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A Novel stand-alone solar-powered agriculture greenhouse-desalination system; increasing sustainability and efficiency of greenhouses

Hassan E.S. Fath
Egypt-Japan University of Science and Technology (E-JUST), Borg El-Arab, Alexandria, Egypt
Hassan.fath@ejust.edu.eg

Akbar A. Javadi
Department of Engineering,
University of Exeter, Exeter, EX4 4QF, UK
+44 (0) 1392 723640
a.a.javadi@exeter.ac.uk

Mohammad Akrami
Department of Engineering,
University of Exeter, Exeter, EX4 4QF, UK
+44 (0) 1392 724542
m.akrami@exeter.ac.uk

Raziyeh Farmani
Department of Engineering,
University of Exeter, Exeter, EX4 4QF, UK
+44 (0) 1392 723630
r.farmani@exeter.ac.uk

Abdelazim Negm
Faculty of Engineering, Zagazeg University,
Zagazeg 44519, Egypt
amnegm@zu.edu.eg

Tapas Mallick
Environment and Sustainability Institute
University of Exeter, Cornwall, TR10 9FE, UK
+44 (0) 1326 259465
t.k.mallick@exeter.ac.uk

ABSTRACT

The countries in the Middle East and North Africa (MENA) region are suffering from the scarcity of freshwater resources. With the economic development and population growth, planning the additional water supplies is critical for this region. Desalination of saline water is, therefore, considered as a strategic alternative water resources and technology to be adopted in MENA region. On the other hand, open field agriculture in such conditions is not economical particularly with high ambient temperature and solar intensity. Agriculture Greenhouses (GH) present a suitable alternative for different plants growth for the region's desert. In most cases GHs can reduce about 90% of irrigating water demand compared open field. With the available high solar energy, integration of solar – GH – desalination presents a real challenge and is the field of newly funded N-M R&D proposal.

This paper presents an integration of solar energy, agriculture GH and suitable desalination processes targeting the development and pilot testing of a novel stand-alone system that grows its energy and irrigation water demand.

Keywords

Solar power, water desalination, greenhouse, sustainability, Agriculture.

1. INTRODUCTION

The limitations of freshwater resources and the need for additional water supply is prevalent in many regions around the world. In addition, by considering the effects of climate change, population growth and industrial and economic development, the demand for fresh water has increased. Since the economic, political and social stabilities are linked with these water resources [1, 2], different construction projects or overuse of these precious resources can cause adverse effects on other countries/states, located in the downstream levels [3]. This may also cause adverse conditions in the food production, energy planning and economics of the region. In response to these challenges, many MENA countries have started to desalinate the saline water resources. Recent improvements in desalination technologies have made it appealing for water supply [4] while sustainability and efficiency are still being studied. One of the few viable options for many nations is high-performance desalination, using solar energy (SE) as the driver for the desalination process. The intended application of desalination, also in the MENA countries, is in line with the trends to ensure the provision of fresh drinking water to all citizens, particularly those in remote areas.

So far, Multi-Stage Flash (MSF) [5] and Multiple Effect Distillation (MED) [6] are the main reliable thermal desalination technologies for very large scale plants. Reverse Osmosis (RO) [7, 8], is also another isothermal membrane technology capable of flexible capacity (from few litres/day to hundreds of thousands of m^3/day) [9]. Reverse osmosis is based on pushing saline water at high pressure through a special membrane which permits water molecules to pass by filtering the dissolved salts [10]. This technology has significantly reduced the cost of water treatment as compared to MSF and MED, especially for small unit capacities and using low salinity feed-water. Emerging methods of desalination have mostly relied on reducing the specific energy consumption and water production cost like Membrane Distillation (MD) [11], Forward Osmosis (FO) [12], Capacitive De-ionization (CDI) [13, 14], Nano Filtration (NF) [15], Humidification De-Humidification (HDH) [16-18], and Solar Stills (SS) [19]. By merging the desalination techniques, the volume of generated brine water can be reduced. One of the novel techniques in this field is integrating Solar Still (SS) and Membrane Distillation (MD) [20-23]. In such cases, the MD technology, which is highly effective for small rural communities can be utilised to produce water. SS can also be designed and easily manufactured as a reliable desalination technology.

2. SYSTEM DESCRIPTION AND METHODOLOGY

In arid regions, GHs are utilised to increase the plant's productivity and efficiency. GHs can reduce nearly 90% of migrating water compared with the required irrigation water in open flows [24].

