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Ground water distillation by basin type solar still for different basin water depth under the climatic condition of Rewa

AbhayAgrawal[1], R. S. Rana[2], P.K. Shrivastava[3]
1 Assistant Professor, Department of Mechanical Engineering, Rewa Engineering College, Rewa, MP, India
2 Assistant Professor, Department of Mechanical Engineering Maulana Azad National Institute of Technology, Bhopal, MP, India
3 Associate Professor, Department of Mechanical Engineering, Rewa Engineering College, Rewa, MP, India

Abstract
Adequate quality and reliability of drinking water supply is a fundamental need. Without potable water or drinking water (less than about 500 ppm of salt) human life is not possible. Only 1% of Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both diseases and toxic chemicals. For this reason, purification of water supplies is extremely important.

Keeping these things in mind, we have devised a model which will convert the saline ground water into pure and potable water using the renewable source of energy (i.e. solar energy). Solar energy is an abundant, never lasting, and available on site and pollution free energy.Solar Energy is freely available and can be used as a very cheap option to convert saline ground Water through Solar Distillation, by using Solar Stills. The conventional single basin and single slop Passive Solar Still can be used to purify water but the main problem is that the per square meter distillate output is less. So it is need to modify the design of solar still for high output of solar distillate

Solar still is easy to construct, can be done by local people from locally available materials, simple in operation by unskilled Personnel, no hard maintenance requirements and almost no operation cost. Simplest basin type models of solar still in earlier days, researchers have progressed a lot to increase its efficiency. Suitable modification of solar still can produce high output using minimum areas of land and even in cloudy days. Experimental study is done at Rewa M.P. on two different basin water depth solar stills. Low water depth solar water still is produced more distillate than high water depth still by the experiment.

Keywords: Solar still, saline Water, Evaporation, Basin Water and Solar Distillation.

I. Introduction

More than two-thirds of the earth’s surface is covered with water. Most of the available water is either present as seawater or icebergs in the Polar Regions. More than 97% of the earth’s water is salty; rest around 2.6% is fresh water. Less than 1% fresh water is within human reach. As the available fresh water is fixed on earth and its demand is increasing day by day due to increasing population and rapid advancement of industry, there is an essential and earnest need to get fresh water from the saline/brackish water present on or inside the earth. Fresh water from saline/ brackish water can be obtained using different water treatment processes.According to World Health Organization (WHO), the permissible limit of salinity in water is 500 ppm andfor special cases up to 1000 ppm while most of the water available on earth has the salinity up to 10,000 ppm whereas seawater normally has salinity in the range of35,000–45,000 ppm in the form of total dissolved salts. Excess brackishness causes the problem of taste, stomach problems and laxative effects. One of the control measures includes supply of water with total dissolved solids within permissible limits of 500 ppm or less. This is accomplished by several desalinationmethods like reverse osmosis, electro dialysis, vapourcompression, multistage flash distillation, multiple-effectdistillation and solar distillation, which are used for purification of water.

The Conventional method of producing fresh water is by burning fossil fuels. But this contributes to current energy crisis and environmental problems. Hence the need for non-conventional method in future seems necessary. Solar distillation is a process where solar energy is used to produce fresh water from saline or brackish water for drinking, domestic and other purposes. The basic principles of solar distillation are simple, solar energy heats the water, as the temperature of water increases, vaporization occurs at the surface of water and water starts evaporating. The evaporated vapors are condensed at the condensing surface (glass surface). This distillate obtained is free from impurities such as salts and heavy metals. The evaporation process also kills the micro-organisms, thus giving a portable drinking water. Thus, solar energy can be important way of meeting fresh water requirement in future in regions with high solar insolation.

Solar distillation appears as one of the best practical and the most economical, especially for mass production of fresh water from high saline water like seawater[1]. High energy cost of the evaporation process contributes most of the running expenditure in variousdistillation methods. The advantage of solar energy based small desalination plant is the requirement of small quantities of energy which is mostly collected from the sun. This should be the most economical solution to provide potable water tovillagers residing at remote areas where proper infrastructure is lacking. Solar distillation looks very attractive as it utilizes the free source of energy the heat from the sun.

