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DIRECT CURRENT HEATER- ASSISTED TRIANGULAR SOLAR STILL FOR WATER PRODUCTION

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DIRECT CURRENT HEATER- ASSISTED TRIANGULAR SOLAR STILL FOR WATER PRODUCTION

By

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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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May 2013

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This study involves the design and development of a panel heater triangular solar still (PHTSS) for producing distilled water from saline and contaminated water. The PHTSS was fabricated with cheap, lightweight and locally acquired and durable materials for easy maintenance. The PHTSS consists of a trough, main frame, polythene cover, support structure, DC heater and solar PV system. A number of field experiments were carried out using seawater, pond water and synthesized salt water of varying salt percentages (1, 2, 3 and 5% salt). The variation of temperatures, relative humidity and the solar radiation were monitored along with the hourly water production. The effect of initial water depth on the production was obtained and an inverse relationship was found between them. Other relationships were also obtained namely, between the daily solar radiation and daily production, between the temperature difference (cover-water) and daily water production, and between the average ambient air temperature and daily production. The water quality analysis of the feed and product water

was performed before and after the experiments, respectively. The water quality parameters tested were pH, redox, electrical conductivity, salinity, total dissolved solids (TDS), Escherichia coli (E.coli) and arsenic for feed and product water. The results obtained from the laboratory tests were then compared with various drinking water standards and found that most of the values were within the acceptable ranges provided by the standards. The daily productions of PHTSS are 79.8, 81.3, 77.3 and 43.9% higher than the TSS on July 20, October 1, September 20 and September 24, 2012, respectively. It was found that on average the production of PHTSS is 70.5% higher than the TSS and the highest total daily production of PHTSS is 4.7 kg/m^2/day. The relation between the daily water production and the solar radiation shows a positive linear relation, i.e. when solar radiation increases the daily production also increases. A linear proportional relationship is also obtained between the daily production and the temperature difference between water and cover. The relation between the daily production and the salt concentration is inversely proportional, i.e. increasing the salt concentration in feed water will decrease the production. An inverse relationship is also observed between the daily production and the initial water depth. A few models developed earlier (Dunkle, Murugeval et al., Ahsan and Fukuhara) cannot precisely predict the production flux of PHTSS; however the proposed model can reproduce well the production flux. Finally, it is concluded that the PHTSS is capable of producing distilled water from saline and contaminated water and can be applied to remove arsenic, pathogen and TDS as well.

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

PEMANAS ARUS TERUS- MEMBANTU PENYULINGAN SURIA SEGI TIGA UNTUK PENGELUARAN AIR

Oleh

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Kajian ini melibatkan reka bentuk dan pembangunan panel pemanas penyulingan suria segi tiga (PHTSS) untuk menyediakan air suling daripada air masin dan air tercemar. PHTSS telah direkabentuk dengan menggunakan bahan-bahan yang murah, ringan dan mudah diperolehi dari bekalan tempatan yang tahan lama untuk memudahkan penyelenggaraan. PHTSS terdiri daripada bekas tadahan, kerangka utama, sarung penutup, struktur sokongan, pemanas dan sistem PV. Beberapa uji kaji telah dijalankan menggunakan air laut, air kolam dan air garam yang mengandungi peratusan garam yang berbeza. Perubahan suhu, kelembapan relatif dan radiasi solar telah dipantau bersama-sama dengan pengeluaran air setiap jam. Kesan kedalaman air pada awal ujikaji mempengaruhi pengeluaran air bersih dimana hubungan songsang diperolehi. beberapa hubungan yang lain juga diperolehi, contohnya antara sinaran suria harian dan pengeluaran harian, antara perbezaan suhu (penutup dan air) dan pengeluaran air harian, dan di antara purata suhu udara luar dan pengeluaran

