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Development and experimental study of an improved basin type vertical single distillation cell solar still

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HIGHLIGHTS

- Divided wick structure with individual feed tubes achieved better wetting than single wick structure.
- Third external control plate was effective in controlling the temperature drop of single distillation cell.
- Better cumulative efficiency than conventional basin still of same glass and basin area
- No cross flow of feed water due to longitudinal rubber spacers and gravity feeding method

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ABSTRACT

This paper presents an experimental study on basin type solar still having tilted double glass cover and having single vertical distillation cell consisting of two closely spaced vertical parallel plates, at the backwall. The feed water side of plate was covered with partitioned wick structure and individual feed water channels were used for each of the partitioned wick structure areas to ensure uniform wetting of wick. In order to increase the productivity of proposed improved still, the temperature drop across the distillation cell was maintained low by controlling the cooling of second plate by placing a third external vertical plate at a gap of 25 mm from second plate of distillation cell. The cumulative efficiency of the proposed improved still with 10 mm partition gap was found to be 10–15% (magnitude) higher than that of the conventional basin type still of same basin area and glass cover area.

1. Introduction

Clean and pure water is a necessity for healthy human habitation in any part of the world. In many parts of the world which are facing scarcity of drinking water, water is available, but it is either saline as in coastal regions or brackish in nature and therefore unfit for human consumption. The available fresh water resources in human habitations are rapidly being polluted due to urbanization, industrialization and population growth [1]. All the water desalination techniques utilize, either heat energy produced from fossil fuels and other sources or electricity produced from conventional sources of energy. Therefore, in places where conventional sources of energy are either not available or are not cost effective, solar desalination is an attractive and viable alternative. The single slope basin type still, although simple in construction, has low productivity. The multiple effect stills have high productivity due to the recycling of the solar heat energy which also results in lowering the per litre generation cost of pure water. In the vertical multiple effect diffusion stills, a number of vertical plates are arranged at a constant gap with each other. All the plates are having a wick surface on one side, on which saline water is fed from top end. The first plate is heated, by any method on plain side, so that water evaporates from wick surface on the other side of the plate. The vapor condenses on the plain side of the facing plate and transfers its latent heat of condensation to it. This in turn causes evaporation from the wick surface on the other side of the plate and condensation on plate placed next to it. In this way the heat energy is recycled many times in a multiple effect diffusion still.

Many efforts have been made to improve the efficiency of solar distillation and have been reported in literature. A literature review of the experimental work done in the field of vertical multiple effect diffusion still was done, to gain understanding of design parameters and operational and maintenance issues in these type of stills. Elsayed et al. [2] studied experimentally a three effect vertical plate diffusion still. The first plate was heated with hot water circulation from a constant temperature source and the last plate was cooled with circulation of constant temperature cooling water from an overhead tank. They found

Abbreviations: HDPE, high density polythene; PVC, polyvinyl chloride; RH, relative humidity; TDS, total dissolved solids; VMED, vertical multiple effect diffusion; VSDC, vertical single distillation cell.

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Nomenclature

A	area, m^2
D	diffusivity of water vapor in air, $m^2\ s^{-1}$
f	feed water flow rate, $g/m^2/s$
f_p	pipe friction, m
G_g	global solar radiation on glass surface, W/m^2
ΣG_g	cumulative daily solar radiation on glass cover for experimental period, $MJ/m^2/day$
H	elevation head, m
H_{fg}	latent heat of water, J/kg
$\dot{m}_e$	mass flux of water vapor, $kg/m^2/s$
m_d	mass of distillate, kg
p	partial pressure of water vapor, Pa
P	total pressure, Pa
R	gas constant of water vapor, $Jkg^{-1}\ K^{-1}$
t	temperature, °C
T	absolute temperature, K
Greek letters	
δ_{pg}	thickness of partition gap, m
η_c	cumulative efficiency
Subscripts	
cs	condensing surface
es	evaporating surface
g	glass cover
s	saturated water vapor
m	mean value

