ISSN (online): 2349-6010

Review on Water Desalination using Renewable Solar Energy

B. Sri Hari Priya
Student
Department of Chemical Engineering
Andhra University, Visakhapatnam

V. Sridevi
Professor
Department of Chemical Engineering
Andhra University, Visakhapatnam

R. Santhoshi Kumari
Student
Department of Chemical Engineering
Andhra University, Visakhapatnam

M. Tukaram Bai
Assistant Professor
Department of Chemical Engineering
Andhra University, Visakhapatnam

Abstract

The availability of drinking water is the very important for all. Plenty of water sources are available on the earth but only 1% of the Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both pathogens and toxic chemicals. Though there are many physical and chemical processes like reverse osmosis, electro dialysis, multi effect desalination to treat sea water, solar distillation is chosen due to its economic viability. Combining renewable solar energy and desalination would generate a sustainable source of fresh water as well as energy. This combination is highly valued as it limits and reduce air pollution emissions and greenhouse gases generated by the combustion of fossil fuels. So, we can say that solar distillation seems to be a promising method and find an alternate way to produce fresh water. Several solar stills deigns have been proposed and many have them found significant applications.

Keywords: Desalination, Fresh Water, Sea Water, Solar Distillation, Solar Energy, Solar Stills

---

I. INTRODUCTION

The world's water consumption rate is doubling every 20 years, out pacing by two times the rate of population growth. The availability of good quality water is on the decline and water demand is on the rise. Worldwide availability of fresh water for industrial needs and human consumption is limited. Various industrial and developmental activities in recent times have resulted in increasing the pollution level and deteriorating the water quality. Water shortages and unreliable water quality are considered major obstacles to achieve sustainable development and improvement in the quality of life. The water demand in the country is increasing fast due to progressive increase in the demand of water for irrigation, rapid industrialization, population growth and improving life standards. The existing water resources are diminishing (i) due to unequal distribution of rain water and occasional drought, (ii) excessive exploitation of ground water sources and its insufficient recharge, (iii) deterioration of water quality due to the discharge of domestic and industrial effluents without adequate treatment. This is resulting into water stress/ scarcity. In addition, a large number of villages in different parts of the country are known to be suffering from excess salinity, fluoride, iron, arsenic and microbial contaminations of ground water.

Seawater, brackish water and fresh water have different levels of salinity, which is often expressed by the total dissolved solids (TDS) concentration. Water is considered potable when its TDS is below 500 mg/L. Seawater has a TDS of about 35,000 mg/L and brackish water has a TDS between that of potable water and seawater. Waste water is another category containing dissolved salts mostly in the low brackish level. The reclaimed water from waste water can be used for irrigation, cooling water and other industrial applications. Since the projected industrial and irrigation requirements would be far exceeding that of domestic requirements, recycle and reuse of waste effluents apart from desalination make enormous sense for future water management[1].

In the next decades, increased potable water consumption and fresh water resources depletion will cause a worldwide water scarcity problem. Nearly one third of the world population will suffer from a problem of water scarcity. Rare faction of potable water has become a major concern in many countries and therefore new techniques are required to produce fresh water.

To overcome from this problem, there are various methods to produce fresh water from sea water, saline water or brackish water. Desalination processes have received great attention as an alternative solution for fresh water production. Conventional desalination processes based on distillation involve phase change. These are multistage flash distillation(MSF), multi effect distillation (MED) and vapor compression (VC), which could be thermal VC or mechanical VC. MSF and MED processes consist of a set of stages at successfully decreasing temperature and pressure. MSF process is based on the generation of vapors from seawater or brine due to a sudden pressure reduction when seawater enters to an evacuated chamber. The process is repeated stage by stage at successively decreasing pressure. This process requires an external steam supply, normally at temperature around 100^oC. The maximum temperature is limited by the salt concentration to avoid scaling and this maximum limits the performance of the process. On MED, vapors are generated due to the absorption of thermal energy by the seawater. The steam generated in one stage or effect is able to heat the salt solution in the next stage because next stage is at lower temperature and pressure. The performance of the process is proportional to stages or effects. MED plants normally use an external steam supply at temperature about 70°C. On TVC and MVC, after initial vapor is generated from the saline solution, this vapor is thermally or mechanically compressed to generate additional production.

