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Design, Development and Performance Evaluation of Fresnel lens based Solar Desalination unit

Shivam Dadhich¹

P.G. Student, Department of Renewable Energy Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture & Technology, Udaipur, Rajasthan, India¹

ABSTRACT: The study on Fresnel lens based Solar Desalination unit was carried out. The research work fabricated and tested at Department of Renewable Energy Engineering, College of Technology and Engineering, MPUAT, UDAIPUR, Rajasthan-313001. The study area situated at 24°35'35.01" North Latitude and 73°44'18.09" East Longitude and at an altitude of 582.17m above mean sea level. Objective are to design and develop fresnel lens based solar desalination unit and to evaluate performance of solar desalination unit. All measurements were taken from 18th May, 2022 – 24th May, 2022 during the period of 9:00 AM to 5:00 PM. It was found that in no load maximum temperature of 123°C and 111°C with and without Fresnel lens respectively occurred at 1.00 P.M. In testing process, the solar still is loaded to its full capacity of 24 liters. It was found that in full load maximum temperature of 72°C and 64°C with and without Fresnel lens respectively occurred at the water outlet at 2 P.M. The maximum volume of distilled water obtained was 220 ml with efficiency of the distillation tank 10.86 % at an average yield of .9 l/m²/day and the maximum volume of distilled water obtained was 294 ml with efficiency 13.50 % at an average yield of 1.2 l/m²/day with and without Fresnel lens respectively at full load. It was found that maximum yield of 2.56 kg/m²/day and 2 kg/m²/day respectively with and without Fresnel lens and maximum yield of 625 ml and 490 ml with and without Fresnel lens respectively occurred at 1 cm. It was found that maximum efficiency of 39.7 % and 24.48 % respectively with and without Fresnel lens occurred at 1 cm. Yield varies from 240 ml (full load) to 490 ml (1 cm) without lens and 294 ml (full load) to 625 ml (1 cm) with lens efficiency varies from (10.7% to 24.47%) without lens and (13.5% to 39.7%) with lens. Percentage change in efficiency is 62% at (1 cm) and 26% at (full load). Distilled water output yield (0.9 - 2 kg) without lens and (1.2 - 2.56 kg) and percentage change in still efficiency is very from 27 to 33%. It was found that TDS varies from (10 to 30 ppm) and (110 to 140 ppm) with and without Fresnel lens and percentage change 96% and 66% with and without Fresnel lens respectively.

KEYWORDS : Solar Desalination unit, Fresnel lens, TDS, Performance Evaluation.

I. INTRODUCTION

India has a population of 1.3 billion people and one of largest growing economies in the world. Therefore, there is a strong demand of energy. Global climate change has resulted to hunt for non-conventional energy sources in place of conventional fossil fuel-based energy sources. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. India is located to the north of the equator, which receives yearly mean solar irradiation of 6.5 kWh/m²/day, India receives annual sunshine of 2600 to 3200 hours . The continuous increase in the level of greenhouse gas emissions and the increase in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy.

Leonardo da Vinci once said, "Water is the driving force of all nature." No water, No life, No blue, No green. Water scarcity is a major threat for future as the fresh water resources are being exploited and polluted rapidly by mankind. The increasing demand for water puts enormous strain on the underground aquifer, which results in lowering water levels and increasing salt content. The global water concern is mainly about the scarcity of fresh water resources despite the abundance of saline and brackish water. Natural fresh water resources are being depleted rapidly, as a result of population growth and socio-economical development. Humans need to drink an average of 2.5 liters of potable water per day in order to prevent dehydration. Water purification has become one of the urgent requires of modern life due to the increase of the human population and the variety of contaminant sources. The desalination method can eliminate salinity. Solar desalination presents a promising alternative to produce fresh water from saline water with

