17th International Computing & Control for the Water Industry Conference
1-4 September 2019, Exeter, United Kingdom

A stand-alone Zero-Liquid-Discharge greenhouse model with rainwater harvesting capability

Maxime Porcheron[1], Mohammad Akrami[1], Akbar Javadi[1], Raziyeh Farmani[1], Abdelazim Negm[2], Hassan Fath[3]

[1]Department of Engineering, University of Exeter, Exeter, EX4 4QF, UK
[2]Faculty of Engineering, Zagazeg University, Zagazig 44519, Egypt
[3]Egypt-Japan University of Science and Technology (E-JUST), Borg El-Arab, Alexandria, Egypt
a.a.javadi@exeter.ac.uk

Keywords: Greenhouse, Zero-Liquid-Discharge, rainwater harvesting

EXTENDED ABSTRACT

Introduction

Global warming is a prevalent topic throughout the world. The IPCC [1] predicts that the maximum potential global temperature increase will be 4.8 °C by 2100. It has been concluded that a temperature rise of 1.4 °C or higher will have statistically significant impacts on global precipitation levels. Therefore, there is a need to investigate the future trends of precipitation and subsequent irrigation methods [2]. This study will discuss a new multi-functional zero liquid discharge (ZLD) system for a greenhouse, incorporating a humidification dehumidification (HDH) mechanism, solar still desalination and rainwater harvesting. The focus of this paper is on analysing the water production of the system. Although previous literature discusses the inefficiency of solar still (SS) desalination [3], the fresh water produced during similar experiments has shown otherwise, desalinating 0.95 L/m²/hr of saline water [4]. Using multiple panels could therefore give a substantial output of distilled water for certain usage such as agriculture. Implementing solar stills of large surface area would also allow the collection of rainwater thus increasing the total water productivity of the system. The ZLD system aims to produce no waste product and use the output brine water for aquaculture and salt cultivation.