On the other hand the membrane processes such as reverse osmosis (RO) and electro-dialysis (ED) do not involve phase change. The first one require electricity or shaft power to drive the pump that increase the pressure of saline solution to that required. This required pressure depends on the salt concentration of the resource of saline solution, which is normally around 70 bar for sea water desalination. Both of them RO and ED (membrane processes) are used for brackish water desalination whereas distillation is applicable to the entire range of salinities up to seawater. In fact it is the only process, which removes with certainty any organisms (bacteria, viruses and also pyrogens) contained in feed water. Theoretically distillation is capable of removing all non-volatile matter. In practice, however, some carryover of dissolved and colloidal matter into the distillate may take place. End product purity expressed in specific conductivity is between 4.0 and 0.066 µg/cm at 25°C, depending upon the technique used[2].

Existing desalination plants used fossils fuels as a source of energy. These conventional distillation process namely reverse osmosis, electro dialysis, multi-effect evaporation etc are not only energy intensive but also uneconomical when the demand for the fresh water is small [3].To take advantage of natural resources, attention has been focused on desalination of sea water or brackish water/saline water. At the same time, the gradual depletion of nonrenewable fuels and the related climate change consequences should lead to key changes in energy supply and use of energy. Hence solar distillation is one of the best method which is suitable for potable water and lesser cost effective and is recognized as a possible means to augment the water supply using natural resources for meeting the growing demand of water[4].The demand for reliable and autonomously operating solar desalination systems is increasing continuously. These systems are meant for a basic need of drinking water and fresh water supply.

II. SOLAR WATER DISTILLATION

A water distiller captures the process of evaporation and condensation in a chamber, leaving behind all impurities, such as inorganic materials and chemicals. It can even purify seawater. Distillation is one of the mankind's earliest forms of water treatment, and it is still a popular treatment solution throughout the world today. In ancient times, the Greeks used this process in their ships to convert sea water to drinking water and also to treat water in other area that are fouled by natural and unnatural contaminants. Solar still having the advantage of low capacity and self-reliance is best suited as; they can produce pure water by using solar energy only, and do not need other expensive energy sources such as fuel or electricity. Among the various types of solar stills, the single passive solar distillation system is the most simple and least expensive. This system is complete and requires no additional infrastructure except the necessary raw water and sufficient sunlight[5].

III. BASIC CONCEPT OF SOLAR POWERED WATER DISTILLATION

A solar powered distillation device will contain three basic components: a basin in which the contaminated water is contained, a surface above the said feed water for the water vapor to condense onto (i.e. a glass pane), and a catch basin for the distilled water to drain into. During operation of the distiller, solar energy is collected by the feed water. When enough energy is absorbed by the water, the water undergoes a phase change. The water vapors then rise and come into contact with the cooler transparent, inclined surface. Here the vapor once again goes through a phase change from vapor back to liquid. The water then condenses and runs off the transparent inclined surface into a collection bin. The distillation process rids the contaminated water of any impurities and most commonly found chemical contaminants within the environment. These contaminants are left behind in the basin. The basic experimental setup is as shown in the Fig. 1.

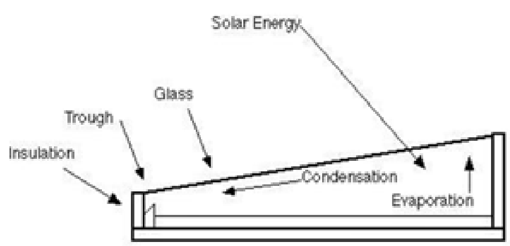

Fig. 1: Basic Experimental Setup

IV. DIFFERENT TYPES OF SOLAR STILLS

Solar distillation systems (solar stills) are classified broadly into two categories: passive and active solar stills. Passive systems are those in which solar energy is collected by the structure elements (basin liner) for evaporation of saline water. Various types of passive solar stills are described in the literature like conventional solar still, vertical solar stills, plastic solar stills, cascade type solar stills, multi wick solar still, multi effect or multi stage solar still, multi basin solar still, greenhouse type solar still, spherical solar still etc. In the case of active solar still, an additional thermal energy by external mode is required for faster evaporation. The extra energy may be obtained from a flat plate solar collector, additional condenser, inverted absorber[2].These active and passive are further classified as shown in the Fig. 2.

