Basin-Type Solar Distiller Associated with PVT Collectors—A Comprehensive Review

A. K. Singh, D. B. Singh, Navneet Kumar, V. K. Dwivedi, Gajendra Singh and Rajeev Kumar

Abstract Potable water is one of the prime needs for the existence of life on earth. However, the amount of water on earth is getting polluted due to industrial growth and fast urbanization. The need for potable water is gradually increasing due to exponential growth in human residents. The use of contaminated water is responsible for many waterborne diseases and it sometimes leads to death depending on the intensity of contamination . There are various methods for producing potable water; however, solar desalination is one of the best economical and user-friendly methods for potable water production as its operation resembles natural hydrological cycle and it works solely on solar energy. Basin-type active solar stills are capable of providing potable water as well as DC electric power to the society. The potable water yield for passive solar still ranges from 1 to 3 kg/m^2 and that for active solar still, it ranges from 4 to 15 kg/m^2. In this work, basin-type solar still integrated with PVT collectors has been reviewed and the future scope has been presented.

Keywords Basin-type solar still · PVT collectors · Productivity · Efficiency

1 Introduction

Filtered water is the basic necessity for survival and continued growth on the earth. More demand of fresh water by all sectors like agriculture, industry and domestic purposes forces to use more roughly to the freshly available and limited naturally available water sources like rivers, well, lake, and underground water. So, the controlled use with available sources and with new innovative and significant water purification techniques can manage the demand for potable water.

There are various techniques available for the purification of dirty water in which basin-type solar distillation method is the most versatile economic and self-sustainable technique which utilizes abundantly available solar energy.

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Basin-type solar still concept was initially mentioned by Nebbia and Menozzi [1]. Then, Malik et al. [2] presented the various methods of basin-type solar distillation techniques. Soliman [3] gave the utilization concept of flat plate collectors in the solar still. Basin-type active solar still was revealed by Rai and Tiwari [4]. A variety of different designs and different condensing covers in basin-type solar still were studied by various researchers [5–8]. Kumar et al. [9] studied active solar distiller with PVT collectors and reported better performance in comparison with the conventional solar still. Liu et al. [10] presented solar still with evacuated tubular collectors (ETC) than El-Baily et al. [11] reported the economic performance of active solar still. Singh and Tiwari [12] experimented on solar distiller with PVT collectors along with the partially covered system. Tiwari et al. [13] presented different active solar desalination systems with N number of PVT modules for the same climatic conditions and other design parameters.

2 Solar Still

Solar stills utilize solar energy as a primary source of energy and it may be either passive solar still or active solar still. Passive-type solar distiller consumes solar energy for heating basin water and producing potable distillate. Active solar distiller consumes solar energy for heating basin water and for further increase in potable water productivity, it uses secondary energy sources and related additional elements as electrical energy, PVT cells, flat plate collectors, etc. Active solar stills can also be the nocturnal type or high-temperature still type and active solar still in forced mode was presented by Rai and Tiwari [4], after that various active solar stills have been reported.

3 PVT Collectors

PVT collectors are photovoltaic–thermal modules associated with flat plate collectors which receive direct solar thermal energy useful for heating basin water and producing DC electrical power utilized for running pump and other electrical appliances. PVT collectors are applicable for active solar stills and other solar systems also and as a result, it shows better performance with greater efficiency than passive solar stills.

4 Solar Distiller Associated with PVT Collectors

Singh et al. [12] presented basin type active solar still of single and double slope type along with compound parabolic concentrator (CPC) and NPVT modules as shown in

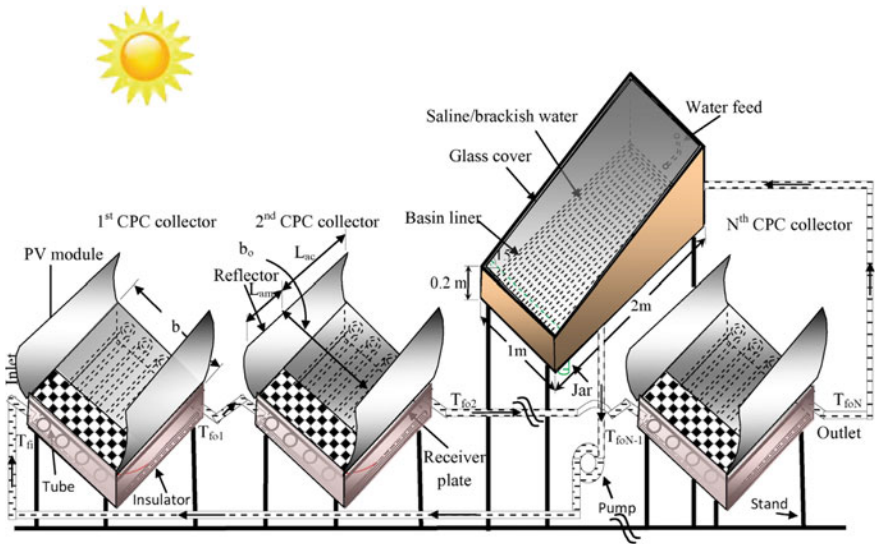

Fig. 1 Pictorial view of active basin-type solar distiller with NPVT CPC collectors [12]

