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Parametric investigation of a vertical multiple-effect diffusion solar still coupled with a tilted wick still

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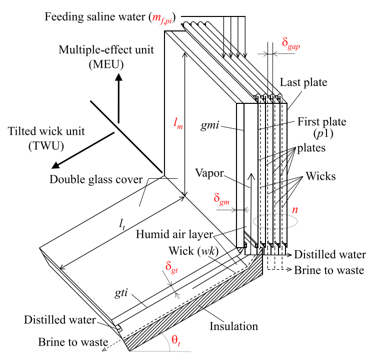
HIGHLIGHTS

- Vertical multiple-effect diffusion solar still coupled with tilted wick still
- Parametric investigation was performed to determine optimum conditions.
- Design and operation conditions were analyzed theoretically.
- Distillate productivity is equivalent to other types of multiple-effect stills.

GRAPHICAL ABSTRACT



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ABSTRACT

A parametric investigation was performed theoretically for a solar still consisting of a vertical multiple-effect unit (MEU) and a tilted wick unit (TWU). Thermal input to MEU is the latent heat of vapor from TWU and solar radiation directly incident on MEU. Parameters analyzed in this study were the inclination angle of TWU, the ratio of the height of MEU to the length of TWU, air gap sizes in double glass covers of MEU and TWU, and the distance between the plates and number of plates used in MEU. Each parameter was analyzed to find the optimum value to produce the maximum daily production of distilled water. With optimum conditions, the total daily production of the still would be competitive with other types of multiple-effect stills. Outdoor experiment with 4-effect MEU was also performed, and it was found that the discrepancy between experimental and theoretical results was about 10%.

1. Introduction

MEDS (multiple-effect diffusion solar still) is constructed from a number of plates. Each plate has a wick which works as an evaporating surface. All plates are arranged parallel to each other with small gaps. Evaporation and condensation are repeated in MEDS by recycling the latent heat from condensation. As a result, MEDS has been found to produce a greater amount of distilled water than other types of solar still experimentally and theoretically [1–30]. These studies were reviewed by Rajaseenivasan et al. [31] and also in a past paper [32].

For this research, a new kind of MEDS was introduced and its basic behavior was analyzed numerically [33], and validated in outdoor experiments with a single-effect unit instead of a multiple-effect unit (MEU) [32]. MEU was set vertically and works together with a tilted

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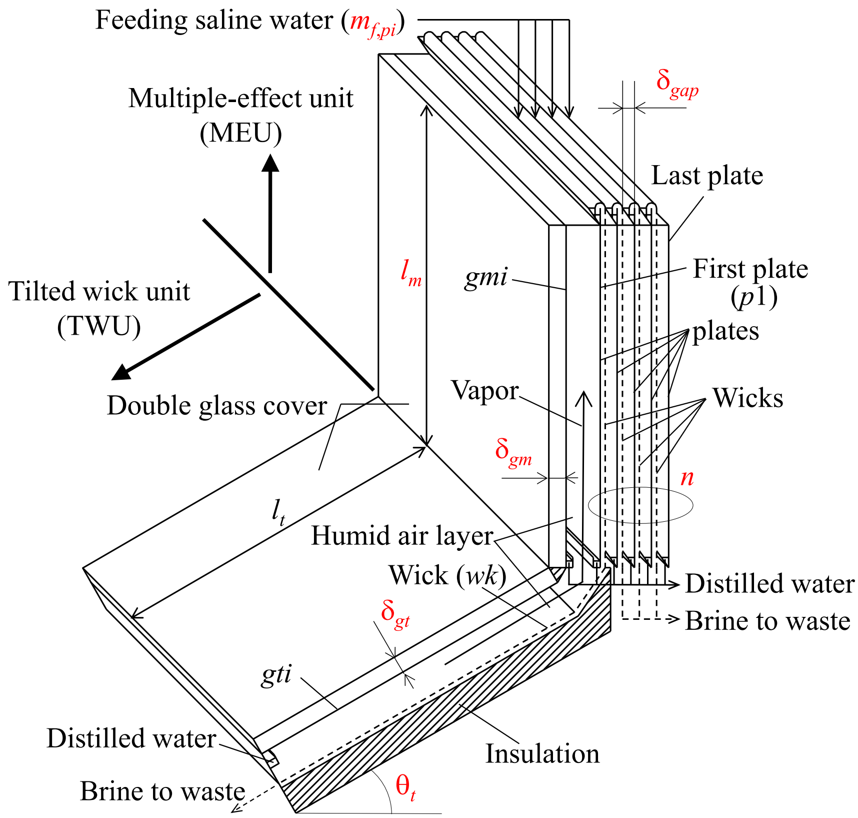

