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Performance evaluation of inclined copper-stepped solar still in a wet tropical climate

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ABSTRACT

In this study, an evaluation on the efficiency of an inclined copper-stepped solar still was performed through theoretical and experiment. Inclined trays were used to increase the efficiency of a system. The theoretical calculations and the experiment were conducted by the Faculty of Engineering and Built Environment, UKM, Bandar Baru Bangi, Selangor. Experimental data was utilized to test the theoretical model and the results show good acceptance between the experimental and theoretical data. The convective, evaporative, and radiative heat transfer coefficients and the water productivity and efficiency were calculated for each hour. The findings revealed that the maximum hourly productivity in the inclined copper-stepped solar still for the theoretical and experimental were 474 mL/m^2 h and 605 mL/m^2 h. Additionally, the daily efficiency varied between 28.33 and 29.5% for the inclined copper-stepped solar still from September to December 2016.

1. Introduction

Water covers about 70% of the earth [1]. Fresh water is the greatest gift from God, and there would not be life without water. Water is required not only for humans but also for all kinds of life on the planet [2–5]. Potable water is an essential in improvement of nations and countries [4,6]. Existing sources of fresh water are scarce to meet lasting needs [7]. Fresh water resources are depleted as fewer than 0.5% of the total fresh water supply of the earth originate from groundwater and rivers [8,9], the remaining 97% of the plant's water is in the ocean, and another 2% is frozen in the polar regions [4,10], the depletion of natural freshwater has become a major issue in several countries around the world, especially with population explosion, improvement of standard of living, promotion of industry and agricultural activities [7]. Water is abundant in nature. On the other hand, many places around the world lack of fresh water supply [11,12].

Living standards have increased, but 2,000,000 persons pass away yearly due to water insufficiency and shortages [13]. Approximately more than 1 billion people do not have the privilege of drinkable water supplies. The amount of drinkable water needed to meet personal needs is one thousand cubic meter per capita per year. One hundred and sixty-six million people were living below this level in 1995. Therefore, it is estimated as 2050 approaches, almost1.7 billion people from 39 states will fall under this level [14]. Because of the number and diversity of water problems, there is no lone key to meet the water needs of a given state [13].

Fresh water is generally polluted by industrial and agricultural activities, causing water-borne diseases. Water-borne diseases are diseases carried by water that affect human health. To solve these issues, numerous advanced desalination technologies have been developed using either thermal or membrane processes. These systems can have desalting capacity ranging up to 10,000 kg of water per day. The most general technique of exposure (flash distillation and reverse osmosis) cannot separate all clean water from brackish or contaminated source and should be discharged at a concentration of up to 50% of the intake [15]. This inefficiency can influence global warming and is associated with increased economic setbacks [16].

There is no doubt that solar still distillation systems are widely used for the desalination of seawater [4,17,18]; therefore, in arid areas with shortage of potable water but have inexpensive land and plenty of solar intensity, the utilization of solar energy can be an another choice for alternative source of heat [19–21]. The utilization of solar stills as an inexpensive and basic tools for supplying consumable water with minimal environmental impacts is of great research interest [22,23].

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Nomenclatures

A_b	Area of basin liner (m^2)
A_g	area of glass (m^2)
A_w	area of water (m^2)
$C_{p,b}$	specific heat of the basin (J/kgC)
$C_{p,g}$	specific heat of the glass (J/kgC)
$C_{p,w}$	specific heat of the water (J/kgC)
K_i	thermal conductivity
L_i	thickness of the insulation
m_b	mass of basin (kg)
m_{ew}	water productivity, (kg/m^2)
m_g	mass of glass (kg)
m_w	mass of water (kg)
$h_{e,w\text{-}g}$	evaporative heat transfer coefficient from water to cover (W/m^2C)
$h_{r,w\text{-}g}$	radiative heat transfer coefficient from water to cover (W/m^2C)
$h_{r,w\text{-}sky}$	radiative heat transfer coefficient from water to sky (W/m^2C)
$I(t)$	solar radiation on the horizontal surface (W/m^2)
P_g	partial pressure at cover temperature (N/m^2)
P_w	partial pressure at basin water temperature (N/m^2)
$Q_{e,w\text{-}g}$	evaporative heat transfer from water to cover (W/m^2)
$Q_{c,b\text{-}w}$	convective heat transfer from base to water by conduction (W/m^2)
$Q_{c,g\text{-}sky}$	convective heat loss from cover to sky (W/m^2)
$Q_{c,w\text{-}g}$	convective heat transfer from water to cover (W/m^2)
$Q_{r,g\text{-}sky}$	radiative heat loss from cover to sky (W/m^2)
$Q_{r,w\text{-}g}$	radiative heat transfer from water to cover (W/m^2)
Q_{loss}	heat side loss from basin to ambient (W/m^2)
T_a	ambient temperature (°C)
T_g	glass temperature (°C)
T_b	basin temperature (°C)
T_{sky}	sky temperature (°C)
T_w	water temperature (°C)
V	wind velocity in (km/h)
U_b	side heat loss coefficient from basin to ambient (W/m^2C)
η	efficiency of solar still (%)
ε_{eff}	emissivity between water and cover (−)
ε_g	emissivity of glass (−)
ε_w	emissivity of water (−)
α_b	absorptivity of basin material (−)
α_g	absorptivity of glass cover material (−)
α_w	absorptivity of water (−)
σ	Stefan-Boltzmann constant (5.67×10^{-8} $W/m^2 K^4$)

