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Solar Distillator - A Review

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Abstract: ***The most important aspect for sustaining life on earth is water. In spite of its abundant availability, a small percentage can be used for drinking purpose. There are several techniques available to convert saline or brackish into fresh water like vapour compression, reverse osmosis, electro-dialysis etc. Among these techniques solar distillation is most prominent; it has inherent advantages of low energy consumption. Moreover, it is simpler and more economical than other methods. Different theoretical and experimental studies carried out in the field of solar distillation with green-house effect, have shown that global efficiency of a simple solar still are affected by physical and building parameters, especially by the difference of temperature between the evaporation surface and that of the condensation. Optimizing this difference allows us to obtain a solar still with a better efficiency. In this paper review on solar distillation is done.***

Keywords: Solar distillation, temperature difference, passive solar distillation, active solar distillation, nocturnal production

1. Introduction

Fresh water is the essence of life and it is the most important constituent of the environment. Water is a basic human requirement for domestic, industrial and agriculture purposes. Supplying fresh and healthy water is still one of the major problems in different parts of the world especially in arid remote areas [1].Solar stills can provide a solution for those areas where solar energy is available in plenty but water quality is not good. This device can be used for producing drinking water. Solar stills are cheap and having low maintenance cost but the problem of solar still is the low productivity [2]. Solar stills can be used for low capacity and self-reliance water supplying systems since they can produce drinking water by solar energy only, and do not need other energy sources such as fuel or electricity. There are many methods for converting brackish water in to potable water [3]. Some of the water distillation ways are described as:

1.1Desalination: In this method, the brackish or saline water is evaporated using thermal energy, and resulting steam is collected and condensed as final product.

1.2 Vapour compression: In this process of desalination water vapour from boiling water is compressed adiabatically and vopour gets superheated. The superheated vapour is first cooled to saturation temperature and then condensed at constant pressure.

1.3 Reverse osmosis: In this process saline water is pushed at high pressure through special membranes allowing water molecules selectively to pass and not the dissolved salts.

1.4 Electrodialysis: In this method water is passed through a pair of special membranes, perpendicular to which, there is an electric field. Water does not passed through the membranes while dissolved salts, pass selectively.
Among non conventional methods, distillation is the most prominent; the conventional distillation plants, round the globe, are energy intensive and utilizes non-renewable energy. Solar distillation has the inherent advantages of low energy consumption. Moreover, it is simpler and more economical than other methods. It requires simple technology and easy maintenance hence it can be used at any place without much problem [4].

2. History

The first documented work in the field of solar distillation is that of Arab alchemists in 1551. The work of Della Porta published in 1589. Della Porta used earthen pots full of herbs, kept inverted over collecting vessels. The earthen pots were exposed to sun rays which heated the herbs inside the pots by the processes of convection and radiation. Water from the herbs got evaporated and condensed on the inner surface of the pot and finally tricked down into the collecting vessel. French chemist, Dremost Lovoisier (1962) used glass lenses to concentrate solar energy on the distillation flask Mouchot (1869) has described the used of silver or aluminum coated glass reflectors for concentrating solar energy for distillation. Carlos Wilson, a Swedish Engineer, was first to design a conventional solar distillation apparatus, called solar still, in 1872, in Northen Chile. After 1880 till the end of world war–I no documented work on solar distillation is available. After words several designs of solar stills were investigated i.e. roof type, suspended envelope, tubular and air inflated still etc. Kaushch (1920) and Pasteur (1928) mention the use of solar concentrators for solar distillation. Abbot (1930) used cylindrical parabolic aluminum coated reflectors to focus solar energy on evacuated tubes of water and also tracked the motion of the sun. During world War – II, air inflated plastic stills were used for the U.S. Navy and Air Force. In such stills, inflated transparent plastic bags containing porous felt pad saturated with seawater and having collector bottles at the bottom, were kept in the sun. The water from the pad evaporated, got condensed and tricked down in the bottle. During the war period, as many as 200,000 of such inflated plastic stills were used. Subsequently efforts were made to improve the operating efficiencies of the various types of solar stills for better output [5].