free solar energy. The conventional process of desalination is used thermal energy source as a fossil fuel, however there is less accessible assets of fuel due to which there is absence of renewable energy sources for desalination. Desalination industry has shown increased threats of CO₂ emissions and severe environmental impacts. Desalination industry can be made sustainable if they are integrated with renewable energy and if proper brine disposal methods are followed. Solar energy driven desalination units can cut off carbon emissions and can provide desalinated water in a sustainable way with minimal impacts on environment and are highly suitable for remote and rural areas where provision for power supply and fresh water pipe lines are not possible. One of the solar desalination technologies is the solar still system, which is a portable unit capable of producing distilled water by evaporating brackish or saline water by using solar thermal energy. This is achieved by using both solar and Fresnel lens for efficient heating and increased output. Principle of working of lens is based on the law of refraction. Fresnel lens is an optic device which concentrates the incoming light onto a spot or onto a line.

This research work makes a review about the influence of the Fresnel lens on the conversion of saline water into drinking water was investigated using the double slope single basin solar still. And there is a comparative study between conventional solar still and effect of Fresnel lens on solar still parameters as absorber plate temperature, glass cover temperature, inner temperature, efficiency, yield and cumulative yield. It will determine the % change in TDS of feed water. Although the present application scale is small, the ongoing research and development works suggest that Fresnel lens solar concentrators, will bring a breakthrough of commercial solar energy concentration application technology in the near future.

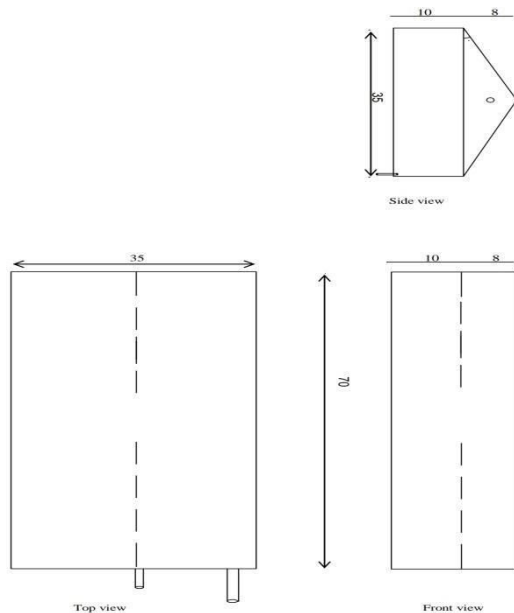
Choong et al. (2020), conducted as an initial investigation to observe the applicability of the Flat Fresnel lens as a cheap CSP device. A Fresnel lens has been used to concentrate solar energy onto a spot to increase the local temperature of feedwater and the evaporation rate. Flat Fresnel lenses on a double sloped passive solar still were used, where the focal points were adjusted to fall directly on the feedwater. It was found that using two Fresnel lenses instead of a single one provides multiple hotspots gives a boost to the production of freshwater per unit solar irradiation by 39%. The increased length/width ratio caused significant improvement in production of 41.8% for the Fresnel lens associated model. Saline solution with a concentration of 20,000 ppm was used as the feedwater. The produced water has a total dissolved solids (TDS) value of 37 ppm, which is well within the drinking water standard range according to the World Health Organization. Alktraneea et al. (2020) investigated experimentally the importance of using the Fresnel lens technique to enhance the productivity of a