Fig. 1 and result found double-slope solar still presents improved presentation than single-slope distiller as 4519.54 and 4757.70 kg annual distillate for single-slope and double-slope solar distiller correspondingly. It is because of more solar radiation gain in double slope solar still but single slope still is more economical than double-slope solar distiller as it has less embodied energy.

Sahota et al. [14] revealed double-slope active solar still with heat exchanger and nanofluids (water-based Al_2O_3, TiO_2, and CuO nanoparticles) as shown in Fig. 2. The result shows better performance for the combination of solar still with CuO water-based nanofluid and without heat exchanger as 2961.24 kg annual yield rather than other combinations of solar distillation systems with and without nanofluids and heat exchanger. As heat exchanger in the given set up in not much economical due to its high embodied energy and still with water-based CuO performs better due to its best suitability under recommended concentration ratio of nanofluid which is the best part of this type of solar stills.

Singh [15] presented the improved recital of single-slope basin-type solar distiller with NPVT flat plate collectors and found 21.98% cogeneration efficiency and 5845.23 kg annual yield which are much better than other solar systems with same configuration in similar climatic conditions due to better design parameters and optimum numbers of NPVT flat plate collectors as it utilizes maximum solar irradiation energy with minimum losses and minimum embodied energy.

Singh et al. [16] presented an experimental study for active double-slope solar distiller with CPC and NPVT collectors and found reasonable result as 4757.70 kg annual distillate output which is less than single-slope solar distiller with NPVT collectors.

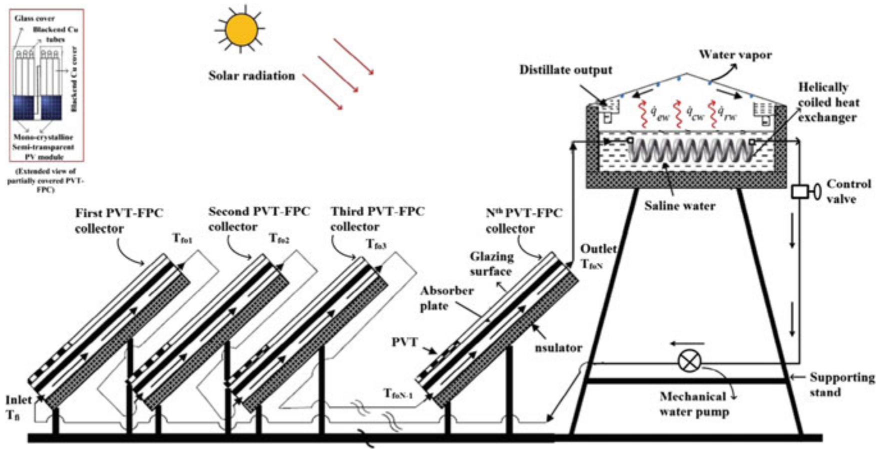

Fig. 2 Active double slope with NPVT flat plate collectors with helical heat exchanger and nanofluids [14]

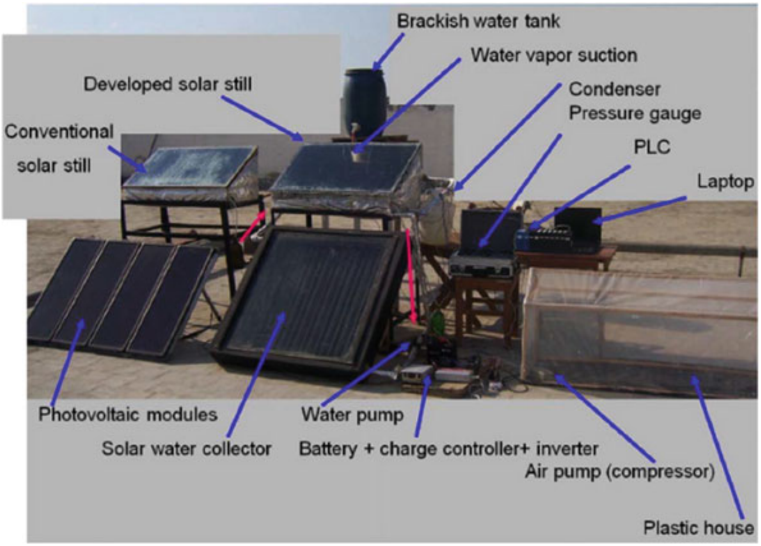

Fig. 3 Setup of conventional and developed solar still with NPVT and flat plate collectors [17]