harian. Kualiti air telah dijalankan sebelum dan selepas eksperimen. beberapa parameter kualiti air seperti pH, redoks, kekonduksian elektrik (EC), jumlah pepejal terlarut (TDS), kemasinan, Escherichia coli (E-coli) dan arsenik untuk makanan telah diuji. Pengeluaran air yang terhasil kemudiannya dibandingkan dengan pelbagai piawaian air minum dan didapati bahawa kebanyakan nilai diperolehi dalam julat yang boleh diterima yang disediakan oleh piawaian. Pengeluaran air harian untuk PHTSS adalah 79,8, 81,3, 77,3 dan 43.9% lebih tinggi daripada TSS pada 20 Julai, 1 Oktober, 20 September dan 24 September, 2012. Oleh itu, purata pengeluaran air harian PHTSS adalah 70.5% lebih tinggi daripada TSS dan pengeluaran air harian tertinggi bagi PHTSS dicatatkan sebanyak 4.75 $kg/m^2/day$. Hubungan antara pengeluaran air setiap hari dan jumlah sinaran suria menunjukkan hubungan linear yang positif, iaitu apabila sinaran suria meningkatkan pengeluaran harian juga meningkat. Satu hubungan berkadar linear juga diperolehi antara pengeluaran harian dan perbezaan suhu antara air dan penutup. Hubungan antara pengeluaran harian dan kepekatan garam menunjukkan hubangan yang berkadar songsang dimana peningkatan kepekatan garam dalam air akan mengurangkan pengeluaran air PHTSS. Hubungan yang songsang juga diperolehi antara pengeluaran air harian dan kedalaman air. Beberapa teori model pengiraan (Dunkle, Murugeval et al, Ahsan dan Fukuhara) tidak menunjukkan pengeluaran air dari PHTSS yang tepat, namun model yang dicadangkan boleh menunjukkan pengeluaran yang hampir tepat. Akhir sekali, kesimpulan yang dapat dibuat didapati PHTSS mampu menghasilkan pengeluaran air harian daripada air masin dan air tercemar, ia juga dapat menghilangkan arsenik, patogen dan juga TDS.

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I certify that a Thesis Examination Committee has met on 17th May 2013 to conduct the final examination of Nur Syuhada binti Ahmad on her thesis entitled "Direct Current Heater Assisted Triangular Solar Still for Water Production" 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 submitted to the Senate of 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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DECLARATION

I hereby declare that this thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it is not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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NUR SYUHADA BINTI AHMAD

Date:

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LIST OF ABBREVIATIONS

ADWG	Australia Drinking Water Guidelines
BBC	British Broadcasting Corporation
BDWS	Bangladesh Drinking Water Standards
EC	Electric Conductivity
EPA	Environmental Protection Agency
EU	European Union
IPCC	Intergovernmental Panel Climate Change
ORP	Oxidation- Reduction Potential
OSHA	Occupational Safety and Health Administration
PHTSS	Panel Heater Triangular Solar Still
ppb	Part per billion
ppm	Part per million
PVC	Polyvinyl Chloride
RM	Ringgit Malaysia
RMSE	Root mean square error
TDS	Total Dissolved Solids
TSS	Triangular Solar Still
UNEP	United Nations Environment Programmed
UPM	Universiti Putra Malaysia
US	United States
USEPA	US Public Environment Protection Agency
WHO	World Health Organization

Nomenclature

A	Area (m^2)
A_w	Area of water surface (m^2)

B	Width of trough (m)
C	Constant
C_p	Specific heat capacity (J/kg K)
D_v	molecular diffusion coefficient of water vapor (m^2/s)
d	Glass thickness (mm)
g	Gravitational acceleration (9.807 m/s^2)
Gr	Grashof number
Gr'	Modified Grashof number
h_{1w}	Total internal heat transfer coefficient ($W/m^2/K$)
h_{ew}	Evaporative mass transfer coefficient from water to humid air (m/s)
h_{cw}	Convective heat transfer coefficient between water surface and humid air ($W/m^2/K$)
h_{fg}	Latent heat of vaporization (J/kg)
h_{rw}	Radiative heat transfer coefficient between water surface and cover ($W/m^2/K$)
k	Thermal conductivity (W/m°C)
$K_{\circ}$	Diffusion coefficient of the water vapor (kg/m.s. Pa)
L	Length (m)
L	Latent heat of evaporation (J/s)
m	mass (kg)
$\dot{m}_{ew}$	Hourly productivity (kg)
M_v	Molecular weight of the water vapor (18.016 kg/kmol)
Nu	Nusselt number
P	Hourly production mass flux ($kg/m^2/hr$)
P_g	Partial vapor pressure at glass temperature (N/m^2)
P_w	Partial vapor pressure at water temperature (N/m^2)
Pr	Prandtl number
q_{cw}	Convective heat flux between water surface and humid air (W/m^2)
q_{ew}	Evaporative heat flux from water surface to humid air (W/m^2)