The stepped solar still is well known for its maximum production capacity in comparison with conventional (basin) solar still [24].

The water production rate of solar stills is insufficient, which is considered to be the main partition to be implemented instead of advance desalination techniques. Metrological, design and operational parameters are the main reason for its low productivity. In spite of this obstacle, solar still desalination is a proper key for fresh water deficiency; though its weak yield prevents its use [25]. Several research carried out to enhance solar still productivity based on multiple variables that plays a role in manipulating the efficiency of the system [26], which ranges between 2.5 and 5 ($L\,m^{-2}\,d^{-1}$), by either seawater desalination or groundwater purification [27]. To enhance solar still water production, numerous studies have been carried out by theoretical and experimental investigations [9,27–44]. Different techniques include semicircular absorber solar still with baffles [45], bubbling column type, solar water heater and the integration of PV/T collectors into basin type solar stills, pulsating heat pipe, parabolic trough collectors, double basin waste heat recovery, parabolic concentrator, to enhance the yield of fresh water [26]. It is commonly understood that only passive solar stills are economically efficient in providing pure water [41].

Prediction performance of solar stills over the world was conducted via mathematical under different metrological conditions. Dunkle [46] derived a widely used and widely analysed semi-empirical relationship for estimating the mass transfer and internal heat within solar distillation units. A Dunkle's relationship is an empirical relationship is commonly used. Referring on this relationship, solar still desalination techniques with different designs have been analysed by various studies [47].

The main objectives of this research are to examine the performance of the inclined copper-stepped solar still in a wet tropical climate; to carry out a numerical analysis of an inclined copper-stepped solar still; and to validate the distillate output, outer glass cover, water temperature and basin (tray) plate temperature using theoretical and experimental data.

2. Experimental setup

A prototype inclined copper-stepped solar still was invented and installed outdoors in the parking area of the new administration building at the Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, UKM, Bandar Baru Bangi, Selangor. The study was carried out over three months during the wet season from of September 2016 to December 2016, from hour 8 am to hour 19 pm. Here, this case is carried out in an almost stable tropical climate throughout the year as an overall profile and there are slight differences in the main inputs (solar radiation, ambient temperature) during the rest of the month [48]. In addition, researchers conducted another period of desalination study. In [49], 2 weeks of expensive laboratory and site studies are utilized to test solar intensity even in New Mexico State University's South Mexico New Mexico state. In addition, [50]6 days outdoor experience uses transportable solar hemispheres under Iranian Dhahran climatic conditions [34]. Carried out an experimental study in Iran using an integrated basin solar still with a sandy heat reservoir for 3 days. Based on the characteristics of tropical climate and literature, the use of 3 months of continuous data cannot affect the purpose of this study [51].

The system photograph is shown in Fig. 1. With inner dimensions of W 1.2 m, L 1.8 m, and H 0.20 m, consisting of 28 trays made from copper sheets that were 1 mm thick with a 60° inclination angle for the purpose of increasing the thermal capacity of the system, as copper has high thermal capacity (k = 390 W/mK) compared to steel and aluminium [11,52,53]. Therefore, the copper can ensure extra water production and efficacy. The basin (copper trays) firstly receive solar

Fig. 1. Photograph of the inclined stepped solar still.