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# Experimental study of basin type vertical multiple effect diffusion solar still integrated with mini solar pond to generate nocturnal distillate

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ABSTRACT

In present study, the conventional basin type vertical multiple effect diffusion (VMED) solar still has been modified to enhance the diurnal productivity of still and produce nocturnal distillate from the still. Multiple floating wicks were used in the basin to enhance the diurnal productivity of the still and mini solar pond was used to supply heat to basin water in batch mode during night to produce nocturnal distillate from the still. The performance of modified still was compared with conventional basin type VMED still under same weather and operating conditions by running both stills simultaneously. Both stills were constructed of same material and dimensions, and consisted of four effects. The diurnal, nocturnal and overall total productivity of modified still was found to be 49.87%, 71.21% and 56.92% respectively, more than the corresponding productivities of conventional still. The daily cumulative efficiency of modified and conventional still was found to be 80.29% and 59.6% respectively, when the total solar radiation on glass cover was 23.1 MJ/m$^2$/day, average ambient temperature was 25.3 °C and feed rate was 0.13 g/m$^2$/s.

## 1. Introduction

In present world, the available water resources are being polluted due to industrialization and urbanization, which has resulted in shortage of potable water. There are various water purification techniques which use electricity produced from fossil fuels. However, solar still is a device which utilizes solar energy to produce drinkable distilled water. Presently, the focus of developed or developing countries is on climate change and utilizing renewable resources of energy to meet the demands of people is one of the solution. A basin type solar still absorbs solar energy in basin water and heated water evaporates from surface of water and then condenses on the glass cover. Basin type stills are simple in design but main disadvantage is that its productivity is low. Solar still can be classified into passive and active solar stills. The passive stills receive direct solar radiation as a source of energy while in active stills additional heat is supplied to basin water from external sources such as flat plate collector, concentrating collector and solar pond. Active stills have been developed to overcome low productivity of passive stills and significant gain in performance of active solar stills has been achieved by various researchers [1,2].

Several improvement methods such as use of sponge cubes and phase change material in basin, enhancing condensation, installing reflector, coupling with flat plate collector etc., have been proposed by various researchers to increase the performance of solar stills [3,4]. The basin type solar still coupled with flat plate collector increased the basin temperature and showed substantial improvement in its productivity [5–7]. Faegh et al. [8] found that using external latent heat storage medium along with heat pipe can produce significant amount of distilled water during off sunshine hours and achieved 6.5 kg/m$^2$ with the rise of yield by 86%. To improve the performance of basin solar still, several researchers have used wicks and sponges in basin to enhance evaporation rate of basin water and observed significant gain of productivity of still [9–13].

Solar ponds have been used by various researchers to supply additional heat to solar stills to boost their performance. Velmurugan et al. [14] performed analytical simulation and experimental validation of solar still integrated with mini solar pond. El-Sabaii et al. [15] theoretically estimated that the performance of basin solar still integrated with solar pond enhanced by 52.36% through open mode of heat extraction from pond. El-Sabaii et al. [16] experimentally found that productivity of basin solar still integrated with shallow solar pond was 6.68 kg/m$^2$-day as compared to 5.29 kg/m$^2$-day of still without solar pond. Appadurai et al. [17] increased the surface area of still and pond by using fin type solar still with fin type solar pond and observed productivity gain by 50% over conventional still.

In spite of several improvements made by researchers in single effect basin type solar still, its productivity is found to be less than that of multiple effect solar still. It is due to utilization of absorbed solar energy

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**Nomenclature**

| | |
|---|---|
| $A_g$ | glass cover surface area, $m^2$ |
| $C$ | specific heat of water, kJ/kg/K |
| $F$ | feed water rate on each plate, g/$m^2$/s |
| $G_T$ | cumulative total solar radiation on glass cover of still, kJ/$m^2$/day |
| $m_d$ | mass of distillate, kg |
| $m_{sp}$ | mass of water in solar pond, kg |
| $P_p$ | pump power, W |
| $Q_{sp}$ | heat supplied from solar pond to modified still, kJ |
| $T_a$ | average ambient temperature, °C |
| $T$ | total running time of pump, sec |
| $W_p$ | pump work, kJ |

*Greek letters*

| | |
|---|---|
| $\Delta t$ | drop in average temperature of solar pond, °C |
| $\eta$ | daily cumulative efficiency, % |

*Abbreviations*

| | |
|---|---|
| *VMED* | vertical multiple effect diffusion |
| *CPVC* | chlorinated poly vinyl chloride |

only once to produce distillate on glass cover because the latent heat released on account of condensation is lost to atmosphere through glass cover in single effect basin solar still. While in multiple effect still the absorbed solar energy is utilized multiple time to produce distillate several times by recovering and reutilizing the latent heat of condensation before losing to atmosphere. Horizontal multiple effect solar still have been studied by various researchers and observed improvement in productivity and efficiency [18–22].

