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WATER DISTILLATION METHOD USING SOLAR POWER

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Abstract*- Distillation is a process that removes filths and contaminants to produce still water from available water. Numerous process is there to distill water; equipment based on solar energy is the clean & affordable. Solar distillation process begins with water vaporization after that the water condensate on cooler surface then this condensate water runs off to collection bin. There is some patent research on solar distillation. Basin type distillation system is discussed in this paper. A prototype design & parameters is untaken here on this basis.*

Keywords: Solar Distillation, Basin Type Still, Solar Insolation, Flat Plate Collector.

1. INTRODUCTION

Solar distillation has the advantage of cost saving over other types of distillation such as reverse osmosis, because solar energy is limitless and easily available and likewise seawater is readily available, there is an abundance of these sources. Solar distillation has proved to be highly effective in cleaning up water supplies to provide safe drinking water [1]. As energy requirement to produce 1 liter (i.e. 1kg since the density of water is 1kg/liter) of pure water by distilling brackish water requires a heat input of 2260kJ. Distillation considered only where there is no local source of fresh water [2]. In order to evaporate 1 kg of water at a temperature of 30°C about 2.4 × 106 J is required. Assuming an insolation of 250 W/m^2, averaged over 24 h, this energy could evaporate a maximum of 9 L/m2/day. In practice, heat losses will occur and the average daily yield, which might expected from a solar still, is 4–5 L/m2/day. Today’s state-of-the-art single-effect solar stills have an efficiency of about 30–40% [3]. This research work aims to build a theoretical model for active solar still and predict its output under the Bangladesh’s coastal area climate.

2. BASIC PRINCIPLE OF SOLAR STILL

The basic principles of solar water distillation are simple, yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. This process removes impurities, such as salts and heavy metals, and eliminates microbiological organisms. The end result is water cleaner than the purest rainwater [4].

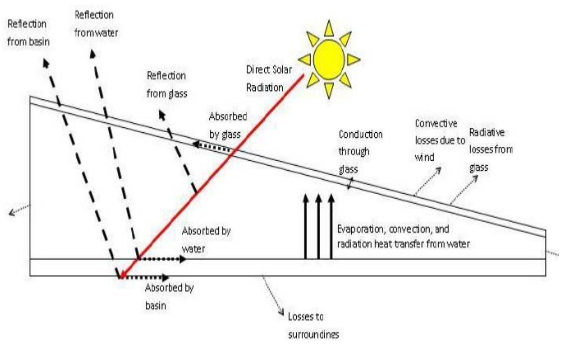

Fig.1: Simple water distillation process [4].

3. PATENT RESEARCH

Some patent research revealed numerous designs and ideas related to the use of solar power to distill water.

3.1 Solar collection system with radiation concentrated on heat absorber vanes

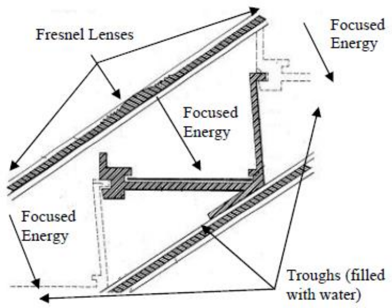

Fig.2: Fresnel lens for multiple effects (cross section) [5].

This patent contained a few key ideas such as the use of Fresnel lenses to increase the efficiency and overall production of the distiller by focusing the incoming radiation onto a trough of water. The second idea that this patent introduced was the use of individual water troughs instead of a large water basin in the distiller. At the base of the troughs were tightly spaced vanes that utilize the capillary action of water to increase the surface area of the water that is exposed to the incoming solar radiation, further increasing overall efficiency. By using troughs, the distiller is able to maximize available surface area and minimize water volume in the distiller. As shown in Figure 2 above, each trough has a Fresnel lens focusing energy onto the water [5].

3.2 Solar water distillation system

One elaborate patent available outlines the utilization of electrical power generation to aid in increasing the fresh water output. Using heat exchangers and a complicated water plumbing system (Figure 3), the phase changes from water to water vapor can be completed and maintained at a constant rate.