II. Solar Still

Solar still is possibly the oldest method of desalination of water. Its principle of operation is the greenhouse effect; the radiation from the sun evaporates water inside a closed glass covered chamber at a temperature higher than the ambient. A schematic diagram of typical basin type solar still is shown in figure 1.

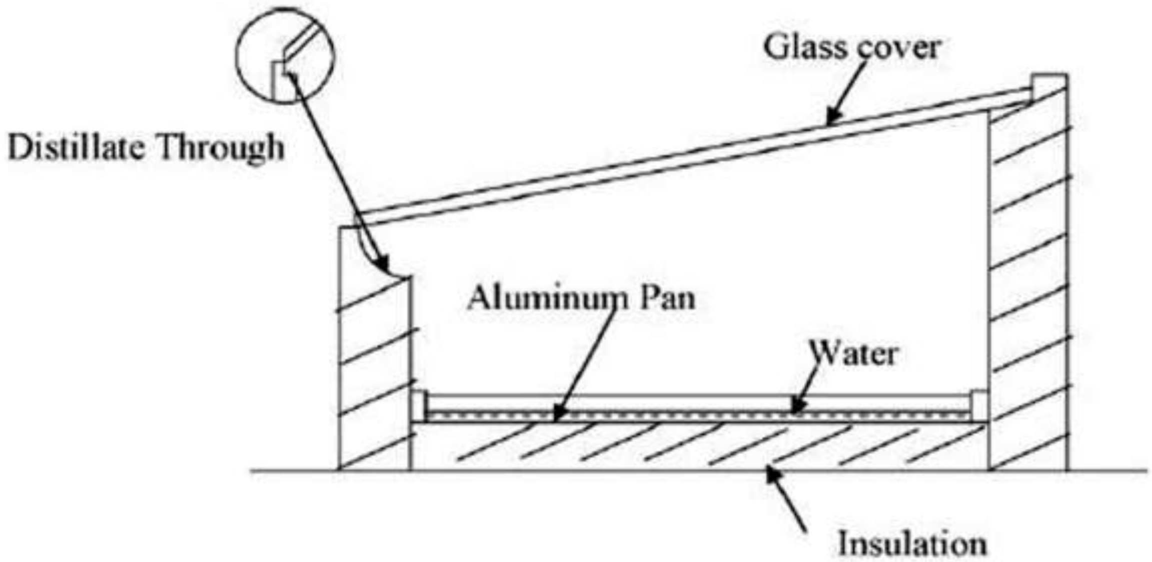

Figure 1: Schematic diagram of a simple solar still[2]

The saline water is fed on a black plate in the lower portion of the solar distiller. The heat of the sun causes the water to evaporate and water vapor condenses to form purely distilled droplets of water when it reaches the cool transparent leaning surface made of glass or plastic. The droplets slide down along the leaning surface and are collected through special channels located under the leaning surface.Solar still has a long history. The first documented use of solar stills was in the sixteenth century and, in1872, the Swedish engineer, Carlos Wilson, built large-scales solar still to supply a mining community in Chile with drinking water.

III. Classification of solar distillation

Solar still is mainly classified into to categories, passive distillation and active distillation systems [3] as shown in figure 2