Eltawil [17] presented an experimental study on conventional and developed single-slope solar still with PVT modules and flat plate collectors as shown in Fig. 3 and found developed single-slope solar still performs better with 5.450 l/m^2/day distillate amount produced as compared to usual single-slope solar distiller.

Al-Nimr Moh'd et al. [18] presented a novel concept of solar distiller with PVT and outside finned condenser as shown in Fig. 4 and reported better performance due to additional condensation and evaporation because of finned condenser as it

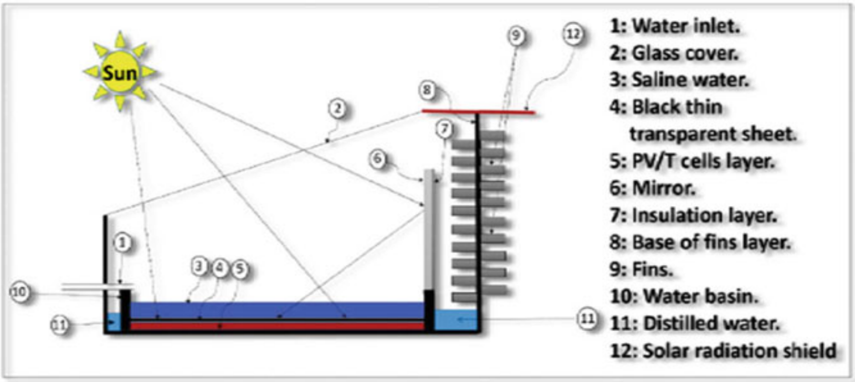

Fig. 4 Image of solar distiller with PV/T and outside finned condenser [18]

increases condensation surface area and a solar radiation shield provides a better environment for condensation which leads to more distillate output.

Yari et al. [19] gave another method for desalting impure water as well as electricity production with the help of PVT modules as shown in Fig. 5 which is solar distiller covered with transparent PVT module associated with ETC in natural circulation mode. The result was found with better effects as per the given Eq. 7 and shown in Fig. 6 as per the given thermal modeling of active single-slope solar distiller with ETC and semi-transparent PVT module.

Energy balance equation for semi-transparent photovoltaic module

$$R_g \alpha_c \beta_c I_s(t) A_c + h_{1w} A_b (T_{sw} - T_c) = h_o A_c (T_c - T_a) + \eta_m R_g \beta_c I_s(t) A_c \tag{1}$$

where α_c, β_c are the design parameters of the PVT module and the electrical efficiency (η_m) given as follows:

$$\eta_m = \eta_{r,m}[1 - \beta_{r,m}(T_c - 25) \tag{2}$$

Solar still basin liner energy balance equation

$$\alpha_b'(1 - \beta_c) R_g I_s(I) A_b = h_{bw} A_b (T_b - T_{sw}) + h_{ba} A_b (T_b - T_a) \tag{3}$$

Energy balance equation for the water mass inside the solar distillation system

$$N_c \dot{m} C_{cw} (T_{cw} - T_{sw}) + \alpha_w'(1 - \beta_c) R_g A_b I_s(t) + h_{bw} A_b (T_b - T_{sw}) = h_{1w} A_b (T_{sw} - T_c) + M_{sw} C_{sw} \frac{\mathrm{d}T_{sw}}{\mathrm{d}t} \tag{4}$$