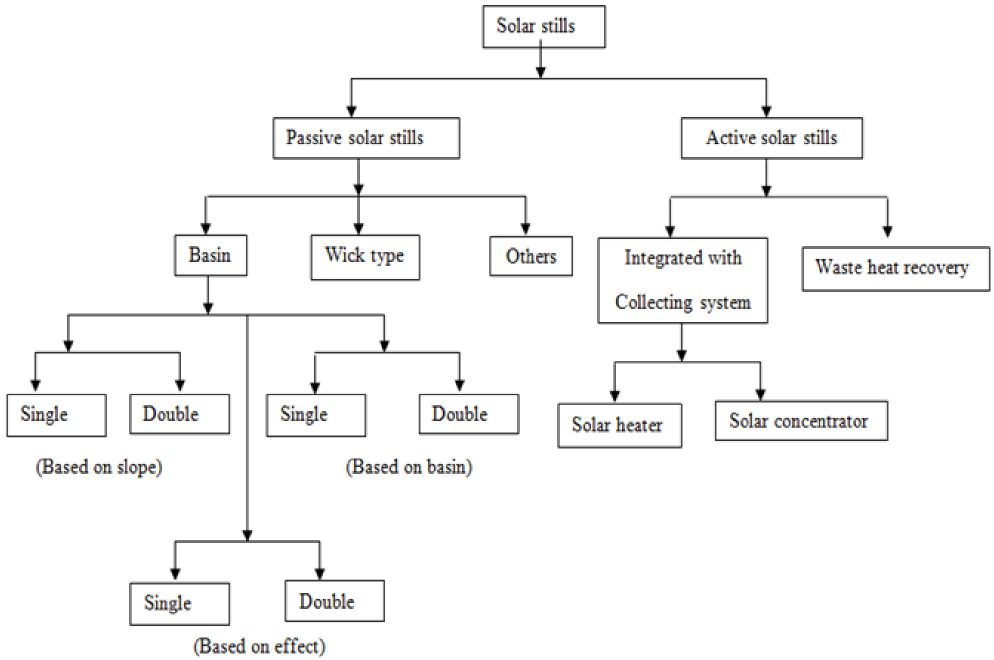

Fig. 2: Classification of Solar stills

V. THE BASIC HEAT TRANSFER MODES IN A SOLAR STILL

The physics of solar stills is mainly a superposition of heat and mass transfer by molecular diffusion and buoyant convection and of radiative heat exchange between the surrounding surfaces. The latter is practically independent from the foregoing two, but these are very complex processes, whose components must not be investigated separately.

The operation of a solar still is governed by various heat transfer modes, convection and radiation being the prominent ones. Free convection accompanied by evaporative mass transfer and radiation are modes of heat transfer between the water surface and the glass cover inside the still. The coefficient of heat transfer is corporate in Nusselt number which is related to the Grashof and Prandtl numbers as,

$$N_u = f\left(G_r.P_r\right) \quad (1)$$

$$N_u = \frac{h_{cw}.x}{k_f} \quad (2)$$

$$G_r = \frac{x^3.\rho^2{}_f.g.\,\beta.\,\Delta T}{\mu_f{}^2} \quad (3)$$

$$P_r = \frac{C_p.\,\mu_f}{k_f} \quad (4)$$

The predicted performance of a single effect solar still has been in the technical literature and solar energy textbooks for some times. Mainly, the predictive of the solar still performance is based on empirical relations. The first thermal model for solar still was outlined by Dunkle (1961),[6], and this model based in part on Sharply and Boelter's,[7] experiments (1938) on the evaporation of water into quiescent air (Malik et al.; 1982[8]).

Clark (1990),[9] examined the validity of Dunkle's model. Clark 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 simulator of spotlights bank. Therefore, the applicability of Clark's relations for the outdoor work needs to be investigated. The applicability of Dunkle's original model for a wide range of operating conditions was examined by Adhikari et al.(1995),[10]. Adhikari found that Dunkle's relations need some modifications for higher range of operating temperatures. In the work of Malik et al. (1982)[8], some assumptions were made to simplify the theoretical derivation of the heat transfer coefficient relations.

Ghoraba (1987),[11] obtained general relations of heat and mass transfer inside 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 uses an immersed electrical heater as an energy source. Generally, in spite of the many publications on solar stills, there appears to be little in the way of carefully validated mathematical models for predicting long term performance over a wide range of real operating conditions and design characteristics.

The steady state performance of a basin type solar still can be predicted following the solar energy textbooks [6,7,8] heat transfer model which has been in the technical literature for some time. This basic heat transfer model is described below. The basic heat transfers in a still can be grouped into two categories:

A. Inner Heat Transfer (Between the Water Surface and the Glass Cover):

The basic heat transfer modes between the water surface and the glass cover are convection, radiation and evaporation. The radiative, convective, and evaporative heat transfer coefficient between water surface and glass cover (Dunkle [6]) are given below assuming water surface and glass cover as two infinite parallel plates.

