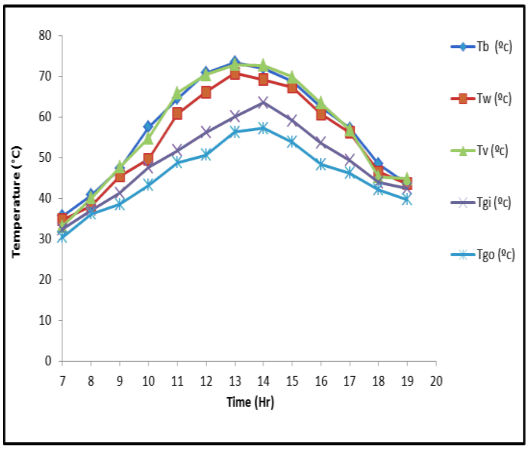

Fig.10. Measured temperatures for pyramid solar still

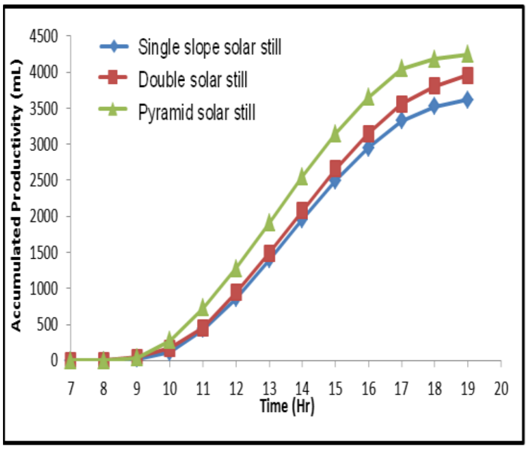

Fig. 1. Comparisons between productivity of the three stills' configurations

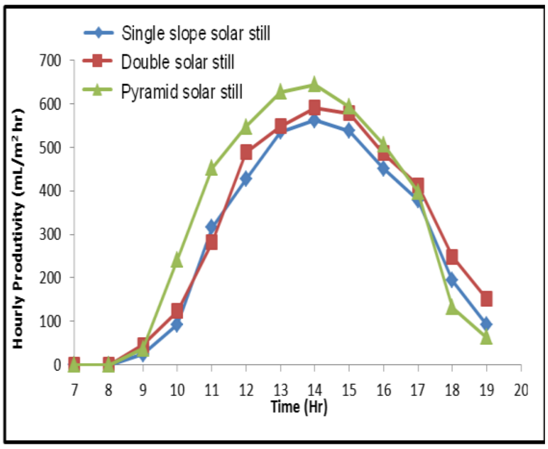

Fig.12. Comparisons between productivity of the three stills on hourly basis

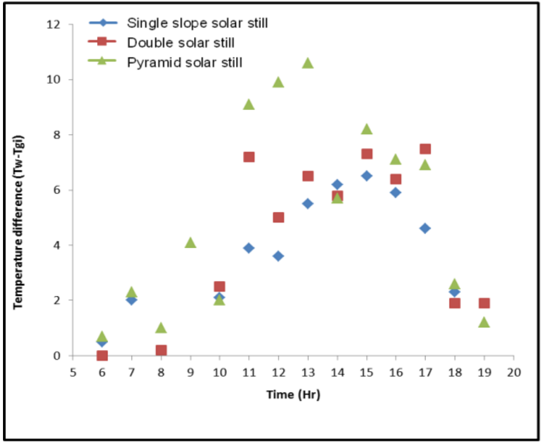

Fig.13. Temperatures difference (Tw-Tgi) for three stills' configurations

4. Conclusions

An experimental study is carried out to study the effect of different solar still configurations, The solar stills productivity was found to be 3.6L/day, 3.95L/day and 4.25L/day for single slope, double slope and pyramid stills respectively. Pyramid shape solar still enhances the productivity by about 17.5% compared to single slope solar still. The highest productivity obtained from the pyramid still may be attributed to the fact that it receives extra and more direct sun rays and having smaller space volume.

Nomenclature

Ta	Ambient temperature (°C)
Tw	Water basin Temperature (°C)
Tv	Vapor Temperature (°C)
Tb	Basin temperature (°C)
Tgi	Glass cover inner surface Temperature (°C)
Tgo	Glass cover outer surface Temperature (°C)

Tc Condensate water Temperature (°C)
Twi Inlet water temperature from the tank (°C)

References

Abdallah, S., and Badran, O. O. (2008). Sun tracking system for productivity enhancement of solar still" Desalination, 219(25): 222-230.

Aburideh, H., Deliou, A., Abbad B., Alaoui, F., Tassalit, D., and, Tigrine, Z. (2012). An experimental study of a solar still: Application on the sea water desalination of Fouka, Procedia Engineering, 33, 475 – 484.

Agboola, O. P., and Egelioglu, F. (2011). An experimental investigation of an improved incline solar water desalination system in Famagusta. Scientific Research and Essays, 6(15): 3298-3308.

Ahmed, H. M. (2012a). Experimental investigations of solar stills connected to external passive condensers. Journal of Advanced Science and Engineering Research, 2, 1-11.

