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CURRENT STATUS OF SOLAR DISTILLATION: A REVIEW

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ABSTRACT

Fresh water is the basic commodity of human life. Using renewable Solar energy and Desalination certainly produce an inexhaustible source of drinking water. Development of such systems which can fulfill the world's population of 6 billion to have access of clean drinking water using natural resources is a need of the hour. Solar still is such a simple and affordable device for converting brackish water into potable water. Many more features are attributed to this simple instrument apart from its simplicity, like eco-friendly, economical, low maintenance charges, ease of handling, sustainability, material availability and 99% purity. The present communication elaborates the advancement of solar still till date and also the scope for further research.

KEYWORDS: Solar Still, Potable Water, Desalination, Solar Distillation

INTRODUCTION

Availability of potable water is limited; however population growth is expected to increase from a present value of 6 billion to 9 billion in the year 2050. Needless to say, it will bring demands of development of urban region whereas change in lifestyle has put the stress on the limited water resources even further [1]. Considering solar energy as alternate source of energy with its competent applicability, the desalination process is the only remedy of the current scenario. Solar distillation is a simple technique and is helpful in obtaining fresh water with the help of solar still. Its utility is especially more in the places which lie on solar belt like Africa, China, India and Middle East countries having plenty of solar power. The earth receives more energy from the sun in just 1 hour, than what the whole world consumes in 1 year. The salt contents present in the water not only cause bad taste but it also creates stomach problems and laxatives effects [2]. Solar still not only achieve the desired limit of 500 ppm but it also removes pathogens and toxic metals like lead, arsenic, cadmium and mercury. Now days a number of technologies are available for water purification. Vapor Compression is such a process where boiling water gives water vapor which is compressed without transfer of heat and mass and the resultant vapor gets superheated.. Reverse osmosis is another process in which impure water is passed through a semi-permeable membrane at high pressure where only water molecules can pass leaving behind the dissolved solids. Other processes are electrolytic methods where water gets purified using a pair of special membranes and an electric field applied perpendicular to it. But all these processes require skilled manpower, high maintenance and are energy intensive. However solar distillation requires low maintenance and has simple technology. In the present paper, reviews of different types of solar stills have been done.

Solar Still: Working Principle

Solar still is a very simple device for converting brackish/saline water with the use of inexhaustible & renewable source of energy. Brackish water is filled into the basin and solar radiations are transferred from the glass cover of the still to heat the basin water. Since there is difference in temperature of water and glass surfaces, water gets evaporated leaving behind all the impurities in the basin of the still. This distillate condenses on the inner side of glass and drips down to another vessel. Figure 1 represents conventional single slope solar still with its heat transfer coefficient..

