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Theory and experimental investigation of a weir-type inclined solar still

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Abstract

A weir-type solar still is proposed to recover rejected water from the water purifying systems for solar hydrogen production. This consists of an inclined absorber plate formed to make weirs, as well as a top basin and a bottom basin. Water is flowed from the top basin over the weirs to the bottom collection basin. A small pump is used to return the unevaporated water to the top tank. Hourly distillate productivity of the still with double- and single-pane glass covers was measured and the latter showed higher production rates. The average distillate productivities for double- and single-pane glass covers are approximately 2.2 and 5.5 l/m^2/day in the months of August and September in Las Vegas, respectively. Mathematical models that can predict the hourly distillate productivity are developed. These compared well with the experimental results. Productivity of the weir-type still with a single-pane glass was also compared with conventional basin types tested at the same location. The productivity of the weir-type still is approximately 20% higher. The quality of distillate from the still is analyzed to verify the ability of the still to meet the standards required by the electrolyzers.

Keywords: Solar still; Distillation; Hydrogen; Weir-type still; Renewable; Theoretical; Experimental; Electrolyzer; Double-pane glass

1. Introduction

The ever-increasing need for energy and environmental concerns has focused much attention on sustainable energy resources. An important drawback of renewable energy sources such as solar and wind is their intermittent nature. Making hydrogen, which can be stored and used on demand, using renewable sources allows the intermittent resources to be decoupled from the use. The University of Nevada, Las Vegas Center for Energy Research, is developing a hydrogen filling station at the Las Vegas Valley Water District (LVVWD). An electrolyzer is a component of this project, which makes hydrogen from water through electrolysis. Pure water needed for the electrolyzer is conventionally obtained from a water purifying system consisting of a de-ionizer (DI). The proposed project consists of a DI system, which rejects 8 l/h while using 1 l/h. Water is a precious commodity and recovering a significant portion of the rejected water is an important aspect of this project. A solar still can be used for this purpose.

Unlike other distillation methods, solar stills use solar energy to distill water in an environmentally friendly manner. These are broadly divided into passive and active types. Passive stills are further divided into basin and inclined types. Extensive research was reported on different methods to improve the productivity of these stills [1–10]. The important parameters affecting the performance of a still are also reported [11]. The level of water on the absorber surface has been shown to be an important factor affecting the productivity [11]. Still performance was shown to increase with thinner water films [11]. This can be achieved by different designs of the absorber surface. Common designs are inclined [2] and stepped [5] absorber surfaces. In an inclined still, water flows from the top to the bottom of the absorber surface. To maintain uniform thickness of water, a wick, which draws water through capillary effect, is used. Stills with inclined absorber surfaces are reported to have significantly higher productivity compared with basin-type stills [2,6,8]. A new design combining the advantages of both inclined and basin-type

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Nomenclature

A area of the absorber plate (weirs) (m^2)
A_{Bbasin} area of the bottom basin (m^2)
A_{TBasin} area of the top basin (m^2)
b breadth of the sill (m)
C_w specific heat of water (J/kg K)
g acceleration due to gravity (m/s^2)
Gr Grashof number
h_b bottom loss coefficient from basin to the ambient ($W/m^2 K$)
h_{cw} convective heat transfer coefficient from water surface to the glass cover ($W/m^2 K$)
h_{ca} convective heat transfer coefficient from glass cover to the ambient ($W/m^2 K$)
h_{cb} convective heat transfer coefficient from bottom to the ambient ($W/m^2 K$)
h_{ew} evaporative heat transfer coefficient from water surface to the glass cover ($W/m^2 K$)
h_{cgi} convective heat transfer coefficient between glasses of double-pane glass ($W/m^2 K$)
h_{rgi} radiative heat transfer coefficient between sheets of double-pane glass ($W/m^2 K$)
h_{gi} total heat transfer coefficient between glasses of double-pane glass ($W/m^2 K$)
h_{1w} total heat transfer coefficient from water surface to the glass cover ($W/m^2 K$)
h_{rb} radiative heat transfer coefficient from bottom to the ambient ($W/m^2 K$)
h_{rw} radiative heat transfer coefficient from water surface to the glass cover($W/m^2 K$)
h_{1g} total heat transfer coefficient from glass cover to the ambient ($W/m^2 K$)
H length of the still (m)
I solar radiation incident on the glass cover of the still (W/m^2)
k thermal conductivity (W/m K)
L characteristic length between glasses of double-pane cover (m)
l latent heat of evaporation (J/kg)
L_i thickness of insulation (m)
$\dot{m}_{ew}$ hourly distillate productivity (kg/h)
$\dot{m}_w$ mass flow rate of water over the absorber plate (kg/s)
m_{TBasin} mass of water in the top basin (kg)
m_{BBasin} mass of water in the bottom basin (kg)
$\bar{N}u$ average Nusselt number
Pr Prandtl number
P_w partial vapor pressure at water temperature (N/m^2)
P_g partial vapor pressure at glass temperature (N/m^2)
Ra Rayleigh number
T_a ambient temperature (°C)
T_g glass temperature (°C)
T_{gi} inner glass temperature (°C)
T_{go} outer glass temperature (°C)
T_w water temperature (°C)
$T_{WTBasin}$ temperature of water in the top basin (°C)
$T_{WBBasin}$ temperature of water in the bottom basin (°C)
TDS total dissolved solids (mg/l)
TOC total organic carbon (μg/l)
t time (s)
U_b overall bottom heat loss coefficient ($W/m^2 K$)
U_L overall heat loss coefficient ($W/m^2 K$)
U_t overall top loss coefficient ($W/m^2 K$)
V wind velocity (m/s)

Greek letters

ε_{eff} effective emissivity
ε emissivity
σ Stefan–Boltzman constant, 5.67×10^{-8} ($W/m^2 K^4$)
β slope of the still
β^1 volumetric thermal expansion coefficient (K^{-1})
ν kinematic viscosity (m^2/s)
α thermal diffusivity (m^2/s)
γ surface azimuth angle
γ_s solar azimuth angle
τ_w fraction of solar energy transmitted to water through glass cover
Δt time-step

solar still was also proposed [7]. The performance of a stepped still is also reported to have higher productivity [5]. An important issue with these designs is the formation of scale on the absorber surface, which significantly effects the absorptivity of the surface and hence the productivity of the still. A weir-type still with a nylon wick, and a small circulation pump to recover sensible energy of water leaving the absorber plate is proposed in this project.

The temperature difference between the water and condensing surfaces is an important factor affecting the productivity of a solar still. A higher temperature difference between these surfaces yields higher productivity. To maintain this temperature difference, various methods were proposed [12,13]. Unlike solar collectors, a double-pane glass reduces the productivity of a solar still by reducing the temperature difference between the water and condensing surfaces. To verify this fact the productivity of the still with both single- and double-pane glass are compared. To predict the performance of different types of solar stills, various mathematical models are proposed. In the present study, a mathematical model was developed to compare with the experimental results based on the model proposed by Shukla et al. [14].