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Review on passive solar distillation

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ABSTRACT

In this communication an attempt has been made to review in brief on passive solar distillation. The review includes the historical background, passive solar distillation and classification of solar still. The heat transfer modes responsible for the analysis of various design of solar stills have been discussed.

Keywords: Passive solar distillation; Review

1. Introduction

The provision of fresh water is becoming an increasingly important issue in many areas in the world. There is a growing realization that the long term solution to shortage of water lies in a coordinated approach involving water management, purification and conservation. A desperate solution to this approach in the development of environmental friendly and sustainable water purification techniques. The solar distillation might be an ideal technology that can partially solve the fresh water problem for both domestic and agriculture use. The feature of this process is the production of vapors above the surface of the liquids by the absorption of solar radiation, the transport of vapor to condensing surface, the cooling of air vapor mixture after releasing latent enthalpy, condensation and precipitation. This process of getting fresh water from Saline/blackish water can be done by desalination.

Hence solar distillation is the most prominent method. Since it requires simple technology, low maintenance and can be used anywhere with lesser number of problems.

2. Historical review

The first documented work on solar distillation was by Arab Alchemists in the 16th Century [1]. In 1589, Della Porta used earthen pots which were exposed to solar rays and water evaporates and the condensate was collected into vases placed underneath [2].

Many researchers have reviewed the historical background of solar distillation. In 1970, Talbert et al. presented the historical background and in 1973 Delyannis and Delyannis reviewed the major solar distillation plants around the world. The review elaborates the work of Delyannis [3], Delyannis and Piperoglou [4] and Delyannis and Delyannis [5].

The work on passive solar distillation till 1982 was reviewed by Maliket al. [6] and was updated by Tiwari [7] which also included active solar distillation, later was updated by Tiwari et al. [8]. As per scenario in

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India, Gomkale [9] studied in detail the solar distillation followed by Fath [10] who reviewed various designs of solar stills suitable for providing potable water.

3. Principle of solar distillation

The solar still has a shallow black basin to hold the salt water and absorb solar radiation; water vaporizes from the brine is condensed on the underside of a sloped transparent cover and runs into the trough and is collected in tanks at the end of the still. The working principle of the distiller unit is described below.

"Solar radiation is transmitted inside the enclosure of the distiller unit after reflection and absorption by the glass cover. The transmitted radiation is partially absorbed by the water mass and partially reflected by the water mass. The transmitted radiation further reaches the blackened surface where it is mostly absorbed. The thermal energy absorbed by the basin liner (i.e., the blackened surface) is then convected to the water mass in the basin and the rest of the energy is lost in atmosphere by conduction through the insulated bottom and sides of the distiller unit. Due to convection of energy by the basin liner, the water mass in the basin gets heated and the temperature of the water mass is higher than the glass cover temperature, there occurs internal heat transfer from the water surface to the glass cover. The heat is transferred by radiation, convection and evaporation. The evaporated water is condensed on inner surface of glass cover after releasing the latent enthalpy to the condensing surface. Due to cover's small inclination, condensate flows by gravity into the collection troughs at the lower edge of the glass cover. The cover is at sufficient slope such that surface tension of the condensate water causes to flow only into the collection trough and not to drop back into the basin. Finally the condensed water is trickled into the container. The collected water is taken out of the system for an appropriate use. Externally the thermal energy received by the glass cover is lost to ambient by convection and radiation".

4. Basic heat and mass transfer in solar still

The operation of a solar still is governed by two basic heat transfer modes namely internal and external heat transfer modes. The internal heat transfer occurs within the still and the external heat transfer occurs between the still and the atmosphere. The main difference between the internal and the external heat transfer is that, within the still convective heat transfer occurs simultaneously with evaporative mass transfer while in external heat transfer no such mass transfer occurs. Radiative heat transfer occurs in both the regions along with the other modes.

5. Internal heat transfer

The glass cover receives heat from water surface through the heat transfer modes of convection, evaporation and radiation.

5.1. Convective heat loss coefficient

The convective heat transfer is conveniently considered in terms of four dimensionless parameters viz., the Nusselt number (Nu), the Grashof number (Gr), the Reynold number (Re) and the Prandtl number (Pr). The expression for the number is

$$\text{Nusselt number}\,(N_u) = \frac{h_{cw}X_1}{k_i} \tag{1}$$

$$\text{Grashof number (Gr)} = \frac{X_1^3 \rho_f^2 g \beta^1 \nabla T}{\mu_f^2} \tag{2}$$

$$\text{Reynolds number (Re)} = \frac{\rho_f V_f X_1}{\mu_f} \tag{3}$$

Where $\nabla T = \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{268.9 \times 10^3 - P_w} \right]$. The coefficient of heat transfer h_{cw} is usually incorporated in the Nusselt number. In the case of heat transfer by free convection, the Nusselt number is related to the Grashof and Prandtl number i.e., Nu = f(Gr,Pr). For the heat flow from the horizontal water surface in the upward direction i.e., against force of gravity, Jakob and Gupta [11] has arrived Nu = C(Gr,Pr)^n by correlating the experimental data of Mull and Reicher [12].

Dunkle's [13] approach for h_{cw} is independent of average spacing d_f and has arrived at the following expression as

$$h_{cw} = 0.884 \times \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{268.9 \times 10^3 - P_w} \right]^{1/3} \tag{4}$$

due to the value of n = 1/3. Hence the rate of convective heat transfer is given by

$$q_{cw} = h_{cw}(T_w - T_g) \tag{5}$$

Where $h_{cw,}$ q_{cw} are convective heat transfer coefficient and convective heat between water surface and cover respectively.

5.2. Radiative heat loss coefficient

Considering the water surface and glass cover as infinite parallel planes, the rate of radiative heat transfer (q_{rw}) from water surface to the glass cover is given by Singh and Tiwari [14] as

$$q_{rw} = \varepsilon_{ff}\sigma\left[(T_w + 273)^4 - (T_g + 273)^4\right] \tag{6}$$

$$q_{rw} = h_{rw}(T_w - T_g) \tag{7}$$

where ε_{ff} is the effective emissivity of the water surface and h_{rw} is the coefficient of heat transfer from water surface to the glass cover and is given by

$$h_{rw} = \varepsilon_{ff}\sigma\left[(T_w + 273)^2 + (T_g + 273)^2(T_w + T_g + 546)\right] \tag{8}$$

$$\varepsilon_{ff} = \left[\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1\right] \tag{9}$$

where ε_g and ε_w are the emmissivities of the glass cover and water surface.

5.3. Evaporative heat loss coefficient

Baum [15] has made the following assumptions in deriving the mass transfer coefficients in terms of convective heat transfer coefficient. They are

(i) There is no significant rate of exchange of water vapor with the boundary layers at the water and glass surfaces.
(ii) P_w and P_g are considerably smaller than P_T.

