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Optimization of Condensing Cover on an Active Solar Still without Direct Radiation

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ABSTRACT

Scarcity of drinking water has been a major problem that most parts of this world are facing since years. Though many methods are there like electric water purifiers, they all are having very high initial and operational cost. Solar still is an exception for this. But, due to its lower yield, it is not yet commercialized. Most of those works to improve solar still efficiency and yield were given emphasize to improve the evaporation rate. But the condensation characteristics are also important. Condensing cover of the solar still and its inclination is one of such areas where detailed study is required. This research paper is intended to find the optimum inclination for the condensing cover for a solar still so as to get the maximum yield.

Introduction

Most of our earth surface is covered by water; however, less than 1% of total available water is fresh water which is mostly available in lakes, rivers and underground. Again, about one-third of that potential fresh water can only be used for human needs due to mixed factors [5]. The lack of potable water poses a big problem in arid regions of the world where freshwater is becoming very scarce and expensive. Clean drinking water is one of the most important international health issues today [6]. The global water crisis could reach unprecedented level in the years ahead with growing per capita scarcity of water in many parts of the developing world over the next 20 years, the average supply of water worldwide per person is expected to drop by a third water resources will steady decline because of population growth, pollution and expected climate change [4].The increasing world population growth together with the increasing industrial and agricultural activities all over the world contributes to the depletion and pollution of freshwater resources [2].

Desalination is one of mankind's earliest forms of water treatment, and it is still a popular treatment solution throughout the world today. In nature, solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the surface and is moved by the wind. Once this vapour cools down to its dew point, condensation occurs, and the freshwater comes down as rain. This basic process is responsible for the hydrologic cycle. This same principle is used in all man-made distillation systems using alternative sources of heating and cooling [1]. Distillation is an oldest technique to distillate brackish or salty water in to potable water. Various technologies were invented for desalination from time to time and it has been accepted by people without knowing future environmental consequences. Many developed countries have given utmost priority to rural water supply in their development plans. Large commercial desalination plants that use fossil fuels are in use in most of the countries suffering from water shortages. For instance, a number of oil-rich countries use fossil fuel to supplement the energy for water desalination supply. In contrast people in many other areas of the world have neither the financial nor oil resources to allow them to develop in a similar manner. The production of 1000 m3 per day of freshwater requires 10,000 tonnes of oil per year, which can be considered highly significant energy consumption [2].

Distillation of brackish or saline water, wherever it is available, is a good method to obtain fresh water. However, the conventional distillation processes such as Multi-effect evaporation, Multi stage flash evaporation, thin film distillation, reverse osmosis and electrolysis are energy intensive techniques, and are feasible for large stage water demands [2]. The alternative solution of this problem is solar distillation system. Solar still is a solar water distillation system which utilizes solar energy to purify water. It is very simple to construct, but due to its low productivity and efficiency it is not popularly used in the market. Solar still is working on solar radiation which is free of cost but it required more space. All the materials are easily available in the market and it doesn't require a high level skill for its maintenance. So many works are done to increase the simple solar still efficiency. Compared to passive solar still active solar still has higher productivity [2].

Solar Water Distillation

The most economical and easy way to accomplish desalination is by using a solar still. The solar still is a simple and sustainable water production method that has been in operation for many years. Its main limitation is the relatively low productivity compared to other desalination methods. This challenge has been the focus of intensive research with the objective of developing modified solar stills with higher productivities. A major concern while increasing productivity is nonetheless to maintain economic feasibility and simplicity in construction, maintenance and operation. Modified solar stills, which may include separate condensers, heat collectors, reflectors, sun-tracking devices and others often require extra space, are more complex and hence the increased productivity of the still may not compensate for the additional entailed costs of those proposed modifications [4].

Exhaust heat from power plants were also deployed as an alternative for running desalination systems. These are large

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desalination systems though. However, not all water demands are coupled with the need for additional electric power. Solar energy may be deployed to produce fresh water from the sea. This may be accomplished in a large system or in a simple basin-type solar desalination unit. On a practical basis, certain things ought to be taken into consideration while designing and operating a solar still. For instance, shallow basins require large expanse of land. This land has to be cleared and levelled in readiness for the installation of the still; obviously this attracts some additional cost. Oftentimes and because the water to be treated is salt water, salt crystals build up on the dry part of the basins. This can reduce the overall absorption area of the basin, thereby impacting negatively on the effective basin area.

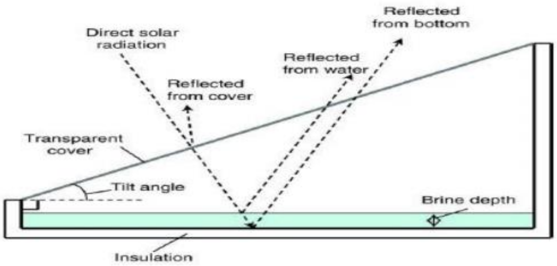

Figure 1. Schematic diagram of a basin-type solar still [2]

Leakage can cause distillate to leak back into the basin or even leak out of the basin [3]. It is equally necessary to flush the still basin on a regular basis so as to remove accumulated salts and microbes that might have grown in the brines. The use of algaecides might also be encouraged to control the growth of algae [2].