q_{rw}	Radiative heat flux between water surface and cover (W/m^2)
Q	Heat transfer, energy (W)
Q_{cc}	Convective heat transfer between cover and atmosphere (J/s)
Q_{cdha}	Condensation heat transfer between humid air to cover (J/s)
Q_{cha}	Convective heat transfer between humid air and cover (J/s)
Q_{cw}	Convective heat transfer between water surface and humid air (J/s)
Q_{ew}	Convective heat transfer between cwa and atmosphere (J/s)
Q_{cc}	Evaporative heat transfer from water surface to humid air (J/s)
Q_{rc}	Radiative heat transfer between cover and atmosphere (J/s)
Q_{rw}	Radiative heat transfer between water surface and cover (J/s)
Q_{tha}	Convective heat transfer between trough and humid air (J/s)
Q_{tw}	Convective heat transfer between trough and water (J/s)
q_{ew}	Rate of evaporative heat transfer (W/m^2)
R	Universal gas constant (8315 J/kmol/K)
R_s	Solar radiation flux (W/m^2)
R_v	Specific gas constant of the water vapor (461.5 J/kg.K)
RH	Relative humidity (%)
Ra	Rayleigh number
t	time (s)
T	Temperature (K)
T_c	Cover temperature (°C)
T_a	Ambient temperature (°C)
T_{ha}	Humid air temperature (°C)
T_g	Glass temperature (°C)
T_w	Water temperature (°C)
$\overline{T}$	Average temperature (°C)
U	Overall heat transfer coefficient (W/m^2 K)
W_h	Hourly evaporation mass flux ($kg/m^2/hr$)

Greek symbols

α	Absorption coefficient
β	Volumetric thermal expansion coefficient (1/K)
μ	Dynamic viscosity (kg/m.s)
θ	Solar incidence angle, degree
$\in$	Emissivity
Δt	Time interval
ΔT	Temperature difference between water surface and cover (K)
ρ	Density (kg/m^3)
ρ_v	Water vapor density (kg/m^3)
ν	Kinematic viscosity (m^2/s)

Subscripts

a	Ambient air or atmosphere
av	average
b	Basin
c	Cover
c	Convection
e	Evaporation
g	Glass
ha	Humid air
t	Trough
sky	Sky
vw	vapor on the water surface
vha	vapor in humid air

w	Water

CHAPTER 1

INTRODUCTION

1.1 Introduction

Many people have been suffering from the shortage of safe drinking water in arid, remote and coastal areas in India, China, Kenya, Ethiopia, Nigeria, Peru, Bangladesh, USA and many other countries of the Arabian Gulf (Figures. 1.1-1.2) (Tiwari and Tiwari, 2008). Although water covers about two-thirds of the Earth's surface, most is too salty for use and only 2.5% being fresh water as shown in Figure 1.3. Of these freshwater resources, about 24 million km^3 or 70% is in the form of ice and permanent snow cover in mountainous regions, the Antarctic and Antarctica regions (UNEP, 2011).

Figure 1.1: Women gather at a well to collect water at India (Reuters, 2009)

Figure 1.2: People queuing for water in Bangladesh (Bolsover, 2010)

In 1999, UNEP reported that 200 scientists in 50 countries had identified water shortage as one of the two most worrying problems for the new millennium (UNEP, 2000). According to the United Nations (2009), about 1.1 billion people cannot have easy access to safe drinking water (BBC, 2000; UNESCO, 2006). The population will increase from the current 6.6 billion on 2007 to 9.3 billion by the year 2050, but the total world water resources will remain the same and no increase. The United Nations (2009) and World Bank (2008) warned that the world needs to act urgently to avoid a global water crisis (United Nations, 2009; World Bank, 2008; Picow, 2009)

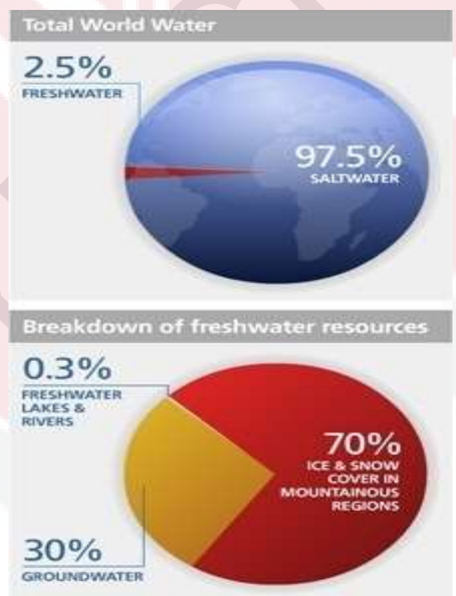

Figure 1.3: Total world water and breakdown of fresh water resources
(UNEP, 2011)

