INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.5 Issue 1, January 2017 Pgs: 14-25

A Review on Recent Innovations in Desalination Systems

Ravi Kant Dwivedi[1] and Rajiv Varshney[2]

[1]*M. Tech. Scholar, Deptt. of Mech. Engg., Radharaman Institute of Research &Technology, Bhopal*
[2]*Director, Radharaman Institute of Research &Technology, Bhopal*

Abstract

Water is one of the prime requirements of human life for their sustenance. Solar still is one of the best options to distillate the impure water in this time of energy crises where traditional sources of energy like coal and petroleum are in the verge of depletion. This paper attempts to study various researches done by academicians worldwide to enhance the productivity of solar still. The performance of the solar still is highly influenced by different parameters like depth of water, area of absorption, inlet water temperature, heat storage, feeding system, type and orientation of reflector, water circulation, etc. Double basin solar stills have higher productivity as compared to the single basin solar still and double slope solar stills also have higher productivity as compare to the single slope solar still. Preheating of the feed water in to the still basin plays an important role to increasing the productivity of the still. In multi stage system productivity increases with the decrease in mass flow rate because evaporation increased which was due to the thin layer in the stages. Stepped solar still with and without reflectors has higher efficiency as compare to the conventional solar still. Weir type cascade stepped solar still have higher productivity as compare to the cascade stepped solar still.

Keywords: Incline solar still, absorbing material, stepped solar still, desalination.

1. Introduction

One of the most important aspects for the sustenance of human life is water. Water is useful for different purposes like drinking, irrigation and domestic purposes like cooking, washing etc. The most important issue of health hazard in today's world is the unavailability of fresh water. More than two-thirds of earth's surface is covered with water of which around 97% is salty, 2.6%

is present as icebergs and only less than 1% of fresh water is within human access. Fresh water sources on earth's surface are now getting depleted at a much faster rate [1].

To ensure availability of fresh water in remote areas at a very low cost solar still is viewed as the alternate renewable energy technology. Solar still requires very less maintenance and it is easy to fabricate on small scale [2]. It consists of shallow blackened basin covered with a transparent cover such as glass. To absorb maximum solar heat, inside surface of the basin is painted black. To absorb the solar radiation brackish or saline water is kept in the basin and thus increase the temperature of water [3]. Hot water slowly evaporates and gets condensed when it comes in contact with the glass cover. This condensed water is collected by separate channels as a distillate [4].

A lot of research has been carried out by various researchers to increase the productivity of solar desalination systems by varying various factors like different depth of water [6, 7], area of absorption [8, 9], and inlet temperature [10, 11, 12, and 13], multi effect system[15], use of weir [16, 17], orientation of reflector [18, 19], water circulation [20], spray feeding system [21] and parabolic concentrator [25].

2. Solar still

The process of converting impure brackish water into fresh drinking water using solar energy is called solar desalination. Solar stills are mainly classified into two categories namely single effect and multi effect stills. These stills are again classified as active and passive type depending upon the source of heat to evaporate water either directly through sun or using some other means such as solar collectors namely flat plate collectors, concentrating collectors and Evacuated tube collectors which are coupled to the desalination unit [5].

3. Factor affecting the performance of solar still.

(i) Water depth

Rajamanickam conducted experiments on single slope solar still and double slope solar still at the same environmental conditions to enhance the productivity of solar still. The areas for solar stills were kept same and experiment was conducted for different depths of water such as 0.01m, 0.025m, 0.05m and 0.075m. The productivity of double slope solar still was 3.07l/m2/day and for single slope solar still 2.34l/m2/day. It was found that the productivity of solar still decreases, with increase in basin water depth [6].

Elango et al. experimented on single and double basin solar still having same basin area. Tests were done by varying the depths of water inside the solar still from 1 to 5cm under insulated and un- insulated condition. They evaluate that for lowest water depth double basin solar still at insulated and un-insulated condition, still has 17.38% and 8.12% higher production then the single basin still [7].