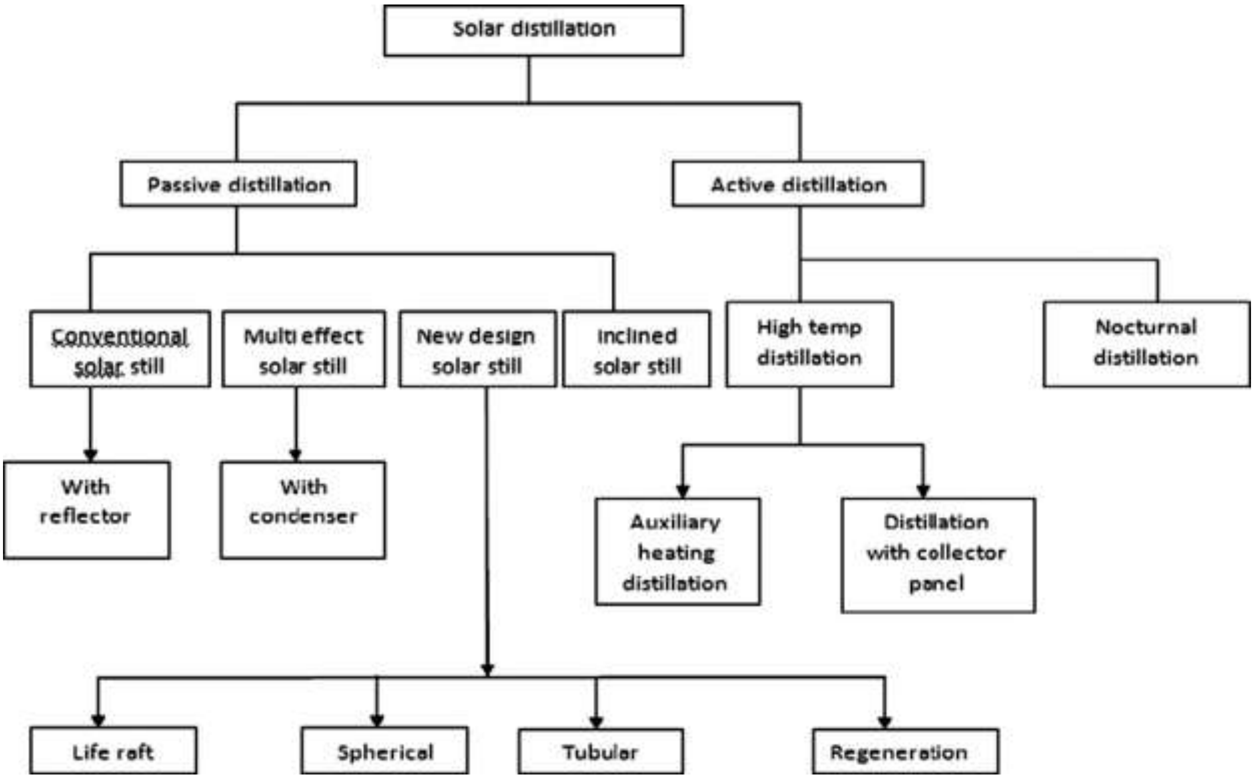

Figure : 2 Classification of Solar Distillation Systems

In passive distillation system, it does not employ an outside source of energy. The advantages of such solar distillers are their design simplicity, low installation cost, independent water production and simple maintenance. But they also have several disadvantages such as low efficiency and deposition of salt, scale and corrosion. In passive distillation system, the advanced solar stills prove more effective than conventional basin type one especially during winter and rainy seasons. One such example is coupled solar stills. A simple solar still assisted by an external solar collector shows increase in fresh water productivity with the increase in solar collector area of the assisting device. The net efficiency of the coupled system is higher than that of a similar simple still by a value that depends mainly on the system configuration and independent of the meteorological conditions [4].

In active solar distillation, an external source (such as a flat plate or concentrator collector) for additional thermal energy is used to increase the temperature of the saline water in the basin. This class is suitable for commercial production of distilled water. The external sources connected with the simple basin still are flat plate collector, concentric collector, hybrid PV/T system, heat exchanger, solar pond, multiple basins and additional condenser. Voropoulos et al. [5] experimentally investigated the conven- tional solar still coupled with a solar collector field and hot water storage tank. The results show significantly higher distilled water output compared with that of an uncoupled still.