Ahmed, H. M. (2012b). Seasonal performance evaluation of solar stills connected to passive external condensers. Scientific Research and Essays, 7(13), 1444-1460.

Ahmed, H. M, Al Taie, A, Alme, M. (2012). The comparison between solar water distillation with and without a cooling tube. Journal of Energy and Power Engineering, 6, 195-200.

Ahmed, M.I., Hrairi, M., and Ismail, A. F. (2009). On the characteristics of multistage evacuated solar distillation" Renewable Energy, 34, 1471-1478.

Ahsan, A.; Imteaz, M.; Thomas, U. A.; Azmi, M.; Rahman, A.; Nik Daud, N. N. (2014). Parameters affecting the performance of a low cost solar still. Applied Energy, 2014; 114: 924-930

Alfaylakawi, K. A. (2012). Experimental studies of different parameters affecting solar stills productivity. Mechanical Engineering Department, College of Engineering, Gulf University, kingdom of Bahrain.

Al-Hinai, H., Al-Nassri, M. S., and. Jubran, B. A. (2002). Parametric investigation of a double-effect solar still in comparison with a single- effect solar still, Desalination, 150,75 –83.

Alramadan, M. S., Solar plus compressor heat declinator esalinator water still" International Journal of Engineering Research and Applications 2012; 2(1): 1002-1008

Arunkumar, A., Jayaprakash, R., Denkenberger, D., Ahsan. A., Okundamiya, M. S., kumar, S., Aybar, H. S. (2012). An experimental study on a hemispherical solar still Desalination, 286, 342-348.

Aybar, H. S. (2007). A Review of desalination by Solar still. Solar Desalination for the 21st Century, 207–214.

Dev, R., Abdul-Wahab, S. A., and Tiwari, G. N. (2011). Performance study of the inverted absorber solar still with water depth and total dissolved solid. Applied Energy, 88(1), 252-264.

El-Zahaby, A.M., Kabeel, A. E., Bakry, A. I., El-Agouz, S. A., Hawam, O. M. Enhancement of solar still performance using a reciprocating spray feeding system—An experimental approach. Desalination 2011; 267: 209–216.

Fath, H.E.S., El-Samanoudy, M., Fahmy, K., and Hassabou, A. Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations Desalination 2003; 159(1): 69-79.

Foster, R. E., Amos, W., and Eby, S. (2015). Ten years of solar distillation application along the US-Mexico border, in: Solar World Congress, International Solar Energy Society, Orlando, Florida.

Gnanadason, M. K., Kumar, P. S., Jemilda, G., Jasper, S. S. Effect of nanofluids in a modified vacuum single basin solar still", International Journal of Scientific & Engineering Research 2012; 3(1): 1, 1-7.

Kabeel, A. E., and El-Agouz, S. A. (211). Review of researches and developments on solar stills. Desalination, 276(12), 1-12.

Khalifa, A. N. (2011). On the effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes" Energy Conversion and Management, 52: 431–436.

Murugavel, K. K., and Srithar, K. Performance study on basin type double slope solar still with different wick materials and minimum mass of water. Renewable Energy 2011; 36: 612-620

Patel, M. I., Meena, P. M. and Inkia, S. Experimental investigation on the single slope double basin active solar still coupled with evacuated glass tubes. International Journal of Advanced Engineering Research and Studies E-ISSN2249 – 8974 IJAERS/ 2011; (1).

Panchal, H. N. (208). Effect of various parameters on productivity of single and double slope solar still, XXXII National System conference, NSC.

Panchalm H. N., and Shah, P. K. (2011). Modelling and verification of single slope solar still using ANSYS-CFX. International Journal of Energy and Environment, 2(6), .985-998

Rajamanickam, N. R., and Ragupathym A. (2012). Influence of water depth on internal heat and mass transfer in a double slope solar still. Energy procedia, 14, 1701-1708.

Rajaseenivasan, T., Murugavel, K. K., Elango, T., Hansen, R.S. (2013). A review of different methods to enhance the productivity of the multi-effect solar still. Renewable and Sustainable Energy Reviews,17: 248–259.

Sampathkumar, K., Arjunan, T. V., Pitchandi, P., and Senthilkumar, P. Active solar distillation—A detailed review, Renewable and Sustainable Energy Reviews 2010; (14): 1503–1526.

Shankar, P., and Kumar, S. (2012|). Solar Distillation – A Parametric Review. VSRD-MAP, International Journal of Mechanical, Automobile & Production Engineeringm, 2 (1): 17-33.

Varun A. K. Solar stills: A review. Renewable and Sustainable Energy Reviews 2010; 14: 446-453.

Youssef, M. S., Kassem, Talal K., Al-Osaimy, A. S., and Hamed, A. M. Development of solar system for saline water desalination in KSA: (2011). Review, Global Journal of Pure & Applied Science and Technology, 1(2), 22-32

Xiao, G., Wang, X., Ni, M., Wang, F., Zhu, W., Luo, Z., Cen, K. (2012) A review on solar stills for brine desalination. Applied Energy, 103: 642–652