UNIVERSITI PUTRA MALAYSIA

DESALINATION OF REVERSE OSMOSIS EFFLUENT USING INTEGRATED SOLAR POND WITH SOLAR STILL SYSTEM

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By

OSAMAH ABDULHAMEED KADHIM AL-MUSAWI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

Auguet 2016

DEDICATION

To my parents, my brothers, and my sisters,
To my wife for all her contribution, patience and understanding throughout my master study, she incredibly supported me and made it all possible for me,
To my daughters Maryam and Rahmah,

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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August 2016

Chairman : Professor Fakhru'l-Razi B. Ahmadun, PhD
Faculty : Engineering

A hybrid system of mini solar pond combined with single-slope still was used to increase the production of the distilled water from R.O rejections and to harness the generated thermal energy from this mini solar pond. This study is focused on the solar distillation coupled with solar pond technique as a renewable energy method in Iraq and as a case study for desalination of R.O rejects with no negative ecological effects. This eco-friendly system has a potential to maintain in the reduction of the fossil fuel energy consumptions, water supply by reusing RO effluents and maintenance of the up-stream environmental water sources. The solar pond and solar still were manufactured from steel and isolated by glass-wool with a set of isolation piping to conserve the amount of the heat captured. The meteorological data was collected (near to Baghdad) and system was observed during the period of study (50 days). Daily efficiency and recovered water were studied for 12 working hours per day, and the optimum value of mass flux was 12 kg/m^2.day of the R.O. effluent. The experiment and theoretical calculations were carried during 50 days in May, June, and July 2015. Climatic conditions during the experiment were mentioned and collected throughout the period of study. Experimental tests showed the temperature profiles of the mini solar pond and the maximum temperature was 64 °C at the LCZ of the mini solar pond with an efficiency of ~10.8 %. The productivity of distilled water obtained from the solar still alone, solar still integrated with mini solar pond, and sunshade added to the system was tested ~ 1.25, 2.5, and 2.77 kg/m^2.day, respectively. Add to that, the efficiency of water production was evaluated ~ 24.8%, 29%, and 30.5%, respectively. The improvement percent was ranged ~ (66% - 70%) for the evaporation rate of the system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGURANGAN DALAM KESAN ALAM SEKITAR REVERSE OSMOSIS MENOLAK OLEH POND SOLAR

Oleh

OSAMAH ABDULHAMEED KADHIM AL-MUSAWI

Ogos 2016

Pengerusi : Profesor Fakhru'l-Razi B. Ahmadun, PhD
Fakulti : Kejuruteraan

Sistem hibrid kolam solar mini digabungkan dengan satu cerun masih digunakan untuk meningkatkan pengeluaran air suling dari penolakan R.O dan memanfaatkan tenaga haba yang dihasilkan dari kolam solar mini ini. Kajian ini memberi tumpuan kepada penyulingan solar ditambah pula dengan teknik kolam solar sebagai kaedah tenaga boleh diperbaharui di Iraq dan sebagai kajian kes untuk penyahgaraman R.O menolak dengan tiada kesan ekologi negatif. sistem yang mesra alam ini mempunyai potensi untuk mengekalkan dalam pengurangan bahan api fosil konsumsi tenaga, bekalan air dengan menggunakan semula efluen RO dan penyelenggaraan up-aliran sumber air alam sekitar. The kolam solar dan solar masih dibuat dari keluli dan diasingkan oleh kaca bulu dengan satu set paip pengasingan untuk menjimatkan jumlah haba yang ditangkap. Data meteorologi dikumpulkan (berhampiran Baghdad) dan sistem diperhatikan sepanjang tempoh pengajian (50 hari). kecekapan setiap hari dan air yang dijumpai akan belajar selama 12 jam kerja dalam sehari, dan nilai optimum fluks jisim adalah 12 kg / m2.day daripada r.o. yang efluen. Percubaan dan pengiraan secara teori telah dijalankan sepanjang 50 hari pada bulan Mei, Jun dan Julai 2015. keadaan iklim penting eksperimen telah dikumpulkan sepanjang tempoh pengajian. ujian eksperimen menunjukkan profil suhu kolam solar mini dan suhu maksimum 62-64 ° C di LCZ kolam solar mini dengan kecekapan ~ 10.8%. Selain itu, produktiviti air suling yang diperolehi daripada solar masih bersendirian, solar masih bersepadu dengan kolam solar mini, dan pelindung matahari ditambah ke dalam sistem telah diuji ~ 1.25, 2.5 dan 2.77 kg / m2.day, masing-masing. Tambah itu, kecekapan pengeluaran air dinilai ~ 24.8%, 29%, dan 30.5% masing-masing. Peningkatan peratus telah berkisar ~ (66% - 70%) bagi kadar penyejatan sistem.