conventional solar still (CSS) under the climate conditions of Basra city (30.5258°N latitude and 47.7738°E longitude), Iraq. The experimental showed that the productivity of the CSSFL improved over the CSS by about 68.6% at 1 cm depth and about 59.3% at 2 cm depth. Moreover, the average daily thermal efficiency of the CSS and the CSSFL at 1 cm depth was 21% and 36%, respectively. Daily average thermal efficiency increases by about 71% at 1 cm depth. Sansom et al. (2019) developed a water desalination unit integrated with a Fresnel lens solar concentrator to evaluate the enhancement in the performance of the system and was compared with the existing desalination unit. The surface area of the Fresnel lenses total 3 m². The targeted production rate of purified water will be 100 L/day with an efficiency close to 50%. The study shows that Fresnel lens concentrator alone as pre-heating device can improve the yield of the desalination system up to 30.8 liters with an efficiency of 55%. The yield was increased by reducing the water level in the desalination tank and the increased yield was 2.8 liters with 15 liters of water in the desalination tank with 55% efficiency. Huang et al. (2017) studied that the radial Fresnel lens can achieve a sunlight concentration ratio 3.9 times higher than that of the linear lens with a much smaller receiving area. Sharon and Reddy (2015) studied the effect of Fresnel lens on yield and found that using multiple Fresnel lenses instead of a single one provides multiple hotspots and causes more evaporation of feed water, thus leading to higher total production per total solar irradiation by 39%. Jaime (2015) studied the effect of a Fresnel Lens upon solar still productivity. The use of a Fresnel lens on a solar still resulted in a 44% increase in water production. The still using the Fresnel lens produced a greater amount of water than the control still. Abdelsalam and Mesih (2014) tested experimentally to augment the incoming solar radiation falling on glass surface by concentrating extra solar radiation to the solar still system. Manual sun tracking was implemented for the Fresnel lenses structure every 30 min. The results showed that the integration of linear Fresnel lens has approximately tripled the productivity of distilled water and enhance the desalination performance by averagely improving the productivity by 231.17 % and improved efficiency of a solar still, by about 68.76 %, when compared to a conventional non-concentrating solar still. Younis et al. (2013) calculated mathematically the performance evaluation of a solar water still of area 0.24 m² coupled with a Fresnel lens (1.3m²). The overall efficiency of the system was 57%, which is 62% more than the efficiency of simple solar water stills. Kapurkar and Kurchania (2013) developed system of 70lt Concentrated solar water heater-cum-distillation unit. Refractive type Fresnel lens was used as solar concentrator along with a copper plate as an absorber. The yield of distilled water was 4.72 kg/m²/day and efficiency of the distillation unit was 28.78%. Mehta et al. (2011)