Based on this assumptions it is given as

$$\frac{h_{cw}}{h_{ew}} = \left[\frac{L}{C_{pa}} \times \frac{M_w}{M_a} \times \frac{1}{P_T}\right] \tag{10}$$

If the physical properties of the air at the still operating temperature range are substituted in the equation, the group in brackets would have values ranging from 0.014 to 0.015. A value of 0.013 was reported in the literature by Malik et al. [6] for this group was obtained by assuming saturated air at 50°C. It is given by

$$h_{ew} = 0.013 \times h_{cw} \tag{11}$$

In order to account for the effects of water pressure, Dunkle [13] has used an experimental value of 0.0163 for the above group and hence the error introduced in the equation was eliminated but only within the operating temperature range and it is given by

$$h_{ew} = 0.0163 \times h_{cw} \tag{12}$$

and hence

$$q_{ew} = h_{ew}(T_w - T_g) \tag{13}$$

For small time interval operation of solar distillation system, the initial water and glass temperature can be used to evaluate h_{ew} and h_{cw}.

6. External heat transfer mode

6.1. Top loss coefficient

As the thickness of the glass cover is small, the temperature of the glass is assumed to be uniform. The external radiation and convection losses from the glass cover to ambient can be expressed as

$$q_a = q_{rg} + q_{cg} \tag{14}$$

by Kumar et al. [16]

where $q_{rg} = \varepsilon_g\sigma\left[(T_g + 273)^4 - (T_{sky} + 273)^4\right]$

$q_{rg} = h_{rg}(T_g - T_a)$

where $h_{rg} = \dfrac{\varepsilon_g\sigma\left[(T_g + 273)^4 - (T_{sky} + 273)^4\right]}{(T_g - T_a)}$

$$T_{sky} = T_a - 6 \tag{15}$$

and

$$q_{cg} = h_{cg}(T_g - T_a) \tag{16}$$

where (a) $h_{cg} = 2.8 + 3.0V$ [17]

(b) $h_{cg} = 5.7 + 3.8V$ [18]

V is the wind velocity and h_{cg} ia heat transfer coefficient due to wind.

There is so significant change in the performance of the distillation system when h_{cg} is evaluated by either one of the expressions.

6.2. Bottom and side loss coefficient

Externally the heat is lost from the water in the basin to the ambient by radiation and convection from the bottom and side surface of the basin through the insulation. Duffie and Beckman [18] expressed the bottom loss coefficient (U_b) as

$$U_b = \left[\frac{1}{h_w} + \frac{1}{\frac{k_i}{L_i}} + \frac{1}{h_{cb} + h_{rb}}\right] \tag{17}$$

$$h_b = \left[\frac{1}{\frac{k_i}{L_i}} + \frac{1}{h_{rb} + h_{cb}} \right] \quad (18)$$

As there is no wind velocity at the bottom of the insulation the value of can be obtained by substituting $V = 0$.

For natural convection, Mc Adams [19] evaluated h_w by using the following relation.

$$Nu = \frac{h_w L}{k} = C(Gr, \Pr)^n$$

Grashof and Prandtl numbers can be determined at an average temperature of the basin. Nayak et al. [20] calculated the values of h_w for upward and downward flow as 135 W/m^2°C and 67.5 W/m^2°C respectively. There is no significant effect on the performance of the system when the values of h_w are changed.

Since the sidewall area of the system A_{ss} is very small compared to the area of the still basin area A_s, the side loss coefficient U_e can be approximated as

$$U_e = \frac{U_b A_{ss}}{A_s} \quad (19)$$

7. Overall heat transfer

7.1. Top loss coefficient

The top loss coefficient (U_t) from the water surface to ambient air can be determined by the equation as

$$U_t = \left[\frac{1}{h_a} + \frac{1}{h_w} \right]^{-1}$$

by Singh and Tiwari [14].

where $h_a = h_{cg} + h_{rg}$

$h_w = h_{cw} + h_{rw} + h_{ew}$

Hence the rate of heat loss in upward direction of distillation system as

$$q_t = U_t(T_w - T_a) \quad (20)$$

by Singh and Tiwari [14].

7.2. Bottom loss coefficient

The rate of heat loss from water surface to ambient through the bottom of the insulation is given by

$$q_b = U_b(T_w - T_a) \quad (21)$$

by Singh and Tiwari [14].

From the bottom and top loss coefficients U_b and U_t, the overall heat lost from water surface to ambient air can be obtained as

$$U_L = U_t + U_b \quad (22)$$

The total rate of heat lost from water surface to ambient air is given by

$$q_{loss} = U_L(T_w - T_a) \quad (23)$$

8. Evaluation of distillate output

The distillate water output is the amount of energy utilized in vaporizing water in the still over the latent heat of vaporization of water. Then the mass of hourly distillate output from the still of evaporation area is given by

$$m_w = \frac{q_{ew} \times 60 \times 60 \times A_s}{L} \text{ kg}/A_s\text{hr.} \quad (24)$$

by Singh and Tiwari [14].

Where L is the latent heat of vaporization.

Before calculating the hourly distillate, it is important to note the behavior of h_{ew}, T_w and T_g. The expression for h_{ew} by Dunkle [13] has been used by most of the scientist working in research area of solar distillation to validate either their indoor simulation or outdoor field experimental observations. It is observed that most of the experimental results are in good agreement with the theoretical results obtained through the same expression of h_{ew}.

The values of C and n in the various ranges of values of different Grashof number are in Table 1.

9. Classification of solar stills

The classification of solar distillation design is presented in Table 2, which is indispensable to have the thorough knowledge of the design.

10. Efficiency of the distiller unit

Solar still efficiency (η) is the amount of energy utilized in vaporizing water in the still over the incident solar energy on the still. There are two types of efficiencies namely instantaneous efficiency and overall efficiency (daily) of the distiller unit.

Table 1
Values of C and n for different Grashof number range

S. no.	C	*n*	Range	Source
1.	1.00	0	$Gr < 10^3$	Mull and Reicher [12]
	0.21	1/4	$10^4 < Gr < 3.25 \times 10^5$	
	0.075	1/3	$3.3 \times 10^5 < Gr < 10^7$	
2.	0.07477	0.36	$2 \times 10^3 < Gr < 6 \times 10^4$	Van der Held [21]
	0.05238	0.36	$2.5 \times 10^5 < Gr < 10^7$	
3.	0.05814	0.4	$2 \times 10^3 < Gr < 5 \times 10^4$	De Groaf and Van der Held [22]
	3.8	0	$5 \times 10^4 < Gr < 2 \times 10^5$	
	0.04836	0.37	$2 \times 10^5 < Gr$	
4.	0.3	1/4	$2.8 \times 10^3 < Gr < 2.1 \times 10^5$	Jakob and Gupta [11]
	0.1255	1/3	$4.2 \times 10^3 < Gr < 4.2 \times 10^9$	
5.	0.0322	0.4114	$1.794 \times 10^6 < Gr < 5.724 \times 10^6$	Kumar et al. [23]
	0.0538	0.383	$5.498 \times 10^6 < Gr < 9.128 \times 10^6$	

