Experimental Investigation of Solar Concentrating Still

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Abstract : Solar energy concentration technology is an approach of using sunlight effectively. This paper depicts the information about concentrated solar energy application using Fresnel lens. Having the assets of compact volume, less weight, minimal focal length and low cost, Fresnel lenses are applicable for solar radiation concentration. An experimental investigation is done on solar still using Fresnel lens for attaining distill pure water without any conventional energy. Fresnel lens is integrated for enhancing the solar insolation to the still. The inclination of solar distillation unit has been done on the basis of recent studies. Finally the influence of using Fresnel lens is encapsulated.

Key Words -Fresnel lens, Solar concentrator, Solar collector, Solar still, Solar distillation, Solar insolation.

1. INTRODUCTION

1.1 SOLAR STILL

More than two-third 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. A very large-scale process of solar distillation naturally produces fresh water [1]. As population of this planet has rapidly grown, we have increasingly tapped deeper into our planets fresh water resources. The trend of population growth is quite obvious. The availability of water in sufficient quantities and quality is a challenge of significant importance in many regions as it is scarce and unevenly distributed resource. Water scarcity is a function of supply and demand and an indicator of the gap between them [2].

Supplying drinking water to rural populations can be achieved by solar distillation of brackish and saline water available generally. If solar distillation is performed at elevated temperatures over those commonly employed, distillate output can be enhanced and levels of bacteria present in contaminated water sources may also be further reduced [3]. Solar desalination is a process of separation of pure water from saline or sea water using solar energy. The use of solar still is a simple and cheap method to obtain clean water [4]. Solar stills are simple in design and consist mainly of a blackened tray holding some water in it which is covered with a transparent sheet, preferably of glass. However the internal heat and mass transfer process which is finally responsible for the still productivity is complex. This process is affected by climatic parameters such as solar radiation, ambient air temperature, wind speed, atmospheric humidity, sky conditions, etc. and design parameters such as thermo physical properties of the material used in its construction, orientation of the still, inclination of the glass cover spacing between the water surface and the transparent cover, number of glazing's, insulation of the base, vapour tightness, etc. and the operating parameters such as water depth in the tray, absorptance transmittance properties of the still, initial temperature of the water, etc[5].

1.2 FRESNEL LENS

Solar radiation is concentrated by reflection or refraction through mirrors or lenses. The mirrors can be plane, called heliostats, or parabolic; the lenses can be simple lenses or Fresnel lenses (FL). Concentrators are used to improve the solar energy caption in specific applications. In 1748 Georges- Louis Leclerc had the idea of reducing lens weight and size acting on the lens surface, but it was a French mathematician and physicist, Augustin-Jean Fresnel, who built, in 1820 the first lighthouse using Leclerc's design [6,7]. A Fresnel lens can capture more oblique light from a light source. Plastic Fresnel lenses are used as magnifiers when a thin, light lens is needed. Fresnel lens is moulded into many circular, concentric ridges. A lens, then, can be considered as a series of prisms of increasing apex angle as one move away from the optical center of the surface. Fresnel lenses are designed in variable forms to meet the requirements of solar concentrators, such as a convex linear Fresnel lens (Nelson et al 1975, Kritchman et al 1979), a flat linear Fresnel lens (Khalil et al 1998), a point focus Fresnel lens (Whitfield et al 1999) etc[8-10].

As from the above literature review, there is a huge scope for increasing the efficiency of a solar still. Hence distillation integrated with the non imaging Fresnel lens yields higher efficiency of solar still.

2. DESIGN AND FABRICATION

The design illustrated in the figure1,2 consists of a standard solar still basin fabricated from wood of dimensions 1 meter length and 0.63 meter width , a 28^{o} slope of condensing surface i.e. glass cover was obtained by the height of back and front walls being 0.43 and 0.1 meters respectively. A semi cylindrical channel for water drainage is attached across the top side of front wall of basin. A thin aluminium sheet is formed to a length of 0.95 meters, width of 0.58 meters and 0.32 meters height and is fixed inside the still basin and coated with black.