developed a solar water still that produces 1.5 liters of pure water from 14 liters of dirty water, efficiency of the still being 64.37%. The TDS (total dissolved solids) in the pure water is 81 ppm. Panchal et al. (2011) proved experimentally that the productivity of a solar water still increases by 35% when coupled with a flat plate collector. Xie et al. (2011) studied the recent developments of concentrated solar energy applications using Fresnel lenses. The efficiency of solar appliances can be increased by incorporating solar concentrators on solar water heating and distillation units, having capacity of 70 lt was tested for its technical as well as economic feasibility. Overall efficiency of the solar water heater was 42.38 %. The yield of distilled water was 4.72 kg/m² /day and efficiency of the distillation unit was 28.78 %. Hashim et al. (2010) investigated that the best solar still is that which has symmetric double slope, the best inclination angle is 45° and that the lesser inner surface area (11645 cm²) give the best productivity. Qiblawey et al. (2008) Production rates reported vary from 12.5 L/day up to 180,000 L/day depending on the technique used multi-stage flash (MSF), multi-effect distillation (MED), vapor compression (ME), membrane distillation (MD) and the size of the solar collector field (Qiblawey et al., 2008).

Experimental Setup

The study was divided into two phases. The first phase included the design and construction of the desalination system. The second phase of the study included the pilot testing with and without Fresnel lens of the solar powered desalination system. Conventional solar desalination units are equipped with an inclined transparent condensing plate placed over a feedwater basin containing saline water. In this study, a Flat Fresnel lenses on a double sloped passive solar still has been used, where the focal points were adjusted to fall directly on the feedwater to concentrate solar energy onto a spot to increase the local temperature of feedwater and the evaporation rate. The solar still that held the salt water were 24L capacity. The basin is made from a stainless steelsheet of 20 gauge thickness with dimensions of 70 cm × 35 cm × 10 cm for length, width and height, respectively. The bottom of still is rectangular with (70 cm × 35 cm) dimensions while, the elevation of side walls are 10 and 18 cm on longer and shorter side, respectively. The interior surface of the water basin was painted in black to increase the solar absorptivity. Solar still holder was made of GI with a gauge thickness no. 22. All four sidewalls and bottom space between the basin and the GI box was filled with a 300 mm thick thermocol board as a thermal insulating layer to reduce heat loss to the ambient and to minimize heat losses from the stills. The top glass cover is inclined by about 24.5° to the horizontal to gain the highest beam solar radiation at different times considering the best inclination angle at the studied location. The top casing is covered by two glass (70 cm × 20 cm) for 100% transmission of solar energy into the basin for evaporation. Steel pipes were used as inlet and outlet channels. The basin is given inlets for filling of water and has one outlet to collect desalinated distilled water. Removal of salts from basin from outlet at bottom of basin. The condensate collector was made of 500 ml glass bottles. Solar still placed on iron stand of size (75 cm × 40 cm) on castor wheels which move solar still on ground where the insolation were adjusted to fall directly on the feedwater. A refraction based methodology for concentrating sunlight is proposed to augment the pure water production of a conventional solar still. The solar concentrator was composed of the Fresnel lens and its support. Here, the sun rays are shed upon the Fresnel lens which will concentrate the beams. The Fresnel lens (FRL) was integrated with a single-basin, double slope passive solar still to refract the incident sunlight to a focal point that was constantly located on the basin bottom. Fresnel lens made of PMMA sheet of dimension (84cm × 42 cm) can be used as a solar concentrator for a solar powered desalination system. It is spot type Fresnel lens which concentrate radiation on basin water and increase temperature of basin water which increase evaporation rate and increase yield. The distance between the installation position of Fresnel lens and the center point of the basin bottom is approximately equaled to the focal length (1.0 m). The framed Fresnel lens was hinged to two galvanized iron pipes 1000 mm high and spaced 700 mm apart. The hinges allowed the lens to rotate 360° in vertical motion. The angle of the lens was measured relative to the ground. The position of the sun varies every hour so it perpendicular to basin. Galvanized iron was chosen because the stand had to be stable enough to support the lens even during windy conditions. By above mechanism the lens remains perpendicular to sunrays so we can get maximum intensity of sun rays throughout the day. Thermocouples are used to measure the temperature of basin, basin water, glass cover, inner temperature of still. Thermometer measure inlet water temperature. Other instruments used are pyranometer, multi-channel data logger, thermometer, electronic weight balance, digital tds meter

Figure representing top view side view and front view



Performance Evaluation

The water desalination unit tested for no load, full load and maximum efficiency load conditions to evaluate its performance with and without Fresnel lens. Maximum efficiency test is carried out to estimate the optimum load to give the maximum distillation yield. During testing, temperatures at absorber plate temperature, glass cover temperature, inner temperature were recorded by multi-channel data-logger also solar radiation were measured by Pyranometer at set time interval.

No-Load Performance

The no-load testing was performed with two replications with and without Fresnel lens to evaluate the performance of solar water heater without load (water) in the container. It was observed that initial temperatures at the absorber plate temperature, glass cover temperature, inner temperature at 9.00 AM were 64°C, 46°C and 56°C, respectively. Maximum temperature of the absorber plate was 111°C, reached at 13.00 hours, when solar radiation was 868.727 W.m⁻² at ambient temperature of 46.3°C. During testing with lens, It was observed that initial temperatures at the absorber plate temperature, glass cover temperature, inner temperature at 9.00 AM were 67°C, 49°C and 61°C, respectively. Maximum temperature of the absorber plate was 123°C, reached at 13.00 hours, when solar radiation was 872 W.m⁻² at ambient temperature of 47.7°C.