Table 2
Classifications of solar distillation systems

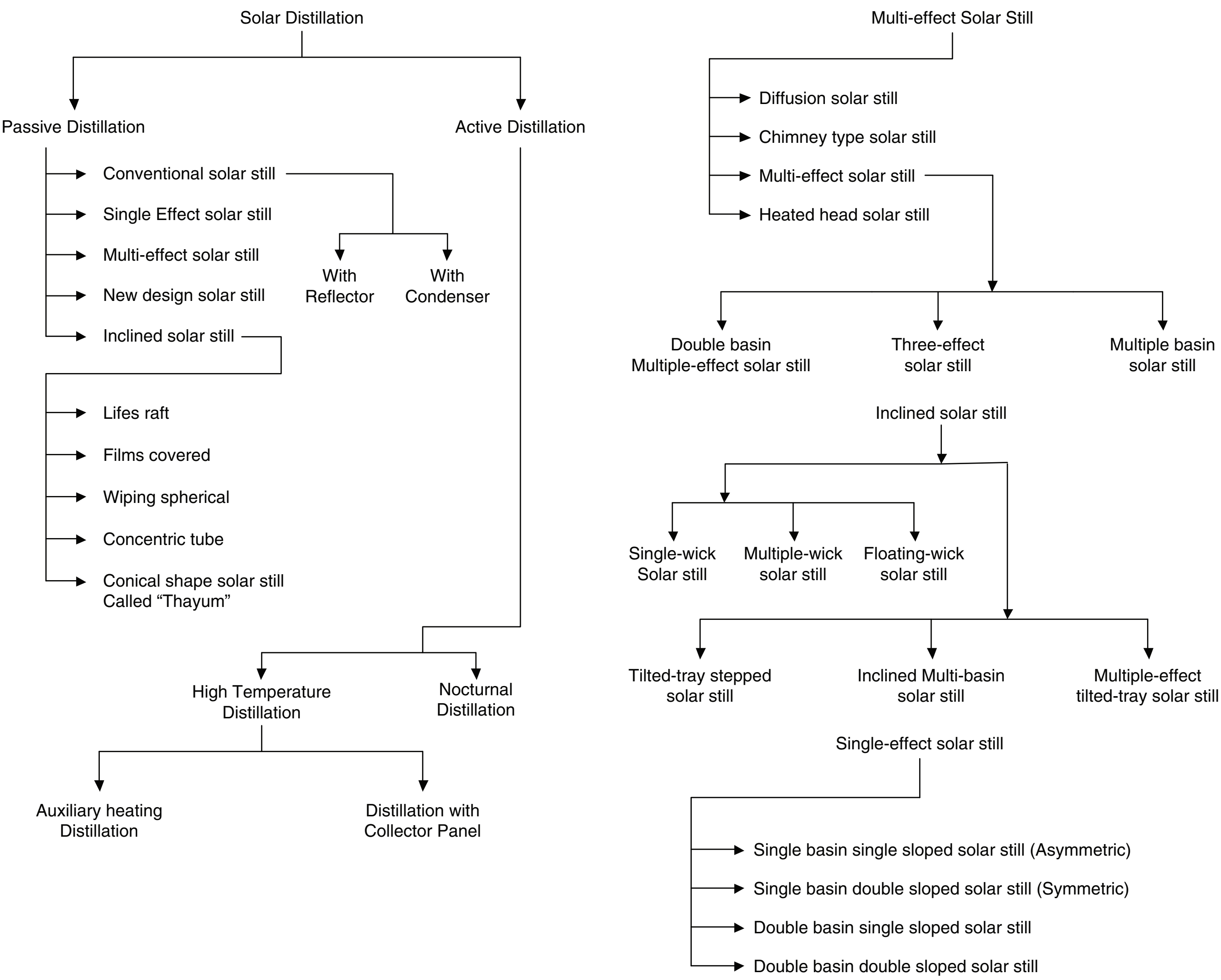

Table 3
Review of solar stills

S. no.	Reference	Aim of the work/design	Authors' remark
1.	Cooper [24]	A method to calculate the fraction of incident solar radiation in solar stills has been presented.	The equation presented can be used to find a mean effective absorptance for any given values of variables (day of the year, latitude, cover slope, orientation, diffuse radiation and insolation intermittency).
2.	Cooper [25], Sodha et al. [26], Garg and Mann [27] and Akash et al. [28]	Constructed a conventional solar still and examined the effect of the addition of dye in the basin containing the water mass.	Addition of dye in the water mass of the basin had shown improvement in the productivity of the still.
3.	Solimon [29], Garg and Mann [27] and Tiwari and Kailash Thakur [30]	Attempts were made to find the effect of wind velocity on the performance of the still.	Discontinuous wind over the still, the increase in wind speed when the temperature of the water in the basin is high and increase of wind velocity for fixed values of other parameters increased the efficiency of the still.
4.	Garg and Mann [27], Morse and Read [31] and Cooper [25]	Examined the effect of ambient temperature on the performance of the still.	The output decreases with the decrease of ambient temperature beyond 26.7°C.
5.	Frick. G and Von Sommerfeld [32]	Examined the inclined evaporating wick for 8 y.	Efficiency of about 30% decreased due to decolourisation of the wick.
6.	Baibutaev et al. [33]	Analyzed the effect of salt concentration of the water to be distilled on the output of the still.	The distillate output decreased when the salt concentration of the water to be distilled increased beyond the saturation point.
7.	Cooper [34]	Designed and analyzed a conventional single effect solar still.	Attained a maximum thermal efficiency of about 60%.
8.	Talbert et al. [35], Hirschmann, Rheinlaender [36] and Moustafa et al. [37]	Compared conventional basin-type solar still and tilted-wick type solar still.	Tilted-wick solar still had some advantages over basin-type solar still.
9.	Sodha et al. [38]	Designed and analyzed the simple multiple wick solar still	The distillate output was 2.5 l/m^2d on a cold sunny days corresponding to an overall efficiency of 34% (as compared to a maximum of 30% for basin type solar still) and moreover still cost was less than half of the cost of a basin-type solar still.
10.	Sodha et al. [39]	Analyzed periodically and observed the performance of a double basin solar still.	Distillate production was increased on the average of 36% higher than that of a single basin solar still.
11.	Garg and Mann [27] and Ho-Ming-Yeh and Lie-Chang-Chen [40]	The effects of climatic and design parameters of wick-type solar still had been found.	Distiller unit without insulation reduced the distillate yield.
12.	Egarievwe et al. [41]	Analyzed a solar still with a glass roof and a concrete basin lined with black Polyvinyl Chloride (PVC).	Addition of charcoal, coal and combination of charcoal and coal pieces on the impure water increases the efficiency of the still.
13.	Tiwari and Dhiman [42] and Morcos [43]	Constructed still coupled with flat-plate collectors and examined.	Better performance was obtained.
14.	Franco and Saravia [44]	Compared two stills one with inclined glass surface in the upper surface and the other with multistage inclined surface within the still provided the saline water preheated by solar collector.	The performance of multistage still was good.