1) The Radiative Heat Transfer Coefficient,

$$h_{rw} = \frac{\sigma\left[\left(T_w + 273\right)^4 - \left(T_g + 273\right)^4\right]}{\left(1/\ \varepsilon_g + 1/\ \varepsilon_w - 1\right)\left(T_w - T_g\right)} \tag{5}$$

and rate of heat transfer by radiation is expressed as

$$Q_{rw} = h_r\left(T_w - T_g\right) \tag{6}$$

2) The heat transfer between the water surface and glass cover is by free convection. The convective heat transfer coefficient,

$$h_{cw} = 0.884\left[\left(T_w - T_g\right) + \frac{\left(P_w - P_g\right)\left(T_w + 273\right)}{\left(268.9x10^3 - P_w\right)}\right]^{1/3} \tag{7}$$

and rate of convective heat transfer is expressed as

$$Q_{cw} = h_{cw}\left(T_w - T_g\right) \tag{8}$$

Dunkle [6] made use of the relation between Nusselt number and Grashof number for turbulent convection in a horizontal enclosed air space. The buoyancy term in Grashof number is modified by the density effect due to composition (due to evaporation) as well as temperature based in part on experiments with the evaporation of water into quiescent air[7]. Malik et al. [8] have explained the mathematical development. The correlation assumes that the air is saturated with water vapour at the temperature of water in the basin and at the temperature of glass cover.

3) The Evaporative Heat Transfer Coefficient,

$$h_{ew} = \left[\frac{9.15*10^{-7} h_{cw}\left(P_{w-}P_g\right) h_{fg}}{\left(T_w - T_g\right)}\right] \tag{9}$$

is based on the relation between mass transfer and heat transfer, assuming a Lewis number 1.0.

B. Outer Heat Transfer (Between the Glass Cover and the Environment)

1) The radiative heat transfer coefficient between glass cover and the ‘‘sky’’ (atmosphere) is given by,

$$h_{rg} = \sigma\ \varepsilon_g\left(T^2{}_g + T^2{}_s\right)\left(T_g + T_s\right) \tag{10}$$

where Ts is the apparent (effective) temperature of the atmosphere which acts as the sink for radiative heat transfer.

2) Bottom and Edge Heat Transfer

The heat is also transferred or loss from water in ambient through the insulation and subsequently convection/radiation of the bottom or side surface of the box. Hence the bottom loss can be written as

$$U_b = \left[\frac{1}{\left(K_i / L_i\right)} + \frac{1}{\left(h_{cb} + h_{rb}\right)} + \frac{1}{h_w}\right] \tag{11}$$

where L_i, K_i, h_{rb}, h_{cb} and h_w are thickness, thermal conductivity of the insulation, radiative and convective heat transfer coefficients from bottom to ambient and the convective heat transfer coefficient between basin liner of the still and the water. However last two terms in the above expression do not contribute significantly and the heat loss can be considered only through conduction from bottom,

$$U_b = K_i / L_i \tag{12}$$

Similarly edge loss is also mainly by conduction through the insulation and can be written as

$$U_e = \frac{U_b . A_e}{A_b} \tag{13}$$

where A_b, A_e are bottom and edge areas of the still.

3) The The convective heat transfer coefficient due to wind, For calculating the convection losses from the glass cover to the ambient air, wind heat transfer coefficient, may be expressed as a linear function of wind velocity. However, as pointed out by Shukla et al. [12, 13] the heat transfer coefficient in natural environment can be larger by a factor of two or three.

VI. LITERATURE REVIEW

Several experiments have been conducted on solar stills depending upon how the shape, inclination of the glass and the area of the basin affect the productivity in order to increase the productivity. By trying out different shapes; single slope, double slope and pyramid shape, Hashim et al., (2010),[14] found that the highest yield was in the symmetric double sloped still. He also examined which effect the inclination of the glass had, and the area of the basin. The production increased with increasing inclination, but he said that the still with the lowest inclination, here 15°, would be preferable due to smaller size and lower cost, compared to a still with inclination 45°. The highest average daily output was 4.5 l/m^2 day.