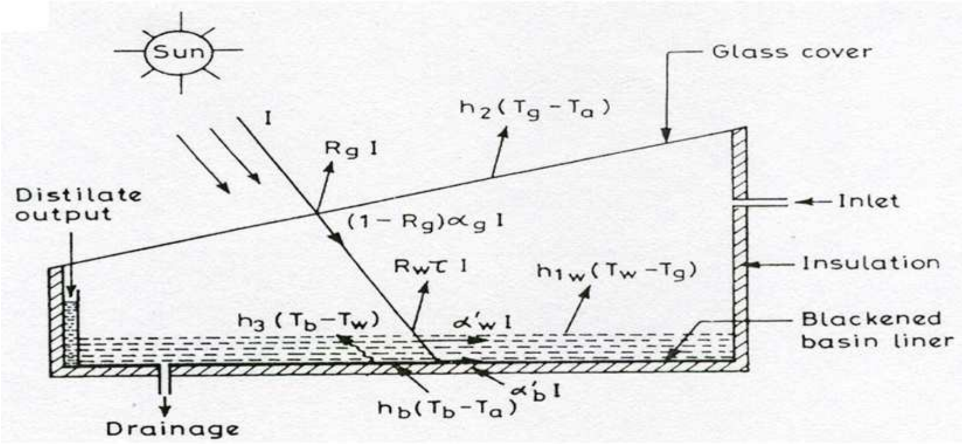

Figure 1: Diagram of a Conventional Single Slope Solar Still

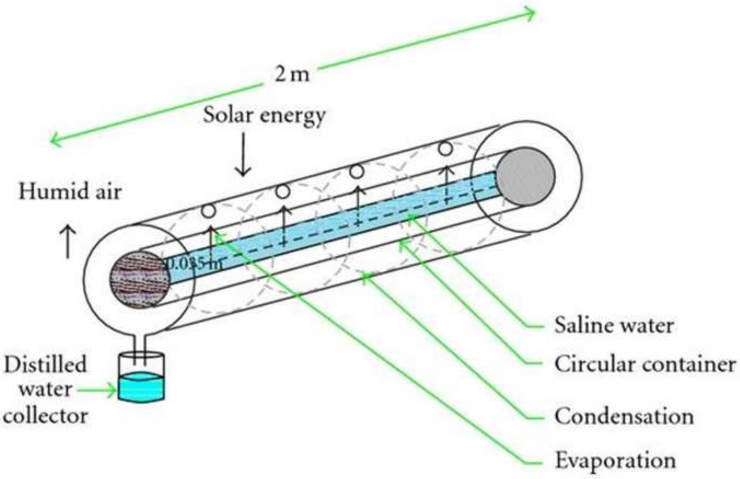

Figure 2: A Solar Still in Tubular Form

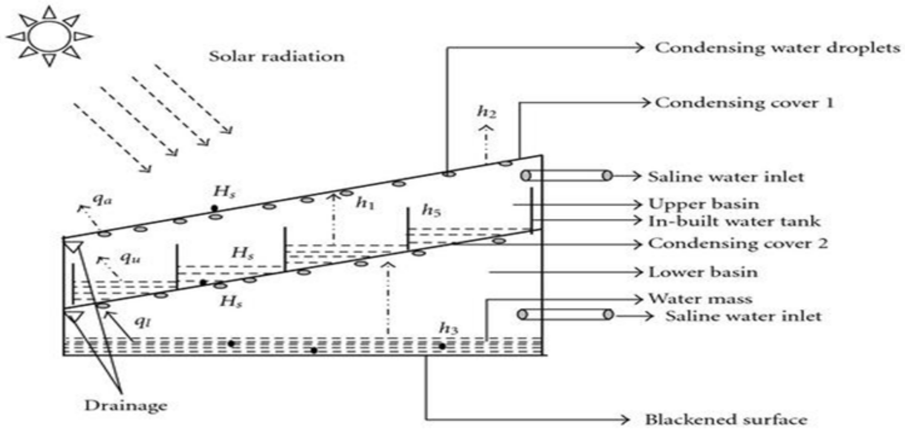

Figure 3: The Cross-Sectional View of Solar Still Has Double Basin Glass

Arunkumar, Vinothkumar and Ahsan [3] has designed various solar stills and evaluated their performances in converting the saline water into potable water. Figure 2 shows various components of tubular solar still designed by using an absorber of rectangular size, where the two circular tubes say, inner and outer are positioned with a 5 mm gap. Figure 3 shows a solar still of double basin with overall size of the inner basin is 590 mm x 440 mm x 440 mm and the outer basin is 600 mm x 460 mm x 460 mm. Figure 4 represents solar still in hemispherical form constructed with a diameter of 0.95 m & a height of 0.10 m using mild steel. Figure 5 shows a circular basin of dimension 2m length having 0.035 m radius of pyramidal form of size 1m x 1m.

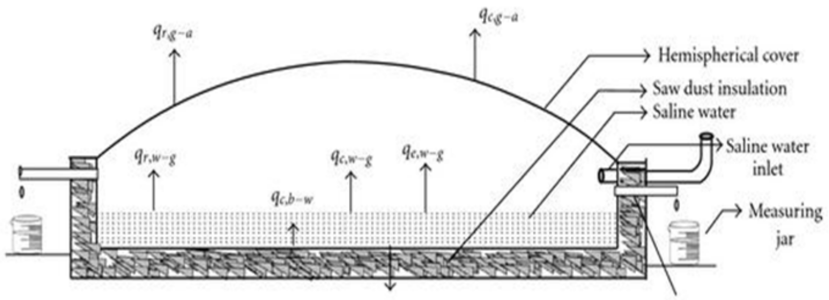

Figure 4: Schematic View of Solar Still of Hemispherical Form

The above mentioned solar stills are tested for the five months (January to May 2011) in The same climatic conditions to study the influence of the modifications on the distillate. It was observed that the compound parabolic concentrator –assisted tubular solar still Shows the maximum yield. It was observed that the maximum output was given by the compound assisted tubular solar still.