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
15.	Riffat [45]	Designed a system with flat-plate collector, absorber, condenser and evaporator.	Absorption system using H_2O/LiBr thermodynamically produced low efficiency but significant heat output.
16.	Al-Karaghouli [46]	Analyzed the floating-wick still i.e., the blackened jute wick in a corrugated shape had been floated with a polystyrene sheet in the water mass of the basin.	Higher distillate output was obtained when compared with basin-type solar still.
17.	Porta et al. [47]	Constructed a Mc Cracken Porta solar still with effective distillation area of 8.18 m^2 which had added insulation at the bottom and edges.	Due to large thermal inertia, the overnight production increased but overall production decreased.
18.	Aboul-Enein et al. [48]	Designed a single basin solar still of area 1 m^2 with 15° tilted top glass cover with deep basin.	The water depth had reverse effect on the productivity in daylight and overnight.
19.	Mink et al. [49]	Designed a solar still with still module, solar simulator, two vapor separators, heat exchangers, persistable pump, gas flow meter, magnetic valves and the electric balance.	The still gave a maximum total productivity of 3.05×10^{-4} kg $m^{-2}s^{-1}$.
20.	Abd Elkader [50]	Constructed three stills of different base slope and glass cover tilt angles with area of each 1 m^2.	The best result coincided with base slope of 15° and glass cover slope angle of 35°.
21.	M. Rommel [51]	A new absorber made of plastic material sputtered with metal layer which acts as an IR mirror.	Selectively coated polymer absorbers in flat-plate collector had shown attractive performance for desalination applications.
22.	Mueller-Holst et al. [52]	Designed a pilot solar multieffect humidification (MEH) desalination system.	The system ensured a reliable supply of high quality drinking water for decentralized use in rural areas.
23.	Bouchekima [53]	Distiller unit with several stage of evaporator formed by a thin fabric held in contact with over-hanging plate making the plate-fabric interface a capillary film.	The efficiency had increased when the temperature of the brine, solar intensity and number of stages increased.
24.	El-Bahi and Inan [54]	Solar still with an evaporator area of 1 m^2 covered with two parallel glass sheets of 3 mm thickness integrated with the condenser through horizontal slot provided with vertical reflector had been designed.	The efficiency increased significantly.
25.	Balladin et al. [55]	Constructed an insulated cascade solar still of minimum size of 60″ x 48″.	The still had shown an economic feasibility to produce distilled water for routine laboratory work.
26.	Haddad [56]	Basin type solar still integrated with an external condenser i.e., packed bed storage tank had been constructed.	The productivity increased with the increase of solar radiation but the still efficiency was decreased.
27.	Rubio-Cerda et al. [57]	Constructed a triangular solar still with effective evaporation area of 8.8 m^2 formed by the evaporator dimensions of 3.64 m by 2.42 m with double slope glass covers of 0.005 m thickness at an angle of 45° oriented with North-South and East-West.	The North-South and East-West orientation reproduced satisfactorily the measured production of each cover

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
28.	Haralambopoulos [58]	Designed a solar still for dewatering of wastewater sludge using activated sludge process.	The distillate had increased contamination due to the intense production of vapor carrying volatile organic compounds inside the still.
29.	Bannat [59]	Designed a solar still of 0.98 x 0.98 m with inclination of 19° using shell and tube membrane module.	The salt concentration was marginal due to membrane module.
30.	Zheng Hongfei and Ge Xinshi [60]	A still of two chambers with central partition with a vertical tube falling film evaporation condenser, gas liquid separator with heat exchangers and an air fan.	The performance ratio was two or three times greater than that of a conventional basin-type solar still.
31.	El-Wify and Metias [61]	A L-type solar still of aspect ratio 2.0 with South, East and West facing walls covered by highly reflecting material from the outer surface and covered by glass cover slope of 25°.	The productivity increased considerably.
32.	Valsaraj [62]	Constructed two identical single slope stills one with perforated and black coated thin rectangular aluminium sheet folded into 'V' shape was positioned afloat in the still.	The yield was high in the aluminium sheet afloated still when the depth remained high.
33.	Rahim [63]	Desalination unit with thermally insulated at the bottom and heat storage zone formed by placing aluminium sheet painted black at the top surface had been constructed and analyzed.	The efficiency is higher than the insulated shallow horizontal solar still.
34.	Al-Kharabsheh [64]	Designed a system consisting of heat source, evaporator, condenser and discharge pipes based on innovative passive vacuum technique.	Solar stills coupled with thermal solar system had increased productivity during the day as well as in the night.
35.	Lianying Zhang et al. [65]	Constructed a solar desalination system with a solar collector or area 2.01 m^2.	The distillate output was high per unit area as compared with other designs of solar still.
36.	Al-Hayek and Badran (2003)	Attempt made to predict the Performance characteristics of Asymmetric greenhouse type solar still (ASGHT) and Symmetric greenhouse type solar still.	The productivity of Asymmetric Greenhouse type solar still has found to be 20% higher than that of Symmetric Greenhouse type solar still.
37	Abdallah and Badran [66]	Single slope solar still with asphalt basin liner and sprinkler is constructed and studied experimentally	The still productivity is increased upto 51% when combined with enhancers.
38	Hanson et al. [67]	Laboratory and field trials have run on the performance of single basin solar stills for the removal of a selected group of inorganic, bacteriological and organic contaminates.	The ability to remove contaminates did not vary significantly between the units and the ability to remove the organic compounds is found to be directly depend on the volatility of the compound measured by Henry's law constant.
39.	Ward. J [68]	A plastic solar still is designed and constructed	The distillate yield upto 9 l/m^2 are obtained at 35°C ambient or approximately 1000 W/m^2.
40.	Tripathi and Tiwari [69]	An attempt has been made to find the effect of water depth on internal heat and mass transfer for active solar distillation.	It is found that more distillate yield is obtained for decreased water depth during off shine hours as compared to daytime for higher water depths in solar still (0.10 m and 0.15 m) due to storage effect.