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I am indeed grateful to my parents, my wife, my daughters Maryam and Rahmah for their endless support and encouragement. I would also like to express my heartfelt thanks to my brothers and sisters for their help. Special thanks go to my wife's mother, for their loving and support.

I certify that a Thesis Examination Committee has met on 25 August 2016 to conduct the final examination of Osamah Abdulhameed Kadhim Al-Musawi on his thesis entitled "Desalination of Reverse Osmosis Effluent using Integrated Solar Pond with Solar Still System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Name of Member of Supervisory Committee: Dr. Dayang Radiah B. Awang Biak

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Name of Member of Supervisory Committee: Dr. Anees Abdullah Khadom

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The input net radiation flux from the (NCZ) which move into lower (heat store) layer (LCZ).

The input net radiation flux from the (UCZ) which transfer into intermediate layer (NCZ).

The amount radiation flux at depth x_2.

The amount radiation flux at depth x_1.

Emissivity of water surface.

Humid heat capacity of air.

Surface area of wall sides of the pond.

Refraction angle at the pond's surface.

Incident angle at direct radiation to horizontal plane with zenith angle (normal).

Monthly average insolation incident on horizontal surface from the sun.

Latent heat of vaporization of water.

Partial pressure for the water surface temperature in UCZ.

Partial pressure of water vapor at the ambient air.

Atmospheric pressure.

The transient heat by conduction(Q out of the upper zone (UCZ) into the surrounding of solar pond.

The transient heat by conduction(to the zone from the next layer into the preceding layer in solar pond (from NCZ to UCZ).

The transient heat by conduction(to the zone from the next layer into the preceding layer in solar pond (from LCZ to NCZ).

The thermal energy (heat) input.

The net collected thermal energy (heat) at each layer in the solar pond.

Thermal energy (heat) output from solar pond, it is also heat loss.

Q_{solar}	The fallen net amount of solar irradiation which captivated by solar pond at (UCZ).
$Q_{surrounding}$	Heat loss into the surroundings from the (UCZ).
Q_{wall}	Heat loss through sides of the pond.
T_{LCZ}	Temperature at the lower convective zone.
T_{NCZ}	Temperature at the non- convective zone (NCZ).
T_{UCZ}	Temperature at the upper convective zone (UCZ).
$T_{amb.}$	Ambient temperature.
T_{sky}	The sky temperature.
U_{wall}	Wall heat transfer coefficient.
X_2	Thickness of NCZ layer.
X_3	Thickness of LCZ layer.
h_c	Convection heat transfer coefficient.
q_c	Heat lost as a result of convection to surrounding.
q_e	Heat lost due to evaporation.
q_r	Heat lost radiation in the upper zone to surrounding.
H	Specific humidity in kg water vapor per kg dry air in the mixture.
LCZ	The lower convective zone or the heat storage zone.
NCZ	The intermediate convective zone or the non-convective zone.
UCZ	The upper convective zone of the solar pond.
X_1	Thickness of the UCZ layer.
Hx_3	The amount radiation flux at depth x_3.
K	Thermal conductivity of water.
N	The day of the year ($1 \leq N \leq 365$).
V	Average monthly wind speeds.

