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Characteristic equation of double slope passive solar still

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ABSTRACT

In this paper, a new approach has been made to obtain the characteristic equation of a double slope passive solar still (DSPSS) based on experimental observations. The performance of DSPSS has been analyzed for the composite climatic condition of New Delhi, India. To obtain the characteristic equations under quasi-steady state condition, regression curves have been plotted for instantaneous gain and loss efficiencies with respect to a non-dimensional representative factor $(\{(T_w-T_a)/I(t)\}/\{(T_w-T_a)/I(t)\}_{max})$ of climatic and operational parameters together. From the analysis, it has been concluded that non-linear characteristic curves are more accurate for analyzing the performance, thermal testing and further design modification depending upon various parameters associated with design, climatic and operational conditions.

1. Introduction

Water is one of the precious resources to man. It is used in many activities such as drinking, washing and irrigation etc. But man is facing scarcity of fresh water due to poor water management, pollution and ignorance over the decades. It is becoming a challenge to avail of low cost fresh water to mankind. Several technologies such as Reverse osmosis (RO), Multistage flash (MSF) and Distillation etc., have been developed to overcome this problem. These technologies use electrical power which is an environmental concern because a large portion of this power is generated by coal or gas based power plants [1]. Hence a water purification technology having the ability to protect the environment with reliability, renewability and affordability, is highly desirable for solving the problem of potable water.

Solar distillation can be a good solution for production of fresh water. It is a process of purifying brackish and underground water by using solar energy [1]. Many scientists have worked on it and formulated several correlations. Dunkle [2] developed mathematical expressions for convective, radiative and evaporative heat transfer coefficients for the solar still. Rubio et al. [3,4] studied asymmetries in various temperatures and amount of distillate for a double slope passive solar still (DSPSS) and proposed mathematical models, one in terms of lumped parameters and another for controlled temperatures of glass cover and basin. Agrawal et al. [5] made an attempt to develop the convective mass transfer relation for condensing chamber of a DSPSS for different operating temperature ranges. Tiwari et al. [6] studied the effect of inclination of condensing cover on internal heat and mass transfer in a passive solar distillation system under indoor conditions. Hongfei et al. [7] developed a group of improved heat and mass transfer correlations of basin type solar stills. Shukla and Sorayan [8] experimentally validated a thermal model of solar stills on the basis of heat transfer coefficients for both summer and winter conditions. Omri et al. [9] simulated the natural convection effects in solar stills and optimized the dimensions of a solar distiller. Dwivedi and Tiwari [10] carried out an energy, exergy and life cycle cost analysis of single and double slope solar stills. They reported that double slope solar still gives higher distillate in summer with low annual distillate, higher exergy efficiency, low cost of production and low energy payback time (EPBT) in comparison to single slope solar still.

Al-Hinai et al. [11] studied the effect of climatic, design and operational parameters such as solar intensity, ambient temperature, wind velocity, cover slope angle, feed water temperature, brine water depth and basin material. Akash et al. [12] showed that lower water depth and salinity give higher distillate for the DSPSS. Al-Hayek and Badran [13] obtained 20% higher distilled water from an asymmetric greenhouse type solar still in comparison to symmetric greenhouse type solar still.

Regarding the design of a solar still for optimum distillate along with the parametric studies as inclination of glass cover, ambient temperature, wind velocity, feed water temperature, salinity, water depth and other effects like heat transfer coefficients, influence of binary mixture thermo-physical properties, effect of thermal storage, solar intensity and symmetry–asymmetry of design of DSPSS, efficiency is an essential parameter to understand the performance of that system. Hence, it is required to use the concept of efficiency for designing and improving the performance of solar stills. Cooper [14] studied that the upper limit of the solar still's efficiency can reach up

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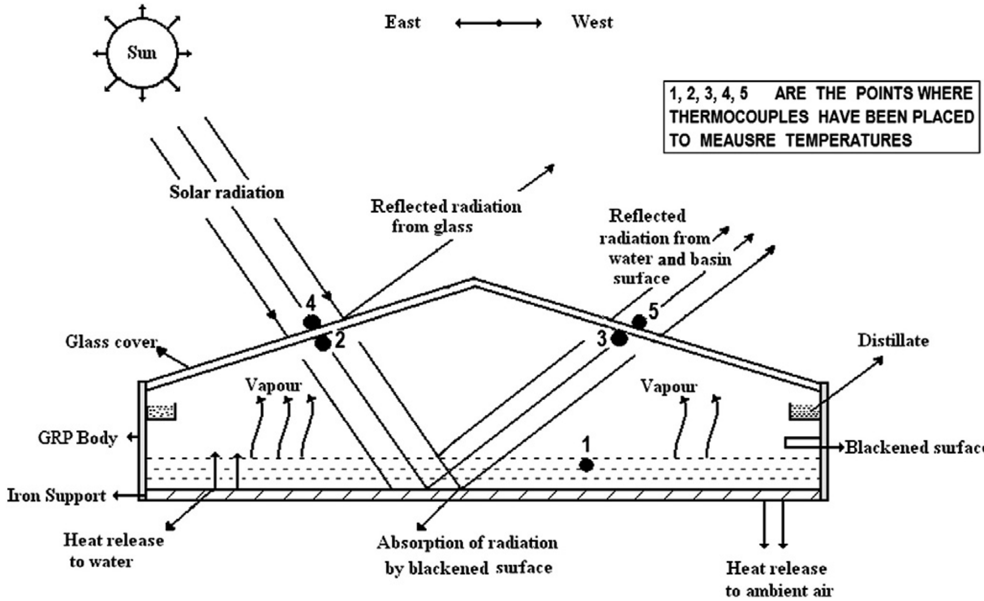