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
41.	Singh and Tiwari [70]	Attempts have been made to find the monthly performance of passive and active solar stills by numerical computations for hourly variations of average insolation at Chennai, Jodhpur, Kolkata, Mumbai and New Delhi stations.	The numerical computations reveals that the annual yield significantly depends on water depth, inclination of condensing cover and collector for both passive and active solar stills and the annual yield for a given water depth increases linearly with the collector area for an active solar still.
42.	Sow et al. [71]	An attempt has been made to analyse single-, double- and triple-effect distiller exergetically and energetically.	The energetic analysis is useful to find the energy necessary for vapour condensation and the power consumption per unit mass of pure water. The exergetic analysis had shown the most significant exergy losses are condenser losses and water alimentation losses.
43.	Boukar and Harmim. A [72]	A vertical solar still is constructed and tested to study the parameters affecting the performance of the still under desert climatic conditions.	The study had shown that the productivity of ths still strongly depends on solar radiation, ambient temperature and solar orientation.
44.	Tanaka et al. [73]	The parametric influence of a vertical multiple-effect diffusion-type solar still coupled with a heat-pipe solar collector is tried	It has been found that the productivity increases with an increase in the number of partitions and the temperature of the saline water fed to the wicks, and with a decrease in the ratio of the solar collector area to each partition area, the thickness of the diffusion gaps between partitions, and the feeding rate of saline water to the wicks.
45.	Tanaka et al. [74]	A vertical multiple-effect diffusion-type solar still coupled with a heat pipe solar collector is constructed and indoor experiment is carried out to find the performance of the still	The result reveals that the overall production rates or the still is about 93% and the heat pipe of the still can transport thermal energy well from the solar collector to the vertical multiple-effect diffusion-type solar still.
46.	Boukar and Harmim [75]	An indirect vertical solar still with flat-plate collector, an evaporation chamber and condensation chamber is constructed and tested.	The daily productivity of the solar still during winter period varied from 0.863 to 1.323 l/m^2d when the solar radiation intensity in the range 19.15 to 26.08 MJ/m^2, under daily ambient temperature varied from 10.68 to 15.19°C and the maximum hourly efficiency ranged from 47.69 to 57.85%.
47.	Badran and Al-Tahaineh et al. [76]	The effect of coupling of a flat-plate solar collector on solar still productivity has been tried experimentally.	It has been found the productivity of the still is increased by 36% when coupled with a solar collector and the productivity decreases with increase of water depth and proportional to the solar radiation intensity.
48.	Sahoo et al. [77]	Present work has been carried out to remove the fluoride content in drinking water using a solar still and also to modify the basin liner and insulation to increase the efficiency of the still	The results had shown that the fluoride reduced by 92-96% and the efficiency increased by 6% with suitable blackened basin liner and thermo coal insulation
49.	V.K. Kumar and K. Bai [78]	Has been built a basin type solar still of 0.5 m^2 with improved condensation technique and tested with different samples such as tap water, sea water and dairy industry effluent	The maximum daily production was about 1.4 l/m^2 d and its efficiency was about 36% with corresponding average solar radiation of 28 MJ/d

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
50.	Shanmugan et al. [79]	A solar still with acrylic booster mirror has been fabricated with commercial aluminium sheet and insulated with a thermo coal sheet	For boosted distillation unit, the distillate output was 4.2 l/m^2 day at 890 W/m^2max
51.	Basel [80]	Hemispherical solar still has been fabricated to find the performance of the still	The average daily distillate output ranged from 2.8 to 5.7 l/m^2 day and its efficiency was found to be 33%. The efficiency decreases by 8% with increase in water depth of 50%
52.	Zhani et al. [81]	Designed a new desalination system working with humidification dehumidification method. A set of algebraic system of equations have been derived based on heated and mass transfers in each component of the unit in steady-state regime.	The developed equation is used to simulate the HD system in order to investigate the steady state behaviour of each component of the unit.
53.	Soufari et al. [82]	A solar humidification dehumidification desalination unit has been constructed for 10 l/h fresh water production. Theoretical equations developed have been validated with experimental observation.	The theoretical results are in good agreement with the experimental me.
54.	Murase et al, [83]	A tube–type solar distiller hybridized a conventional basin solar still an air gap membrane distiller and the tube type solar distiller coupled with basin solar still with a flat –type membrane distiller have been fabricated and tested in Japan.	The daily productions was 2.18 kg/m^2d at as irradiative intermits of lamps per a day 22.6 m^3/d.m^2d..Ther hybrid solar distiller enhanced the productivity for practical applications.
55.	H. Mousa and M. Abu Arabi [84]	Energy balance equations have been written for solar desalination unit with falling film and equations solved using MATLAB by Runga-kutta four order methed .	The productivity increased by decreasing the flow of feed water, glass cover temperature and by increasing the feed water temperature and solar radiation intensity.
56.	A.J.N. Khalifa and A.M. Hamood [85]	The root mean square value has been found for the performance correlations developed by researchers regarding basin –type solar still.	For brine depth, R^2 value increased from 0.832 to 0.865, from 0.734 to 0.793 for tilt angle and from 0.833 to 0.904 for the effect of dye.
57.	A.K. Hossain and P.A. Davies [86]	Solar power reverse osmosis combined with a greenhouse has been made. An innovative multieffect heat pipes desalination system with falling film evaporation has been designed and tested	The salt concentrate from RO module is used to cool greenhouse through as evaporative pad and had shown the evaporative cooling successfully using RO. The unit has a good potential for practical applications. The MED with heat pipes has small heat transfer area reduced by 25%.
58.	Gao et al. [87]	A photovoltaic powered reverse osmosis system has been designed to irrigate green house in stand alone arrangements. To asses the sizing and cost of the system, energy balance equations have written.	There exist liner relation among the variables, solar radiation, fresh water output and evapotranspiration demand.
59.	Chen et al. [88]	A quadrupole effect regeneration absorption solar desalination unit was tested in doors to predict the performance ratio and flow rate of fresh water at different operating temperature and fresh pressure.	The optimal parameters which are solar collector area storage volume, start up and break temperature illustrated the advantage of absorption of desalination system.

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
60.	H.S. Aybar and H. Assefi [89]	Simulation of conventional solar still to investigate water depth and glass angle has been done.	The simulated results are good agreements with the experimental results.
61.	H.S. Aybar and H. Assefi [90]	An attempt has been made to predict the performance of basin solar still and wick type solar still connected in series with a solar pond and step stepped solar still.	Theoretical analysis of the still is in good agreement with the experimental results.
62.	Abu-Arabi et al. [91]	Theoretical analysis of a one-step azimuthal tracking tilted–wick solarstill with a vertical flat plate reflector has been carried out four type days, the spring and equinox and summer and solarstice days at 30°N latitude.	The proper tilt angle of the still according to seasons increased the daily amount of distillate yield.
63.	Velmurugan et al, [92]	An attempt has been made to develop geometrical modal to calculate the radiation reflected from an external reflector of a basin type solar still	The productivity of still is increased for smaller augmentation in summer and the benefit of the reflector less summer.
64.	H. Tanaka and Y. Nakatake [93]	An attempt has been made to design a desalination unit at low temperatures and low pressures by a applying barometric head without any mechanical energy input.	The new design has the potential to evaporate saline water at near ambient temperature.
65.	H. Tanaka [94]	Theoretical analysis of a tilted wick solar still with an include flat plate external reflector has been carried out on a winter solstice day at 30°N latitude.	The distillate yield increased by 15% or 27%, greater than that with a vertical reflector when the reflectors length is a half or the same the stills length.
66.	A. Madhlopa and C. Johnstone [95]	A new model for the computation of solar fraction in a single slope solar still has been tried to predict the performance.	The results indicate that the splitting of solar fraction into beam and diffuse parts improved the accuracy of the performance of single slope solar still as compared with the previous model.
67.	A.J.N. Khalifa and A.M. Hamood [96]	A correlation equation has been developed from all brine depth data to predict the influence of brine depth on the productivity of basin type solar still.	The still productivity is influenced by the brine depth by up to 48%.
68.	K. Vinoth Kumar and R. Kasturi Bai [97]	A basin type solar still of area $0.5m^2$ with improved condensation technique has been designed and performance study has been found.	The water circulation through tube attached on the walls of surface enhanced the efficiency of the still.
69.	A. Madhlopa and C. Johnstone [98]	The passive solar still with one basin in the evaporation chamber and two bases in the condenser chamber with a glass over the evaporator basin and an opaque condensing cover over basin 3 has been designed and tested.	It is conceded that the productivity of the solar still with separate condenser is sensitive to the absorptance of the liner basin 1, and the mass of water in basins 1 and 2.
70.	Jiang et al. [99]	The performance of a directly heated solar distillation system integrated with flash equipment has been designed and analysed.	Experimental results are in good agreement with the theoretical analysis.