Methods and Materials

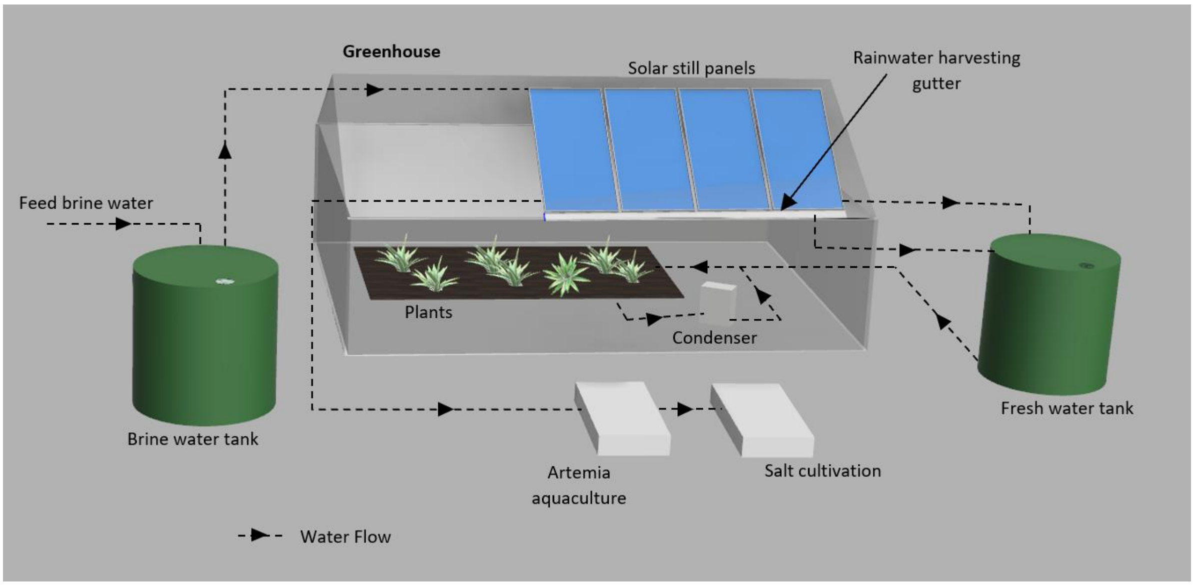

Figure 1. Conceptual model of the zero liquid discharge and desalination system

The conceptual model of the system is shown in Figure 1. The model consists of a feed of saline/ brackish water into a tank using a pump. This is fed to aluminium framed solar still panels each covered by a polycarbonate membrane [4], positioned on the roof of the greenhouse and used to produce desalinated water. Solar stills used the solar irradiance to evaporate water absorbed by an absorbing fabric. This evaporation process leaves the salt and impurities behind. A percentage of the input water is distilled and collected in the fresh water tank. The concentrated brine water from the solar still is recycled back into the system for further distillation (Figure 1). Once concentration levels are high, the brine will be stored in ponds/tanks for Artemia aquaculture. Some of this brine can also be used to cultivate salt which can be used locally.

A condenser is used to liquify the high level of humidity generated by the plants and entrapped by the greenhouse air. This fresh water can therefore be recycled to water plants or stored in the freshwater storage tank. Ensuring that there is a limited amount of loss due to ventilation, a ZLD system is therefore created. Water losses are recovered using saline water from nearby sources as well as rainwater harvested by the large surface area of the solar still panels which will be subsequently stored in a fresh water tank. By continuous monitoring of the soil moisture, irrigation is adjusted using the fresh water storage tank to provide additional fresh water to supply the plants' need. This system analysis was performed by manufacturing solar stills and building a single gable glass greenhouse, purchasing a dehumidifier and crops. This system ran continuously to analyse the productivity of water production of each component for sustainable agriculture within the greenhouse obeying a zero-liquid discharge. Continuous digital data for the temperature (°C) and relative humidity (%) inside and outside the greenhouse as well as the solar intensity (Wm^{-2}) throughout a day was recorded. A thermocouple was also implemented on the inside and outside of the polycarbonate membrane to investigate the correlation between the temperature difference and the rate of condensation. Fresh water level was recorded every 24 hours to examine the amount of water lost or gained by the system. Photovoltaic panels were implemented to power pumps, condenser and electrical monitors to ensure the high stand-alone sustainability of the scheme in this greenhouse system. Experimentation were completed in the United Kingdom.

Results and Discussion

Due to the limited amount of solar irradiance in the United Kingdom compared to countries in the MENA region, the low water output from the desalinating panels which are found to be 10-100ml per day per panel can be recovered by the additional precipitation collected by the large solar still panels into gutters. The HDH system showed a water output between 3000-9000ml in a single day during an average relative humidity of 55%. The experiment proved the feasibility of the system and implementing it in hotter countries such as Egypt where high solar intensity is expected to produce 15-20 litres of distilled water per panel per day. Although rainwater harvesting will be limited, it can still collect and store water during an event of rain preventing rainwater from ground runoff therefore reducing the likelihood of contamination. Connecting panels in series as shown in figure 1, the projected water output from this ZLD configuration will exceed 100 litres a day. Although this irrigation system focuses on agriculture, the excess water could well be used for drinking and other purposes requiring purified water. The highly concentrated brine water is therefore used for the aquaculture of Artemia shrimps which are mainly used as preys, and can be used by local farmers to feed fish due to their high nutritional benefits [5].

Conclusions

Overall, this study analyses the irrigation of a ZLD system targeted for less economically developed countries in need of fresh water for agriculture. Under any climatic conditions, this system delivers a substantial amount of water from various elements, proving a multi-functional system. Large tanks are used to store brine and fresh water during rainy seasons to use during dry seasons. The system can run continuously, sustainably for prolonged period of time.

Acknowledgement

We acknowledge the British Council (BC) and Science & Technology Development Fund (STDF), Egypt for supporting this research paper through funding the project titled "A Novel Standalone Solar-Driven Agriculture Greenhouse - Desalination System: That Grows its Energy and Irrigation Water" via the Newton-Musharafa funding scheme (Grants ID: 332435306 from BC and ID 30771 from STDF.

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