h	Local time.
α	Latitude angle.
ζ	Declination angle.
σ	Stefan-Boltzman's constant.
ω	Hour angle which it defines as an angular gauge of the time measured from noon according to local time h.
m_d	Specific fresh water production.
h_e	The corresponding mass transfer coefficient
P_w	Vapour pressures of water inside basin still at basin temperature (T_w).
P_g	Vapour pressures of water at cover temperature (T_g).
$h_{c,wg}$	Convective coefficient for the still.
T_w	Temperature of the water basin in still
T_g	Temperature the glass cover in still
ηi	Efficiency of solar pond.
η	Efficiency of solar still.
A_{ss}	Solar still area.
T.D.S	Total dissolved solids.
T.H.	Total hardness.
E.C.	Electrical conductivity.
T.S.S	Total suspended solids.
M.Alk.	M. alkalinity test.

CHAPTER 1

INTRODUCTION

1.1 Introduction and background of the study

The nexus of water and energy interconnected together with so many features of the frugality, humanity and the environment. Water is fundamental to the continuance of lifecycle. Energy is important as water for the growth because it influences on the actions of all mankind. Water demands of the worldwide are predicted in increase about 55% by 2050. The accessibility of potable-water would be worried, furthermore with around 40% of the worldwide population is forecasted to live at the shortage water regions by 2050 (Water, U. N., 2014).

Desalination is the process of removing salt from water to produce potable water. Potable water is termed as containing less than 1000 mg/L of salts or total dissolved solids (T.D.S). The World Health Organization has a drinkable water taste threshold of 250 mg/L, and the U.S. Environmental Protection Agency (EPA) has secondary standards of 250 mg/L chloride and 500 mg/L as T.D.S (Greenlee et al., 2009). The Reverse Osmosis membrane (RO) technology was developed more than 40 years ago to contribute 44% of the world desalination capacity and 80% of the desalination units constructed worldwide (Greenlee et al., 2009). A substantial rejected salty water quantity from desalination plants by RO was approximated around 25-30% from the feed water to any reverse osmosis unit (Younos, 2005). Most of the rejected flow is deposited into sources of water such as the main watercourses, natural water bodies, canals and seaways or landfill with lagoons. Salt removal process is a power exhaustive know-how particularly utilising salt-water (water with high total dissolved solids). As a result, desalination incurred abnormal costs and too enormous carbon outline when the different salt removal processes utilized regular energy suppliers.

The overall ecological effects of desalination as well as general costs can be reduced by increasing the uses of sustainable desalination processes. According to NASA, Iraq has excellent solar beams with the range of irradiation from 1800 to 2390 kw/m^2/yr (Kanan et al., 2014; NASA website, 2015). The sustainable energy is the suppliers of energy that use other than coal, gas and oil or their close by products, plus nuclear energy, which do not depend on the burning of fossil fuels or splitting atoms. The increasing attention in this field of study comes from the undesirable impacts of pollution from the burning of fossil fuels. Fortunately there are many ways of harnessing energy which has less damaging effects on our environment (Raluy et al., 2005).

1.2 Problem statement

In general, the rejects of reverse osmosis units have high solute concentration than feed water. The reject solutions are discharged to upstream sources of raw water or disposed to landfill which effect on water sources as they increase salinity and influence marine life or increase salinity of groundwater.

The high solute concentrate can be disposed-off in an environmentally benign manner by evaporating to get extra water recovery and reduce the amount of disposed solutes to the source water. Moreover, this disposed solute can be used to produce salts after subjecting to the drying process. The high solute concentrate can be recovered in different processes such as evaporation in which recovered water and became usable. The evaporation process of the reject solutes will be required to consume further energy consumption (thermal energy) which can be produced by combustion of fossils fuels and then lead to grow in air pollution and rise in cost. So that, it is better to use renewable energy for the complete evaporation process and water recovery which it is suggested idea in this work. In this study, this technique of solar pond combined with solar still is more practical suggestion which positively reflect in reducing thermal energy consumption with clean water production and subsequently reduce the effect of salinity.