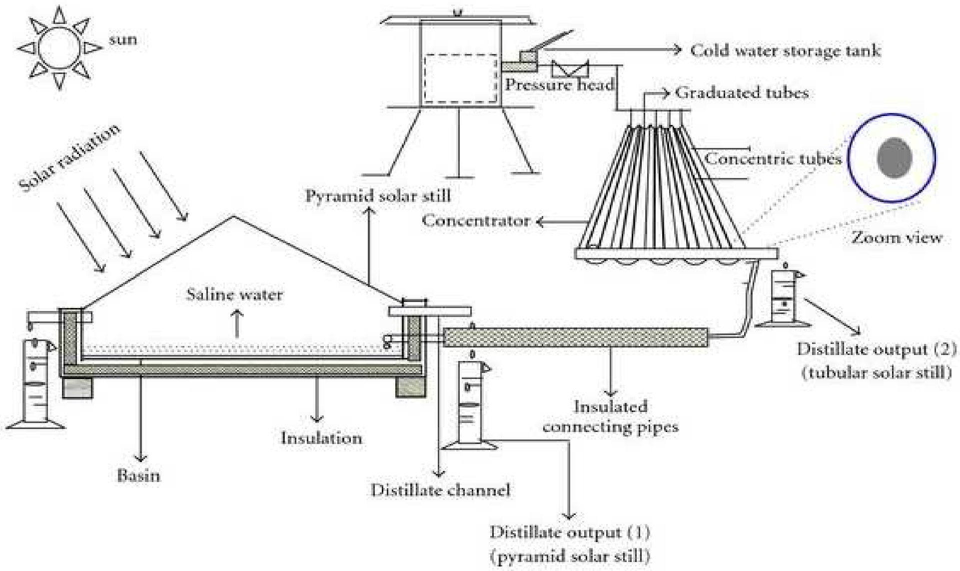

Figure 5: Cross Sectional View of Coupled Tubular and Pyramid Solar Still.

Design of Solar Distillation Plant / Solar Still: A Historical View

The daily output per m^2/day in conventional solar still depends on many factors but the main governing factor is the temperature difference of evaporative and condensing surfaces [4].Voluminous research have been done in order to improve the daily output of single slope solar still by changing its design to get the maximum difference in temperature between the evaporative and condensing surfaces. Fath [5] developed a conventional slope solar still where the condensing surface was separated from the solar still chamber. Since most of the condensation is taking place in the condensing chamber, so it is required to maintain the temperature difference between the glass cover and basin water, which causes faster evaporation and hence distillate output is more. In this case the still efficiency is increased by 45 percent. Qudais, Huleh and Othman [6] has done his research on the design of solar still to enhance the productivity using condensing chamber and electrically operated fan. This is referred as hybrid solar distillation system. Kumar and Tiwari [7] have developed a reverse absorber solar still.by using the concept of an inverted flat plate collector and maintain the temperature difference between the condensing cover and water surface for higher yield.. Sodha, Kumar, Tiwari and Tyagi [8] achieved the maximum temperature difference between the condensing cover and water surface by reducing the heat capacity of the water mass in the basin and named it as a multi-wick solar still. Malik, Tiwari, Kumar and Sodha [9] designed a conical solar still where they kept the area of evaporation and condensing surfaces equal by increasing the heat transfer coefficient. Kumar and Tiwari [10] studied the active solar distillation where the different temperatures of evaporating and condensing surfaces is achieved by increasing the additional thermal energy from the flat plate collector in to the basin of solar still. The flat plate collector is integrated to the basin of solar still and water is circulated through flat plate collector either in a natural circulation mode or a forced circulation mode depending upon the requirement. The connecting pipes are insulated to avoid thermal losses from the hot water in the pipe to ambient during hot water circulation.