(ii) Area of absorption

Srivastava et al. conducted experiments on a modified solar still with porous absorbers which have low thermal inertia. Jute cloth is used as a absorber and they float on themocole insulation in basin water. The dry spot problems at basin are overcome by these floating absorbers because of wetted absorber surface. They found that the modified solar still have productivity 68% more as compare to simple solar still and on cloudy day 35% more. Distillate was produced even at nights because the basin water below the floating absorber remained warm during off-shine hours [8].

Samual Hansen et al. conducted experiment on inclined solar still with different wick materials on different absorber plate. These wick materials were classified for porosity, absorption, water repellence capillary rise and heat transfer co-efficient. Based on that analysis, water coral fleece material with, absorbency (2 s), porosity (69.67%), capillary rise (10 mm/h and heat transfer coefficient (34.21W/m2 °C) was the most suitable wicking material for higher productive solar still. still performance was compared with different wick materials (wicking water coral, polystyrene sponge and wood pulp paper wick) on the various absorber plate configurations (stepped absorber with wire mesh, flat absorber). They were concluded that use of water coral fleece along with weir mesh–stepped absorber plate give maximum distillate 4.28 l/day [9].

(iii) Inlet water temperature

Feilizadeh conducted experiment on multistage active solar still and investigated the distillate production over collector basin area. The system consists of three flat pale collector of same area. The experiments were conducted in both summer and winter. The hourly basis distillate from multistage solar still was measured. He found that in winter, the basin produced 11.56 kg of distillate when it coupled to one solar collector (CBA = 3.45) and increased the production by 96% by adding a second collector (CBA = 6.90) to the system whereas increased it by only 23% by adding a third one (CBA = 10.35). While in summer, by adding the second and third collector productivity was obtained 48% and 23% more, respectively [10].

Singh et al. Conducted experiments on a solar still integrated with Evacuated Tube Collector. Evacuated Tube Collector was used to preheat the feed water in natural mode. Investigation has been done on depth of water, no of tube and size of the tube to optimize the energy and exergy efficiency. The maximum water circulation on individual tube was 44kg/h and maximum basin water temperature was 80°C. At the water depth of 0.03 m in the basin with 10 evacuated tubes the maximum daily energy and exergy efficiencies was found to be 3.3% and 2.5%, respectively [11].

Karuppusamy conducted experiments on a single slope solar still integrated with evacuated tubes. Experiments have been done to enhance the productivity of the still such as still with evacuated tubes, still with evacuated tubes, black gravel, still alone and still with black stone. They was found that by coupling the evacuated tube with the still the productivity increased by 49.7% and by integrating evacuated tubes with the still containing gravel was 59.48% [12].

Rajaseenivasan et al. have done comparative study on single slop single basin solar still and flat plate collector basin solar still. Both the still has same basin area 1m2. The modification has been done by means of horizontal flat plate collector to form six small components in the basin. The temperature of the basin water increase due to the preheating the water by flat plate collector and projected space in the basin. Evaporation rate increase and mass of water decrease for the same depth of water due to extended surface. The flat plate collector basin still has 60% higher distillate as compare to the conventional still at the same basin condition [13].

4. Recent developments in solar still

Single and double basin double slope solar still

Rajaseenivasan and Kalidasa performed theoretical and experimental work on a double slope single basin and double basin solar still. Both the still have same basin area and experiment were conducted under same climate conditions. The results were compared by varying the water mass in double basin and single basin still. The result showed that by providing extra basin increase the productivity of the still. The productivity of the double basin has 85% more compare to the single basin [14].

Multi-effect distillation system

Reddy et al. have conducted experiments on multistage solar desalination system in which latent heat were utilized to enhance the productivity. The Multistage evacuated desalination system consists of no of stage and each stage was the combination of evaporative condenser and flat plate collector. Each stage has condenser on top side and evaporative surface on bottom side. They found that for maximum productivity the optimum no of stage was 4. Gap between the stages and mass flow rate was 100mm and 55kg/m^2/day. The maximum and minimum yield was 28.04kg/m^2/day and 13.33kg/m^2/day, respectively [15].