Full-load Performance

The full-load testing was performed with two replications with and without Fresnel lens to calculate the efficiency of solar still on full load when still is fully filled of maximum depth to evaluate its performance in actually loaded condition. In testing process, the solar still is loaded to its full capacity of 24 liters. In the morning, atmospheric temperature as well as intensity of solar radiation remained lower than in the noon. Maximum solar energy input was available at 13:00 hour. After 13:00 hour, there was gradual decrease in the incident solar radiation. With increase in solar radiation, the temperature of water increased. It was found that the average temperature at 9 AM at storage was 34.1°C, when the solar radiation was 630.7236 W.m⁻² and ambient temperature was 31.5°C. It was found that maximum temperature of 64°C at the water outlet occurred at 2 P.M when solar radiation was 747.5633 W.m⁻² and ambient temperature was 41°C. The temperature of outlet water retained at 5 P.M was 61.5°C. The maximum volume of distilled water obtained was 220 ml. The efficiency of the distillation tank was found out to be 10.86 % at an average yield of .9 l/m² day. During testing with lens, It was found that the average temperature at 9 AM at storage was 38°C, when the solar radiation was 648 W.m⁻² and ambient temperature was 31.9°C. It was found that maximum temperature of 72°C at the water outlet occurred at 2 P.M when solar radiation was 745 W.m⁻² and ambient temperature was 41.7°C. The temperature of



outlet water retained at 5 P.M was 64°C. The maximum volume of distilled water obtained was 294 ml. The efficiency of the distillation tank was found out to be 13.50 % at an average yield of 1.2 l/m² /day.

Maximum Efficiency Performance

The testing was done to find out the optimum volume of water that can be stored to get the maximum efficiency. The testing procedure is similar to that of full load test. A variation in the volume of water stored results in a change in efficiency. And the maximum efficiency for distillation unit was found to be 24.48 %. The volume of water stored in the heating tank was 2.5 liters and the output from the distillation tank in the subsequent morning was found to be 490 ml. The average amount of distilled water per unit area of distillation tank was 2 l/m² day. During testing with lens, maximum efficiency for distillation unit was found to be 39.7 %. The volume of water stored in the heating tank was 2.5 liters and the output from the distillation tank in the subsequent morning was found to be 625 ml. The average amount of distilled water per unit area of distillation tank was 2.56 l/m² day.

Area of Fresnel lens	Area of Absorber plate	Concentration ratio (C)
$A_a = \text{Length} \times \text{Width}$ $= 0.84 \text{ m} \times 0.48 \text{ m}$	$A_r = \text{Length} \times \text{Width}$ $= 0.70\text{m} \times 0.35\text{m}$	$C = \frac{A_a}{A_r}$
A_a = 0.4032 m²	A_r = 0.245 m²	C = 1.67

Efficiency

The efficiency of the method was measured in terms of the energy required for the vaporization versus the energy of the sun’s radiation. The solar still using Fresnel lens will be tested for full load and maximum efficiency condition to evaluate its performance.

$$\text{Efficiency} = \frac{\text{Energy required for the vaporization of distillate recovered}}{\text{Energy in the sun's radiation that falls on the still}} \quad e = \frac{w \times h}{i \times a \times t} \times 100$$

Where, e=efficiency of solar still. %, w = water collected in flask, kg, h = heat of vaporization of water, kJ / kg, i = solar insolation, W/m², a = area of basin, m², t = time, sec

		Average solar insolation, W/m ²	Water collected in flask, kg	Time, sec	Area basin m ²	Heat vaporization of water, kJ / kg	Efficiency solar still %
Without lens	1cm	641	490	7	.245	2260	24.48
	2cm	662	323	7	.245	2260	15.68
	Full	659	220	7	.245	2260	10.86
With lens	1cm	697	625	7	.245	2260	39.70
	2cm	644	439	7	.245	2260	21.80
	Full	504	294	7	.245	2260	13.50

Change in TDS of water

measured by TDS meter which is firstly dipped in saline water and then it dipped in distillate collected in flask. We will get decrement in TDS concentration from this solar still.



$$h = \frac{T_1 - T_2}{T_1}$$

Where, T₁ = TDS of water before desalination, T₂ = TDS of water after desalination, h = % change in TDS

	Without lens			With lens		
	TDS before	TDS after	% change in TDS	TDS before	TDS after	% change in TDS
1cm	330	110	66	330	10	96
2cm	330	140	58	330	30	90
Full	330	160	52	330	30	90