A Fresnel lens of length 1.4 meters, width 1.09 meters, a focal length of 2 meters and radius of focal point being 0.08 meters is fixed to a wooden frame and is placed above the still basin for receiving the solar radiation with the help of a telescopic iron stand. Holes are drilled for the stand for the height adjustment according to the focal point for maximum solar insolation. The properties of the Fresnel lens are given in table-1.

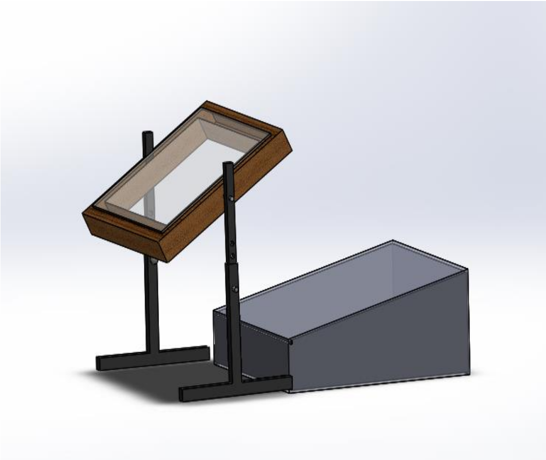


Fig-1: Solid works design of the experimentation

Fig-2: Experimental setup

Table-1: Properties of polycarbonate Fresnel lens

Index of refraction	Reflectivity	Absorptivity	Transmissivity	Tensile modulus (10^3 PSI)	Flexural modulus (10^3 PSI)	Hardness	Thermal expansion (10^{-6}/°C)	Specific gravity
1.586	0.002	0.08	0.9	345	340	M70-M72 (Rockwell)	68	1.2

3. THEORETICAL SIMULATION

In solar distillation, there are basically three modes of heat transfer namely Radiation (Q_{rw}), Convection (Q_{cw}) and evaporation (Q_{ew}) from water surface to glass cover.

The rate of heat transfer per unit area from water surface to glass cover by convection in upward direction through humid fluid can be estimated by

$$Q_{cw} = h_{cw}(T_w - T_g)$$

Dunkle (1961) derived the following expression for convective heat transfer coefficient as,

$$h_{cw} = 0.884\left[\left(T_w - T_g\right) + \frac{(P_w - P_g)(T_w + 273)}{268.9\times10^3 - P_w}\right]^{1/3}$$

Where $P_w = \exp\left[25.317 - \frac{5144}{T_w + 273.15}\right]$

$P_g = \exp\left[25.317 - \frac{5144}{T_g + 273.15}\right]$

The rate of heat transfer per unit area from water surface to glass cover through evaporation is given as,

$$Q_{ew} = h_{ew}(T_w - T_g)$$

where $h_{ew} = (16.273 \times 10^{-3})\ h_{cw} \frac{(P_w - P_g)}{(T_w - T_g)}$

The radiative heat transfer per unit area between water surface and glass cover is given as,

$$Q_{rw} = h_{rw}(T_w - T_g)$$

The radiative heat transfer coefficient is given as,

$$h_{rw} = \varepsilon_{eff}\ \sigma[(T_w + 273)^2 + (T_g + 273)^2](Tw + T_g + 546)$$

Where $\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1}$

The hourly yield per m^2 area from the solar still basin can be evaluated by using the expression

$$m_w = \frac{Q_{ew}\times3600}{h_{fg}}$$

Solar intensity through Fresnel lens is calculated as

$$I_L \times A_L = I_F \times A_F$$

External Heat Transfer for the Still

Heat loss due to conduction and convection for top glass cover is given by

$$Q_{cg\text{-}a} = \frac{T_g - T_a}{\frac{1}{h_{cb}} + \frac{L_g}{K_g}}$$

The convective heat transfer coefficient between glass and air is given by

$h_{cb} = 5.7 + 3.8v$

Heat loss due to radiation in the still is given as

$$Q_r = \frac{\sigma A_{co} (T_w^4 - T_g^4)}{\frac{1}{\varepsilon_c} + \frac{A_{co}}{A_g}(\frac{1}{\varepsilon_g} - 1)}$$