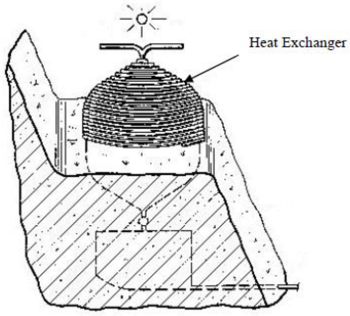

Fig.3: Complex Solar Distillation System [6].

Although this patent outlines a design that increases the overall water output of the system, the construction of heat exchangers, complicated plumbing, and electrical power generation lead to a device that is simply too expensive and impractical to be utilized in the areas that would require such a device [6].

3.3 High output solar distillation system

This patent describes a useful multiple effect system. The term “multiple effects” refers to a system designed in such a way that evaporated water from one surface condenses on the bottom of another surface and subsequently transfers thermal energy to the second surface, which also contains evaporating water.

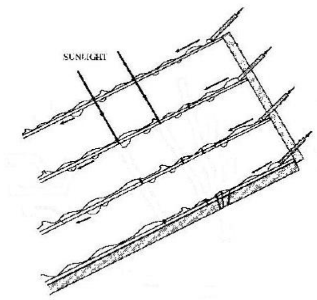

Fig.4 : Multiple effects wicking system [7].

The design uses an inclined wicking system in an enclosed area, similar to a basic distiller, to supply a constant feed of water through the still. The saturated wick allows for some of the feed water to vaporize for condensate and the rest of the feed water run out of the distiller as hot water. Figure 4 shows the multiple wicks absorbing solar radiation. The design is simple, cost effective, but less efficient as it does not convert all of the feed water to distilled water [7].

3.4 Single basin wicking system

This device uses a more traditional single basin design, but again uses a water wicking system. The wick system maintains a constant feed rate that can be predetermined based on the wick size.

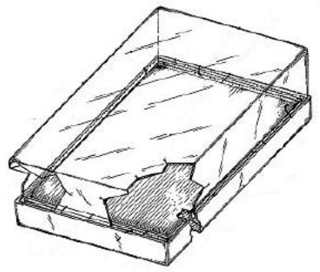

Fig.5: Single Basin Wicking System [8].

It also introduces the idea of preheating the feed water to increase efficiency, and creating a vapor circulation system inside the distiller to further increase efficiency. However, as with all wicking systems, the ability to clean the still effectively is compromised because each of the wicks would have to be cleaned with water at the end of each day of use. Refer to Figure 5 [8].

4. THEORITICAL ANALYSIS

The first step in the design process was to develop and analyze the thermal circuit for a simple asymmetrical solar distiller. The simplified thermal circuit that was developed is shown in Figure 6. This thermal circuit models the convection, conduction, and radiation of energy throughout the device, as well as the evaporation and condensation processes. The energy balance shown below along with pertinent definitions.

Assumptions:

- Temperature difference between one sides of the glass to the other is negligible
- Temperature difference between Tw and the basin is negligible
- There is no heat loss through the sidewalls
- Tw is uniform
- No vapor leakage
- $q_{evap} = q_{cond}$

Equation 1: at node T_w

$$q_{solar} = q_{evap} + k_{ins} A \frac{(T_w - T_\infty)}{l_{ins}} + h_w A (T_w - T_{air}) + A\varepsilon\sigma(T_w^4 - T_g^4)$$

………………………………………………………. (1)

Equation 2: at node T_{air}

$$h_w A(T_w - T_{air}) = h_g A(T_{air} - T_g) \text{ ....} \quad (2)$$

Equation 3: at node T_g

$$A_g \varepsilon\sigma (T_g^4 - T_\infty^4) + A_g (T_\infty - T_g) = q_{cond} + h_g A_g (T_{air} - T_g) + A_g \varepsilon\sigma (T_g^4 - T_\infty^4) \text{ ....} \quad (3)$$

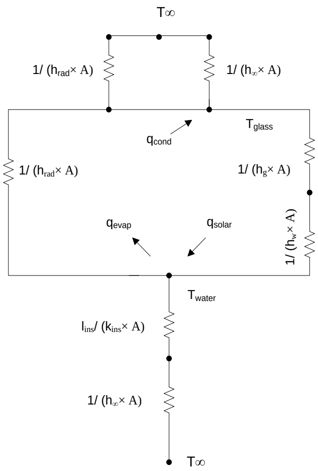

Fig.6: Simple thermal circuit [9].