% Change in yield				% Change in efficiency			
	Without lens yield (kg/m ² /day)	With lens yield (kg/m ² /day)	% change yield		Without le nefficiency	With le nefficiency	% change iefficiency
1 cm	2	2.56	27.55	1 cm	24.48	39.7	62
2 cm	1.31	1.8	35.9	2 cm	15.62	21.8	39.56
Full	.9	1.2	33.63	Full	10.7	13.5	26.16

II. RESULT AND CONCLUSION

The study on Fresnel lens based Solar Desalination unit was carried out. The Fresnel lens based Solar Desalination unit was fabricated and tested at Department of Renewable Energy Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan 313001. The study area situated at 24°35'35.01" North Latitude and 73°44'18.09" East Longitude and at an altitude of 582.17m (1909 feet) above mean sea level. The designed system was tested for its technical feasibility of solar water heating and distillation units. The information was gathered during the no load and full load testing of the framework. Design of Fresnel lens based solar desalination unit will be

L × W × H = 70 cm × 35 cm × 10 cm

- Solar Still Capacity 24L
- Slope = latitude (24.5°) which is the latitude of Udaipur.
- The still is made of steel having gauge thickness no. 18.
- The elevation of side walls are 10 and 18 cm on longer and shorter side respectively.
- The construction of the solar still was started in Solar still holder was made of GI with a gauge thickness no. 22.
- All four sidewalls and bottom space between the basin and the GI box was filled with a 300 mm thick thermocol board.
- The top casing is covered by two glass (70 cm × 20 cm).
- Fresnel lens made of PMMA sheet of dimension (84cm × 42 cm) and the focal length (1.0 m).

the month of april 2022 and the readings were •

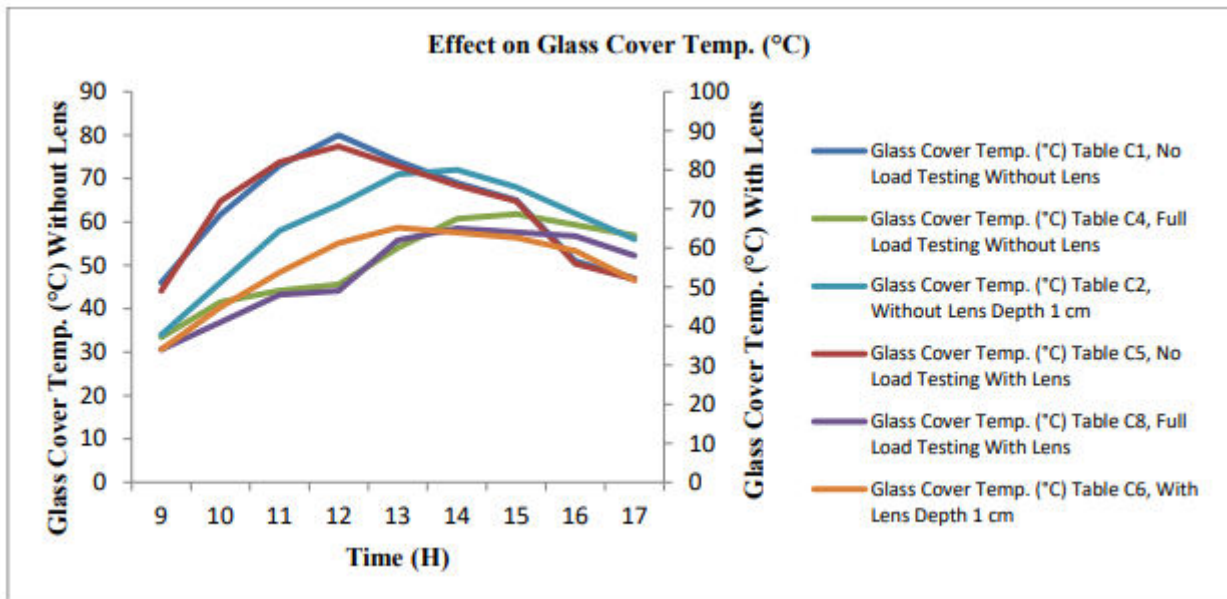
The timing of the readings were from 9:00 AM to 5:00