The design of an integrated solar-driven agricultural GH-desalination system presents an exciting opportunity to support agricultural activity in hot climate conditions of Egypt and the region's remote areas where only sea or brackish water is available. A standalone system has been can be self-sufficient in energy and irrigation water. The new system utilizes the surplus solar energy during the day to produce fresh irrigation water for the GH as well as its thermal and electrical energies. The supporting components include; a semi-transparent GH roof, external solar Photo Voltaic / Thermal solar-driven RO unit and Humidification De-Humidification (HDH) desalination process. The proposed solar GH desalination system consists of a set of semi-transparent sheets placed in the GH air circulation channel (riser) (see Figure 1) that allows the light required for the plant's photosynthetic process to pass through, converting part of the excess solar energy into absorbed thermal energy. The circulating air in the riser recovers the absorbed thermal energy and uses it for water production via HDH system in the down-comer of the air re-circulation channel (2) and in the GH cavity (3). The GH riser (and downcomer) act as a thermal chimney (4), to naturally drive the ventilation / re-circulated air and eliminate the need for mechanical air fans. The system's air channel reduces the cooling load of the GH cavity through absorbing excess thermal energy and circulation of colder air. The system also recovers the plants' transpiration humidity via the outlet condenser (5). External solar Photo Voltaic / Thermal (PV/T) panels, (6), are used for system's electrical and thermal energy generation. Cooling the panels increases PV efficiency and electricity generation. The recovered thermal energy from cooling is used to support the air circulation.

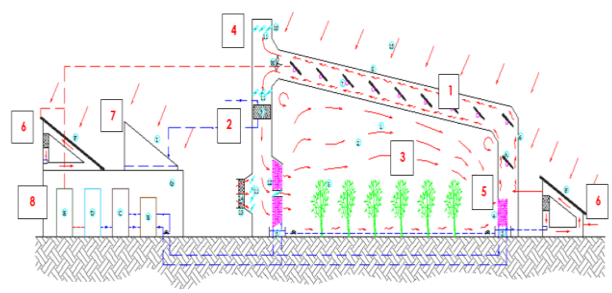

Figure 1 Conceptual configurations of solar driven GH-desalination system [25]

The Solar PVC/T panels are designed to be used in greenhouses (GH) for cultivation. The size and structure of the GH are designed based on the RO-HDH systems in order to host the bank of solar panels and the generated desalinated water is used for agricultural purposes. This helps to create new products, reduce the population density around the freshwater resources, improving the global efforts to mitigate the negative impacts of climate change.

3. RESULTS AND DISCUSSIONS

The angle of radiation highlights as an important factor that has been designed to change between 25 and 35 degrees based on the geographical location where the system is located. For the proposed GH system, a tilting mechanism is designed to change the radiation angle based on the geographical conditions. In order to optimise the number of panels, initially, the rate of distilled water from each panel was measured. It is expected each panel can produce 8-20 litres of distilled water per day, based on the geographical, climate conditions and also the solar panel efficiency.

In order to increase the efficiency of the GH, natural ventilation is used as suggested in the literature [26-29]. It has been shown that natural ventilation is effective if the outside temperature is low and the air temperature within the GH is not too high. Otherwise, the forced ventilation needs to be added to the system [30-33] in order to make the system efficient, for example in the summertime due to the high ambient air temperature.

4. CONCLUSION

The proposed system introduces the integration of panels for water desalination using RO and HDH. Simple salts precipitation process and recovery (as a by-product) and bio-fuel plants irrigation using the residual brine can significantly reduce the generated brine water. The system uses the cooling of the panels using micro-channels to enhance its electrical efficiency. The recovered thermal energy is used as the driver of the thermal desalination system.

The simplicity of assembling market-available components of the proposed desalination technology and operation is another benefit of the system. The local reproduction of the developed solar desalination unit would lead to a cost-effective system which will require minimum operation and maintenance and technical capabilities. The proposed solar desalination unit could be a module for larger and higher water capacity plants of multiple units. The current model has some limitations. In order to improve the model, the instrumentation and remotely controlled devices can be added to monitor the operation of the integrated system. The water produced from the solar panel sub-systems can be blended with part of the pretreated feed water for acceptable potable water salinity. Common supporting and auxiliary components should be added to the system for continuous and efficient operational performance.

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REFERENCES

1. Haddadin, M.J., *Water scarcity impacts and potential conflicts in the MENA region.* Water international, 2001. 26(4): p. 460-470.
2. Sowers, J., A. Vengosh, and E. Weinthal, *Climate change, water resources, and the politics of adaptation in the Middle East and North Africa.* Climatic Change, 2011. 104(3-4): p. 599-627.
3. Wu, X. and D. Whittington, *Incentive compatibility and conflict resolution in international river basins: A case study of the Nile Basin.* Water Resources Research, 2006. 42(2).
4. Ghaffour, N., T.M. Missimer, and G.L. Amy, *Combined desalination, water reuse, and aquifer storage and recovery to meet water supply demands in the GCC/MENA region.* Desalination and Water Treatment, 2013. 51(1-3): p. 38-43.
5. Khan, A.H., *Desalination processes and multistage flash distillation practice*. 1986: Elsevier New York.
6. Al-Shammiri, M. and M. Safar, *Multi-effect distillation plants: state of the art.* Desalination, 1999. 126(1): p. 45-59.