4. Thermal modeling of solar still with the help of heat and mass transfer principal

Many research works have been reported in the literature on the experimental investigations to find a better design for solar desalination systems. Generally, the experimental researches are so costly and time consuming. Therefore, mathematical modeling may be the best alternative to find better designs and operational parameters for solar stills. Mathematical models or thermal models can be developed based on the energy balances for various components of the still. A solardistillationsystemcanbeefficiently designedforagiven capacity byusingthermalmodelingwithoutspendingmuchcostand time. Thermal modelscanhelptomake decisionsregardingshape, size, type,operatinganddesignparameters,etc.ofthedistillationunit for achievingmaximumdistillateoutputunderknowncircumstances. The simulationofthermalmodelswill behelpfultoinvestigatethe effects ofachangeincertainparameters duringthedesignstageitself. Theycanbesimulatedtoanyrealoridealconditions.

The heat and mass transfer relations governing the operation of a solar still in the steady state have been stated by Dunkle [6] to which a thermal storage term is added to allow for changing conditions. The still receives the

solar radiation at a rate of I per unit area of the glass cover. An amount α_g I is absorbed by the glass cover and τ_g I is transmitted through the cover whereas a small fraction of the radiation is reflected back to the ambient. Thus the energy input to the still is the part of the solar radiation α_g I absorbed by the glass cover plus $\alpha_w\tau_g I$ absorbed by the basin water. The basin water stores some energy, whilst the heat lost to the surrounding is through the glass cover and the base.
The energy balance in the solar still can be expressed as,

$$\alpha_g I + \alpha_w\tau_g I = q_{ga} + q_{bwa} + C_w\frac{dT_w}{dt} \quad (4.1)$$

The glass cover receives heat from the basin water and the incident radiation. The heat balance for the glass cover can be expressed as,

$$q_{ga} = q_{cwg} + q_{ewg} + q_{rwg} + \alpha_g I \quad (4.2)$$

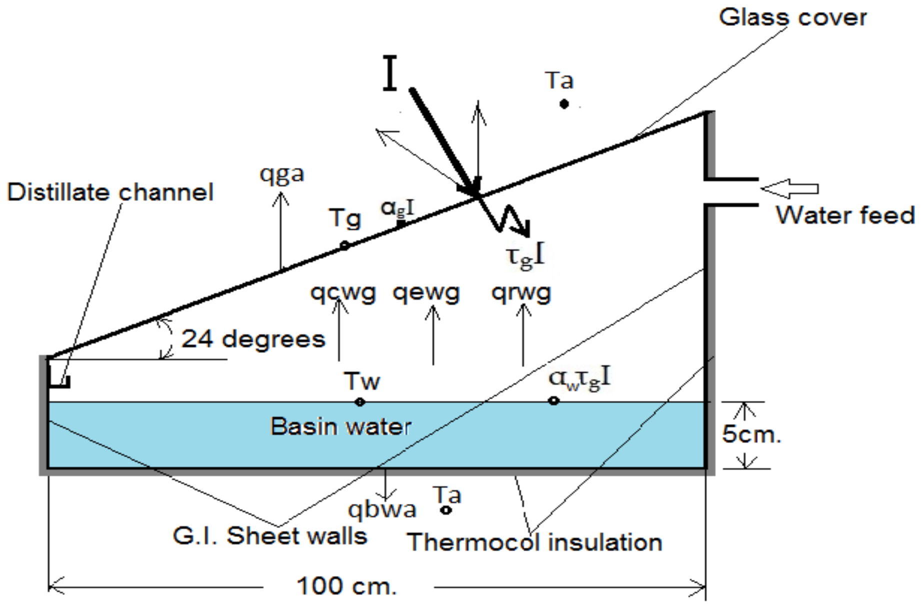

Figure : 3 Construction and energy transfer inside a solar still. [7]

Heat transfer from the basin water to the glass cover, occurs by the modes of convection, evaporation and radiation. The evaporation of water depends upon the evaporative heat transfer coefficient, which is dependent on the convective heat transfer coefficient between the evaporation surfaces and the glass cover. The convective heat transfer between the basin water and the glass cover can be calculated from the following expression:

$$q_{cwg} = h_{cwg}(T_w - T_g) \quad (4.3)$$

Where the convective heat transfer coefficient is calculated by an empirical relation, which is given by Dunkle[6]

$$h_{cwg} = 0.884\left[(T_w - T_g) + \frac{(P_w - P_g)T_w}{(268.9*10^3 - P_w)}\right]^{1/3} \quad (4.4)$$