Inclined solar still with wick material

Hansen et al. experimentally investigated the performance of inclined solar still with different new wick material. To select a suitable material for the solar desalination application the new wick materials were characterized for heat transfer coefficient, absorption, porosity, capillary rise and water repellence. Still performance was compared with different wick materials (water coral fleece fabric, wood pulp paper wick and polystyrene sponge) on the various absorber plate configurations (stepped absorber, flat absorber and stepped absorber with wire mesh). The most suitable wicking material for higher productivity of the solar still was water coral fleece which has heat transfer coefficient (34.21W/m2 °C), absorbency (2 s), porosity (69.67%), capillary rise (10 mm/h). They were found that by using the water coral fleece with weir mesh-stepped absorber plate maximum distillate from the still was 4.28 l/day [9].

Weir-type cascade solar stills with steps

Ziabari et al. have done theoretical and experimental study of cascade solar stills. He was reported Experimental data of 1 month from a solar still site and described the technical and operational problems of this site which was contributed to the total cease of the site. In order to solve the site's problems a detailed analysis was investigated on a prototype. 1 month of experimental results of the final design showed that the last prototype could be used to solve the current problems of the site. They found that modified cascade solar still gave average fresh water production around 6.7 lit/day m2, which was 26% higher as compare to the initial site's units. The conductivity of the produced distilled water decrease 10–20 lS/cm which is an acceptable range in the solar still science. To simulate the modified still a mathematical model was also proposed. The experimental data and model results show a significant increase in the fresh water production in compare with the initial site's stills [16].

Kabeel et al. have done Theoretical and experimental parametric study of modified stepped solar still. To improve the performance of solar still stepped basin was used. The performance of the stepped solar still influence by width and depth of trays was investigated. Wick on the vertical sides was added to the stepped still and Vacuum tube solar collector was used to vary the feed water temperature in the stepped still. They were concluded that the productivity of the stepped solar still depends on the tray width and depth. Maximum productivity of the stepped solar still was achieved at a tray width 120 mm and tray depth 5 mm, which is about 57.3% more than that of the conventional solar still [17].

Stepped solar still with internal reflector

Omara et al. Performed experiments on a stepped solar still with internal reflectors. The comparative study was done on the stepped still with trays (5mm depth, 120mm width) and a conventional still under the same climatic conditions. The productivity of the stepped still without and with reflectors was higher than the conventional still by 57% and 75% respectively. The efficiency of the stepped still without and with reflectors was 53% and 56% respectively, while, the efficiency of the conventional still was only 34% [18].

Stepped solar still with internal and external reflector

Omara et al. conducted experiment to investigate the performance of stepped solar still with internal and external reflectors. The reflectors were used to enhance energy input to the stepped still. The effect of internal and external (top and bottom) reflectors on the performance of the stepped solar still was investigated. The productivity of the modified stepped solar still with internal and external (top and bottom) reflectors was higher than that for conventional still approximately by 125%. Also estimated the cost of 1 l of distillate for conventional solar stills and stepped still with reflectors and it was approximately 0.049$ and 0.031$ respectively [19].

Stepped solar still with continuous water circulation

El-Agouz investigated the performance of stepped solar still with continuous water circulation. To evaluate the performance of developed desalination system under the same climate conditions a comparison study between conventional solar still and modified stepped was carried out. The distillate productivity was investigated by installing the storage tank and cotton black absorber in modified stepped solar still. The results show that, the productivity of the modified stepped still is higher than that for conventional still and it was approximately by 43% for sea water and 48% for salt water with black absorber, while 53% for seawater and 47% for salt water with cotton absorber.. The maximum efficiency of modified stepped still was obtain at a feed water flow rate of 3 LPM for salt water and 1 LPM for sea water. Seawater and salt water have the total dissolved solids (TDS) 41 and 27 mg/l after its desalination [20].