Fig. 1. An outline of the still and parameters analyzed in this study.

wick unit (TWU) as shown in Fig. 1. The double glass covers insulate MEU and TWU, and form a connected and sealed humid air layer enclosed by four surfaces; the wick of TWU (*wk*), the first plate of MEU (*p*1) and the inner surfaces of the double glass covers of MEU (*gmi*) and TWU (*gti*). The vapor from *wk* is distributed to and condenses on the other inner surfaces, i.e., *p*1, *gmi* and *gti*. The thermal input to MEU is not only the sunlight directly incident on *p*1 but also the latent heat released from the vapor from *wk* and condensed on *p*1. Therefore, it is preferable to increase the ratio of condensation on *p*1 in order to increase the thermal energy delivered to MEU.

In this study, some parameters which affect the total daily production of distilled water and/or the ratio of condensation on *p*1 to the total amount of vapor from *wk* were analyzed numerically to determine the optimum conditions. Outdoor experiment with 4-effect MEU was also performed to validate the theoretical results.

2. Theoretical analysis

Theoretical analysis of the proposed still was performed [33]. Listed in Table 1 are the conditions and physical properties determined in this study. In the parametric study, all parameters were set at the values listed in Table 1 except for each single parameter which was varied to determine its effect on production. Parameters analyzed in this study are shown as red letters in Fig. 1. The parameters are inclination angle of TWU, θ_t; length ratio, l_m/l_t (l_m is height of MEU and l_t is length of TWU); feed ratio, $m_{f,p1}/(m_{e,p1}^* + m_{e,wk}^*)$ or $m_{f,pi}/m_{e,pi}^*$ ($m_{f,pi}$ is rate of feeding water to wicks of *pi*, and $m_{e,pi}^*$ and $m_{e,wk}^*$ are evaporation rates at steady state from wicks of *pi* and *wk*); air gaps between the double glass covers of MEU, δ_{gm}, and TWU, δ_{gt}; distance between plates, δ_{gap}; and number of plates, *n*.

In a previous paper [32], it was assumed that there is no natural convection in the air gap between each double glass cover since the air gap was very small (6 mm). However, in this paper, δ_{gm} and δ_{gt} were considered as parameters of the calculations, and δ_{gm} and δ_{gt} includes the range at which natural convection cannot be neglected. Therefore, *Nu*

Table 1
Weather, design and operational conditions and physical properties.

Weather conditions
Latitude and longitude: 33° and 130° (Kurume, Japan)
Transmittance of atmosphere: 0.7
Ambient air temperature: 25 °C (spring), 33 °C (summer), 30 °C (autumn) and 20 °C (winter)
Ambient air velocity: 1 m/s
Design conditions
Width of the still: 1 m
$l_m = 1$ m
$l_t = 1$ m
$\theta_t = 30°$
$n = 10$
$\delta_{gap} = 5$ mm
Thickness of humid air layers of both units: 60 mm
Thickness of each glass plate: 4 mm
$\delta_{gt} = \delta_{gm} = 6$ mm
Operational condition
$m_{f,p1}/(m_{e,p1}^* + m_{e,wk}^*) = m_{f,pi}/m_{e,pi}^* = 2.0$
where $m_{e,pi}^*$ and $m_{e,wk}^*$ are evaporation rates at steady state from wicks of *pi* and *wk* calculated with solar radiation at peak of the day.
Physical properties
Absorptance of *p*1 and *wk*: 0.9
Absorptance of each glass plate: 0.085
Emittance of each glass plate, *wk* and *pi*: 0.9
Thermal conductivity, density and specific heat of glass: 1.03 W/mK, 2520 m^3/kg and 0.80 kJ/kgK
Thickness and thermal conductivity of insulation of TWU: 50 mm and 0.04 W/mK