7. Greenlee, L.F., et al., *Reverse osmosis desalination: water sources, technology, and today's challenges.* Water research, 2009. 43(9): p. 2317-2348.
8. Mousa, K., A. Diabat, and H. Fath, *Optimal design of a hybrid solar-wind power to drive a small-size reverse osmosis desalination plant.* Desalination and Water Treatment, 2013. 51(16-18): p. 3417-3427.
9. Li, D. and H. Wang, *Recent developments in reverse osmosis desalination membranes.* Journal of Materials Chemistry, 2010. 20(22): p. 4551-4566.
10. Kaushal, A., *Solar stills: a review.* Renewable and Sustainable Energy Reviews, 2010. 14(1): p. 446-453.
11. Alklaibi, A.M. and N. Lior, *Membrane-distillation desalination: status and potential.* Desalination, 2005. 171(2): p. 111-131.
12. Cath, T.Y., A.E. Childress, and M. Elimelech, *Forward osmosis: principles, applications, and recent developments.* Journal of membrane science, 2006. 281(1-2): p. 70-87.
13. Oren, Y., *Capacitive deionization (CDI) for desalination and water treatment—past, present and future (a review).* Desalination, 2008. 228(1-3): p. 10-29.
14. Ghazy, A. and H.E. Fath, *Solar desalination system of combined solar still and humidification–dehumidification unit.* Heat and Mass Transfer, 2016. 52(11): p. 2497-2506.
15. Hilal, N., et al., *A comprehensive review of nanofiltration membranes: Treatment, pretreatment, modelling, and atomic force microscopy.* Desalination, 2004. 170(3): p. 281-308.
16. Nafey, A., et al., *Solar desalination using humidification dehumidification processes. Part I. A numerical investigation.* Energy conversion and management, 2004. 45(7-8): p. 1243-1261.
17. Nafey, A., et al., *Solar desalination using humidification–dehumidification processes. Part II. An experimental investigation.* Energy conversion and management, 2004. 45(7-8): p. 1263-1277.
18. Giwa, A., H. Fath, and S.W. Hasan, *Humidification–dehumidification desalination process driven by photovoltaic thermal energy recovery (PV-HDH) for small-scale sustainable water and power production.* Desalination, 2016. 377: p. 163-171.
19. Fath, H.E., et al., *Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations.* Desalination, 2003. 159(1): p. 69-79.
20. Qtaishat, M.R. and F. Banat, *Desalination by solar powered membrane distillation systems.* Desalination, 2013. 308: p. 186-197.
21. Hassan, A.S., et al., *Dynamic performance of vacuum membrane distillation system.* Desalination and Water Treatment, 2016. 57(48-49): p. 23196-23205.
22. Janajreh, I., D. Suwwan, and H. Fath, *Numerical Simulation of the Flow in the Direct Contact Membrane Distillation Flow.* 2014.
23. Hassan, A.S. and H.E. Fath, *Review and assessment of the newly developed MD for desalination processes.* Desalination and Water Treatment, 2013. 51(1-3): p. 574-585.
24. Armanuos, A.M., A. Negm, and A.H.M. El Tahan, *Life Cycle Assessment of Diesel Fuel and Solar Pumps in Operation Stage for Rice Cultivation in Tanta, Nile Delta, Egypt.* Procedia Technology, 2016. 22: p. 478-485.
25. Hassan, G.E., et al., *Optimum operational performance of a new stand-alone agricultural greenhouse with integrated-TPV solar panels.* Solar Energy, 2016. 136: p. 303-316.
26. Boulard, T. and B. Draoui, *Natural ventilation of a greenhouse with continuous roof vents: measurements and data analysis.* Journal of Agricultural engineering research, 1995. 61(1): p. 27-35.
27. Fatnassi, H., et al., *SE—Structures and Environment: Ventilation Performance of a Large Canarian-Type Greenhouse Equipped with Insect-Proof Nets.* Biosystems Engineering, 2002. 82(1): p. 97-105.
28. Demrati, H., et al., *SE—Structures and Environment: Natural ventilation and microclimatic performance of a large-scale banana greenhouse.* Journal of Agricultural Engineering Research, 2001. 80(3): p. 261-271.
29. Teitel, M. and J. Tanny, *Natural ventilation of greenhouses: experiments and model.* Agricultural and Forest Meteorology, 1999. 96(1-3): p. 59-70.
30. Fuchs, M., et al., *Effects of ventilation on the energy balance of a greenhouse with bare soil.* Agricultural and Forest Meteorology, 1997. 86(3-4): p. 273-282.
31. Willits, D., *Cooling fan-ventilated greenhouses: a modelling study.* Biosystems engineering, 2003. 84(3): p. 315-329.
32. Kittas, C., M. Karamanis, and N. Katsoulas, *Air temperature regime in a forced ventilated greenhouse with rose crop.* Energy and buildings, 2005. 37(8): p. 807-812.
33. Kittas, C., N. Katsoulas, and A. Baille, *Influence of greenhouse ventilation regime on the microclimate and energy partitioning of a rose canopy during summer conditions.* 2001.