The evaporative heat transfer between the basin water and the glass cover can be obtained from the relation,

$$q_{ewg} = 16.28\, h_{ewg}(T_w - T_g) \quad (4.5)$$

The radiative heat transfer between the basin water and the glass cover can be given as,

$$q_{rwg} = h_{rwg}(T_w - T_g) \quad (4.6)$$

where, the radiative heat transfer coefficient can be obtained by the relation,

$$h_{rwg} = 0.9\sigma(T^2_w + T^2_g)(T_w + T_g) \quad (4.7)$$

The amount of distillate per hour per square meter can be obtained from the relation,

$$m_w = \frac{q_{ewg}}{h_{fg}} \quad (4.8)$$

The efficiency of the still is given by the relation,

$$\eta = \frac{q_{ewg}\int dt}{I\int dt} \quad (4.9)$$

Figure : 4 Experimental view of the solar still

5. Experimental Set-up and Procedure:

The experimental study was conducted at city of Rewa M.P. (24°33' 20.81″N 81°18' 49.1″E). Two single sloped basin type solar stills ofthe same size were constructed of expanded polystyrene foam as shown in Fig. 4 with basin area of the stills about 0.5 m^2. The coverslope was given an angle of 24° which is nearly equal to the latitude angle of Rewa[8] since, very low cover inclination causes the distillatedroplets to fall back to the basin water, whereas large cover inclination increases the vapour length and the inside still air mass, resulting in delayed saturation of inside air and reduced output. Besides, glass cover with inclination equal to latitude angle, receives solar radiations normal to it for most parts of the year. Plane ordinary glass of 3 mm thickness was chosen for the glass cover. A PVC tube was fitted through the rear wall of the stills for feeding water for the basin. A small hole was also made on the rear wall for inserting thermocouple wires into the still. . The inner side of the basin was painted black to maximize the absorption of solar radiation.

The salinity of normalwater is <100 ppm. but, thewater available in Engineering college Rewa M.P. through underground borewell is saltywhose salinity is 1070 ppm and total dissolved solids(TDS)of around 1125 mg/l hence, they cannot be used for drinking purpose. In order to reduce the salinity and make them potable, solar desalination technology wasapplied. The total experimental setupwas arranged in away to face the south direction to receive themaximum solar radiation. A silicon rubber sealantwasused as the seal between the glass cover and the body of the still to prevent leakage of the evaporated vapor. The distillate water condensedfrom the glass cover was collected in the graduated glass bottles through channel.

Out of two stills, one still was kept five centimeter of basin water depth and another kept seven centimeter of basin water depth. After this, the different sets of experiments were started. Hourly variations of the solar intensity, ambient temperature, basin water temperature and the glass cover temperatures were recorded from 7A.M. to 5P.M. and then at 7A.M. on the next morning, thus covering a 24 hours duration. The basin water and the glass cover temperatures were measured with the help of copper-constantan thermocouples connected to a multichannel digital temperature indicator. A digital solar power meter was used to measure the solar intensity, whereas the ambient air temperature was measured with the help of a mercury thermometer. The distillate was collected in the graduated glass bottles. Both the stills were kept side by side with their glass covers facing south. The tests were conducted for two to three days

5. Results and discussion

Fig.5 shows the hourly variation of solar intensity and ambient air temperature for a clear day of the month of November. It can be seenthat the maximum ambient air temperature was reached around 15 h whereas the maximum solar intensity was reached around 12 noon.