1.3 Justification of study

This study has a potential to lessen the ecological effects generated from rejected reverse osmosis despoil, brackish water from marshlands and other widespread water bodies in Iraq. The solar pond integrated solar still was applied as a new technology for energy/water recovery. In the Middle East region, Iraq is one of the countries that are mostly struggling to encounter the increasing needs for water and energy facilities. Iraq has been handling the poorest energy crisis since 1991 until now.

The lack in energy provision leads to the quick depleting of electricity power and the shortcoming concerning the necessity of electricity supply and equipping to this country is enlarging each day. Hundreds of pastoral villages and rural communities are occupying the Iraqi marshlands and suffering from the shortage of any variety of water. However, these outlying districts and distant lands commonly have considerable solar radiation capacity. This capacity can be utilised by the solar desalination notions and systems explicitly capable to provide drinkable water to these areas.

Solar ponds are often brought up as an example of a power source that developing countries can easily operate; easy to design; cheap to build; a maintenance cost inexpensive due to remove accumulating salt crystals; no external storage mechanisms of the absorbed energy because it is a part of the system; It can be used to desalinate water; and it is extremely environmentally friendly.

Solar desalination techniques have little running and maintenance outlays compared with great equipment parts and could be used in isolated territories as high initial investment. In addition to that, concentrated waste removal is feasible and the most important of all is that the setbacks of the desalination ecological technology were observed on the location and management for desalination services. However, the sun irradiation power as the first-hand solar salt removal techniques is gratis, easily obtainable during daylight as well as the availability of the reasonable beneficial energy productivity amount. This type of technology is very evolving that it could be set up effortlessly and no carbon dioxide is increased on the air and the ecological influences into air contamination and water contamination are minimal.

1.4 Objectives of research

The aims of this study are harnessing the collected thermal energy by mini solar pond from landing sun beams and also exploiting this type of sustainable energy to increase the solar still productivity. Therefore, the objectives can be summarized as:

1. To design, construct, and test mini solar pond integrated with single-slope solar still for decreasing the consumption of fossils fuels energy through passing the rejects from reverse osmosis membrane to mini solar pond which considers one of renewable energy techniques.

2. To evaluate the efficiency of solar pond coupled with solar still and assess the amount of water production.

1.5 Scope of work

RO reject was chosen and brought from reverse osmosis unit of Shatt Al-Basra and analysed in chemical laboratory. Manufacturing and fabrication works were done in the workshop to prepare the solar pond plus solar still system and to run many trails for evaluation of this system. A field study and data collection with the experimental work have been employed in this research. The mathematical equations concerning with experiments have been applied and the governing equation for each layer to compute the benefited thermal energy was proposed. Water recovery from the solar still has been calculated by utilising the mathematical equations and estimating the efficiency of the system.

1.6 Significant of the study

The significance of the study is treatment of RO rejects by eco-friendly system which lead to mitigate the salinity in the upstream of water sources and water production by using this system from RO reject to supply the water requirements in Iraq. By the implementation of solar pond with solar still combination system could lead to reduce the effect of the disposed water reject and protect the marine life in Iraq and to investigate the techniques of the renewal energy for desalination.

1.7 Research layout

This thesis is organized into five chapters; Introduction with the background of the study, problem statement, research objectives, and the justification of study are explained in the first chapter. The second chapter is covers the literature review with historical background for the solar pond, solar still, and the water/energy requirements with the challenges in the world as well as the mathematical model equations used in this research. The research methodology is presented in the third chapter which also describes the experimental method and equipment design and explains the materials and instruments utilized in the fabrication system with observation. In the fourth chapter, the results and discussion of data analysis of the study are presented. In addition to that, the implementation of the mathematical equations for solar pond connection with solar still runs and displays by the Excel Microsoft program are illustrated. The conclusion and the future work with the recommendation are summarised in chapter five. Finally, the research ends with references and appendices.

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