(*continued*)

S. no.	Reference	Aim of the work/design	Authors' remark
71.	Ahmed et al. [100]	An attempt has been made to propose a mathematical model of multistage evacuated solar distillation system and structured analysis has been carried out using NASTLAN software.	The analysis revealed that, as the height increases the productivity decreases.
72.	Velmurugan et al. [101]	A steped solar still with effluent setting tank has been fabricated for desalinating the textile effluent.	The productivity increased by 98% when tin, sponge and pebbled are used in the basin.
73.	A.E. Kabeel [102]	A solar still with concave wick surface as evaporation area and four sides of a pyramid shaped still as condensing surface has been fabricated and tested.	The average distillate productivity is 4.11 l/m^2, and the maximum instantaneous efficiency is 45%.
74.	R. Kumar and L. Umanand [103]	A detailed bond graph model for desalination unit with seamless integration of a power flow across electrical, thermal and hydraulic domains has been proposed and validated.	The system is validated in steady state condition by simulation and experimentation.
75.	A.J.N. Khalifa and A.M. Hamood [104]	The effect of insulation on the productivity of a basin type solar still has been analyzed for 30, 60 and 100 mm thickness.	The insulation thickness influenced the productivity of the still over 80%

Table 4
Review of theoretical simulation models of solar still

S. no.	Reference	Aim of the work/design	Author's remarks
1.	Tiwari et al. [38]	Attempts had been made to derive analytical expressions for evaporative heat loss (open-cycle mode) based on the mass transfer rate from a wetted surface to the atmosphere as a function of relative humidity.	Theoretical results were in good agreement with the experimental results.
2.	Tiwari and Rao [105]	Transient performance of a single basin solar still with water flowing over the glass cover had been carried out.	Uniform flow of water over the glass cover decreased the glass cover temperature and increased the productivity.
3.	Tiwari and Salim [106]	Designed a double sloped fibre reinforced plastic multistill and developed analytical expressions for water and glass temperatures and thermal efficiency by incorporating the system design and climatic parameters.	The theoretical results were in good agreement with the experimental results.
4.	Prakash and Kavanthekar [107]	Designed and analyzed the performance of regenerative solar still.	Daily distillate output was about 7.5 lm^{-2}.
5.	Tiwari and Madhuri [108]	Effect of water depth had been studied using a transient analysis of a solar still.	Dependence of yield on water depth was a strong function of temperature of the brine in the basin and daily yield increased for an initial temperature of the brine ≤ 45°C and decreased when the temperature of the brine ≤ 40°C.

(*continued*)

S. no.	Reference	Aim of the work/design	Author's remarks
6.	Tiwari et al. [109]	Analytical study of the multi-effect wick type solar still had been carried out by incorporating the effects of still length, water flow velocity, inclination of absorber etc.	Performance increased with decreased flow velocity for a particular length of the still and optimum number of condensing surface area was 3.
7.	Tiwari et al. [110]	Transiently analysed a single solar still in the presence of dye in terms of attenuation of solar flux with depth of water in the basin.	For larger water depth and low absorption coefficient the theory gave more accurate result.
8.	Lawrence et al. [111]	Studied the effect of water flow over the glass cover of a passive conventional solar still.	Efficiency increased upto 1.5 m/s water flow rate over the glass cover.
9.	Lawrence and Tiwari [112]	Analytical expressions derived by Tiwari et al. (1982) had been used to study the effect of evaporative heat loss on the open-cycle mode of operation of the still.	The expressions were satisfied.
10.	Tiwari and Singh [113]	Designed a double slope solar distiller and developed analytical expressions for the thermal efficiency by incorporating the uniform water flow in both slopes.	Thermal efficiency was significantly increased for least water flow due to capillary action of the wick.
11.	Tiwari and Singh [114]	Developed analytical expressions for the thermal efficiency of evaporative heat loss for open and closed-cycle system in terms of system design and climatic parameters of double-sloped fibre reinforced multiwick solar still.	Numerical results obtained using analytical expressions were in good agreement with the experimental results.
12.	Tiwari and Kailash Thakur [30]	Derived analytical expressions for the efficiency of a conventional solar still.	Efficiency increased for decreased water mass, increased wind velocity and nominal solar insolation when other parameter values were fixed.
13.	Yadav and Ashok Kumar [115]	Designed a basin solar still and derived expressions for flowing water temperature in the basin, glass cover temperature, basin liner temperature, distillate output and efficiency.	The flowing water temperature, distillate output and efficiency increased with decreased mass flow rate, increased still length, increased Absorptivity of basin liner and increased initial water temperature.
14.	Tiwari et al. [116]	Analytical expressions had been developed for various temperature components of double basin solar still.	The distillate yield was enhanced when water depth was less in lower basin and reduced when water depth was high in lower basin.
15.	Yadav and Prasad [117]	Analyzed parametric influence on a basin-type solar still.	Efficiency, distillate output and water temperature increased with increase of initial water temperature, Absorptivity of the basin liner and decreased with increase of water mass in the basin.
16.	Kumar et al. [118]	Transient analysis of double slope double basin solar still had been carried out to predict the performance of the still.	Efficiency was significantly higher than the single basin solar still.
17.	Tiwari and Lawrence [119]	Attempts had made to predict the convective heat transfer coefficient based on physical properties of water vapor in the cavity volume.	The convective heat transfer coefficient depends on temperature of water vapor, inclination of glass cover and spacing between evaporating and condensing surface.

(*continued*)