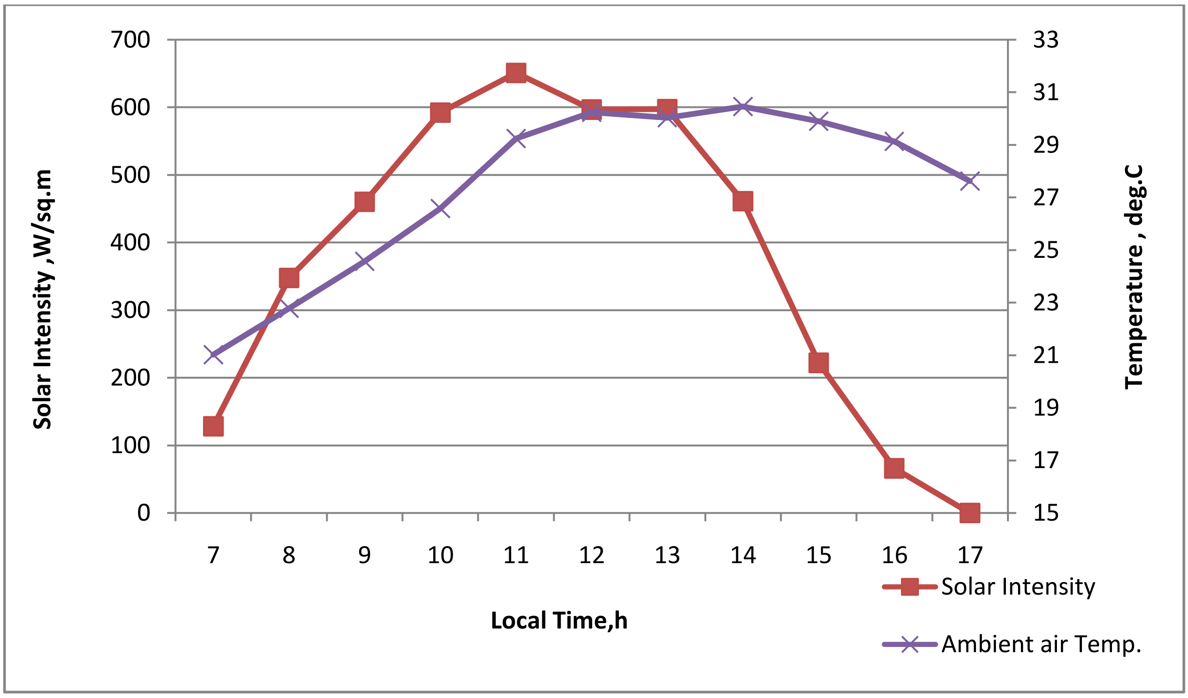

Figure : 5 Hourly Variation of Solar Intensity and ambient air temperature on a clear day

