Desalination 414 (2017) 35–45

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

An experimental study of floating wick basin type vertical multiple effect diffusion solar still with waste heat recovery

A.K. Kaushal [a], M.K. Mittal [a,*], D. Gangacharyulu [b]

[a] Mechanical Engineering Department, Thapar University, Patiala, Punjab 147004, India
[b] Chemical Engineering Department, Thapar University, Patiala, Punjab 147004, India

HIGHLIGHTS

- Multiple float wicks in basin for reducing thermal inertia.
- Feed water pre-heating by heat recovery from waste feed water.
- FW-BVMED-HR still showed better Cumulative efficiency than conventional basin type VMED still of same glass and basin area.
- High convective heat transfer from float wick to first partition plate.
- Increased night distillate due to additional heat stored in multiple floating wicks.

ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 21 February 2017
Accepted 19 March 2017
Available online xxxx

Keywords:
Solar distillation
Floating wick
Vertical multiple effect
Diffusion
Heat recovery

ABSTRACT

In the present study, a floating wick basin type vertical multiple effect diffusion solar still with waste heat recovery (FW-BVMED-HR) has been constructed by modifying the conventional design of basin type VMED solar still (reference still). The reference still has been modified by incorporating improvements like multiple floating wicks in the basin and heat exchanger for waste heat recovery in order to determine the cumulative effect of both of these improvements. The performance of the FW-BVMED-HR still was compared with reference still under identical weather and operational conditions by running them side by side simultaneously. Both the stills were made of same dimensions and materials, and consisted of four effects. On a clear sunny day, the distillate productivity of FW-BVMED-HR still was found to be 21% higher than the reference still. High distillate productivity resulted, due to high convective heat transfer by humid basin air from high temperature float wick surface to first partition plate, feed water pre-heating from waste heat recovery, reduced basin bottom and side losses, and high night distillate productivity as a result of additional heat stored in multiple floating wicks.

1. Introduction

Human population in many areas of the world do not have access to safe drinking water. This often leads to health hazard from water borne diseases. In India, there are few places, inhabited by humans, which are regarded as desert. In few states, due to excessive use of groundwater for irrigation as for paddy sowing and industrial purposes, the groundwater level goes down considerably. This situation aggravates further in summer season as most of the surface water reservoirs also start drying up. Hence some states in India face acute water shortage in summer season. The summer season is also the peak load season for the electrical power consumption from household and industry sector. Moreover in future, the growing human population may have to move into areas which are presently considered deserts having water scarcity. Almost all the conventional water desalination technologies need energy, either in electrical form or heat form. Under such conditions, at least the need for safe drinking water can be met from solar distillation. Existing technology must be constantly upgraded in terms of efficiency and equipment cost in order to reduce the cost of generating per liter of water.

The single slope basin type still, although simple in design, has low productivity. Many efforts have been made by researchers to improve the productivity of basin type stills. Some of these improvements are very simple in implementation and low in cost, but lead to significant rise of still efficiency [1–5]. Solar stills with heat storage medium in basin and stills with inclined wick absorbers have shown significant increase of productivity over the conventional basin stills [6–13].

Multiple effect diffusion stills have higher productivities than single slope basin type stills, since the latent heat of condensation is recycled several times in the partition plate distillation section. Use of wetted wicks in stills reduces the thermal inertia and increases the rate of

* Corresponding author.
E-mail address: madhup.mittal@thapar.edu (M.K. Mittal).

http://dx.doi.org/10.1016/j.desal.2017.03.033
0011-9164/

Nomenclature

A	area, m^2
f	feed water flow rate per unit area of the partition plate, $g/m^2/s$
g	Glass cover
G_g	global solar radiation on glass cover, W/m^2
G_T	cumulative daily solar radiation on glass cover for experimental period, $MJ/m^2/day$
H_{fg}	latent heat of water, J/kg
m_d	mass of distillate, kg
p	partition plate
T_a	average daily ambient temperature, °C

Greek letters

ΔT	rise of water temperature, °C
η_c	cumulative efficiency

Subscripts

f	feed water
g	glass cover
p	partition plate
1–4	number of glass cover or partition plate

Abbreviations

BVMED-HR	basin type vertical multiple effect diffusion solar still with heat recovery
FW-BVMED-HR	floating wick basin type vertical multiple effect diffusion solar still with heat recovery
PVC	polyvinyl chloride
TDS	total dissolved solids
VMED	vertical multiple effect diffusion

heat transfer by evaporation-condensation. The multiple effect diffusion still consists of a multiple plate arrangement in which number of plates are arranged parallel to each other with a narrow gap between the plates. One side of each of the plates is covered with porous wick cloth. Heat is supplied to one side of the multiple plate arrangement and feed water is fed continuously to each of the wick sides of the plates. As heat is supplied to the first plate, water vapors generate from the wick side of the first plate, diffuse through the air gap between the plates and condense on the uncovered surface of the second plate. The latent heat released by condensing vapors conducts through the plate and further evaporates the water from the wick side of the second plate. In this way, the heat energy received by the first plate can be recycled several times to increase the productivity of the still. The multiple effect diffusion still can be classified as horizontal, inclined and vertical multiple effect diffusion still on the basis of orientation of partition plates in multiple effect section. The horizontal and inclined multiple effect diffusion stills have been studied theoretically as well as experimentally by various researchers [14–20]. In spite of high productivity of inclined and horizontal multi effect diffusion still, these type of stills have a serious design drawback, i.e. the position of saline soaked wicks is above the condensing surfaces which may lead to contamination of distillate.