The solar collector was designed by considering latitude of Dhaka 23.7° N and temperature in summer on average. In the month of January, the average solar insolation is 4.21 Kwh/m2/day for Dhaka, Bangladesh. Optimum slope of collector for summer calculated using angle of solar declination (δ) as shown in Equation (4), number of days, latitude at test site, and angle of incidence from the following equation [10]. The numeric sign (positive/ negative) of (β) will indicate the face direction of solar distillation device.

$$\delta = 23.45 \sin [0.9863 (284 + n)] \text{ ....} \quad (4)$$
$$= -21.75^{o}$$

Where, n = Number of days = January 12. Slope of collector (β) is calculated by using the Equation (2):

$$\beta = (\Phi - \delta) \text{ ....} \quad (5)$$
$$= (23.7 - (-21.75))$$
$$= 45.5°$$

Here, Φ = Latitude at test site, = 23.7° N
Positive value of β = Collector should be south facing.
In the prototype design, the glass slope is 24 degree based on the latitude of Dhaka. Instantaneous insolation on the surface was approximately proportional to the cosine of angle of incidence (θ). The angle of incidence for insolation falling on south facing roof at midday can be calculated by using following equation (6) [10].

$$\cos\theta = \sin\delta . \sin\Phi . \cos\beta - \sin\delta . \cos\Phi . \sin\beta . \cos r + \cos\delta . \cos\Phi . \cos\beta . \cos\omega + \cos\delta . \sin\Phi \sin s \cos\omega + \cos\delta . \sin\beta . \sin r . \sin\omega \text{ ....} \quad (6)$$

Where, δ = Angle of incidence; Φ = Latitude of the test; β = Slope of collector, and r = Surface azimuth angle; for structure, this can be considered as its orientation with respect to a north south axis. The angle varies from -180° to +180°; zero is due to south, east is negative and west is positive. The value of r = 0 was used for the present calculation. ω = the hour angle, which is the angular displacement at the sun east or west. It is zero at a solar noon, changes 15°/h. Morning is negative, and afternoon is positive. ω = 0 is used for the present calculation. The following Equation (7) was used to determine the intensity of insolation on collector surface (Ic),

$$Ic = Ih \times \cos\theta \text{ ....} \quad (7)$$

For a horizontal surface, since β = 0 and hence, Cos β = 1 and Sin β = 0.

$$\text{Now, } \cos\theta h = \sin\delta . \sin\Phi + \cos\delta . \cos\Phi . \cos\omega \text{ ...} \quad (8)$$

Where, Cos θh = cosine of angle of beam radiation on horizontal surface. Hence, level of insolation on sloping surface is calculated by following Equation ():

$$Is = Ih \times \cos\theta / \cos\theta h \text{ ....} \quad (9)$$

Where, Ih = intensity of insolation on horizontal surface, W/m2; Cosθ = Cosine of angle of incidence (θ) or angle between the beam radiation on surface and normal to surface. The Distillation efficiency by using Equation (9),

$$\eta_{dist} = \frac{Q_e}{Q_t} \text{ ....} \quad (10)$$

Where, Qe = Heat required, kWh, and Qt = Heat available, kW-hr [11].

5. DESIGN OF SOLAR STILL

The prototype of solar powered still is made of inexpensive materials. The operation of this device is simple. The different feature of this device is unique. Feature such as modular design and water depth regulating system is notable.

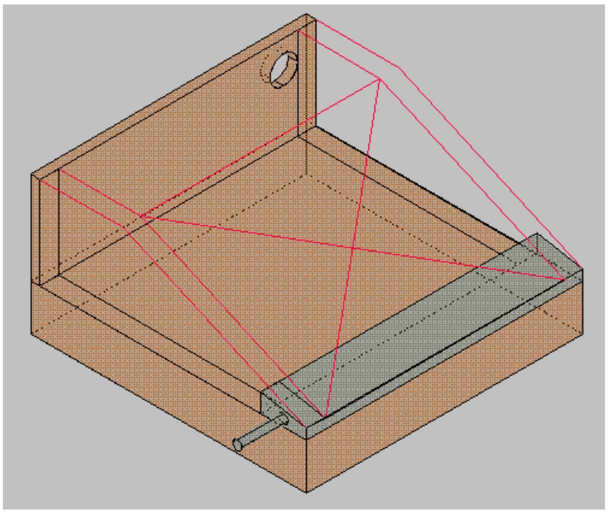

Fig.7: Schematic diagram of solar distillation device.

