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Experimental study of a vertical single-effect diffusion solar still coupled with a tilted wick still

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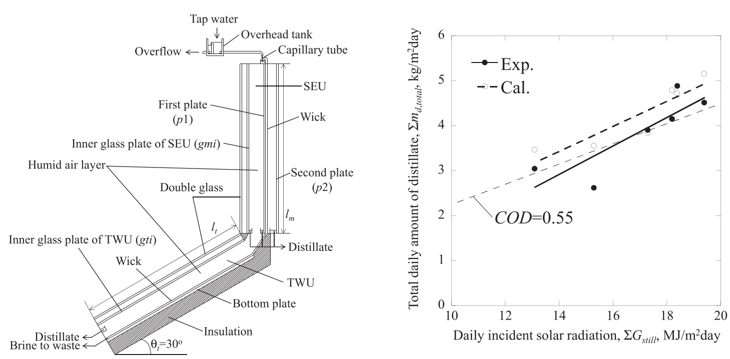
HIGHLIGHTS

- Vertical multiple-effect diffusion still was coupled with tilted wick still.
- Single-effect unit instead of multiple-effect unit was constructed and tested.
- Condensation of vapor occurred on the first plate of the single-effect unit.
- Experimental and theoretical results are in fairly good agreement.

GRAPHICAL ABSTRACT



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ABSTRACT

A single-effect diffusion still, instead of a multiple-effect diffusion (MED) still, combined with a tilted wick (TW) still was investigated experimentally under actual weather conditions to investigate whether the natural convection can transport the vapor from the TW still to an MED still adequately. It was found that the single-effect still can be heated by vapor from the TW still and solar radiation absorbed on the single-effect still. From the experiments in summer and autumn, it was found that an MED still can be heated in both seasons whether the MED still absorbs solar radiation directly or not. The experimental results agreed with the calculation results. The total daily amount of distillate, $\Sigma m_{d,total}$, did not correlate with the daily horizontal solar radiation, ΣG_{day}, but strongly correlated with daily solar radiation incident on the still, ΣG_{still}. The maximum of $\Sigma m_{d,total}$ obtained in experiments was about 4.88 kg/m^2 day when ΣG_{day} and ΣG_{still} were 13.6 and 18.4 MJ/m^2 day, respectively.

1. Introduction

Solar powered stills come in many types, but multiple-effect diffusion stills (MED stills) and tilted wick stills (TW stills) are two of the most common. Both types of still have a wick from which the water evaporates.

TW stills (configured much like the TW unit (TWU) in Fig. 1) basically involve a wick and transparent cover, and salt water flows into the wick continuously. Solar energy serves to heat the salt water and the generated vapor condenses on the transparent cover resulting in distilled water.

MED stills (configured much like the ME unit (MEU) in Fig. 1) utilize several parallel plates, each with its own evaporating wick. The bare surface of each plate serves as both heating and condensing surface, and the surface in contact with the wick serves as an evaporating surface. Salt water flows into the wicks. Plates are positioned with narrow

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Nomenclature

A_{eff}	aperture area of still, m^2
COD	coefficient of distillation
G_{df}, G_{dr}	diffuse and direct solar radiation on a horizontal surface, W/m^2
G_h	global solar radiation on horizontal surface, W/m^2
ΣG_{day}	daily global solar radiation on a horizontal surface, W/m^{2}day
ΣG_{still}	daily solar radiation incident on still, W/m^{2}day
gmi, gti	inner surface of double glass of single-effect and tilted wick unit
H_{fg}	latent heat of evaporation of water, J/kg
I_0	solar constant, W/m^2
l_m	height of single-effect unit, m
l_t	length of tilted wick unit, m
m_d	distillate production rate, kg/m^{2}s
Σm_d	daily amount of distillate, kg/m^{2}day
$\Sigma m_{d,total}$	total daily amount of distillate, kg/m^{2}day
$p1$, $p2$	first and second plate
t	time, hour
t_{start}, t_{end}	start and end time of experimental period, hour
w_s	width of still, m

Greeks

ϕ, φ	elevation and azimuth angles of the sun
θ_t	inclination angle of tilted wick unit from horizontal
τ_{atm}	transmittance of atmosphere

Abbreviations

MED	multiple-effect diffusion
MEU	multiple-effect unit
SEU	single-effect unit
TW	tilted wick
TWU	tilted wick unit

gaps of a few millimeters. The first plate receives solar radiation which in turn heats and evaporates the salt water in the wick placed on the first plate. Condensation of the resulting vapor occurs on the next plate. This condensation releases latent energy which, along with the radiative and conductive thermal energy, serves to evaporate the salt water in the second plate's wick. The performance of MED stills tends to be much more efficient than single-effect stills, since evaporation and condensation are repeated using the same energy.