In order to enhance the solar radiation, the inclination of the glass should be the same as the latitude[15]. In Amman, Jordan experiements were conducted with different inclinations, ranging from 15° to 55°,Akash et al., 2000,[16] found that the still with inclination 35° had the highest outcome, 2.2 $l/day*m^2$ This is approximately the same as the latitude of Amman (31°). In the sultanate of Oman, there was recorded an increase in yield with increased inclination of the cover in the winter season, and a decrease in yield when increasing the angle during the summer[17]. This is was due to negative values for the declination angle in the winter and positive in the summer. Nafey et al., 2000,[18] also proposed this. However, Al- Hinai,2002,[17] concluded that the inclination should be the same at the latitude, to receive the highest amount of radiation throughout the year.

An experiement was conducted by Hassan E.S.Fath et al .,2004,[19] in Egypt,using solar still with passive condenser using natural circulation got 56%,using glass cover got 42%,using condenser got 58% as efficiencies. Janarthanan.B et al.,2006,[20] have observed the increase in efficiency in closed cycle using floating tilted wick as solar still. By using the stepped solar still, sponges, fin, sponges+fin in the solar still, got 60.39%,76%,96% as efficiencies, respectively (Velmurugan.V et al., 2008),[21]. Nafey et al (2001),[22] when comparing the result to a still without materials, found an increase of 20 % and 19 %, using 10 mm thick black rubber and 20-30 mm black gravel in two separate stills. Others have used black ink and black dye to colour the water. Comparing the results for black ink, black dye and a black rubber matt, there was found an increase of 60 %, 45 % and 38 % [23]. The highest outcome was 1.2 l/m^2, 1.1 l/m^2, and 1 l/m^2 respectively. However, the most commonly used lining is asphalt or black butyl rubber [24].

Besides the importance of the black basin, the specific surface area is essential to the productivity. A study was conducted by applying uncoated metallic wiry sponges, coated metallic wiry sponges and black volcanic rocks to the basins, Abdallah et al., 2009,[25] observed an increase of 43 %, 28 % and 60 %,here the main drawback was the corrosion of the metallic wiry sponges. However, the volcanic stones did not corrode. The study also showed that coated metallic wiry sponges were less effective than uncoated ones. Abu-Hijleh et al (2003),[26] also experienced an increase in the productivity, using black and yellow sponges. However, the colour reduced the capillarity force to the sponges, making it more difficult to attract water. He therefore concluded that the capillarity effect is of greater importance than absorbing capacity. In this experiment, there was achieved an increase of up to 273 % when applying uncoloured sponges to the basin.

Naim et al., 2003,[27] showed that using charcoal increased the productivity by 15 % over a wick type solar still. In another experiment, wick materials were compared; black cotton cloth, jute cloth, sponge sheet, coir mat and waste of cotton pieces, and some aluminium rectangles fins were included together with black cotton cloth and jute cloth. Black cotton cloth, without fins, gave the highest production for the wicks, with 1.5 $l/day*m^2$. The basin with black cotton cloths and fins gave a slightly increase in yield over black cotton cloths, 1.55 $l/day*m^2$[28].

In Baghdad, three solar stills where tested. All had black basins, and two of the stills had additionally jute wicks. One wick floated in the basin, the other tilted. For the winter time, an increase of 77% and 70% was achieved for the tilted and floating wick, respectively, over the still without wick material. For the summer, there was a decrease in output for the tilted wick, of 43 %. This is due to higher evaporation rate than to capillarity properties of the wick, resulting in dry spots. In June, the floating wick still had its highest outcome, 10 $l/day*m^2$ (Al-Karaghouli et al., 1995). Moustafa et al., 1979,[30] also stated that wick solar stills have a better performance compared to basin type. Tanaka et al., 1981,[31] found an increase in 20-50 % output for a tilted wick, compared to basin type. Stones can absorb and store heat, hence applying 6.3 mm and 19.0 mm quartzite rock, 6.3 mm naturally washed stones, 38.1 mm cement concrete pieces, 31.7 mm red brick pieces and mild steel scraps to the basins, can enhance the productivity. 19.0 mm quartzite rock was found to give the highest output, 2.0 $l/day*m^2$[32].