The first section of solar still device is basin area, it is where the solar radiation is being absorbed to produce heat. The area of the basin depends on the desired output.

Usually it is recommended to produce 2 to 4 gallon of water. To calculate the basin size a thermal circuit was developed (refer to Section 4).

5.1 Basin Features

In order to increase the efficiency as well as output, specific feature were added to the device. The basin is incorporated with a molded thermostat tray. Slots are made such as it goes through the tray. Each slots have equal interval (Figure 8). The advantage of this kind of design is that it permits maximum surface area with minimum volume of water, allows smaller body of water to heat up much quicker. The optimal water depth is 2 cm [12]. Consequently, common solar radiation will be absorbed by water within first 2 cm. The remaining will slowly evaporate. The water regulation is done by a float valve.

Fig. 8: Basin Tray [9].

The valve maintains the water level 1.5 cm throughout the day. The slat residue left over the basin tray after end of each day. The residue could wiped by a damp cloth or sponge.

5.2 Input design

The water inlet system of the distiller integrated with a fill tank. The back wall of the device is moveable. It is attached by hinges, which could seal or shut down by latches. Before beginning of the operation the back wall is opened and half filled with seawater or polluted water. Then the input tank capacity of 2 gallons, affixed with float valve is inserted through the perforated (Figure 7) back wall. The basin water maintained to 1.5 cm depth by the regulative float valve. Natural gravity provides flow of water form input tank throughout the day. For this reason the input tank is kept above the basin water level. The water in preheated in the input tank because it is painted with red color. The usual value of emissivity of the red color is $.84 \leq \varepsilon \leq .95$. The feed water is heated to $T\infty$ (the outside temperature) while left in the hot sun [9].

5.3 Float valve

The float valve mentioned in the previous section is made on stainless steel rod. One side of this rod is attached to off- the- shelf stainless valve of ½”, the other end to a plastic float. This floating mechanism controls the depth of feed water [9].

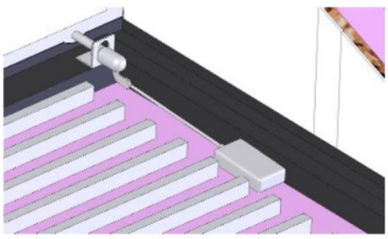

Fig. 9: Float Valve [9].

5.4 Collector slope design

The collector glass slope depends on the test site latitude. As a result the slope angle is 24 degree. The slope should steep enough to receive maximum solar radiation, it also allows the condensate to run down to the collection assembly. The glass panel size is 30”×36” or 0.697 square meter. The thickness of the glass is 0.125” [9].

5.5 Collection mechanism

A chrome channel was fitted under the lower side of the glass cover to collect the condensed water. The channel was ended with a small plastic pipe in order to drain the fresh water into external vessel. The glass was mounted at an angle of 24 degree to the solar still to ensure that the condensate will run down the glass in the condensate-collecting channel.

5.6 Output tank

An output tank capacity of 5 gallons is used as external vessel. The vessel is moveable. The whole device is mounted on a table like structure. The vessel is attached to the bottom of the structure. That will keep the vessel water from absorbing solar radiation [9].

5.7 Design overview

The overall summary of the distillation device is that, the inclined surface allows the sun energy to enter the device. The basin area is well insulated. So, it reduces the heat loss. The back wall of the device, incorporated with reflecting mechanism. All radiation guided towards the basin for this system. The smaller bodies of water heated up and vaporize from basin. The evaporate water then condensate onto cooler glass surface. The float valve regulates the water level of basin [9]. The glass inclined at an angle of 24 degree to the solar still to ensure that the condensate will run down the glass in the condensate-collecting channel. Finally, water is feed into external vessel.