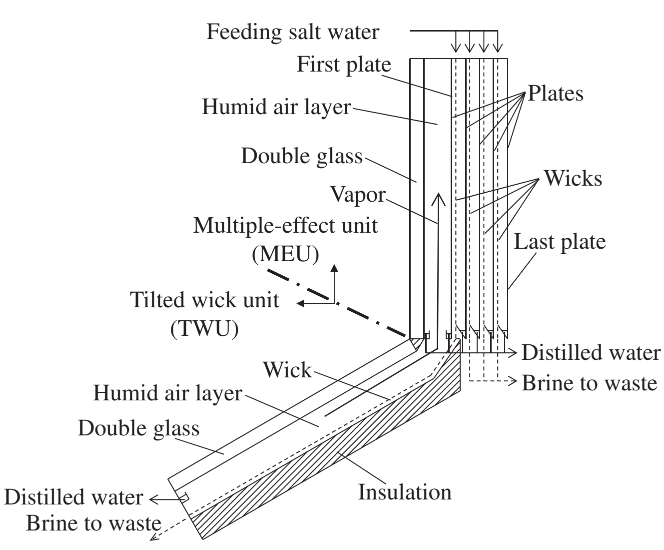

Fig. 1.

This type of still was proposed by Dunkle [1] in 1961, and he constructed a five-effect vertical MED still combined with a solar absorber, and performed experiments as well as numerical analysis. Inclined downward-heating MED still, in which distillation occurs downwards repeatedly, was proposed by Cooper and Appleyard [2], and they constructed and tested a three-effect MED still. Elsayed et al. [3] constructed a three-effect vertical MED still heated by a heat transfer bench. They also performed numerical analysis and reported about the effects of the heating water temperature and the cooling water temperature on the distillate productivity. Tsumura et al. [4] constructed and tested a ten-effect downward-heating MED still, and reported about the relationship between the temperature of a solar absorbing plate and the distillate productivity. Inclined upward-heating MED still, in which distillation occurs upwards repeatedly, was proposed by Tanaka et al. [5]. They constructed a seven-effect MED still combined with an inverted reflector and a five-effect MED still combined with a heat pipe solar collector. They reported that the experimental and theoretical results are in good agreement. Kiatsiriroat et al. [6] experimentally and numerically analyzed a vertical MED still combined with a solar collector, and reported that the distillate productivity increases with an increase in the ratio of the evaporating surface area to the solar collector area. Toyama et al. [7] proposed an upward-heating MED still, in which the lowermost partition plate absorbs solar radiation passing through all the upper plates. Ouahes and Le Goff [8] constructed a three-effect downward-heating MED still and tested it under actual and artificial radiation. Okamura et al. [9] analyzed six-effect and seven-effect downward-heating MED stills. They reported that the feed rate of saline water has to be controlled according to the temperature of the first plate, and it is important to feed saline water to wicks uniformly. Tiwari et al. [10] numerically analyzed an upward-heating MED still, and they reported about the effect of various parameters, such as still length, water flow rate and inclination of the still on the distillate productivity. Ohshiro et al. [11] proposed a downward-heating MED still utilizing hydrophobic PTFE net sandwiched between an evaporating and a condensing wicks to decrease the distance between plates. Bouchekima et al. [12] analyzed a three-effect downward-heating MED still numerically and experimentally, and they reported that the distillate productivity can be increased with an increase in the inlet temperature of feed water as well as the intensity of solar radiation. Yeh and Ho [13] proposed an upward-heating MED still similar to the still proposed by Toyama et al. [7]. In the still, several tiny weirs were used to hold the water on the plates. A vertical MED stills coupled with a basin type still [14], a heat pipe solar collector [15] and a flat plate solar collector [16] were proposed and tested, and the results shows that the distance between plates can be decreased significantly by setting the plates vertically. Fukui et al. [17] experimentally and numerically analyzed a downward-heating MED still which can be floated on water surface for maritime lifesaving. Nosoko et al. [18] numerically analyzed a vertical MED still to produce highly concentrated seawater. Chong et al. [19] proposed a vertical MED still combined with a vacuum-tube collector and heat pipe. In the still, the plates were bent to avoid contamination of distilled water and peel-off of the wicks. Huang et al. [20] constructed and tested a spiral vertical MED still combined with a vacuum-tube collector and heat pipe, and the distillate productivity of the still is highest among the MED stills which have been studied. These studies were reviewed by Rajaseenivasan et al. [21].

2. Proposed still

A vertical MED still combined with a TW still was suggested in a past paper [22]. An outline of the still is shown in Fig. 1. TWU was positioned under MEU. Each unit has double glass for insulation. The humid air layers next to the double glass of both units are connected to allow