Heat loss from base and sides is given by

$$Q_b = \frac{T_w - T_a}{\frac{L_{wo}}{K_{wo}} + \frac{1}{h_{cb}}}$$

$Q_s = U_s (T_w - T_a)$

$U_s = (A_s/A_{co})U_b$

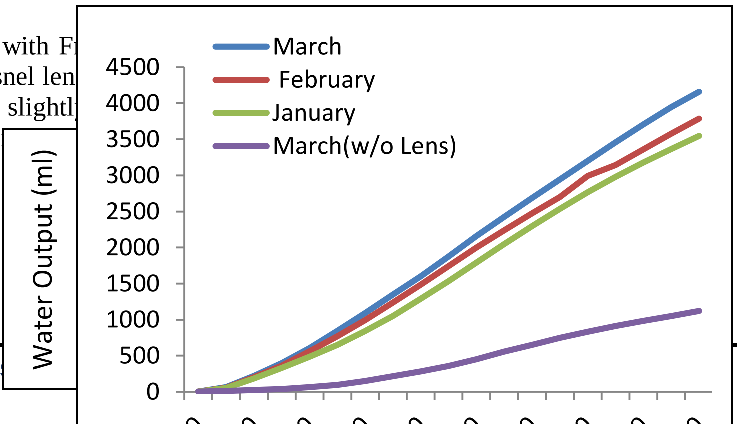
4. RESULTS AND DISCUSSION

The experimental work was carried out on the roof top of, Mechanical Engineering department, MVSR Engineering College (17.2818^0 N, 78.5385^0 E). In conventional solar still, experiments were conducted for different quantities of water, different angles of stills to get the optimum output quantity of water. From this experiment it was found that the conventional still with 6 liters of water integrated with the Fresnel lens gave maximum daily still yield. To evaluate the performance of the solar still with the Fresnel lens experiment was conducted and various parameters were observed such as temperature of water, temperature of glass cover, wind speed, humidity, and angle of lens and output yield for every 30 minutes. Experimental observations were recorded as per given in table 2.

Table-2: Experimental observations of solar still with Fresnel lens

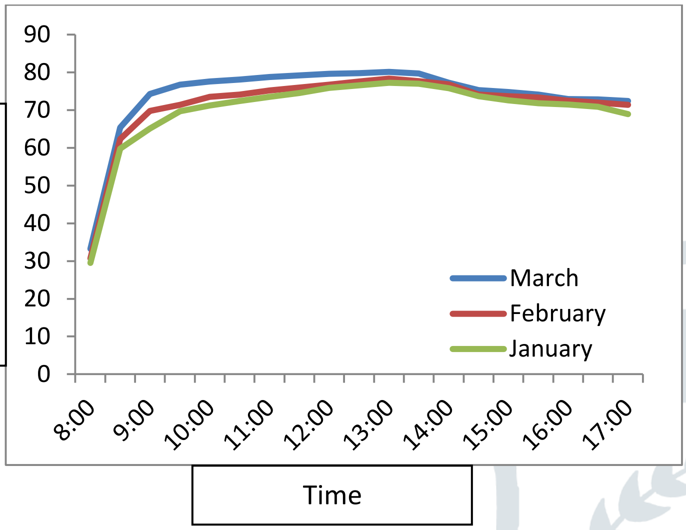
Time	Basin water Temp(°C)	Glass cover temp(°C)	Ambient temp(°C)	Wind speed (Km/hr)	Humidity (%)	Angle of lens(Degrees)	Water Output(ml)
8:00	33.2	29.7	32	7.8	53	70	0
8:30	65.4	58.2	32	7.9	51	62	65
9:00	74.3	65.9	33	8.4	49	56	218
9:30	76.7	67.7	34	8.8	49	47	396
10:00	77.6	69.2	36	9.3	48	39	604
10:30	78.1	71.3	36	9.3	45	33	844
11:00	78.8	71.8	37	9.3	42	25	1088
11:30	79.2	72.1	37	9.3	40	18	1345
12:00	79.6	72.4	37	9.3	35	10	1600
12:30	79.8	72.9	38	9.3	33	5	1873
13:00	80.1	72.7	40	9.4	29	13	2158
13:30	79.7	71.6	39	9.4	28	20	2426
14:00	77.2	70.3	39	9.4	28	28	2688
14:30	75.3	66.9	38	9.4	27	35	2945
15:00	74.8	66	37	8.8	26	41	3200
15:30	74.1	65.8	37	8.8	30	47	3460
16:00	72.9	64.2	36	8.8	32	54	3708
16:30	72.8	63.7	36	8.8	33	61	3947
17:00	72.4	62.5	35	8.8	33	67	4160