S. no.	Reference	Aim of the work/design	Author's remarks
18.	Mowla and Karimi [120]	Mathematical model had been developed for basin-type solar still of area 1m^2 with an inverted V-shape glass cover.	Productivity increased with decreased water depth and theoretical results were in good agreement with the experimental results.
19.	Adhikari [121]	Constructed a multi-stage stacked tray solar still.	Distillate output was high as compared with the conventional solar stills.
20.	Ahamed Taleb Shawaqfeh et al. [122]	Analyzed a single basin solar still with dimensions of 0.98 x 0.98 m to predict the heat and mass transfer.	Dunkle's (1961) model for the heat and mass transfer over predicted evaporation rate of about 30%.
21.	Kumar and Tiwari [23]	Estimated the convective mass transfer for active and passive solar still of area 1 m^2.	From any standard values of C and n, the performance of solar still cannot be evaluated theoretically unless it is validated experimentally.
22.	Yaghoubi and Sabzevari [123]	Empirical method for calculation of the hourly output over a 24 hour cycle by introducing the new variable, the service time had been developed.	The performance improved with the addition of compensation water to the basin for the periodic service time.
23.	Aggarwal and Tiwari [124]	Attempts had been made to discover C and n in Nu=C(Gr Pr)^n by linear regression for different temperature ranges of double-condensing chamber (DCS) and single-sloped conventional solar still (CSS).	The order of C and n were the same as proposed by Dunkle (1961) for low operating ranges and these values changes for operating temperature other than Dunkle (1961).
24.	Sangeeta Suneja and Tiwari [125]	Analytical expressions for the internal heat transfer coefficients of inverted absorber and analyzed the effect of water flow over the glass cover.	For a particular flow rate, the evaporative heat transfer coefficients decreased with the increase of water depth in the basin.
25.	Kumar and Tiwari [126]	Runge-Kutta method had been used to solve one-order coupled differential equations for multi-effect active solar distillation system to evaluate daily yield.	The maximum yield was obtained at different collector areas for a different number of effects for a given basin area.
26.	Aggarwal and Tiwari [127]	A thermal model of a double condensing chamber (DCS) had been developed and experimental observations were carried out for both single sloped conventional solar still (CSS) and DCS for comparison of their performance.	Distillate yield was high for DCS and there was a fair agreement between theoretical and experimental observations.
27.	Tiwari et al. [8]	Review in brief work on solar distillation and its status, water sources, water demand and availability had been attempted.	Gave the recommendations, economic of single and double slope fibre reinforced plastic solar still on the basis of the long-term performance for the future.
28.	Tripathi and Tiwari [128]	Condensing covers with characteristic dimensions of 0.14 cm and 0.07 cm made of Aluminium and copper were used to study the convective and evaporative heat transfer coefficients.	It was found that there were increase of 15% and 7.5% in the evaporative heat transfer coefficients due to the change in the size and material of the condensing cover.
29.	Singh and Tiwari [70]	Monthly and annual performances of passive and active solar stills for different Indian climatic conditions were evaluated.	The annual yield depends water depth, inclination of glass cover and collector for both active and passive solar still. Moreover the annual yield of active solar still for a given water depth increased linearly with the collector area.

(*continued*)

S. no.	Reference	Aim of the work/design	Author's remarks
30.	Tripathi and Tiwari [69]	Studied the effect of water depth (0.05, 0.1 and 0.15 m) for passive as well as active solar distillation system.	More yield obtained during off-shine hours as compared to day-time for higher water depth in solar still (0.10 and 0.15 m) due to storage effect.
31.	Janarthanan et al.[129]	Attempt made to derive the analytical expressions for the thermal efficiency of evaporative heat loss and heat transfer for a open- and closed-cycle systems of floating cum tilted-wick solar still in terms of system design and climatic parameters.	Derived analytical expressions have been used to optimize the design of the still for evaporative cooling (open-cycle) and the distillation unit (closed-cycle) for large scale installations.
32.	Badran et al. (2003)	Constructed an inverted trickle solar still and studied the performance	The still had shown an increase of 18% output and 13% of reduction of salinity of input feed water
33.	Radhwan [130]	Constructed stepped solar still for heating and humidifying agriculture greenhouses (GH)	The daily average efficiency is found to be 63% and total daily yield is about 4.92 l/m^2, out of which 0.81 l/m^2 and the rest 4.11 l/m^2 enters the GH as humidity carried by the circulating air. Decreasing air flow rate has an insignificant influence on the system productivity.
34.	Omri et al. [131]	Numerical simulation of natural convection flows in a triangular cavity submitted to a uniform heat flux using the Control Volume Finite Element method is tried	The study had shown that the flow structure and the heat transfer are sensitive to the cavity shape and to the Rayleigh number.
35.	Tanaka and Nakatake [132]	A basin type solar still with internal and external reflectors is fabricated and numerical anaysis of heat and mass transfer in the still is performed	The internal and external reflectors remarkably increased the distillate productivity throught the year and the increase in the daily amounts of distillate is found to be averaged as 48%.
36.	Vovopoulos et al. [133]	A conventional greenhouse type solar still copled with hot water storage tank heated by a solar collector is investigated with a efficient mathematical model and evaluated experimentally.	The result of the investigation had shown the model as a valuable tool for the design of similar solar distillation systems for their optimization.
37.	Mamlook and Badran [134]	Fuzzy set technique has been tried to find out the effect of different parameters on the solar still output	The fuzzy set implementation has revealed the fact that the yield is affected by wind speed, ambient temperature, solar intensity, sprinklers, salt concentration and water depth.
38.	Ben Bacha et al. [135]	The simulation and experimental validation of the distillation module based on Solar Multiple Condensation Evaporation Cycle (SMCEC) has been found	The developed simulation model can be used to design and test the behaviour of such type of desalination unit.
39.	Mathioulakis and Belessiotis [136]	Attempts have been made to investigate the usage optimization of a simple solar still through its incorporation in a multi-source and multi-use environment	The modeling had given the ability to estimate the expected performance of the system uner given climatic conditions, allowing the choice of the proper design solutions in relation to the desired usage.

(*continued*)

S. no.	Reference	Aim of the work/design	Author's remarks
40.	Tanaka and Nakatake [137]	The numerical analysis of vertical multiple-effect diffusion solar still coupled with a flat-plate reflector is determined by assuming that the still is located at the equator and at 10°, 20°, 30° and 40° northern latitude.	It has been found that the angle of the flat-plate reflector should be fixed at 10° from horizontal and changed to be 0° during the winter season at higher latitudes and the orientation of the still shoud be adjusted according to month at any latitude. The daily productivity of the proposed still is found to more than 30 kg/m^2 at any latitude except for the winter season at 40°N latitude.
41.	Tanaka and Nakatake [137]	A basin type solar still with an internal reflector (two sides and back walls) and an inclined flat-plate reflector on a winter solstice day at 30°N latitude is theoretically analysed to find the effectiveness of the inclination of the external reflector.	The daily amount of distillate of the still with the inclined external reflector is found to be 16% greater than that with the vertical external reflector.
42.	Tsilingiris (2007)	Attempt has been made to signify the effect of binary mixture thermophysical properties on the transport processes and the associated quantities and to evaluate the thermophysical properties of the working medium in the distillation systems.	The investigation reveals that the use of improper dry air daa leads to a significant overestimation of the convective heat transfer coefficient and hence moderate overestimation of distillate output which is estimated to be upto 10%.
43.	El-Sebaii [138]	A triple basin solar still is constructed and a transient mathematical model is presented based on the analytical solution of the energy-balance equations for the various elements of the still.	The daily productivity is found to be 12.635 kg/m^2/d, which is in close agreement with results obtained for triple-effect solar stills.
44.	Kazuo Murase et al. [139]	A tube-type solar still which integrate a conventional still and a water distribution network suitable with the concept of desert plantation is constructed and tested experimentally and numerically.	The simulated result had shown that the performance is not necessary for the insulation of a still and possible for setting up the lower part of the still under the ground.
45.	Anil Kumar Tiwari and Tiwari [140]	Attempts have been made to find the seasonal performance of a single slope passive solar still of cover inclination of 30° for different water depths experimentally and thermal modeling has also been tried.	The result obtained is in accordance to the results obtained by earlier researchers.
46.	Hiroshi Tanaka and Yasuhito Nakatake [141]	Theoretical parametric investigations have been carried out to find the effect of factors that could cause a decrease in the distillate productivity of the multiple-effect diffusion-type solar still coupled with a flat-plate reflector.	It has been found that the actual productivity of the proposed still is significantly greater than that of the conventional single-effect stills.
47.	El-Sebai. A.A [138]	An attempt has been made to write transient mathematical model for a triple basin solar still.	In typical summer day the daily total productivity is found to be 12.635 kg/m^{2}d which is I agreement with the results reported for triple effect solar still.

