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ScienceDirect

Energy Procedia 110 (2017) 262 – 267

Energy Procedia

1st International Conference on Energy and Power, ICEP2016, 14-16 December 2016, RMIT University, Melbourne, Australia

Combined thermoelectric power generation and passive vacuum desalination

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Abstract

This paper proposes a passive water desalination system combined with thermoelectric power generation. Desalination is achieved by reducing the saturation temperature of saline water through vacuum. The vacuum is generated using 5 m of negative head (drop), which significantly reduces the boiling temperature of water. The thermoelectric generator unit (TEGU) uses four thermoelectric cells to generate electricity using Seebeck effect. The cold side temperature of TEGU is maintained by the reduced saturation temperature of saline water, and temperature for hot side can be provided by low grade heat source, e.g. solar, waste heat. The heat transfer through the system is a transient to steady state conduction, and theoretical calculations show that an absolute pressure of 50 kPa can be achieved in the system which reduces the saturation temperature to around 80 °C. Thermal resistance and heat flow networks are used to validate fresh water output, evaporation, and condensation rates based on input heat. The objective is to achieve proof of concept through experimental model, and thermal analysis. Further research is directed into elimination of non-condensable gases in the system and use of passive condensation techniques to reduce energy input.

Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.

Keywords: Passive Vacuum Desalination; Thermoelectric Generator Unit; Seebeck effect; Saturation temperature; Low grade heat; Negative head; Sensible heat; Latent heat; Vaporization.

1. Introduction

The increasing scarcity of fresh water is becoming a primary concern for most of the nations on the planet. At the current growth rate, the population on the planet is estimated to be 8.9 billion by 2050, and the critical level of water required for basic human needs is approximately at 1000 m^3/capita, annually, according to Date, A. et. al [1]. The fresh water currently available on the planet accounts for only 3%, while the remaining 97% is sea-water. Nearly 700

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Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.
doi:10.1016/j.egypro.2017.03.137

million people, across 39 countries, lack access to fresh water, and this figure is forecasted to rise to 1.9 billion by 2050 according to Date, A. et. al [1]. The primary sources for 3% of fresh water are glaciers, rivers, lakes, groundwater, and rainfall. In dry countries such as Israel, Saudi Arabia, Australia, and parts of Africa, where the sources of fresh water are not available, the focus is on desalinating sea water. Therefore, desalination technology is vital for locations with fresh water shortages. This paper focuses on theoretical and experimental analysis of a desalination system that operates through passively created vacuum using 5 m negative head (drop). The system also incorporates a thermoelectric Generator Unit (TEGU) consisting of four thermoelectric cells and heat spreaders to generate electricity. Through this paper, a brief evaluation of existing technologies, design of proposed system, theoretical estimation, and experimental results are presented. The aim of the design is to generate a proof of concept with focus on passive vacuum generation, efficiency of TEG heat spreaders, evaporation of saline water at reduced saturation temperature, and fresh water output. Although the overall efficiency of the system is expected to be low compared to other desalination systems, significant reduction in energy input makes the system economical, and sustainable

Nomenclature

T	temperature (°C)
R	thermal resistance (°C/W)
$\dot{Q}$	rate of thermal energy (W)
TEGU	thermoelectric generator unit
HE	heating element
HS	heat spreader
sw	saline water
fw	fresh water
Ves	vessel
cond	condenser
amb	ambient
sen	sensible heat
lat	latent heat
TE	thermoelectric cell

2. Overview of existing technology

Until today, most of the operating desalination plants around the world utilize Reverse Osmosis (RO) technology which consumes large amount of electrical energy to force the sea-water across membranes. Chennan Li, Yogi Goswami, and Elias Stefanakos [2], reviews current desalination technologies which can utilize solar energy to reduce the dependence on electricity generated by fossil fuels. According to Chennan Li, et.al. [2], solar energy harvesting system is integrated to existing desalination processes such as Multi-Stage Flash(MSF), Electro-dialysis (ED), Heat-pump desalination, Solar Stills, and so on, as a hybrid solution to reduce the energy consumption. But, the integrated hybrid systems still prove to be expensive, with the operation, and output of the plant depending on location and climate. According to Gude, V.G. and N. Nirmalakhandan [3], current desalination technologies either require high quality energy from burning fossil fuels or have limitations such as low efficiency, and low solar yield based on geographical location. The use of negative head to create a passive vacuum was tested in the experiments conducted by Al-Kharabsheh, and D. Yogi Goswami [4, 5]. The experiment uses a drop of 10 m to generate absolute pressure of 3.7 kPa. The prototype desalination system of Veera Gnaneswar Gude and Nagamany Nirmalakhandan [3], uses similar principle to create a vacuum, which enables desalination at low pressure and low temperature, so that the system is suitable to use low grade waste heat. The system uses a 10 m column of water to achieve a constant vacuum of 8.6 kPa which desalinates saline water at a low temperature of 50°C. The system was able to achieve the highest fresh water output of 6 liters per day. In the desalination system designed by G. Venkatesan, S.Iniyan, and Purnima Jalihal [6], vacuum in the evaporator chamber is generated using negative head, and the industrial waste sea water at high temperature is flashed in the evaporation chamber due to reduced saturation temperature. According to theoretical and experimental simulations of Mohammad Abutayeh, D. Yogi Goswami, and Elias K. Stefanakos [7], the desalination system was able to achieve 35 kPa of vacuum using a negative head of 10 m.