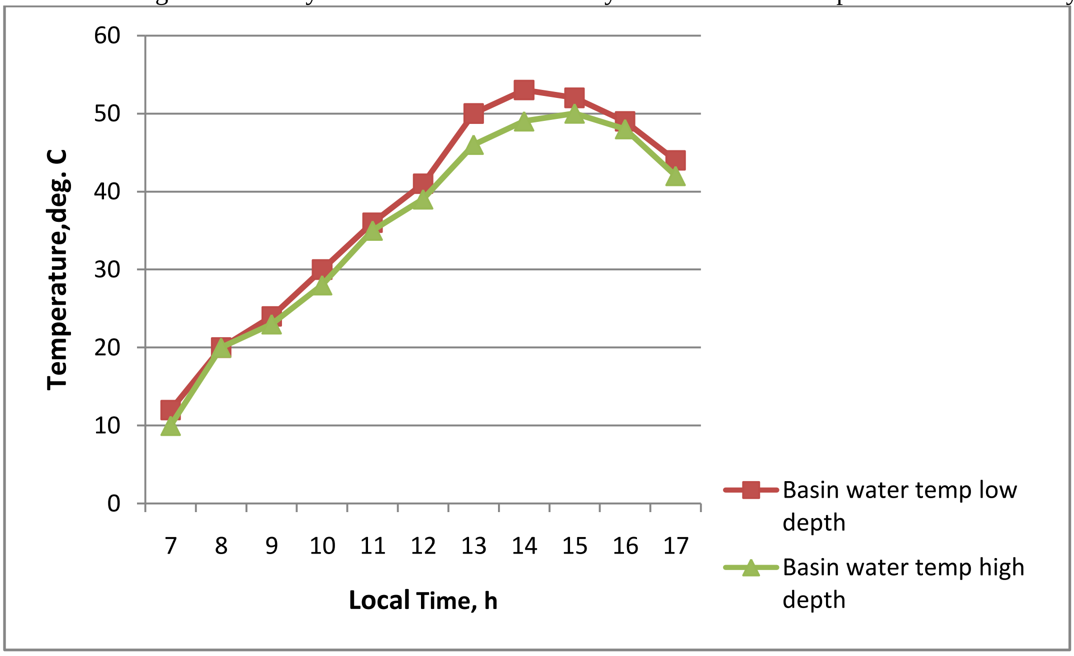

Figure : 6 Comparison of Basin water temperature for low water depth (5cm) and high water depth (7cm)

Fig. 6 shows the comparison of basin water temperature for low water depth (5cm) still and high water depth (7cm) still. It is observed that it starts in the early morning and at the end in the evening the basin water temperatures of both the stills match very closely, but the difference increases and attains maximum value in the afternoon. This difference in the time for the maximum values of solar radiation and that of basin water temperature is due to the higher thermal inertia of the basin water mass.

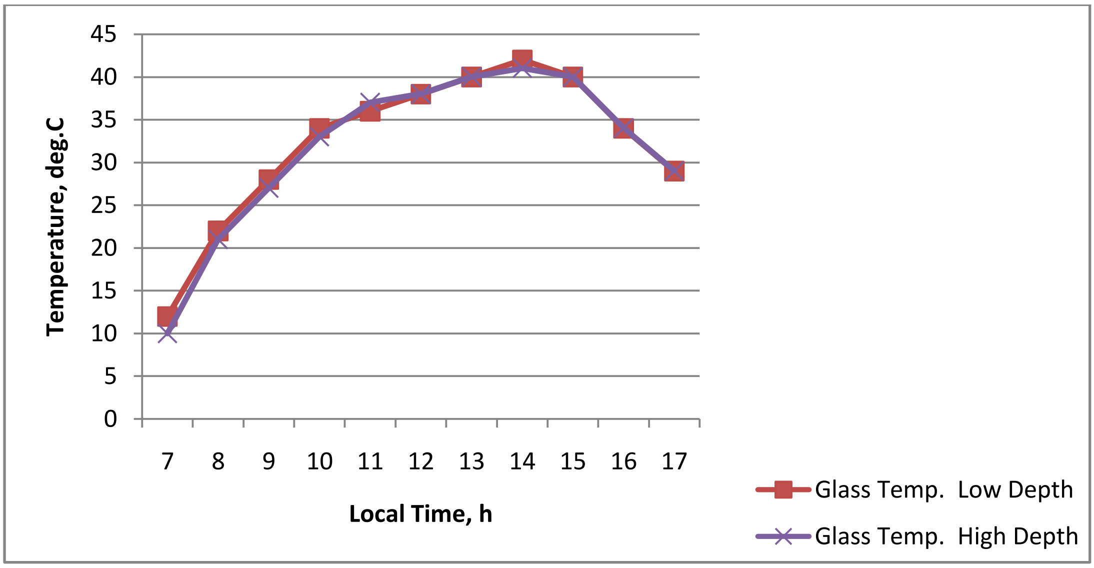

Figure : 7 Comparison of Glass temperature for low water depth (5cm) and high water depth (7cm)

Glass Temperature of low water depth solar still (5cm) and high water depth solar still are compared in the in the Fig. 7 it is observed that both the stills matched very closely and both attain the maximum temperature at 2.00 to 3.00 pm