Many solar desalination systems were developed in years by using the above principle of solar still in the world. So many works done on solar still, on this work solar still is divided in two parts: (i) passive solar still, (ii) active solar still.

In a passive solar still, the solar radiation is received directly by the basin water and is the only source of energy to raise the water temperature and consequently, the evaporation leading to a lower productivity. This is the main drawback of a passive solar still.

Later, in order to resolve the problem of lower productivity, many research work will go on or done on the conventional (passive) solar still and active solar still. This review extends to thermal modelling of some conventional solar distillation systems, comparative studies of different solar stills, scope for further research and recommendation [7]. A variation in the glass cover angle of inclination should affect the dynamics of condensation and movement of the water along the inner surface of the cover [10].

Methodology

Major processes that are taking place inside a solar still are evaporation and condensation. This paper aims to find out the methods that will improve the yield from the solar still by increasing the rate of condensation. The possible methods are discussed below.

Condensation Enhancement Methods

There are several methods to improve the rate of condensation [7, 8]. Some of them are listed below:

Increase the temperature difference between vapour and condensing cover

As we know, the rate of heat transfer will increase according to the increase in temperature difference. To increase this temperature difference, cooling with water is a better solution.

Another solution is to avoid the direct radiation falling on the condensing cover. This direct radiation will increase the temperature of the cover and thereby decrease the output.

Optimise the cover angle so as to increase the condensate removal rate

An analysis on the optimisation is very much necessary as it will increase the rate of condensate removal from the cover. Sometimes at higher angles of the cover, it is difficult for the vapour to reach the height.

And if the angle is close enough to the water surface, it gets heated up quickly and will decrease the rate of condensation. Another problem in small angles is that the condensate may fall back to the basin itself as the slope is too small for its movement through the cover to outside tank.

Usage of material with higher heat transfer characteristics

In all conventional stills, glass was the material used so as to collect the solar radiation. But here the solar radiation is not considered and it is hard to cool the glass. Due to these factors, metal sheets were used in the preliminary study. But it made adverse effects because these metal sheets were getting heated quickly due to the vapour contact.

Increase dropwise condensation

Inorder to increase the dropwise condensation characteristics, surface smoothness is the main parameter. From the above factor, glass was fixed as the material for condensing cover too. So its surface finish cannot be increased.

Another solution is to use smoothening coating that can be applied to the condensing cover. But it is not possible in the case of solar still as it may contaminate the water which is to be distilled.

Mathematical modelling

The solar radiation is given into the still using some collectors or concentrators. Input heat provided by the reflector is given by,

$$Q_{in} = \eta A_r I \tag{1}$$

where A_r is the area of the collector, η is the efficiency of the collector and I is the amount of solar radiation that is incident on earth. Before convection to water, bottom plate will undergo conduction of input heat,

$$Q_{cond} = K_p A_p \frac{(T_{op}-T_{ip})}{x_p} \tag{2}$$

Here conduction equation is given by Fourier's law of heat conduction. K_p is the thermal conductivity, A_p is the area of the copper plate, T_{op} is the outside and T_{ip} is the inside temperatures of the copper plate and x_p is the thickness of the copper plate.

This heat, coming from the copper plate will be absorbed by water by convection from bottom plate,

$$Q_{abs} = h_{p_w} A_p (T_{ip} - T_w) \tag{3}$$

which is given by Newton's law of cooling where h_{p_w} is the heat transfer coefficient and T_w is the initial temperature of water. But these are general energy balance equations which when tested was not able to produce correct results.

Latent heat of vaporization is given by an empirical formula,

$$L_v = 4.18[883 - 0.668(T_w + 273)] \tag{4}$$

Hourly yield (mass flow rate) from the solar still is given by,

$$\dot{m}_{hourly} = \frac{Q_{eva} A_p}{L_v} x3600 \tag{5}$$

where Q_{eva} is the evaporative heat transfer that can be calculated by the equation,

$$Q_{eva} = h_{ev}(T_w - T_c) \quad (6)$$

where h_{ev} is the evaporative heat transfer coefficient and T_c is the temperature of the condensing cover. Evaporative heat transfer coefficient is also found out by empirical relation,

$$h_{ev} = 0.016273 h_c \frac{p_w - p_c}{T_w - T_c} \quad (7)$$

where h_c is the convective heat transfer coefficient, p_w and p_c are the partial pressures of water vapour at water interface and condensing cover interface which is given by,

Partial pressure of vapor on water interface,

$$p_w = \exp(25.317 - \frac{5144}{T_w + 273}) \quad (8)$$

Partial pressure of vapor on condensing cover interface,

$$p_c = \exp(25.317 - \frac{5144}{T_c + 273}) \quad (9)$$

Heat transfer coefficient at inclined flat plate surface is found out by theoretical method as,

$$h_{inclined} = 1.13 \left[\frac{\rho_l(\rho_l - \rho_v)k^3 g \sin\theta\, h_{fg}}{\mu L (t_{sat} - t_s)}\right]^{0.25} \quad (10)$$