that the still cumulative efficiency decreases with the increase of feed rate to the still and increases with the increase in the heating water temperature. Kiatsiriroat et al. [3] performed experiments on a vertical two effect diffusion still, with aluminium partition plates. The first plate was heated by circulating hot water, with a pump, from a flat plate solar collector and the last plate was air cooled. The cumulative productivity of this still was 2 kg/m^2/day. Tanaka et al. [4] performed indoor experiments on a vertical multiple effect diffusion (VMED) still coupled with a heat pipe solar collector, using infrared heating lamps instead of actual solar radiation. The latent heat of condensation of the working fluid in heat pipes, which was distilled water, was transferred to the first partition copper plate through a coiled condensing copper tube. The maximum productivities for this type of still were nearly equal to that obtained for basin type VMED still, being only slightly on the higher side [4,5]. Tanaka and Nakatake [6] conducted outdoor experiments on a vertical single effect diffusion still coupled with a flat plate reflector and validated their geometrical model for predicting the solar radiation absorption on first partition plate. The first partition plate was copper plate painted with a selective absorber on front side and a glass cover was placed at a gap of 10 mm. The second partition plate was of 5 mm thick glass, placed at a partition gap of 10 mm. Maximum productivity obtained for this still was 4.39 kg/m^2/day when global solar radiation on horizontal surface was 16.8 MJ/m^2/day. Tanaka [7] conducted experiments on a vertical multiple effect diffusion still having 4 and 6 effects, with glass cover on first partition plate and coupled with a flat plate reflector. The gap between any two partition plates was maintained by acrylic rods at the two side edges and nine acrylic cubes spread over the evaporating area. The daily productivity obtained for the 6 effect still was about 5.5 times the daily productivity of a conventional basin type still. Tanaka et al. [8] experimentally studied basin type vertical multiple effect diffusion (VMED) solar still with 11 stainless steel partition plates, and 20 wooden cubicle spacers to maintain 5 mm partition gaps. Maximum productivity of 14.8–18.7 kg/m^2/day was obtained when solar radiation on the glass cover varied from 20.7–22.4 MJ/m^2/day and ambient temperature varied from 19 to 30 °C. The first partition plate, which is the heat transfer plate from basin section, and all other partition plates, were of 0.5 mm thick stainless steel. A plastic film was sandwiched between the partition plate and 0.5 mm thick cotton flannel wick. The basin liner and the frame of the still were made of wood. The partition plates had a single evaporating wick cloth, without any sub partitioning. The top end of the wicks were dipped in plastic channels located at the top outside edge of the plates. The author has discussed the maintenance and operational problems in these VMED stills, which were responsible for the loss of distillate.

From the literature survey done by the authors, it was found that no experimental work on basin type vertical single distillation cell (VSDC) solar still has been reported. Further, of all the multiple effect stills, the basin type vertical multiple effect diffusion (VMED) solar still was found to be a rugged, all weather device which requires little maintenance and monitoring as compared to the VMED still coupled with flat plate reflector and relatively less expensive when compared to VMED still coupled with heat pipe flat plate collector. Hence in the present work an experimental study on an improved design of basin type VSDC solar still was done. Based on the problems listed in literature survey, some new design changes were incorporated with an objective to increase the overall productivity and cumulative efficiency of the basin type VSDC solar still. Initially, for comparison purpose, performance study was made on a conventional basin type single slope single glass cover still with mild steel body. Performance study with respect to productivity and quality of distillate was then done on an improved basin type VSDC solar still after modifying the conventional basin still. The improved basin type VSDC still had same basin and glass cover area as the conventional basin still. Double glass covers were used on basin of modified still to reduce the heat transfer from glass covers and two more vertical stainless steel partition plates were added behind the first copper partition plate of still. The first partition plate and second partition plate next to it had thick cotton wicks pasted on them and were fed with feed water. The vapor evaporated from the wick of first partition plate condensed on the second partition plate and the vapor evaporated from wick of second partition plate was allowed to either escape to surrounding atmosphere or condense on the facing third external partition plate. As against the previous designs reported by researchers [4,6–8], the wick structure was divided. Individual feed water tubes controlled by newly designed control valves, fed water through gravity feed mechanism to each such sub-divided wick area. The partition plates were separated by a number of longitudinal spacers to prevent cross-flow of saline water. The feed water, waste feed water drain and distillate channels were placed inside the sealed boundary, to prevent heat and vapor losses from cell. The wick wetting characteristics were also likely to be different from earlier similar experimental works since there is a decrease of area for wick with partitioning and use of longitudinal spacers, and gravity feeding mechanism has been used. The present work has an added specific objective to study the problems related with design, development, operation and maintenance of vertical multiple effect diffusion solar stills. The experience gained thus, will be utilized to develop a high productivity basin type vertical multiple effect diffusion solar still. The solar radiation condition on experimental days was partially cloudy which demonstrates the performance of basin type VSDC solar still under high diffuse radiation condition. The performance testing of the improved basin type VSDC solar still was done under varying weather parameters of solar radiation, ambient temperature and wind speed. The feed water rate was the operational parameter which was varied on the experimental days, to see its effect on productivity (Table 3).

2. Development of distillation section: flat reflector type vertical two effect diffusion still

Since the vertical multiple effect diffusion still technology is relatively new to the Indian subcontinent region and the design aspects,