Stepped solar still with spray feeding system

El-Zahaby et al. conducted experiments to investigates the performance of steeped solar still by using the reciprocating spray feeding system. This approach permits governing the film of saline water on a particular manner and minimum water depth on steps. Saline water was spread in the foam of droplets on the top surface of corrugated stepped shape absorber of solar still by a controlled transverse reciprocating spraying system. They concluded that productivity of solar still over 10 working hours was 6.355 l/m2 and efficiency gained 77.35% [21].

Stepped solar still with water film parameter

El-Samadony et al. theoretically investigated the performance of stepped solar still by using water film cooling over the glass cover. They were found that the proper combinations of film cooling parameters affect the productivity of the stepped still and the best combination was: film thickness from 2.5X104 to 5.5 X 104 m, cooling water volumetric flow rate from 4X105 to 8.5X105 m3/s, and glass cover length from 2 to 2.8 m [22].

Hybrid solar still

Eltawil and Zhengming designed and constructed a new hybrid desalination system consisting of inclined solar water desalination and wind turbine integrated with main solar still. Main solar still has rotating shaft which was driven by a small wind turbine in order to break the layer of basin water. It produces distillate and hot water. The inclined system which is placed below the main still gets hot water which is left out from the main solar still of desalination. The inclined system contains an absorber plate paved with black wick. Experiments were conducted by varying the depth of water (0.01, 0.02 and 0.03 m) and flow rate (25.0, 41.7 and 58.3 ml/min) in two operating modes as tracking the sun and due south. They were concluded that productivity of the still decrees with increasing the water depth at same flow rate. The efficiency of the main solar still and inclined solar water desalination system was 67.21 to 69.59 and 57.77 to 62.01% respectively, when system was tracking the sun [23].

Park et al. conducted experiment to improve the performance of hybrid solar still by using the waste heat. They were designed a multiple-effect diffusion (MED) hybrid solar still with simpler seawater feeding device in which solar thermal energy and waste heat were used. The experiment were done by using waste heat in three operational modes (i) The seawater flow rate to the wick,(ii) seawater level in the basin and (iii) the amount of heat inputted into the hybrid still. They were found that the productivity of the hybrid solar still is proportional to the heat input which is 18.02 kg/m2 at 22.37 MJ/d. And at the lowest seawater level maximum distillate was produced [24].

Solar still with parabolic concentrator

Arunkumar et al. conducted Experiments on a parabolic concentrator integrated with solar desalination system. They used parabolic concentrator with continuous water circulation using a storage tank. Experiments were done in four modes of operations: (i) PC-solar still without top cover cooling; (ii) PC-solar still with top cover cooling (iii) PC-solar still integrated with phase change material (PCM) without top cover cooling and (iv) PC-solar still integrated PCM with cooling. The experiments were carried out for the different flow rates 40 ml/min; 50 ml/ min, 60 ml/min, 80 ml/min and 100 ml/min of water. The variations of ambient air temperature (Ta), top cover temperature (Toc), water temperature (Tw), and production rate were measured at frequent time intervals [25].

Solar still with semicircular trough absorber

Sathyamurthy et al. investigated the performance of semi-circular trough absorber solar still with baffles. The baffles were used to increase the contact time of water in the basin, to increase the productivity of fresh water. For more detail, Experimental as well as theoretical analysis carried out. Efficiency and productivity of present still were analyzed On the basis of number baffles and the water flow rate. The results were observed and found that productivity of the modified solar still was 16.66% higher than conventional solar still [26].

Solar still with heat storage

To improve the productivity of the solar stills the use of absorbing materials also plays a vital role. Abdulla et al. performed experiments by using three different absorbing materials. The absorbing materials are (a) black volcanic rocks (b) uncoated metallic wiry sponges and (c) coated metallic wiry sponges. The above absorbing materials were used in three different still. The fourth still was use as reference with no absorbing material. The reference still has lower productivity than other stills with absorbing materials. The black rocks gain water collection 60% more whereas for uncoated and coated metallic wiry sponges 43% and 28% respectively. Hence it was observed that the coated and uncoated metallic wiry sponges are less effective than black rocks [27].