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S. no.	Reference	Aim of the work/design	Author's remarks
48.	Muhammed Ali Samee et al. [142]	Constructed single basing solar still and analysed the performance in the location of latitude 33.3°N.	It was found that the optimum glass cover inclination was 33.3°N for both summer and winter. The values for total salt dissolved (TDS) and pH value agreed with the WHO guidelines for drinking water quality.
49.	Tsilingiris [143]	Attempts have been made to find the numerical constant in the Nusselt-Rayleigh correlation for the evaluation of convective heat transfer coefficient for higher operational temperature.	The numerical constant is less than 0.05 and also the thermophysical properties, saturation vapour pressure at the brine and condensing plate and the effect of transport properties influenced the convective heat transfer coefficient for higher operational temperature
50.	Torchia-Nunez et al. [144]	Steady state transient theoretical exergy analysis of a passive solar still has been tried and to find the factors focused on the exergy destruction in the still.	Ambient temperature is not an influential parameter for exergy efficiency and insulation thickness shoule be higher than 0.02 m to get higher exergy efficiency. A better thermodynamic performance is obtained when temperature gaps are reduced.
51.	Tanaka and Nakatake [145]	Theoretical analysis of a tilted-wick solar still with an inclined flat plate external reflector has been tried .	The distillate output was found to be 15% or 27% greater than that of still with vertical reflector.
52.	Madhbopa and Johnstonce. C [146]	A new model has been derived to calculate the distribution of solar radiation inside a single slope solar still in dividing the solar fraction on a vertical surface into beam and diffused parts.	It was found that beam solar fraction was affected by both the geometry of solar still and position of sun in the sky where the diffuse fraction depends in the geometry of the solar distillate.
53.	Tanaka and Nakatake [147]	Theoretical analysis of one-step azimuth tracking tilted-wick solar still with a vertical flat-plate reflector has been tried to determine the optimum tilt angle of the still and the optimum orientation of the still on four typical days at 30°N latitude	The still was rotated just once a day at southing of the sun and suitable tilt angle provide the daily amount of 40%, 57%, 40% and 27% greater than that of the conventional tilted-wick still on the spring, equinox, summer solstice, autumn solstice and winter solstice respectively

10.1. Instantaneous efficiency

At thermal equilibrium, the evaporation process inside the distiller to be isobaric, all the absorbed solar radiation is utilized for evaporation and thermal losses.

Hence the instantaneous efficiency is defined as

$$\eta = \frac{m_w \times L}{A_s \times I(t)} \tag{25}$$

where m_w is the hourly distillate output from the still.

10.2. Overall thermal efficiency

Since there are two modes of operation namely passive and active modes, the overall thermal efficiency is defined separately

$$\eta_{passive}(\%) = \frac{\sum m_w \times 100 \times L}{A_s \times \int I(t)dt} \tag{26}$$

by Singh and Tiwari [14].

Where m_w is the total distillate output for the whole day.

$$\eta_{active}(\%) = \frac{\sum m_w \times 100 \times L}{A_s \times \int I(t)dt + nA_c \int I(t)dt} \tag{27}$$

by Singh and Tiwari [14].

11. Literature regarding solar stills

Research has been carried out with various designs of passive solar stills and enormous amount of inferences have been arrived by the researchers. Thermal performance and experimental observations of the various passive designs of solar still have been analysed by the researchers and published. Hence it is necessary to organize the review work in different manner. As the initial step literature review with the experimental results for the designs of passive solar still have been carried out alone. The brief description of the pertinent literature regarding the experimental observations of various designs of solar still is presented in Table 3 and specific comments regarding the literature have also been included.

Among the various designs of solar stills proposed by researchers the performance of wick-type solar still is noticeable as the amount of distillate output is high. Tiwari's FRP double slope wick type solar still is found to economical in rural areas of remote regions to provide drinking water for domestic applications. Furthermore Hiroshi Tanaka and Yaushito Nakatake's (2009) single slope solar tilted-wick solar still with inclined reflector and vertical reflector facing towards south with optimum tilt is fascinating significant performance. A new design of hemispherical solar still [80] with least water depth provides a high distillate output. Moreover some of documented works of the researchers have been abandoned due to less production rate of distillate output. It is observed that the review of solar distillation will provide a useful task for the researchers with optimistic hope to have faster evaporation that result in higher distillate output.

12. Conclusions

The solar distillation is more attractive than other methods for small-scale and large-scale production of distilled water. The distilled water produced by solar distillation units had shown the complete removal of impurities like nitrates, chlorides, iron and dissolved solids. The conventional solar still designs are simple in design and fabrication, easy to handle and low cost of water per litre. Moreover the review will help the researchers to grasp the previous designs and to fabricate a new design of parameters to improve the thermal performance of the solar still to give higher distillate output.

Symbols

A_c — Collector area, m^2
A_s — Solar still basin area, m^2
A_{ss} — Sides area of solar still, m^2
C_{pa} — Specific heat of air at constant pressure, J/kg°C
C_w — Specific heat of water, J/kg°C
d_f — Spacing between water and glass cover, m
g — Acceleration due to gravity, m/s^2
h — Convective heat transfer coefficient, W/m^2°C
h_{cb} — Convective heat transfer coefficient from the bottom of insulation to ambient, W/m^2°C
h_{rb} — Radiative heat transfer coefficient from the bottom of insulation to ambient, W/m^2°C
h_w — Convective heat transfer coefficient from the basin liner to water or vice versa, W/m^2°C
$I(t)$ — Solar intensity, W/m^2
k_i — Thermal conductivity of insulation, W/m°C
L_i — Thickness of insulation
M_a — Mass of the air molecules, kg/m^2
M_w — Mass of the vapor (water) molecules, kg
m — Mass flow rate of water, kg/s
m_w — Distillate output, kg/m^2/s
NU — Nusselt number
P_g — Saturated partial vapor pressure at glass surface, N/m^2
P_w — Saturated partial vapor pressure at water surface, N/m^2
q — Rate of heat transferred, W/m^2
T — Temperature, °C
T_a — Ambient air temperature, °C
T_g — Glass cover temperature, °C
T_{sky} — Sky temperature, °C
T_w — Water temperature, °C
U_L — Overall heat transfer of a still, W/m^2°C
V — Wind velocity, m/s
L — Latent heat of vaporization of water

Greek symbols

â^1 — Coefficient of volumetric thermal expansion, °C^{-1}
$\mathring{a}_g$ — Emmisivity of glass cover
ε_w — Emmisivity of water surface
η — Thermal efficiency of the system (percentage)
μ_f — Viscosity of vapor, Ns/m^2
ρ_f — Density of vapor, kg/m^2
σ — Stefan–Boltzman constant (5.66 * 10^{-8} W/m^{2}K^4)

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