1.2 Problem Statement

The rise of seawater level associated with global warming has caused seawater intrusion towards inland in many parts of the world, e.g. Australia, Grand Cayman, Bahamas, Barbados, Bangladesh, Belize, Jamaica, USA and Vietnam (Confalonieri et al., 2007; Nasreen et al., 2006; Gyan, 1998; Loáiciga et al., 2009). According to IPCC (2007) sea-level rise will not only extend areas of salinity, but will also decrease freshwater availability in coastal areas (Confalonieri et al., 2007). In 2007, the salinity of groundwater aquifers was studied along the coastal area of north Kelantan, Malaysia and it was found that the groundwater in the second aquifer (about 6 km far from the beach) was brackish, with chloride concentration ranged from 500 to 3,600 mg/L probably due to the intrusion of seawater (Samsudin et al, 2006).

Massive scale arsenic (As) contamination in groundwater is a major concern in many countries, e.g. Argentina, Mexico, Chile, USA, Taiwan, Mongolia, Thailand, The Philippines, China, Japan, New Zealand, Vietnam, Cambodia, India, Bangladesh and Nepal (Dhaka Community Hospital, BD, 2003; British Geological Survey, 2001). Drinking of arsenic contaminated water has been linked with skin problems, cancer, cardiovascular diseases, neurological diseases, eye problems and other diseases (Chen et al., 1985; Smith et al., 2002). A sustainable integrated technology to remove both arsenic and pathogen could save millions of human lives.

Generally, Malaysia is not facing shortage of fresh water because Malaysia has enough water supplies. The amount of raw water is generally beyond the needs of the Malaysia population but due to the uneven population distribution especially in rural areas in Sabah and Sarawak, the treated water cannot be supplied due to the hilly topography and logistic problems. Many of the rural people still use water from river, well and others as the main sources of water supply. The problem is sometimes the water is contaminated from nearby development and also due to the excreta of animals and birds, it also decrease the source of water.

To meet the rising demand of fresh water using solar distillation technique is becoming popular from the viewpoints of simple operation, use of only solar energy that is environmentally friendly and zero emission of carbon dioxide, and low installment and operation cost. Other researcher (Singh et. al, 2011; Robio-Carda et. al, 2002 and Wassouf et. al, 20011) have investigated on different designs of simple type of solar still. They used only solar radiation as heat energy and found that the daily water production were minimal. Therefore, a new type distillation, Panel Heater Triangular Solar Still (PHTSS), is designed to meet the requirements by this study where it used DC heater connected to a solar panel and solar radiation as heat energy to produce more water production.

1.3 Objectives

A new type of high efficiency solar distillation, the Triangular Solar Still coupled with a solar panel and a heater, referred to as Panel Heater Triangular Solar Still (PHTSS), is designed and developed to produce distilled water using the solar energy in this study. The specific aims are as follows:

1. To design and fabricate a panel heater triangular solar still (PHTSS) to produce distilled water from saline and contaminated water.
2. To evaluate the production efficiency of the PHTSS by field experiments.
3. To evaluate the quality of the water produced by the PHTSS.
4. To propose an empirical relationships to predict the hourly production flux of the PHTSS.

1.4 Scope of Study

The scope of this study was focused on distillation using solar energy to produce fresh water (potable water) from saline water and contaminated water. A few parameters such as ambient temperature, solar radiation, relative humidity and temperature inside the still were monitored to find the contributing factors. The experimental data was compared with the predicted values (by simulation models) to determine the accuracy of the model.

1.5 Limitations of Study

There were several limitations to complete this project and to achieve the objectives of the project. Due to these limitations, it may affect the accuracy of the outcome and expected results. The limitations were:

i. Errors in experimental measurement especially in weighing the amount of distilled water production would have affected the accuracy of the results if inadequate readings are taken.

ii. The surface area of the trough is quite small that may affect the heat energy absorption and evaporation rate. If the bigger surface of trough was used, it can patch more feed water and the production water also will be increased.

iii. In order to operate efficiently, solar still should be reasonably airtight to avoid leaking of water vapor before condensation and production.

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