Solar still with phase change material (PCM)

Dashtban and Tabrizi studied the thermal analysis of a weir-type cascade solar still integrated with PCM storage to increase the productivity of the still. During the lack of sunshine particularly at night, the use of a heat storage system with 18 kg mass (2 cm thickness) of paraffin wax beneath the absorber plate was sufficient to produce distillated water. The calculated results from the theoretical model with and without PCM were compared by the experimental data. The performance of the still was affected by the different parameters, such as distance between water and glass surface and water level on absorber plate. He found that the productivity of the still was 6.7 and 5.1 kg/m2 day with and without PCM storage. It means the theoretically productivity of the still with PCM was 31% more than that of without PCM. [28].

Conclusion

- The Productivity of the solar still decrease with increase in basin water depth but at minimum water depth dry spot problem may occur.
- Double basin solar still has higher productivity as compare to the single basin solar still and double slop solar still also have higher productivity as compare to the single slop solar still.
- The use of water coral fleece along with weir mesh-stepped absorber plate in inclined solar still give Maximum distillate.
- With the increase in the size of the evacuated tubes collector the productivity does not increase proportionately, due to high thermal losses. 10 evacuated tubes give the maximum productivity.
- Preheating of the feed water in to the still basin plays an important role to increasing the productivity of the still.
- The coated and uncoated metallic wiry sponges are less effective than black rocks because the metallic wiry sponges have corrosion problem.
- In multi stage system productivity increases with the decrease in mass flow rate because evaporation increased which was due to the thin layer in the stages.
- In stepped solar still maximum productivity was achieved at a tray width 120 mm and tray depth 5 mm.
- Stepped solar still with and without reflectors has higher efficiency as compare to the conventional solar still.
- Film cooling parameters are affect the productivity of the stepped solar still and the best combination are: film thickness from 2.5×104 to 5.5 × 104 m, cooling water volumetric flow rate from 4×105 to 8.5×105m3/s and glass cover length from 2 to 2.8 m.

- Weir type cascade stepped solar still have higher productivity as compare to the cascade stepped solar still.

Future scope and recommendations

- Research has to be focused on multistage evacuated system in order to fulfill the requirement of rural population by producing 20 to 25 l per day economically.
- More experimental studies have to be required on the solar desalination system by considering the different operating conditions and design such as variation of temperature, pressure, salt content of water, depth and flow rate of water inside the stage, multistage system etc.

References

1. Tiwari GN, Singh HN, Tripathi Rajesh. Present status of solar distillation 2003; 75:367–73 Solar Energy 2003; 75:367–73.
2. Malik MAS, Tiwari GN, Kumar A, Sodha MS. Solar distillation. UK: Pergamon Press; 1982.
3. Abdenacer PK, Nafila S. "Impact of temperature difference (water solar collector) on solar still global efficiency". Desalination2007; 209:298–305.
4. He T, YanL "Application of alternative energy integration technology in sea water desalination". Desalination 2009; 249:104–8.
5. Kumar P.Vishwanath, Kumar Anil, Prakash Om, Kaviti Ajay kumar "solar stills system design: A review" Renewable and Sustainable Energy Reviews 51(2015)153–181.
6. Rajamanickam MR, Ragupathy A." Influence of water depth on internal heat and mass transfer in a double slope solar still". Energy Proc 2012; 14:1701–8.
7. Elango T, Murugavel K. Kalidasa, "The effect of the water depth on the productivity for single and double basin double slope glass solar stills". Desalination 359 (2015) 82–91.
8. Pankaj Srivastava K, Agrawal SK. "Experimental and theoretical analysis of single sloped basin type solar still consisting of multiple low thermal inertia floating porous absorbers". Desalination 2013; 311:198–205.
9. Hansen R. Samuel, Narayanan C. Surya, Murugavel K. Kalidasa, "Performance analysis on inclined solar still with different new wick materials and wire mesh". Desalination 358 (2015) 1–8.
10. Feilizadeh Mansoor, Estahbanati M.R. Karimi, Jafarpur Khosrow, Roostaazad Reza, Feilizadeh Mehrzad, Taghvaei Hamed "Year-round outdoor experiments on a multi-stage active solar still with different numbers of solar collectors". Applied Energy 152 (2015) 39–46.