6. OUTPUT OF SOLAR STILL

The production of the distill water depends on the level of water in the basin and to the solar radiation. There is an inverse relationship between water level of the basin and solar radiation. As the radiation increases the production rate also increases [12]. The daily production of solar still depends upon the ratio of water vaporization energy and the latent heat of vaporization. An approximate method to calculate the solar still output is given by [13],

$$M_{out} = \frac{\eta_{overall} \times G \times A}{\Delta h_v} \quad \text{..............................} \quad (11)$$

Feni is situated at coastal line along the Bay of Bengal. Monthly average daily solar radiation of Feni is 4.518 kwh/m2/day [14]. By using equation 11, monthly average output is predicted for the prototype distillation device described in section 5.

Here, area of the basin, A = 0.697 m2 (square meter); Enthalpy of vaporization (water), Δh_v = 2.257 MJ/Kg; Typical overall efficiency of solar still [3], $\eta_{overall}$ = 30%; Global Radiation G = 4.518/m2/day = 16.26 MJ/m2/day.

So, from equation 11 the expected output is M_{out} = 1.5 liters per day (weight of 1Kg pure water is 1 Liter).

The (Table 1) illustrate the predicted output of each month for the coastal region area of Feni, with respect to global radiation [14] of that area.

Table 1: Predicted output of solar still for costal area Feni

Month	Global Radiation (MJ/m2/day)	Output (liter)
January	16.596	1.54
February	17.82	1.65
March	18.864	1.75
April	21.276	1.97
May	18	1.67
June	13.716	1.27
July	14.4	1.33
August	14.184	1.31
September	13.896	1.29
October	15.228	1.41
November	15.948	1.48
December	15.408	1.43

7. CONCLUSION

The development of solar powered water distillation has demanded the need of efficient operation to maximize the efficiency. This paper investigates the optimization of different parameter of distillation process, both time and cost cloud minimize. In this paper, basin type water distillation system is discussed. An experimental prototype is presented to evaluate individual factor that affect the performance of water distillation. To begin with, an elementary principle of water distillation is labeled. Some patent model of distillation is presented by focusing the cost and effectiveness towards water purification. After that, a theoretical analysis of an asymmetrical solar distiller is presented. The theoretical analysis is divided into two different categories. At first, the thermal circuit has illustrated to demonstrate the mathematical equation of conduction, convection and radiation process. Also the basin size is calculated through this. Next, by calculating the slope of collector the optimal direction was predicted. Finally, the proposed prototyped design of water distillation system is presented. A schematic structure diagram is depicted with different component that further discussed in detail. Finally, predicted output from prototype device is presented in a table. According to this maximum output is possible in the month of March and April.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T_{water}	Temperature of the water in the basin	Kelvin (K)
T_{glass}	Temperature of the glass surface above the basin	Kelvin (K)
T_{air}	Temperature of the air between the water and glass	Kelvin (K)
T_{∞}	Ambient temperature around the solar still	Kelvin (K)
q_{solar}	Solar energy entering the system	Watt (W)
q_{evap}	Energy required to evaporate a given amount of water	Watt (W)
q_{cond}	Energy required to condense a given amount of water	Watt (W)
A	Area of the basin	m2
A_g	Area of the glass	m2
k_{ins}	Thermal conductivity of insulation	
l_{ins}	Length of insulation	

h_∞	heat transfer coefficient for convection from T_g to T_∞	W/(m2 K)
h_g	heat transfer coefficient for convection from T_{air} to T_g	W/(m2 K)
h_w	heat transfer coefficient for convection from T_w to T_{air}	W/(m2 K)
σ	Stefan-Boltzmann Constant	W/(m2 K4)
ε	Emissivity of glass	
δ	Solar declination Angle	(º) Degree
β	Slope of collector	(º) Degree
Φ	Latitude	(º) Degree
ω	Hour Angle	(º) Degree
Qe	Heat required	kWh
Qt	Heat available	kW-hr
Ih	intensity of insolation on horizontal surface	W/m2
A	Area of the basin	m2
Δh_v	Enthalpy of vaporization	MJ/Kg
$\eta_{overall}$	Overall Efficiency of Solar Still	
G	Global Radiation	MJ/m2/day
M_{out}	Water Output	Liter