3. Working Principle of Solar Distillation

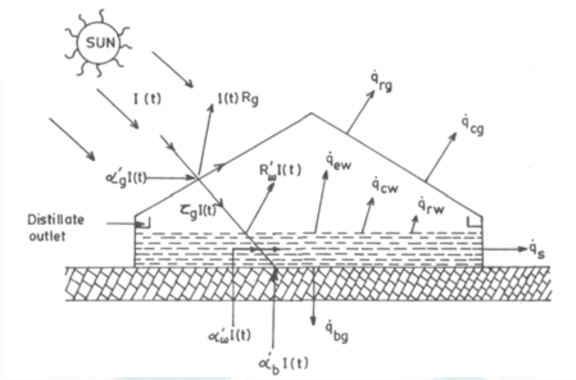

Figure 1: Conventional Solar Still

Figure 1 shows the various components of energy balance and thermal energy loss, in a conventional solar distiller unit. It is an airtight basin, usually constructed out of concreted cement, galvanized iron sheet (GI) or Fiber Reinforced Plastic (FRP) with a top cover of transparent material like glass, plastic etc. The inner surface of the rectangular base is blackened to efficiently absorb the solar radiation, incident at the surface. There is a provision to collect distillated output at lower ends of glass covers. The brackish or saline water is fed inside the basin for purification using solar energy. The solar radiation after reflection and absorption by the glass cover is transmitted inside on enclosure of the distiller unit. This transmitted radiation [τ_g I(t)] is further partially reflected [R_w 1(t) and absorbed [α_w I(t)] by the water mass. The attenuation of solar flux in water mass depends on its absorptivity and depth respectively. The solar radiation finally reaches the blackened surface where it is mostly absorbed. After absorption of solar radiation, most of the thermal energy is converted to water mass and the rest which is very small is lost to the atmosphere. The water thus gets heated leading to an increased of difference of water and glass cover temperature. There are three modes of heat transfer namely radiation (q_{rw}), convection (q_{cw}) and evaporation (q_{ew}), from water surface to the glass cover. The evaporated water gets condensed on the inner surface of the glass cover after releasing the latent heat. The condensed water trickles in to the channels provided at the lower ends of glass cover under gravity. The collected water in the channel is taken out of the system for appropriate use [6].

4. Classification of Solar Distillation Systems

As a result of large interest for water purification, several types of solar still have been evolved. Distillation process is mainly classified into two types, passive distillation and active distillation. Passive distillation includes conventional solar still with reflector or with condenser, multi effect solar still, inclined solar still and new design solar still like tubular, regenerative and spherical [7]. Active distillation is of two type's high temperature distillation and nocturnal distillation [8].

5. Passive Solar Stills

The conventional singly basin solar still, is the simplest and most practical design for an installation to provide distilled drinking water for daily needs. The conventional solar stills are classified as:

1. Symmetrical Double – slopped Figure 2(a), (b), (c) & (e)
2. Non – Symmetrical double slopped Figure 2 (f), (g) and
3. Single slopped Figure 2 (d)