It can be reduced into the equation,

$$h_{inclined} = h_c(\sin\theta)^{0.25} \quad (9)$$

So, it is assumed as, when the angle of the condensing cover is increased, and then rate of condensate removal is also increasing, thereby increasing yield. But the practical difficulty in this is that as the inclination is increasing beyond a limit, it is difficult for the vapor to rise to that height and condense. So in such cases vapor either try to escape through the sideways or will condense on the sidewalls. This convective heat transfer coefficient can be found by the following formula,

$$h_c = 0.88(\Delta T)^{1/3} \quad (10)$$

where,

$$\Delta T = \left[(T_w - T_c) + \frac{(p_w - p_c)(T_w + 273)}{(268900 - p_w)}\right] \quad (11)$$

Most of the theoretical predictions cannot be completely right as the solar radiation and its impact will vary. So, most of the mathematical equations are formed from frequent experimental analysis [14, 15, 16, 18].

Optimization of Angle of Condensing Cover

In the experiment carried out, direct solar radiation was not used. Instead a complete active solar still was considered. As the experiment was to find out the best angle corresponding to the maximum output, electric heating was used so as to keep steady input characteristics. In all the earlier methods, while considering the angle of the condensing cover of the solar still, direct radiation was also considered [9, 13]. As in this paper, direct solar radiation is not considering, instead the input heat is given by any active mechanisms such as collectors or concentrators.

Results

A solar still was constructed in the conventional design. The floor area of the still was 2 feet X 2 feet. Experiment was carried out at four different angles 25, 35, 45 and 55 degrees. The direct solar radiation was not considered. Instead, an active solar still was modelled which has only one source of input and that from the solar collectors. The output corresponding to each angle is shown below in table 1.

Table 1. Variation of mass flow rate from a solar still with the angle of the condensing cover (without cooling)

Angle of the condensing cover (degrees)	Yield from the solar still (L/day)
25°	0.6
35°	1.5
45°	0.9
55°	0.5

A heating mechanism was used that works on radiative heating. The constant input heat was fixed as 900W. From the graph shown below, it can be concluded that 35° is the optimized angle for the experiment conducted.

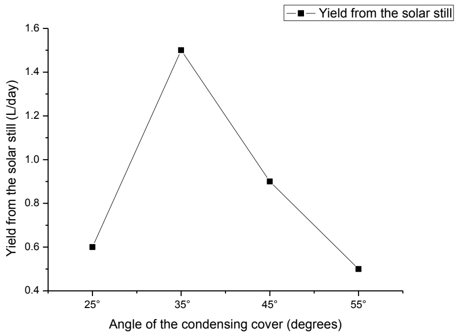

Figure 2. Plot between yields from a solar still with angle of the condensing cover

As the angle is increased further, the vapour is not reaching the condensing surface. Instead the vapour is condensing on the sidewalls. If the angle is decreased, the cover gets heated up easily and thereby decreasing the rate of condensation. Another disadvantage of the low angle is that the droplets are not moved easily though the cover to the collecting area due to low slope. So there is a tendency that the condensed droplets on the cover can fall back into the tank itself. These were the reasons to give an optimised result.

The effect of cooling was also studied. And the results are as shows in the table 2.

Table 2. Variation of mass flow rate from a solar still with the angle of the condensing cover (with cooling)

Angle of the condensing cover (degrees)	Yield from the solar still (L/day)
25°	0.8
35°	1.9
45°	1.2
55°	0.7

A separate cooling was provided for the still according to the requirement of the solar still at different times so as to minimise the temperature of the condensing cover to increase the yield. Here too, the angle 35° was found to be the optimised angle. But the output was increased by 25%.

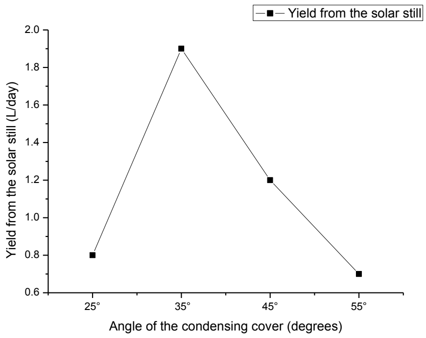

Figure 3. Plot between yields from a solar still with angle of the condensing cover (with cooling)

Conclusion

For studying the condensation characteristics, a solar still without using direct solar radiation was fabricated. The future of that active model is that it can avoid the radiation falling on the condensing glass which will in turn help to increase the rate of condensation. In such a still, if the direct solar radiation is not considered, then the optimized angle for better condensation rate is 35˚. This angle corresponds to higher rate of condensate removal from the surface of the condensing cover. An angle lesser than the optimum angle will have lower yield as the condensate will fall back into the tank, and at higher angles the vapour will not reach the condensing cover surface thereby reducing the rate of condensation.

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