Fig. 1. A schematic diagram of double slope passive solar still.

to 60%. Tamimi [15] characterized the performance of a solar still in a broad domain of characteristic curves between an ideal and the worst conditions. Tiwari and Noor [16] presented the concept of an instantaneous thermal efficiency to characterize the design of solar stills including trapezoidal cavity system. Dev and Tiwari [17] developed the characteristic equation for single slope passive solar still at different water depths and inclinations and showed the importance of threshold solar intensity for the solar stills. They found better performances at a water depth of 0.01 m and an inclination angle 30°. Dev and Tiwari [18] also developed the characteristic equation on an annual basis for the hybrid PV-T active solar still at water depth 0.05 m for the composite climate of New Delhi, India.

An objective of the paper is to obtain the characteristic equation of DSPSS as a method of thermal testing of solar stills based on experimental data. These characteristic equations can be used for further modifications in the existing design of DSPSS in terms of design (i.e. size, angle of inclinations of condensing glass covers, and material), operating (i.e. water depth, mode of operation, shading on condensing covers and use of dye) and climatic factors (i.e. location of the place, input amount of solar radiation, ambient temperature, and wind velocity) etc.

2. Experimental setup and observations

A schematic diagram of double slope passive solar still has been shown in Fig. 1. It has been installed at Solar Energy Park, I.I.T., Delhi, New Delhi, India (latitude 28°35′ N, longitude 77°12′ E, altitude 216 m from mean sea level). The orientation of the solar still has been kept east–west to receive solar radiation for maximum hours of sunshine. The solar still has a box type structure (basin area 2 m^2) made of the glass reinforced plastic (GRP) 0.005 m thick. The heights of the solar still walls have been taken as: 0.22 m at the ends and 0.48 m at the centre. Two simple window glass of dimensions $1.02 \times 1.02 \times 0.004$ m^3 have been placed over the walls of the solar still at an inclination angle of 15° facing east and west directions. To absorb higher amount of solar radiation, an inside surface of the solar still has been painted black in color. An inlet through the rear wall has been provided to feed brackish/underground water into the basin of the solar still. Two troughs are provided inside of each short wall of the solar still to collect the distilled water.

A number of calibrated copper-constantan thermocouples and a digital temperature indicator (resolution 0.1 °C and range −20 to 450 °C) have been used for measuring various temperatures such as: water (T_w) and inner and outer surface of glass cover (T_{ci}, T_{co}). The positions of thermocouples like water (thermocouple 1), inner (thermocouples 2 and 3 respectively) and upper (thermocouples 4

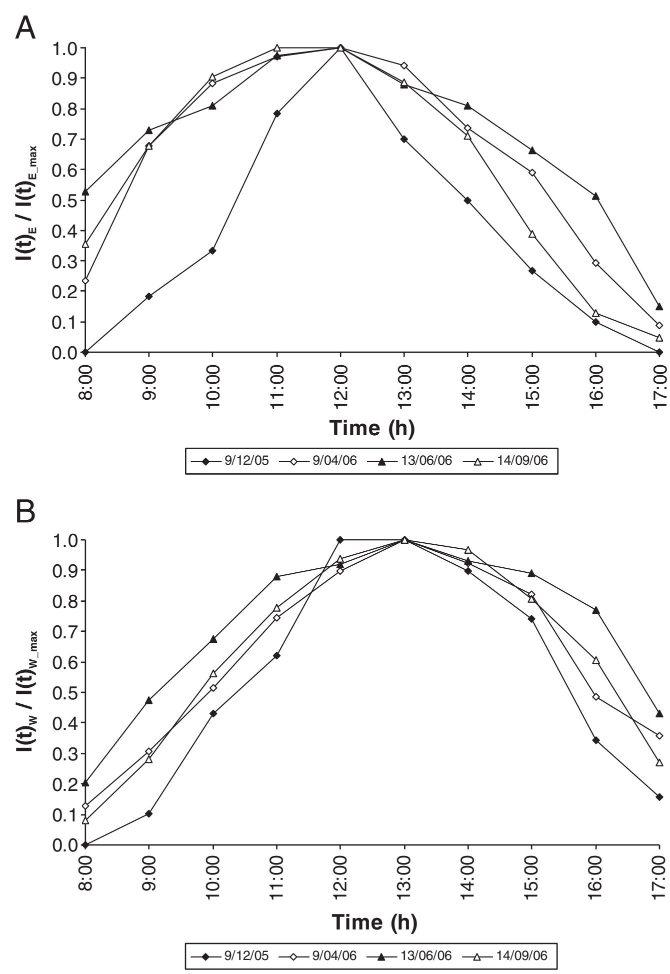

Fig. 2. (A). Hourly variation of $I(t)_E/I(t)_{E\_max}$ in different months for New Delhi, India. (B). Hourly variation of $I(t)_W/I(t)_{W\_max}$ in different months for New Delhi, India.