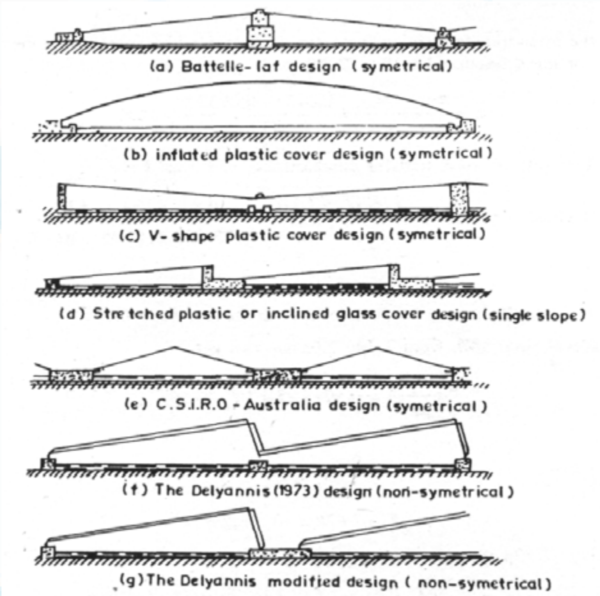

Figure 2: Different Configurations of Conventional Solar Still

The symmetrically double sloped still is positioned to the east-west axis and it is free of orientation requirement. In other two, the low wall faces the equator to receive the maximum solar radiation for higher yield.

6. Thermal Analysis of Conventional Solar Still

It has reviewed the work on solar distillation carried out by many investigators. The review includes the effect of climatic, operational and design parameters of a conventional solar still. Figure 3 is a single slopped conventional solar still. The basic heat flux components at various points have also shown in the Figure 3. The assumptions made for energy balance are

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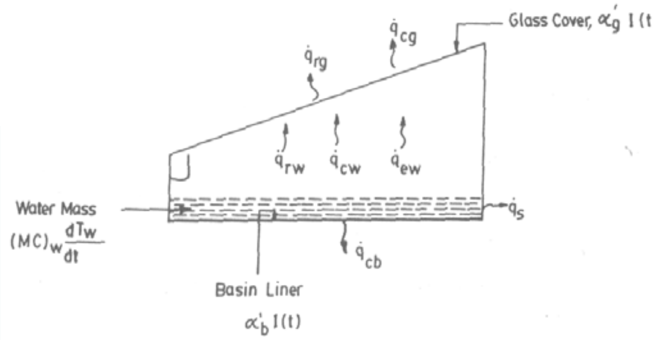

Figure 3: Simple Solar Still.

1. Inclination of the glass cover is very small.
2. The heat capacity of the glass cover, the absorbing material and the insulation (bottom & side) is negligible and
3. The solar distiller unit is vapour – leakage – proof.

The energy balance for different – components are as given below.

Glass Cover
Rate of energy Observed + Rate of energy received from water Surface by radiation convection & evaporation

$$\alpha^1{}_g I(t) + [\dot{q}\,rw + \dot{q}\,cw + \dot{q}\,ew] = [\dot{q}\,rg + \dot{q}\,cg]$$

Water Mass:
Rate of energy Absorbed + Rate of convected energy from basin liner = Rate of energy stored

$$\alpha^1_w I(t) + \dot{q}_b = (mc)w\frac{dT_w}{dt} + \left[\dot{q}_{rw} + \dot{q}_{cw} + \dot{q}_{ew}\right]$$

Basin Liner:
Rate of energy absorbed = Rate of energy lost by convection to water + Rate of Energy lost by conduction through bottom / sides.

$$\alpha^1{}_b I(t) = \dot{q}_b + [\dot{q}_{bg} + \dot{q}_s(A_{SS}/A_S)]$$

7. Active Solar Distillation

The overall system efficiency in terms of daily distillated output can be increased by decreasing the water depth and the use of latent heat of condensation for further distillation. The daily distillate output of passive solar stills can be increased by increasing the temperature difference between the evaporating and the condensing surface. The condition can be achieved either by increasing the evaporating surface temperature or decreasing the condensing surface temperature or combination of both. The evaporating surface temperature can be increased by feeding the thermal energy into the basin from external source. This can be done as follows.

8. Nocturnal Production

The feeding of hot water into the basin once in a day[9]. In a conventional solar still (CSS) with large water depth in the basin water is heated during sunshine hours and most of the thermal energy is stored in water mass. This stored energy is then utilized for distillation during off sunshine hours. This process of distillation in the absence of solar energy is known as nocturnal production [10]. The daily nocturnal production is proportional to the average temperature difference between water and glass cover and it is more for large water depths than that for lower water depths [11]. The efficiency of the system decreases with increase of the stored energy per unit area. Due to larger value of mean bulk temperature, the radiative exchange between the water surface and the night-sky will be more which contributes to the lowering of efficiency [12].