Among the various types of multiple effect stills, vertical multiple effect diffusion (VMED) solar stills shows better performance in respect of productivity and distillate quality, since the chances of mixing of raw feed water and distillate are very less [23]. The VMED solar still consists of a multiple plate arrangement in which number of vertical plates are kept parallel to each other with a small gap between the plates. Each vertical plate is covered with porous cloth on one side. Heat is supplied to first plate of the multiple plate arrangement and raw feed water is fed continuously to each of the cloth covered surfaces of the plates. The heat supplied to first plate generate water vapours from the water-soaked cloth attached on the other side of the plate. These water vapours diffuse through the narrow gap between the plates and condense on the uncovered surface of the second plate. The latent heat of condensation released by condensing vapours conducts through the plate and further generate the water vapours from the cloth covered side of the second plate. In this way, the heat energy supplied to the first plate is reutilized several times to increase the productivity of the still.

Elsayed et al. [24] experimentally investigated three-effect diffusion still performance and developed mathematical model to predict the performance of ten-effect diffusion still. Tanaka et al. [25] presented a basin type vertical multiple effect solar still and theoretically predicted 15.4 kg/$m^2$-day for 10 vertical cell at the gap of 5 mm. Further, Tanaka et al. [26] performed the parametric study for this still and predicted the productivity four times more than a basin type still and 40% more than that of conventional multiple effect still. Tanaka et al. [27] performed experimental study and observed that basin type vertical multiple effect still with 11 effect and 5 mm gap had maximum productivity of 18.7 kg/$m^2$-day. Nosoko et al. [28] theoretical studied vertical multiple effect still and proposed the concept of heat recovery from waste feed water to preheat the feed water on vertical plates.

Tanaka and Nakatake [29] theoretically analysed a VMED solar still coupled with heat pipe solar collector to pre heat the feed water. Tanaka et al. [30] carried out indoor experiments on VMED solar still coupled with heat pipe solar collector, by supplying heat from infrared lamps. Parametric study on VMED solar still coupled with heat pipe solar collector was done by Tanaka et al. [31]. Chong et al. [32] performed experiment on multiple effect solar still coupled with vacuum tube collector and heat pipe having 18 effects with 6 mm gap of polycarbonate plates and found maximum productivity of 23.9 kg/$m^2$-day. Further, Huong et al. [33] designed a spiral multiple effect diffusion solar still coupled with vacuum tube collector and heat pipe and

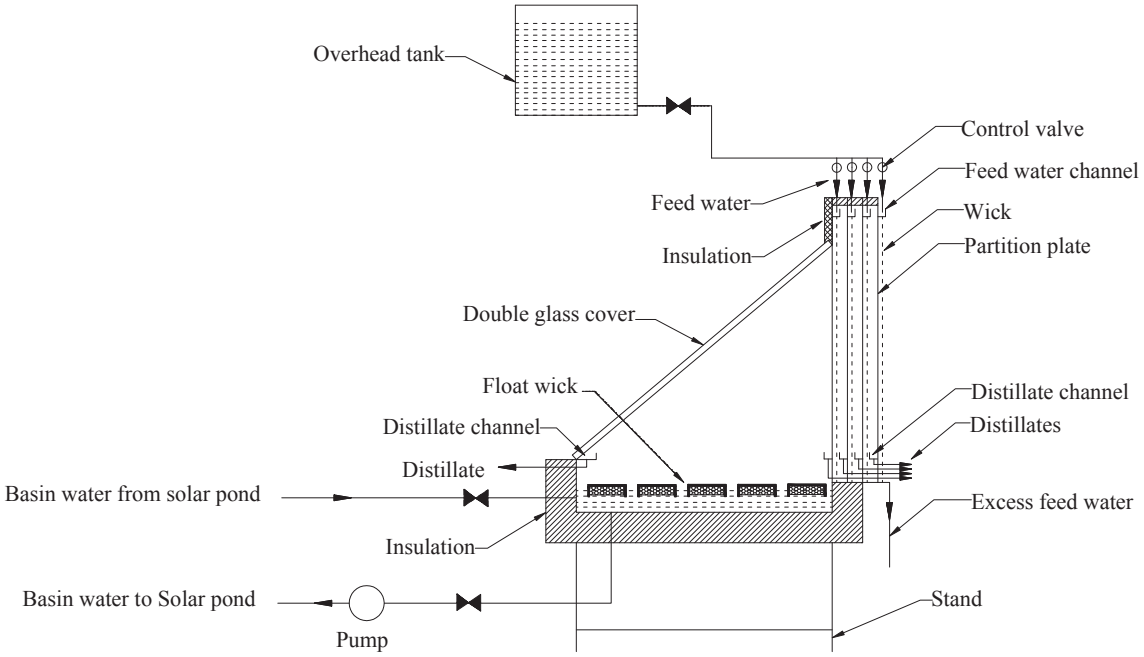


**Fig. 1.** Schematic diagram of basin type VMED solar still with float wick arrangement.

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