Akash et al., 2000[16], Nafey et al., 2000[18], Singh et al., 1995,[33] found that a shallow water depth could increase the daily yield, and tests were conducted with the depths ranging from 2 – 10 centimetres. The experiments showed that the optimum depth was two cm. Akash et al., 2000[16] discovered that the depths were linearly related to the output, and that an increase in depth would decrease the outcome. Tiwari et al., 2007,[34] performed experiments on water depths ranging from 2 to 18 cm during a whole year. For the summer and winter season, the yield increased 33 % and 32 % respectively, for water depth 2 cm compared to 18 cm. An annual increase of 44 % for a 4 cm depth, compared to 18 cm was also registered. When comparing depths of 8 cm to 18 cm depths, and 16 cm to 18 cm, the outcome was reduced with 9 % and 1 %, respectively. Tiwari et al (2007)[34] concluded that for water depths above 8 – 10 cm, the outcome becomes close to constant. When including water-absorbing materials to the basin, the result can differ. By adding sponges to the basin, the yield increased as the water depth increased. This is true up to the water depth of 7 cm[26]. Materials used for constructing a solar still have to withstand high temperatures, solar radiation and restrain leakage of water and vapour over a long period. Materials, which are toxic or corrosive, can off-gas, melt or fracture under these conditions is not suitable for this purpose. A transparent cover, usually glass, transmits the radiation to the basin. 3-4 mm glass is the most frequently used ([35][25][36]). Some also has applied Plexiglas, however; this is known to reduce the effect of the UV light, by making it less intense (www.ehow.com). The distillation channel attached to the glass cover for collecting the condensed water is usually PVC pipe, a piece of glass, GI sheet, or bend aluminium (AL) ([36][37][21][38]).

Akash et al., 2000[16], Akash et al, 1998[23], and Nafey 2001[22] used stainless steel (SS) as a basin, enclosed by black rubber or painted black. Galvanized iron (GI) is also common basins in solar stills [25][38][21]. Another material, which is easily available, is wood, painted black, or enclosed by black PE sheets is used by Srivastava et al., [39] and Gad et al., 2011[35]. Wood can also be applied outside the GI or SS to make it easy to insulate. Insulation of the basin will reduce heat loss to the surroundings, and the most common materials used for this purpose are rock wool, foam and glass wool ([36][22][40][28]). AliSamee et al., 2007[38], Akash et al., 1998[23], Srivastava et al.,2012,[39] found that the cheaper materials like sand, cotton, cloths, sawdust, straw etc., will give a similar effect, but may be less effective. To prevent leakage, silicone sealant is often used, but other materials like an rubber gasket, putty, tars and tape are also an option However, this may be less effective, yet it may be cost-efficient. Akash et al., 2000,[16] stated that the lamps and rubber gasket are also widespread Mirrors inside the basins, can enhance the amount of solar radiation, but may be costly [41].

VII. CONCLUSIONS

To enhance the productivity of the solar still, the design is essential. There are mainly three factors that have impact; solar radiation, the amount of sunny hours and the design of the still Design factors of importance includes water depth, surface area, colour of the basin, inclination of the glass, insulation, materials, temperature of the water, air-tightness, wind velocity and temperature differences in the still and ambient air. In studies conducted on solar stills, the water production has been a major concern. Solar stills have a good chance of success in India for lower capacities which are more than 20 km away from the source of fresh water and where the TDS of saline water is over 10,000 ppm. Scientists have therefore looked into how to improve the efficiency and to the decrease fresh water costs, efforts should be undertaken in the following research to develop a hybrid system of water purification which can overcome the limitations of all existing water purification systems.

APPENDIX

- A Area, m^2
- C_p Specific heat, J/kg ^oK
- dt Time interval, s
- Gr Grashof number
- h Heat transfer coefficient, $W/m^2\,^oK$
- h_{cw} Convective heat transfer coefficient from water surface to the glass cover, $W/m^2\,^oK$
- h_{ew} Evaporative heat transfer coefficient from water surface to the glass cover,$W/m^2\,^oK$
- h_{rw} Radiative heat transfer coefficient from water surface to the glass cover, $W/m^2\,^oK$
- h_{rg} Radiative heat transfer coefficient between glass cover and the atmosphere , $W/m^2\,^oK$
- h_1 Total heat transfer coefficient from water to glass cover, $W/m^2\,^oK$
- h_2 Convective heat transfer coefficient from glass to ambient, $W/m^2\,^oK$
- h_3Convective heat transfer coefficient from basin liner to water, $W/m^2\,^oK$
- i Current, ampere
- I(t) Solar flux on an inclined collector, W
- m Mass, kg
- Nu Nusselt Number
- P Partial pressure, N/m^2
- Pr Prandtl number
- q Heat transfer, W/m^2
- Ra Rayleigh number
- T Temperature, ^oC
- T_s Apparent Temperature of the atmosphere, ^oC
- U_e Edge loss heat transfer coefficient, W/m^2
- U_{ga} Overall heat transfer coefficient from inner glass to ambient, W/m^2
- U_b Overall bottom loss coefficient, W/m^2
- U_t Top loss coefficient, W/m^2
- U_L Overall heat transfer coefficient, W/m^2
- K Thermal conductivity, W/mK