9. Pre-Heated Water

The feeding of hot water into the basin at constant flow rate [13, 14] for this arrangement three types of test can be conducted, are as follows:

1. Solar pre-heated water flow during first hour of the test.
2. Continuous feeding of solar pre- heated water during the duration of the test.
3. The same test (i) but, withdrawal of all water after two hours and repeating test (i) known as intermittent test.

+ Rate of Energy lost to glass cover by radiation, convection and evaporation

The intermittent feeding is superior to continuous feeding by 7%, but since intermittent feeding requires automatic system for its operation, continuous feeding is preferable than any other mode of operations.

10. High Temp Distillation

The operating temperature for a clear day and maximum level of about 900 to 950 w/m^2 is in the range of 20^{0}C-45^{0}C. This temperature can be increased to 70^0 to 80^{0}C by feeding thermal energy from a collector panel into the basin of the solar still. The operation of integrated system (solar still and collector panel) is usually referred to as high temp distillation [13].

The work is being carried out at IIT Delhi, where they used a single slope solar still and a flat plate collector. Also in Tripoli-Libya similar arrangement has been made [14]. The basin area was 2.5m^2. A cooling arrangement for the glass cover has also been made to get higher yields. The results shows a maximum increase in yield of 33% and 80% for without and with water flow over the glass cover respectively [15].

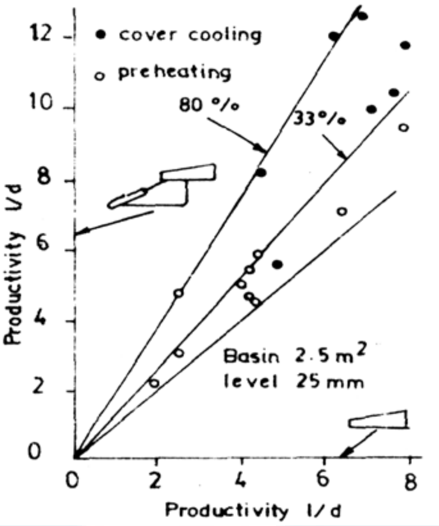

Figure 4: Stills Yield with Brine Preheating and Cover Cooling

However, the instantaneous thermal efficiency of active solar still is less than that of passive solar stills; this is because of higher operating temperature range in active solar still due to additional thermal energy available from the collector. Thermal energy loss increases. Therefore, although the yield increases but the efficiency of active solar distillation decreases.

11. Improvement in Distillate Output

To increase the distillate output of the conventional distillations unit, it is necessary to increase the water temperature for maximum evaporation. The following techniques have been used in distillation unit for improvement of distillate output.

11.1) Back wall as Reflector

In this the inner surface of back vertical wall is polished with highly reflecting material, stainless steel or mirror. The solar radiation incident on the back wall surface is reflected back into the basin water.

11.2) Back wall with cotton cloth

The incident solar radiation can be used for evaporation from back vertical wall with black cotton cloth which sucks water from the basin due to capillary action up to a creation height depending on the porosity of the cloth.

11.3) Regenerative effect in back wall

In Regenerative effect, the raw water is allowed to flow on outside of the back wall, so that, it can be heated. The heated water is fed into the basin for further evaporation.