Graph-1 shows the cumulative yield of solar still with Fr lens for three months and for a conventional till without Fresnel len the month of January and February the cumulative yield is slightl (3.54 & 3.78 liters) compared to the month of March (4.16 l the change in ambient temperature and solar intensity.

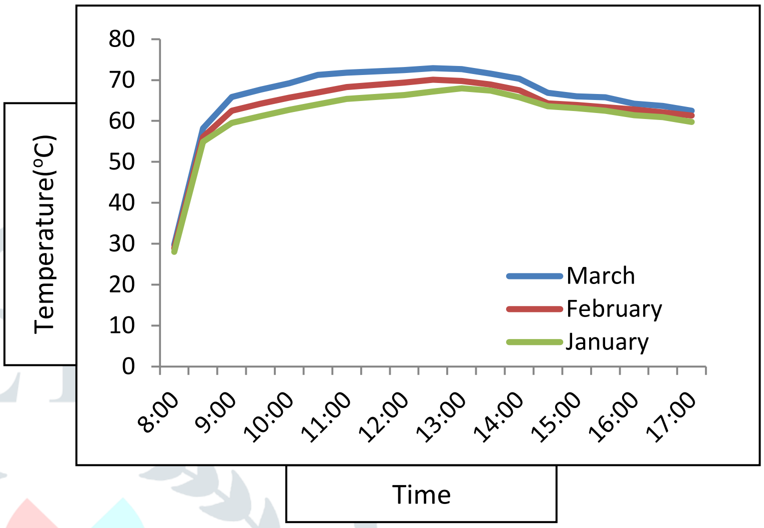


The cumulative yield for the still integrated with the Fresnel lens is 3.7 times more than that of the still without the lens which shows the effectiveness of the usage of the Fresnel lens.

Graph-1: Time v/s Water Output



Graph-2: Time v/s Basin Water Temp



Graph-3: Time v/s Glass Cover Temp

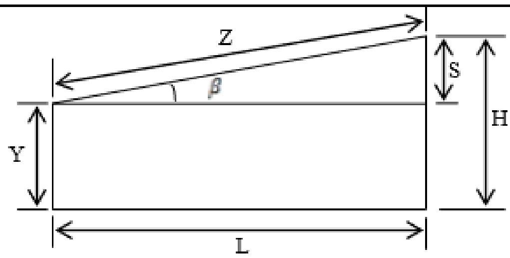
Graph-2,3 shows the variation of basin water temperature and glass cover temperature for three different month January, February and March with respect to time. It is found that glass cover temperature is less than that of the water temperature at the particular time for the condensation process to take place. It is also understood that the water temperature does not decreases very much compared to the conventional still due to the integration of Fresnel lens.

The efficiency of solar concentrating still is found to be 50.07% more than the conventional solar still. The water output collected is tested for purity and the neutral pH value is found to be 6.35 and TDS meter value is 23ppm which is safe for drinking.

Theoretical Calculations

All values of temperatures and wind speed were taken average for the calculations.

Table-3: Physical dimensions of Solar still

S No	Initial data	Calculations & sketches	Results
1	Using $\beta = 28^0$ L =0.63m Y = 0.10m	 From simple trigonometry, $H = Y+S$ $H = Y+ L\times \tan\beta$ $H = 0.10+ 0.63\times \tan(28)$	H = 0.43m
2	Transparent cover	$\cos\beta = L/Z$ $Z = 0.63/\cos(28)$	Z = 0.71m
3	Effective area of the collector A_{co} and glass, L = 0.95m, B = 0.58m	$A_{co} = L\times B = 0.95\times 0.58$ $A_g = 1\times 0.71$	$A_{co} = 0.551m^2$ $A_g = 0.71m^2$

Intensity through the Fresnel lens

I_L = Solar Intensity on the Fresnel lens = 1KW
A_L = Area of lens = 1.526 m^2
I_F = Intensity of the Focal point
A_F = Area of focal point = 5.026×10^{-3}
$I_L \times A_L = I_F \times A_F$
$1\times1.526 = I_F \times 5.026\times10^{-3}$
I_F = 303.58KW.