- L,x Thickness, m
- l Liquid
- s Solid
- v Wind speed, m/s

ACKNOWLEDGEMENT

Foremost, We are thankful to the Head of the Chemical Engineering Department, AUCE Visakhapatnam for her encouragement. We are deeply indebted to our guide Prof V. Sri Devi**,** for her valuable suggestions, ever willing precious guidance for writing this paper. We are also thankful to Prof Tukaram Bhai for her support and encouragement

REFERENCES

[1] Chemical Engineering Group Desalination Division by Bhabha Atomic Research Centre Trombay, Mumbai Government of India Department of Atomic Energy, 400 085, 2010, www.barc.gov.in/publications/tb/desalination.pdf
[2] J. P. Davim (ed.), 2014 Modern Mechanical Engineering, Materials Forming, Machining and Tribology, Springer-Verlag Berlin Heidelberg DOI: 10.1007/978-3-642-45176-8_2 A.N Khalifa , "Evaluation and energy balance study of solar still with an inernal condenser", JSER 3(1) 1-11 (1985).
[3] A.N. Kalifa, "Evaluation and energy balance of study of a solar still with an internal condenser", JSER 3(1)1-11(1985).
[4] 2nd International Conference on Advances in Energy Engineering (ICAEE2011)1876-6102 © 2011 Published by Elsevier Ltd. doi:10.1016/j.egypro.2011.12.887 (2ro0c1e1d)i a0 0104– (020001 2) 1701 – 1708.
[5] Bhramara Panitapu , Vijaya Koneru, Sri Lalitha Swathi Sagi, Ajay Parik.(2014, May) Solar Distillation Using Nano-Material, International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)Volume No.3 (Issue No.5).
[6] Dunkle RV (1961), Solar water distillation: the roof of type still and multiple effect diffusion still, international developments in heat transfer, In: A.S.M.E,Proceeding of International Heat Transfer, part V, University of Colorado, p 895
[7] Bloemer, J. W., J. A. Eibling, J. R. Irwin and G. O. G. Lof, (1963), Analog Computer Simulation of Solar Still Operation. ASME, 63-WA- 313, 1-8.
[8] Malik MAS, Tiwari GN, Kumar A, Sodha MS (eds) (1982), Solar distillation a practical study of a wide rang of stills and their optimum design, construction and performance. Pergamon Press, New York. Clark, J.A., (1990) .The steady- state performance of a solar still. Solar Energy, 44, 43 -49.
[9] Clark J.A.,(1990) ,The steady state performance of a solar still, Solar Energy,44,43-49.
[10] Adhikari, R. S., Ashivini Kumar, and G.D. Sootha, (1995), Simulation studies on multistage stacked tray solar still. Solar Energy, 54, 317-325.
[11] Ghoraba, M.M., (1987),Theoretical and experimental studies of heat and mass transfer inside single-sloped solar stills, PH. D. Thesis, Cairo University.
[12] Shukla SK, Sorayan VPS, Gupta SK (2004) Parametric studies of passive/active solar stills by using modified convective mass transfer relations. Int J Ambient Energy 25(3):212–232.
[13] Shukla SK., Sorayan VPS (2005), Thermal modeling of solar stills: an experimental validation: renewable Energy, Fuel Energy Abstr 30(5):683–699.
[14] A.Y. Hashim, J. M. Al-Asadi, W.A. Taha Alramdhan. (2010), An attempt to solar still productivity optimization; solar still shape, glass cover inclination and inner surface area of a single basin solar still, Vol.28(1),39-48,2010.
[15] Velmurugan, V., & Srithar, K. (2011), Performance analysis of solar stills based on various factors affecting the productivity—a review. Renewable and Sustainable Energy Reviews, 15(2), 1294-1304.
[16] Akash, B. A., Mohsen, M. S., & Nayfeh, W. (2000), Experimental study of the basin type solar still under local climate conditions. Energy Conversion and Management, 41(9), 883-890.
[17] Al-Hinai, H., Al-Nassri, M. S., & Jubran, B. A. (2002b), Effect of climatic, design and operational parameters on the yield of a simple solar still. Energy Conversion and Management, 43(13), 1639-1650.
[18] Nafey, A. S., Abdelkader, M., Abdelmotalip, A., & Mabrouk, A. A. (2000). Parameters affecting solar still productivity. Energy conversion and management, 41(16), 1797-1809.