2.6.4) Solar still with Internal Condenser

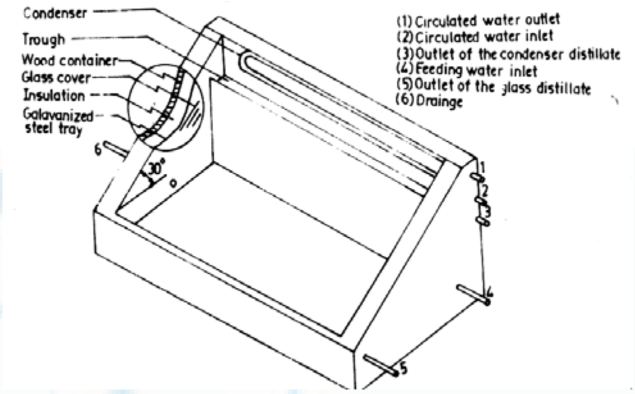

Figure 5: Solar Still with Internal Condenser

As shown in Figure 5, the cold water circulated through a copper pipe through inlet (2). Water gets heated by condensation of water vapour. Hot water is taller out through the outlet (1). The condensed water is collected through a channel (3).

12. Comparison of Methods

Figure 6 shows the comparison of distillation rate obtained from three methods of improvement,

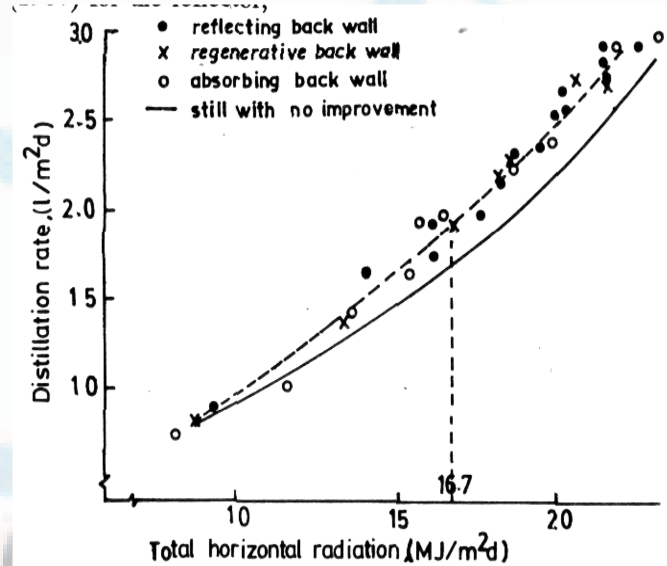

Figure 6: Comparison of Distillation Rate Obtained From Three Methods of Improvement

- The improvement of the daily distillation rate by 13-15% was observed [16].
- The daily efficiency of a single basin solar still is improved by about 10% due to an internal condenser.

This improvement can be achieved for higher slope of glass cover (>45^0) so that height of the back wall is large enough for significant effect.

There is an appreciable increase in overall efficiency about 24-28% due to floating of charcoal pieces for large depths of water. This is because charcoal has two desirable properties i.e. large black surface area for absorption of solar radiation and a large surface area for evaporation [17].

13. Numerical Results and Discussion

The hourly variation of the solar intensity [I (t)] and ambient air temperature (Ta) is shown in Figure 7.

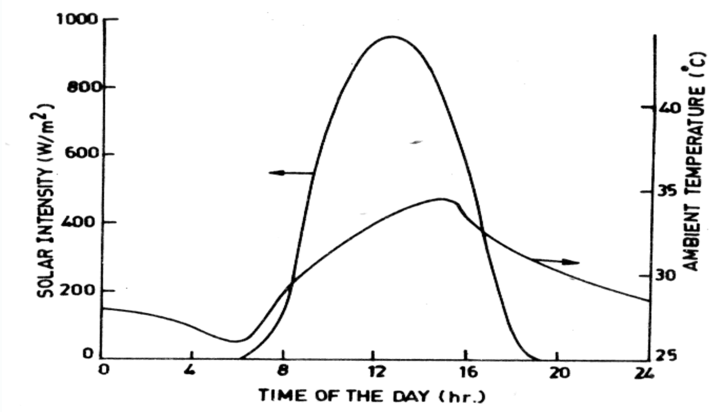

Figure 7: Variation of Solar Intensity and Ambient Temperature

The hourly variation of water (T_w) and glass (T_g) temperatures for a 2 cm depth of water in basin is shown in Figure 8.