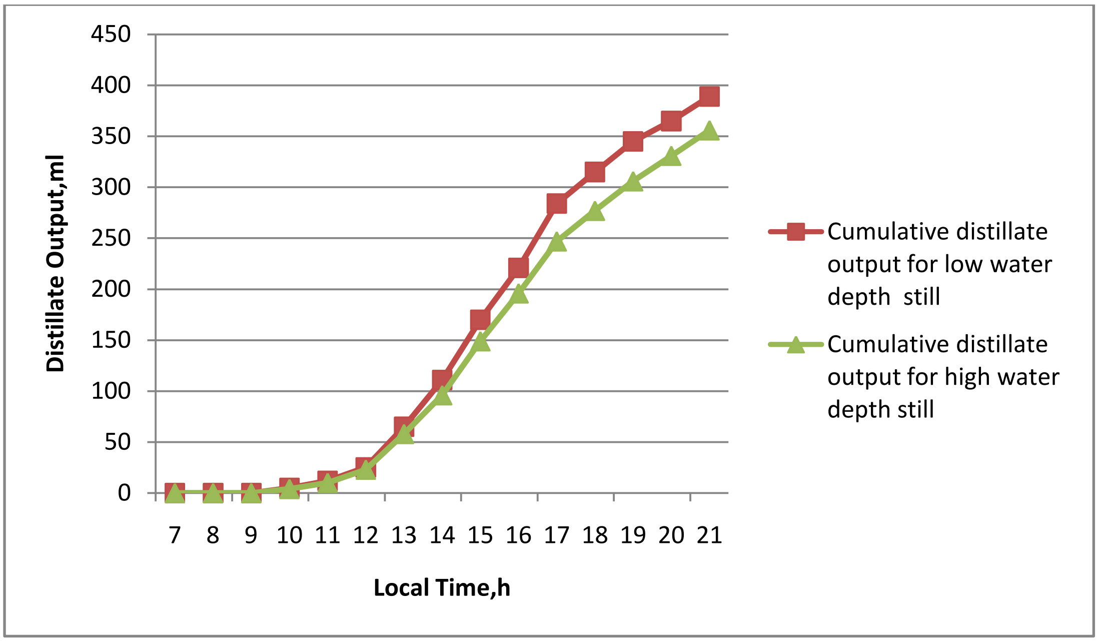

Figure : 8 Comparison of cumulative distillate for low water depth still and high water depth still

The cumulative distillate output of low water depth solar stillis about 10% to 15% more than that of high water depth solar still as shown in Fig. 8 which is mainly due to the higher value of evaporative surface temperature and lower value of condensing surface temperature, both leads to the rise in distillate output.

6. Conclusion

The low water depth solar still operates at higher temperatures as compared to high water depth still and since the temperature difference between basin water and glass cover is higher than that of the high water depth still, higher distillate output is obtained in the former.

Solar distillation can be a very economical option as the cost of the solar still can be recovered within a year of operation.

In the countries like India, where there are large parts of remote and rural areas with sufficiently high incident solar energy input. Solar distillation can be a feasible option for obtaining potable water.

Nomenclatures

h_{fg} Latent heat of vaporization of water, J/kg
h_{cwg} Convective heat transfer coefficient from basin water to glass cover, W/m^2K
h_{ewg} Evaporative heat transfer coefficient from basin water to glass cover, W/m^2K
h_{rwg} Radiative heat transfer coefficient from basin water to glass cover, W/m^2K
h_w Wind heat transfer coefficient, W/m^2K
I Solar Intensity, W/m^2
K_b Base heat loss coefficient, W/m^2K
m_w Distillate output rate, kg/m^2h
p_w Partial pressure of water vapour at temperature T_w, mm of mercury
p_g Partial pressure of water vapour at temperatureT_g, mm of mercury
T_g Glass cover temperature, K
T_w Basin water temperature, K
q_{cwg} Convective heat transfer from basin water to glass cover, W/m^2
q_{ewg} Evaporative heat transfer from basin water to glass cover, W/m^2
q_{rwg} Radiative heat transfer from basin water to glass cover, W/m^2

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