11. Singh RaghVendra, Kumar Shiv, Hasan MM, Khan M Emran, Tiwari GN. "Performance of a solar still integrated with Evacuated Tube Collector in natural mode". Desalination 2013; 318:25–33.

12. Karuppasamy Sampath. Kumar "An experimental study on single basin solar still augmented with evacuated tubes". Therm Sci2012; 16:573–81.

13. Rajaseenivasan T., Nelson Raja P., Srithar K.," An experimental investigation on a solar still with an integrated flat plate collector" Desalination 347 (2014) 131–137

14. Rajaseenivasan T., Kalidasa Murugavel K.,"Theoretical and experimental investigation on double basin double slope solar still". Desalination 319 (2013) 25–32.

15. Reddy KS, kumar K Ravi, Tadhg S, O'Donovan, Mallick TK. "Performance analysis of an evacuated multi-stage solar water desalination system". Desalination 2012; 288:80–92.

16. Ziabari Fatemeh Bakhtiari, Sharak Ashkan Zolfaghari, Moghadam Hamid, Tabrizi Farshad Farshchi, "Theoretical and experimental study of cascade solar stills". Solar Energy 90 (2013) 205–211.

17. Kabeel A.E, Khalil A, Omara Z.M., Younes M.M, 'Theoretical and experimental parametric study of modified stepped solar still". Desalination 289 (2012) 12–20.

18. Omara ZM, Kabeel A.E., Younes M.M., "Enhancing the stepped solar still performance using internal reflectors". Desalination 2013; 314:67–72.

19. Omara ZM, Kabeel AE, Younes MM. "Enhancing the stepped solar still performance using internal and external reflectors". Energy Conversion and Management 78 (2014) 876–881.

20. El-Agouz S.A. "Experimental investigation of stepped solar still with continuous water Circulation". Energy Conversion and Management 86 (2014) 186–193.

21. El-Zahaby A.M., Kabeel A, Bakry A.I, El-Agouz S, Hawam O.M. "Enhancement of solar still performance using a reciprocating spray feeding system experimental approach". Desalination 267 (2011) 209–216.

22. El-Samadony Y.A., Kabeel A.E., "Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still". Energy 68 (2014) 744 e 750.

23. Etawil A. and zhegming Zhao "Wind turbine-inclined still collector integration with solar still for brackish water desalination" Desalination 249 (2009) 490–497.

24. Park Chang-Dae, Byung-Ju Lima, Kyung-Yul Chung, Sung-Soo Lee, Young-Man Kimb "Experimental evaluation of hybrid solar still using waste heat". Desalination 379 (2016) 1–9.

25. Arunkumar T., Denkenberger David, Velraj R , Sathyamurthy Ravishankar, Tanaka Hiroshi, Vinoth kumar K. "Experimental study on a parabolic concentrator assisted solar desalting system". Energy Conversion and Management 105 (2015) 665–674.

26. Sathyamurthy Ravishankar , Nagarajan P.K., El-Agouz S.A., Jaiganesh V, Khanna P. Sathish "Experimental investigation on a semi-circular trough-absorber solar still with baffles for fresh water production". Energy Conversion and Management 97 (2015) 235–242.

27. Abdullah Salah, Mazen Abu-KhaderM, Badran Omar. "Effect of various absorbing materials on the thermal performance of solar stills". Desalination 2009; 242:128–37.

28. Dashtban Mohammad and Tabrizi Farshad Farshchi. "Thermal analysis of a weir-type cascade solar still integrated with PCM storage". Desalination 279 (2011) 415–422.