Among these the most popular is simple basin type stills supplying clean drinking water for small communities and also supplies water such as for battery charging and other analytical purposes. There are several minor variations in the geometric configuration of single basin stills. Rajaseenivasan, Kalidasa and Elango [11] discussed the various methods to increase the yield of the multi effect solar still, where water is heated using the latent heat of condensation. Kabeel, Omara and Essa [12] studied the work to enhance the productivity of solar still by using nanofluids. The productivity of newly designed solar still was examined by using solid nanoparticles of aluminum oxide and cuprous oxide of different concentration without providing vacuum in the basin water. The results concluded that by using cuprous oxide nano-particles, the distillate productivity increased by 133.64% and 93.87% with and without fan respectively as compared to the conventional solar still. George, Malaeb and Saikaly [13] studied the various critical variables in the productivity enhanced solar still. This new type of solar still is in the form of a slowly rotating hollow drum that allows the formation of thin water films which evaporates rapidly.

This new design cylinder gives 200-300% increase of distillate water. Velmurugan and Srithar [14] reviewed the performance of various solar stills and concluded that most proven and simplest type solar still is basin type. Samadony and Kabeel [15] carried out the study on theoretical estimation of the optimum glass cover and water film cooling parameter combinations on a stepped solar still where it was found that the proper combinations of film cooling parameters have a great influence on stepped still productivity and the best combination was: film thickness from 2.5×10^{-4} to 5.5×10^{-4} m, cooling water volumetric flow rate from 4×10^{-5} to 8.5×10^{-5} m^3/s and glass cover length from 2 to 2.8 m. Kannan et. al. [16] worked on a design of solar still having vapor absorption basin where he used activated carbon methanol pair with vapor adsorbent pipe network. Sponges, gravels, sand and black rubbers were used in the vapor adsorption type solar still for improving the yield. Sampath kumar, Arjunan, Pitchand and Senthil kumarl [17] reviewed the active solar distillation over the years.

Tiwari and Tripathi [18] have designed a solar still for better productivity and conducted experiments in the temperature range of 40°C to 80°C. It was found from their results that better output can be obtained with an increase of temperature in the forced mode of operation as compared to natural mode. This increase is attributed to the fact of fast release of heat from the condensing cover. Yeo, Ong and Teo [19] studied the heat transfer as well as energy balance model for conventional solar still. They formulated a mathematical model to express various thermodynamics behavior by considering the critical parameters like slope of glass cover, mass of water in basin and wind speed. Kaushal and Varun [20] made a review of different types of still and concluded that a proper combination of cooling film enhanced the still efficiency by 20 %. Tripathi and Tiwari [21] studied on the different water depths in the basin water and its effect on the heat and mass transfer coefficients. It is inferred that the convective heat transfer coefficient between basin water and inner condensing cover depends mainly on the depth of the basin water. Gnanadason, Hariharan and Senthilkumar worked on a single slope solar still in which the still basin was built with copper sheet and concluded that the rate of heat transfer to water in the still made up of copper is more and hence the increase in the water temperature and productivity. Jabbar and Khalifa [23] performed an experiment on cover tilt angle and studied its productivity in different seasons.

A relation between the cover tilt angle and productivity of simple solar still in various seasons is established together with a relation between the optimum tilt angle and the latitude angle. Badusha and Arjunan [24] hasreviewed the status of solar distillation plant in India where he emphasized on the significance of the solar energy for fulfilling various domestic needs. The paper discusses the overall development in active and passive solar stills in India. They also worked on the performance analysis of conventional single slope solar still where he used heat energy as input which is obtained from solar radiation. The condensation and evaporation process in solar still is developed using computational fluid dynamics (CFD) method, a two phase 3-Dimensional model is developed for simulation result. Simulation result is compared with actual experimental data of solar distillation plant. The various heat transfer coefficient shows that CFD is a significant tool for the performance analysis of conventional single slope solar still. Shivakumar, Ganapathy and Sundaram [25] has reviewed on the improvement techniques and the methodologies of active and passive solar stills. Ayoub and Malaeb [26] studied the relation of the economic feasibility and its enhanced productivity of solar distillation system.