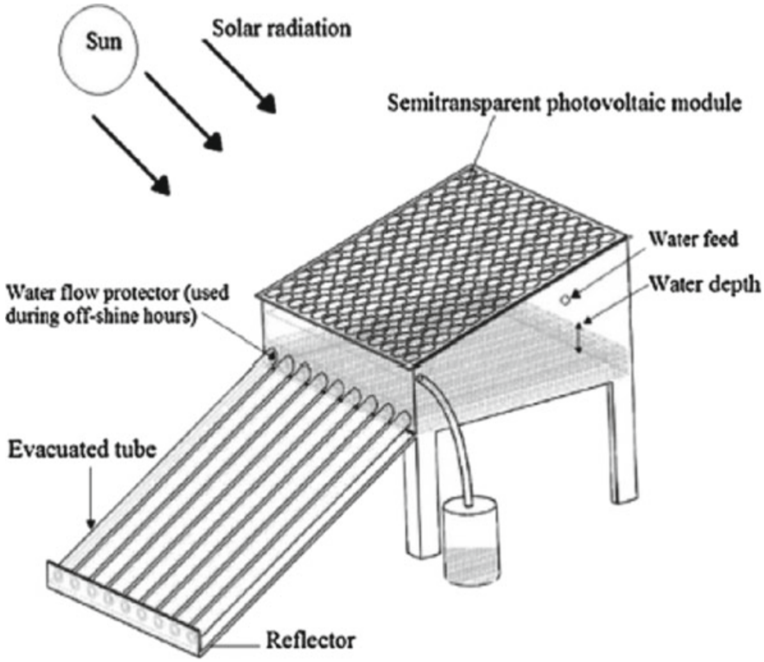

Fig. 5 Line diagram of solar distiller with ETC and semi-transparent PVT module [19]

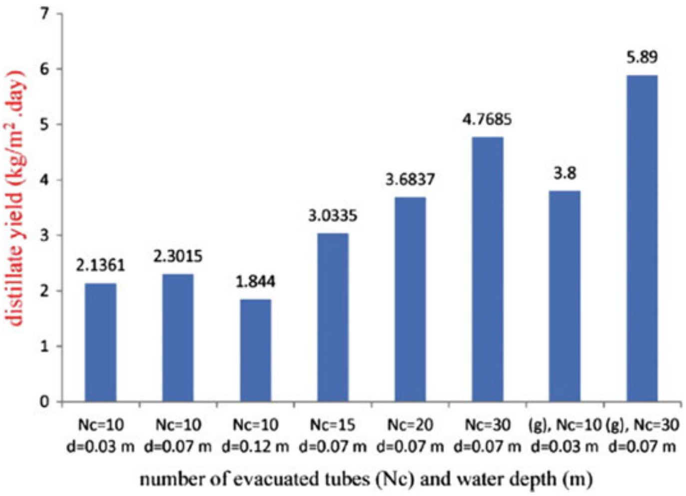

Fig. 6 Variation in yield for various combinations of evacuated tube number and water depth NETC and NPVT collectors [19], (g) [20]

Energy balance equation for ETC

$$Q_{u,\text{collector}} = M_{cw} C_{cw} \frac{\mathrm{d}T_{cw}}{\mathrm{d}t} + N_c \dot{m} C_{cw} (T_{cw} - T_{sw}) \tag{5}$$

where, $Q_{u,\text{collector}}$ represents the useful energy collected to the ETC.

$$T_{sw} = \frac{1}{(\lambda^+ - \lambda^-)} \Big[\Big(\frac{1 - \mathrm{e}^{-c+t}}{c^+} \Big) \big(g_1(t) + \lambda^+ g_2(t)\big) - \Big(\frac{1 - \mathrm{e}^{-c-t}}{c^-} \Big) \big(g_1(t) + \lambda^- g_2(t)\big) + T_{sw0} \big(\lambda^+ \mathrm{e}^{c+t} - \lambda^- \mathrm{e}^{c-t}\big) + T_{cw0} \big(\mathrm{e}^{c-t} - \mathrm{e}^{c+t}\big) \Big] \tag{6}$$

Equation for mass flow rate for distillate output

$$\dot{m}_y = \frac{h_{ew}(T_{sw} - T_c)}{L} \tag{7}$$

All the unknowns in the above equations may be referred by Yari et al. [19]. Further basin type of review studies have been given by the researchers [21, 22]

5 Conclusions

In the present review, various different types of solar distillers especially basin-type solar stills integrated with PVT collectors have been reviewed and the following conclusions have been made as follows:

- Both potable water output and electricity generation are mainly dependent on available solar energy, intensity, and absorbing capability.
- Numbers of solar collectors improve the efficiency and potable water productivity up to the optimized number of collectors with better design parameters.
- Higher temperature of PVT module decreases the efficiency of solar cells which leads to the poor performance of solar still and not economic as well.
- Solar distiller with NPVT module performs better with 5.450 l/m^2/day distillate as compared to others in comparison to distillate output.
- Solar still with PVT module flat plate collectors is itself efficient and self-sustainable for potable water production and electricity production.

6 Future Scope

PVT modules and collectors may be freely placed by the side walls of solar still and also it should be used with optimized dimensions for maximum economic benefits. Auto-cleaning system or some economic arrangement should be there for cleaning PVT module for maintaining better efficiency and utilization in the production of electrical power and distillate output as well.

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