[19] Hassan E.S. Fath and S. M. Elsherbiny, "Effect of Adding a Passive Condenser on Solar Sill Performance", Int. J. of Solar Energy, Vol. 11, pp. 73-89 (1991).
[20] B. Janarthanana, J. Chandrasekarana , S. Kumar. Performance of floating cum tilted-wick type solar still with the effect of water flowing over the glass cover ,Desalination 190 (2006) 51–62.
[21] Velmurugan, V., Deenadayalan, C. K., Vinod, H., & Srithar, K. (2008),Desalination of effluent using fin type solar still. Energy, 33(11), 1719-1727.
[22] Nafey, A. S., Abdelkader, M., Abdelmotalip, A., & Mabrouk, A. A. (2001), Solar still productivity enhancement. Energy conversion and management, 42(11), 1401-1408.
[23] Akash, B. A., Mohsen, M. S., Osta, O.,& Elayan, Y. (1998), Experimental evaluation of a single-basin solar still using different absorbing materials.Renewable Energy, 14(1), 307-310.
[24] Delyannis, E. (2003),Historic background of desalination and renewable energies. Solar Energy, 75(5), 357-366.
[25] Abdallah,S.,Abu-Khader,M.M.,&Badran,O.(2009). Effect of various absorbing materialson the thermal performance of solar stills. Desalination,242(1), 128-137.
[26] Abu-Hijleh, B. A., & Rababa'h, H. M. (2003), Experimental study of a solar still with sponge cubes in basin. Energy conversion and Management, 44(9), 1411-1418.
[27] Naim, M. M., & Abd El Kawi, M. A. (2003).,Non-conventional solar stills Part 1. Nonconventional solar stills with charcoal particles as absorber medium.Desalination, 153(1), 55-64.
[28] Murugavel, K., & Srithar, K. (2011), Performance study on basin type double slope solar still with different wick materials and minimum mass of water. Renewable Energy, 36(2), 612-620.
[29] Al-Karaghouli, A. A., & Minasian, A. N. (1995), A floating-wick type solar still.RenewableEnergy, 6(1), 77-79.
[30] Moustafa, S. M., Brusewitz, G. H., & Farmer, D. M. (1979).,Direct use of solar energy for water desalination. Solar Energy, 22(2), 141-148
[31] Tanaka, K., Yamashita, A., & Watanabe, K. (1981, August), Experimental and analytical study of the tilted wick type solar still. In Solar World Forum (Vol. 2)
[32] Murugavel, K., Sivakumar, S., Riaz Ahamed, J., Chockalingam, K. K., & Srithar, K. (2010).
[33] Singh, A. K., Tiwari, G. N., Sharma, P. B., & Khan, E. (1995),Optimization of orientation for higher yield of solar still for a given location. Energy conversion and management, 36(3),175-181
[34] Tiwari, A. K., & Tiwari, G. N. (2007), Thermal modeling based on solar fraction andexperimental study of the annual and seasonal performance of a single slope passive solarstill: the effect of water depths. Desalination, 207(1), 184-204.
[35] Gad, H. E., El-Gayar, S. M., & Gad, H. E. (2011, May), Performance of a solar still with clothes moving wick. In 15th International Water Technology Conference, IWTC (pp. 28-30).
[36] Badran, O. O. (2007), Experimental study of the enhancement parameters on a single slope solar still productivity, Desalination, 209(1), 136-143.

[37] Venumurugan.V,Mugunthan.K and Srithar.K(2006), Experimental study on solar still integrated with a mini solar pond, proceedings of the 3rd BSME-ASME International Conference on Thermal Engineering,20-22 December,2006.
[38] Ali Samee, M., Mirza, U. K., Majeed, T., & Ahmad, N. (2007), Design and performance of a simple single basin solar still. Renewable and Sustainable Energy Reviews, 11(3), 543-549.
[39] Srivastava, P. K., & Agrawal, S. K. (2012) ,Experimental Investigation of some Design and Operating Parameters of Basin Type Solar Still.
[40] El-Bahi, A., & Inan, D. (1999), A solar still with minimum inclination, coupled to an outside condenser, Desalination, 123(1), 79-83.
[41] Al-Hayeka, I., & Badran, O. O. (2004),The effect of using different designs of solar stills on water distillation. Desalination, 169(2), 121-127.