Energy Balance Equations

Following Tripathi and Tiwari [34], the energy balance equations for different components of an active solar still are given as: Glass cover:

$$\alpha'_g I_{eff} + h_{1w}(T_w - T_g) = h_{1g}(T_g - T_a) \tag{1}$$

Water mass:

$$\dot{Q}_u + \alpha'_w(1-\alpha'_g)I_{eff} + h_w(T_b - T_w) = (MC)_w \frac{dT_w}{dt} + h_{1w}(T_w - T_g) \tag{2}$$

Basin liner:

$$\alpha'_b(1-\alpha'_g)(1-\alpha'_w)I_{eff} = h_w(T_b - T_w) + h_b(T_b - T_a) \tag{3}$$

where

$$\dot{Q}_u = A_c F_R[(\alpha\tau)_c]I_c - U_L(T_w - T_a) \tag{4}$$

For $\dot{Q}_u$ =0, the above equations become energy balance equations for a passive solar still.

Above equations can be solved for T_w and T_g for given climatic and design parameters as given by Tripathi and Tiwari [34]. Further the hourly yield per unit area can be calculated from the known values of T_w and T_g, and is given by

$$\dot{m}_{ew} = \frac{h_{ew}(T_w - T_g)}{L} \times 3600 \tag{5}$$

The daily yield is given as

$$M_{ew} = \sum_{i=1}^{24} \dot{m}_{ew} \tag{6}$$

Mathematical Models

A number of mathematical models have been used to predict the performance of conventional solar distillation system such as computer simulation, thermal circuit sankey-diagrams, periodic and transient analysis and iteration methods.

In solar distillation plant history,Dunkle [28] was the first to present a complete mathematical model for the analysis of heat and mass transfer processes which is purely based on the free convection of heat transfer in the solar still. Cooper [29] analyzed the preliminary mathematical model the with a digital simulation method a to describe the system. common variables such as single basin solar still as double glass cover, still insulation, wind velocity, water depth and cover slope were investigated . Ghoraba [30] obtained general relations of heat and mass transfer process sinside the solar still. These relations have the distinction of considering some of the design parameters such as the glass angle and the solar still dimensions. However, Ghoraba used an immersed electric heater as an energy source. Clark [31] examined the validity of Dunkle’s model and found that the Dunkle’s model needs some modifications for the mass transfer relations inside the solar still. Clark’s results were obtained from an experimental shallow basin with solar simulation of spotlight banks. Therefore, the applicability of Clark’s relations for the outdoor work needs to be investigated. Adhikari, Kumar and Sodha [32] studied the performance of a multi-stage stacked tray solar still by using a computer simulation model. The model was verified by the outcome of simulated experiment on a three stage unit using immersion type electric heater as the heating source. The experimented results obtained from the model were in agreement with the experiments. Kumar and Tiwari [33] estimated the convective mass transfer in solar still system with the help of a regression based theoretical model by providing initial values of glass and water temperatures. Tripathi and Tiwari [34] theoretically calculated solar fraction and used in the solar intensity term to validate their model for passive as well as active solar distillation systems. Omar [35] theoretically studied a single slope active solar distillation system using different operational parameters like thickness of insulation, effective absorptivity, solar intensity and transmissivity. P.T. Tsilingris [36] investigated the validation of a new theoretical model which predicted the mass transport in the barometric enclosure of solar still systems. It has been found that the Chilton-Colburn analogy is applicable for a broad range of Prandtl & Schmidt dimensionless numbers.

Economic Evaluation

The economic value of distillate depends on various factors like the capital cost of the equipment plant and the cost of the energy. The cost of the distillate output depends on the capital cost of solar still, energy cost, its operation and maintenance cost. Its operation and maintenance does not require skilled persons. Hence cost of the equipment plays a major role in finding the economic feasibility of solar stills.