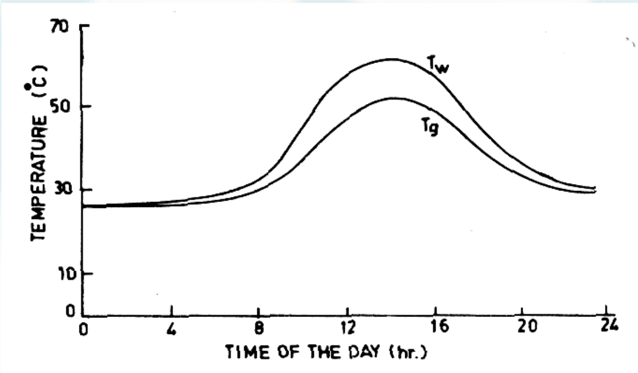

Figure 8: Hourly variation of water and glass temperature

The internal heat transfer coefficients (h_{rw}, h_{cw} & h_{ew}) variation with respect to time given in Figure 9. There is significant variation of evaporative heat loss coefficient as compared to that of radiative and convective heat loss coefficients. And hence the total internal heat transfer coefficient (h_{1w}) should not be considered constant for low depths.Fig no. 2.6. It can be considered as constant at larger depths Fig no. 2.7.

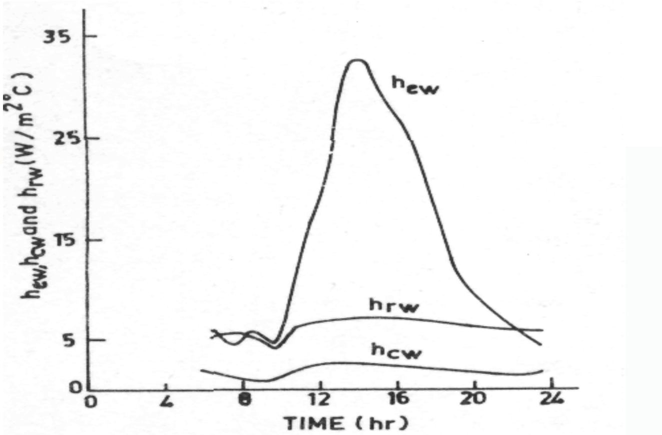

Figure 9: Hourly Variation of Convective, Radiative and Evaporative Heat Transfer Coefficient

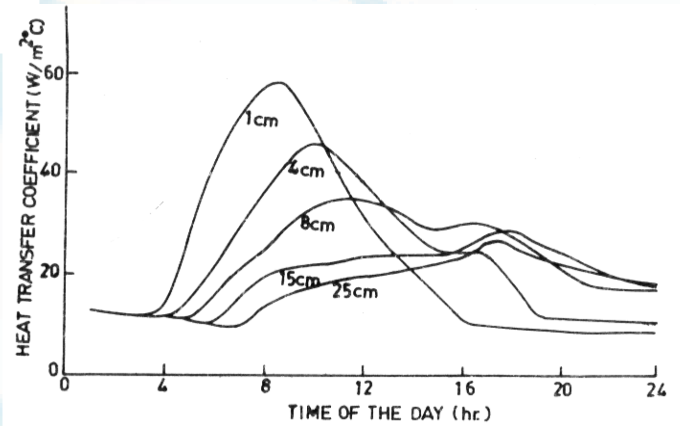

Figure 10: Hourly Variation of Heat Transfer Coefficients from Water Surface to Glass for Different Water Depths

The efficiency of solar still decreases with increase in water depth. The daily yield decreases with decrease in water depth for lower initial water temperature and vice-versa for higher initial temperature [18]. The daily productivity is independent of the water depth for uninsulated solar still.

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