Table-4: Heat transfer calculations of solar still.

S No	Initial Data	Calculations	Results
1	T_w =346.78K, T_g = 339.04K $\sigma = 5.67\times 10^{-8}$ W/m^2K, ε_g=0.95 ε_c = 0.94, A_c =0.551m^2, A_g = 0.71m^2	$Q_r = \frac{\sigma A_{co}(T_w^4 - T_g^4)}{\frac{1}{\varepsilon_c} + \frac{A_{co}}{A_g}(\frac{1}{\varepsilon_g} - 1)}$ $= \frac{5.67\times10^{-8} \times 0.551\times(346.78^4 - 339.04^4)}{\frac{1}{0.94} + \frac{0.551}{0.71}(\frac{1}{0.95} - 1)}$	Q_r = 35.32W/m^2
2	V = 2.23m/s	$h_{cb} = 5.7+3.8v$ $= 5.7+(3.8\times 2.23)$	h_{cb} = 14.174W/m^2K
3	T_a = 309.26K, L_g =0.004m, K_g = 1.05W/m^2	$Q_{cg-a} = \frac{T_g - T_a}{\frac{1}{h_{cb}} + \frac{L_g}{K_g}}$	Q_{cg-a} = 40.047W/m^2
4	L_{wo} = 0.018m, K_{wo} = 0.13W/mK	$Q_b = \frac{T_w - T_a}{\frac{L_{wo}}{K_{wo}} + \frac{1}{h_{cb}}}$	Q_b = 25.78W/m^2
5	A_s = 0.169m^2	$Q_s = (\frac{A_s}{A_{co}}) \frac{T_w - T_a}{\frac{L_{wo}}{K_{wo}} + \frac{1}{h_{cb}}}$	Q_s = 7.90W/m^2
6	ε_w = 0.96	$Q_{rw} = h_{rw}(T_w - T_g)$ $h_{rw} = \varepsilon_{eff}\ \sigma[(T_w)^2 + (T_g)^2](T_w + T_g)$ $\varepsilon_{eff} = (\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1)^{-1}$	ε_{eff} = 0.91 h_{rw} = 8.35W/m^2K Q_{rw} = 64.69W/m^2
7	-	$Q_{cw} = h_{cw}(T_w - T_g)$ $h_{cw} = 0.884\,[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{268.9\times10^3 - P_w}]^{1/3}$ $P_w = \exp[25.317 - \frac{5144}{T_w + 273.15}]$ $P_g = \exp[25.317 - \frac{5144}{T_g + 273.15}]$	P_w = 35717.209 N/m^2 P_g = 25457.07N/m^2 h_{cw} = 2.51W/m^2K Q_{cw} = 19.457W/m^2
8	-	$Q_{ew} = h_{ew}(T_w - T_g)$ $h_{ew} = (16.273\times10^{-3})\ h_{cw}\frac{(P_w - P_g)}{(T_w - T_g)}$	h_{ew} = 54.14W/m^2K Q_{ew} = 419.07W/m^2

The hourly yield per m^2 area from the solar still basin

$m_w = \frac{Q_{ew}\times3600}{h_{fg}} = \frac{419.07\times3600}{2260}$ = 0.65 kg

Total Yield for 8 hrs is $m_w = 0.65\times 8$ = 5.2 kg (1kg = 1.17 liters)
= 4.44 liters.

CONCLUSION

Introducing the Fresnel lens to a solar still has improved the performance (this is relative to the distillate yield) of the conventional single slope solar still by 73.07% with an additional increase in overall estimated efficiency of 50.7%.

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