According to Howe and Tleimat [37] solar stills having capacity less than 200 m^2/day have better economical value as compared to other desalination plants. According to Delyannis and Delyannis [38] ; Tiwari and Yadav [39] ; Mukherjee and Tiwari [40], Yadav and Tiwari [41] the economic analysis of multiple-wick and basin type solar still depends on the effect of subsidy, rainfall, salvage value and maintenance cost of the system. Zein and Al-Dallal [42] studied the mixed water of condensed and well water to produce potable water and compared the quantity which was obtained from industrial distillation plants. However, Kudish and Gale [43] studied the various economic prospects of solar distillation plant in Israel. Barrera [44] did the technical as well as economic study on staircase solar still in Mexico climatic condition and observed that 3.5 times gives better result than chemical water acquisition. Tiwari and Tripathi [45] studied the present status of solar distillation plant in India and its future perspective. They have also analyzed the economic values of single & double slope solar still constructed from the fiber-reinforced plastic (FRP). Samee, Mirza and Majeed [46] observed the higher daily productivity of the simple basin type solar still .Velmurugan, Gopalkrishnan and Raghu [47] analyzed the economic value of single basin solar still by using sponge, wick and fin and it was estimated that there is an enhancement of 15.3, 29 and 45.5, % in productivity respectively. Sow, Siroux and Desmet [48] carried out Energetic and Exergetic analysis of a triple-effect solar still. It was found that the exergetic efficiencies lie between 19 to 26% for a triple effect system, between 17 to 20% for a double effect system and less than 4% for a single effect system. Nunez, Gandara and Gortari [49]have done exergy analysis of a passive solar still and observed that solar irradiance gives maximum productivity. Kumar and Tiwari [50] studied the life cycle cost of a passive single slope solar still and hybrid photovoltaic active solar stills. The calculated cost of 1 kilogram of distillate obtained from hybrid photovoltaic active solar still was found to be 0.049 US$ and that from passive solar still to be 0.017 US$. Kabeel, Hamed and Agouz [51] have found the pyramid shaped solar still is more efficient and higher average annual productivity of 1533 L/m^2 while advanced solar still with Sun Tracking has minimum average annual productivity of 250 L/m^2. Kabeel & Agouz [52] calculated and found that for a production of about $5L/m^2$ /day of fresh water from single effect solar still, the energy efficiencies ranges from 30 to 45%. Plappally and Leonhard [53] studied and compared a passive solar still with a small scale domestic Reverse Osmosis system for calculating energy savings and carbon credits earned. Ranjan and Kaushik [54] analysed the economic model of a solar still by considering the cost of environmental degradation and estimated the cost as US$ 0.24/litre for potable water production from sea water. The payback period n_p can be obtained as

$$n_p = [\log(UA/(UA - i \times P))/\log(1+i)]$$

(where P is initial cost, i the rate of interest and UA is unacost) [1].

The payback period should be less than that of the life of solar still for a useful investment.

CONCLUSIONS

It is difficult to draw a single or sweeping conclusion from the observations presented in the given paper. In the present paper, experimental results, design parameters and performances of the solar stills have been discussed. It can be easily inferred that: A solar still with high basin temperature and low condensing glass temperature is often associated with high productivity. Solar stills are viable options for desalination of water for remote and arid regions, where small amounts of water is the requirement. The advantage associated with solar still is its simplicity, and the non requirement of skilled labor for construction and operation making this process particularly suitable for the use in the developing countries. To improve the efficiency of solar still, various number of contributing factors like material of basin, transmissivity of glass cover and maximum concentration of solar radiations on the condensing cover must be considered and further economic analysis for getting distilled water from solar stills and hence to convert distilled water to get drinking water should be done.

As it is expected that solar stills are mostly to be used in small communities, where it can be proven as a means of employment too. solar still can produce a considerable economic relief over the other desalination system if it is harnessed properly both economically and technically.