Vertical multiple effect diffusion stills have a number of vertical plates placed side by side with wick attached on one side. In these stills, no bending of plates takes place due to self-weight and hence the risk of crossflow of saline water is reduced. Hence, gap between plates can be reduced to as low as 5 mm [21,22]. Elsayed et al. [23] numerically simulated performance for multi-effect diffusion still and validated their model experimentally for a three effect vertical plate diffusion still. Kiatsiriroat et al. [24] presented a mathematical model to predict the performance of a vertical multiple effect diffusion still coupled with flat plate solar collector. Tanaka et al. [25] theoretically studied the performance of a basin type vertical multiple effect diffusion solar still having 10 distillation cells with 5-mm partition plate gaps and conducted a parametric study for such a still [26]. Tanaka et al. [21] experimentally studied basin type VMED solar still with 11 stainless steel partition plates at 5 mm partition gaps and obtained maximum productivity of 18.7 $kg/m^2/day$. A VMED still coupled with a heat pipe solar collector was studied theoretically by Tanaka and Nakatake [27] and parametrically by Tanaka et al. [28]. Tanaka et al. [29] performed indoor experiments on a VMED still coupled with a heat pipe solar collector, using infrared heating lamps. A VMED still with flat plate reflector and attached castors for azimuth tracking of the still manually, was studied both theoretically and experimentally by Tanaka and Nakatake [22, 30–33]. Tanaka [34] presented theoretical analysis of a VMED solar still coupled with a tilted wick still. Recently, Kaushal et al. [35] have dealt in detail the development of an improved basin type vertical single distillation cell solar still and its maintenance aspects. The still had a partitioned wick structure with individual feed water tubes for each such sub-partitioned area, to improve the wick wetting characteristics.

Feed water pre-heating from waste heat recovery, to improve the efficiency of multiple-effect diffusion stills, has been done by various researchers. Nosoko et al. [36] have theoretically analyzed the possibility of heat recovery from hot condensate and hot waste feed water for feed water preheating in VMED still. Chong et al. [37] developed a multiple effect diffusion still with bended-plate design in distillation section. The feed water was pre-heated by recovering heat from hot distillate and feed water waste through a heat exchanger. Huang et al. [38] made a performance study of a novel design of a spiral shaped multiple effect diffusion solar still. The heat recovery was done from saline waste as well as hot distillate to pre-heat feed water, through separate heat exchangers.

Floating wick has been used in the basin, by previous researchers, to improve the performance of basin type solar still. However, there are no reports in the open literature that mention utilization of floating wick in the basin type VMED solar still to improve its performance. The productivity of VMED solar still can also be improved by recovering heat from hot waste feed water for preheating the feed water. Therefore, in the present work, the conventional design of basin type VMED solar still has been modified by incorporating improvements like floating wick in the basin and heat exchanger for waste heat recovery in order to determine the cumulative effect of both of these improvements. This modified still will be referred to as FW-BVMED-HR (floating wick basin type vertical multiple effect diffusion solar still with heat recovery) solar still hereafter in this paper. The still consisted of four effects. A float type wick has very less cost addition to the total system cost but the expected gain in distillate production is quite high [4]. The use of float wick in a basin type still serves many purposes. It maintains a thin water film on the evaporating surface which has minimal thermal inertia leading to quicker start-up for the still. Since the solar radiation does not enter the water mass, it is utilized to raise the temperature of wick surface and subsequently the basin air-vapor mixture temperature. The rate of evaporation is also high from a high temperature wick surface. The float wick has advantage over fixed wick, since it maintains a constant height for capillary rise of feed water to the top flat wick surface. With use of float wick, water can be filled to a greater depth in the basin. This permits use of float valves for feeding water in basin to eliminate dry out conditions in basin and thus permitting minimum human supervision. Dry out conditions may occur in basin type stills in summer, since solar radiation is quite high. Since the distillate had to be measured individually, component wise, on hourly basis, there was a practical difficulty in heat recovery from it. Therefore the heat recovery in the present work has been done only from hot waste feed water. The cost of heat exchanger was very less as compared to the total still cost. Waste feed water from the first three partition plates only was sent to the heat exchanger, as temperature of waste feed water from the last partition plate, was not found useful. The present work aims at finding out