REFERENCES

1. G.N. Tiwari, Solar energy; fundamentals design, modeling & application, New York/New Delhi: CRC Press/ Narosa Publishing house, 2003.
2. S.P. Sukhatme, Solar energy: principle of thermal collection and storage, New Delhi: Tata Mc Graw Hill; 1987.
3. T. Arunkumar, K. Vinothkumar and Amimul Ahsan, Experimental Study on Various Solar Still Designs, ISRN Renewable Energy, Article ID 569381, 2012.
4. Vinoth K.K. and Kasturi Bai R., Performance study on Solar Still with enhanced condensation, Desalination, 2008,230 (1-3), 51-61.
5. H.E.S. Fath, Solar Distillation: A promising alternative for free energy, simple technology and clean environment, Mechanical Deptt. Faculty of Engg., Alexandria University, Alexandria, Egypt. (Personal communication), 1998.
6. Abu-Qudais, Md. Abu-Huleh, B and Othman O.N., Experimental Study & numerical simulation of a solar still using an external condenser, Energy 1996, 21,851
7. S. Kumar and G.N. Tiwari, Estimation of converting mass transfer in solar distillation system, Solar Energy, 1996,57, 459.
8. M.S. Sodha, A. Kumar, G.N. Tiwari and R.C. Tyagi, Simple Multi-wick solar still: Analysis and Performance, Solar Energy, Vol. 27, 127, 1981.
9. M.A.S. Malik, G.N. Tiwari, A. Kumar and M.S. Sodha, Solar Distillation, Pergamon Press, N.Y., 1992.
10. S. Kumar, and G.N. Tiwari, Performance evaluation of an active Solar Distillation system, Energy Vol. 21, 1996.
11. T. Rajaseenivasan, Murugave Kalidasa, K. Elango T. and Samuel Hansen R., A review of different methods to enhance the productivity of the multi-effect solar still, Renewable & Sustainable Energy Reviews, Vol 17, 2013.
12. A.E. Kabeel, Z.M. Omara and F.A. Essa, Improving the performance of solar still by using nanofluids & Providing vacuum, Energy Conversion & Management Vol 86, 2014.
13. George M. Ayoub, Lilian Malaeb and Pascal E. Saikaly, Critical variables in the performance of a productivity enhanced solar still, Solar Energy 2013,Vol. 96, 472-484.
14. V. Velmurugan and K. Srithar, Performance Analysis of solar stills based on various factors affecting the productivity- A review. Renewable & Sustainable Energy Reviews, Volume 15, Issue 2, pages 1294-1304, Feb. 2011.
15. El-Samadony and A.E. Kabeel, Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still, Energy, Volume 68, 2014.
16. R. Kannan, C. Selvaganesan, M. Vignesh, B. Ramesh Babu, M. Fuentes and M.Vivar, Solar still with vapor adsorption basin- Performance analysis, Renewable Energy, 2014, Volume 62, Pages 258-264.

17. K. Sampathkumar, T.V. Arjunan, P. Pitchand and P. Senthil kumar, Active Solar Distillation, A detailed Review, Renewable & Sustainable Energy Reviews, 2010,Vol.4,1503-1526.

18. G.N. Tiwari and Rajesh Tripathi, Study of heat and mass transfer in Indoor conditions for distillation, Desalination 2003,154 , 161-169.

19. Kiam Beng Yeo, Cheah Meng Ong and Kenneth Tze Kin Teo, Heat Transfer Energy Balance Model of a single slope solar still, Journal of applied Science 2014, 3344-3348.

20. Aayush Kaushal and Varun, Solar Stills: A Review, Renewable & Sustainable Energy Review, 2010, 446-453.

21. R. Tripathi and G.N.Tiwari, Effect of water depth on internal heat and mass transfer for Active Solar Distillation, Desalination, 2005, 173,187-200.

22. M. Koilraj Gnanadason, G.Hariharan and P. Senthil Kumar, Enhanced performance of Design of a single basin solar still made up of copper, IJAR, 2013 Vol. 3, Issue 3.

23. Abdul Jabbar and N. Khalifa, The effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes, Energy Conversion & Management 2011, 431-436.

24. Ragil Badusha and T.V. Arjunan, Performance Analysis of Single Slope Solar Still, International Journal of Mechanical Engineering & Robotics Research India, 2013,Vol.2.

25. Shivkumar, V. Ganapathy and E. Sundaram, Improvement Technique of solar still: A Review, Renewable & Sustainable Energy Reviews, Vol. 28, 2013.

26. George M. Ayoub and Lilian Malaeb, Economic feasibility of solar still desalination systems with enhanced productivity. Desalination, Vol. 335 2014,27-32.

27. S. Kumar, G.N. Tiwari and H.N. Singh, Annual performance of an active solar distillation system, Desalination,2000, 127, pp. 29.

28. R.V. Dunkle, Solar Water Distillation, The roof type still& a multiple effect diffusion still, International Development in heat transfer, ASME, Part V, Section A, pp 895, 1961.

29. P.I. Cooper, Some factors affecting the absorption of solar radiation in solar stills, Solar energy, 13, 373, 1972.

30. M.M. Ghoraba, Theoretical & Experimental Studies of heat & mass transfer inside single sloped solar stills, Ph.D., The Fac. Of Engg., Cairo Univ., Egypt, 1987.

31. J.A. Clark, The Steady State Performance of a solar still, Solar Energy,1990, 44 (1), 43-49.

32. R.S. Adhikari, A. Kumar, M.S. Sodha, Simulation studies on a multi-stage stacked tray Solar Still, Solar Energy, 1995 54 (5), 317-325.

33. S. Kumar and G.N. Tiwari, Estimation of converting mass transfer in solar distillation system, Solar Energy, 1996, 57,459.

34. R. Tripathi and G.N. Tiwari, Thermal modeling of passive & active solar stills for different depths of water by using the concept of solar fraction, Solar Energy, 2006, 80 (8), pp 956-967.

35. Omar Badron, Theoretical Analysis of Solar Distillation using Active Solar Still. International Journal of Thermal & Environment Engineering, 2011, 3(2), 113-120.

36. P.T. Tsilingiris, The application & experimental validation of a heat & mass transfer analogy model for the prediction of mass transfer in solar distillation systems, Applied Thermal Engineering, 2013, 50 (1), 422-428.

37. E.D. Howe, and B.W. Tleimat, Twenty years of work on solar distillation at the University of California, Solar Energy, 1974,16, 97.

38. E.E. Delyannis and A. Delyannis, Economics of solar stills, Desalination, 52, 167, 1985.

39. G.N. Tiwari and Y.P. Yadav, Economic analysis of large-scale solar distillation plant. Energy Conversion and Management, 1985,25, 423.

40. K. Mukherjee and G.N. Tiwari, Economic analysis of various designs of conventional solar stills, Energy Conversion and Management, 1986,26, 155.

41. Y.P. Yadav and G.N. Tiwari, Monthly comparative performance of solar stills of various designs, Desalination,1987, 67, 565 .

42. Zein M. and Al-Dallal, Solar desalination correlation with meteorological parameters, In IInd Arab Int. Conference, 1984, pp. 288, 1984.

43. A.I. Kudish and J. Gale. Solar desalination in conjunction with controlled environment agriculture in arid zone, Energy Conversion and Management, 26, 201.

44. E. Barrera, A technical and economical analysis of solar water still in Mexico. Renewable Energy, 1992, 2 (4), 489.

45. G.N. Tiwari, H.N. Singh and R. Tripathi, Present Status of Solar Distillation, Solar Energy, 2003,75, 367-73.

46. M.A. Samee, U.K. Mirza and T. Majeed, Design & Performance of a simple single basin Renewable and Sustainable Energy Review,2007, 11, 543-549.

47. V. Velmurugan, M. Gopalkrishnan and R. Raghu, Single basin Solar Still with fin for enhancing productivity, Energy Conversion and management,2008, 49, 2602-08.

48. O. Sow, M. Siroux and B. Desmet, Energetic and exergetic analysis of a triple effect distiller driven by solar energy, Desalination, 2005,174, 277-86.

49. Torchia-Nunez JC, Porta Gandara MA, Cervantes-de Gortari JG, Exergy analysis of a passive solar still, Renewable energy, 2008, 33, 608-16.

50. S. Kumar and G.N. Tiwari, Life cycle cost analysis of single slope hybrid (PV/T) active solar still.Applied Energy, 86, 1995-2004, 2009.

51. A.E. Kabeel, A.M. Hamed and S.A. El-Agouz, Cost analysis of different solar still configuration, Energy,2010, 35, 2901-08.

52. A.E. Kabeel AE and S.A. El-Agouz, Review of researches & developments on solar stills. Desalination, 2011,276,1-12.

53. A.K. Plappally and J.H.V. Leonhard, Energy requirements for water production, Treatment, end use, reclamation & disposal, Renewable Sustainable Energy, Review 16, 2012, 4818-48.

54. K.R. Ranjan and S.C. Kaushik, Economic feasibility evaluation of Solar distillate systems based on the equivalent cost of environmental degradation & high–grade energy Savings, International Journal of Low-Carbon Technologies, 2013, 12-18.