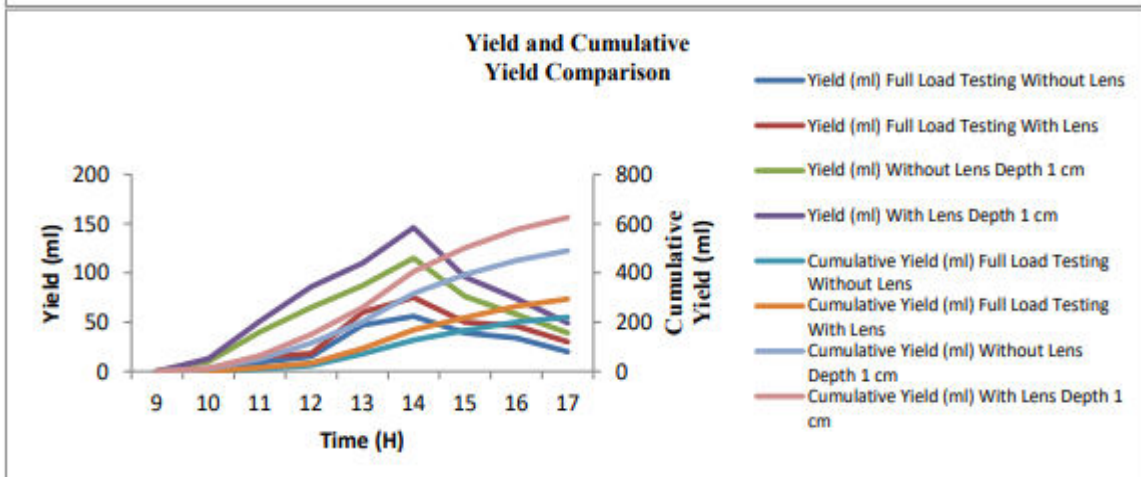
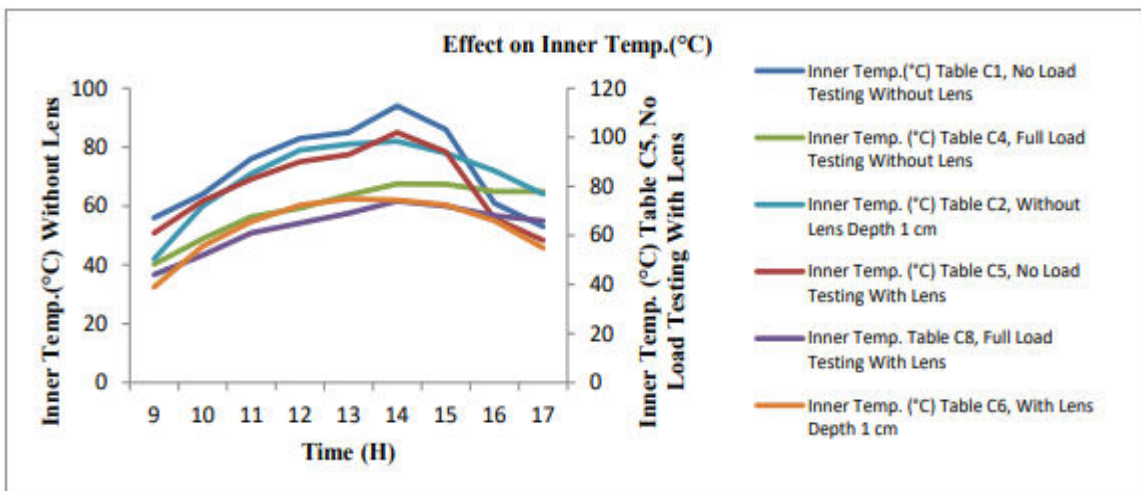
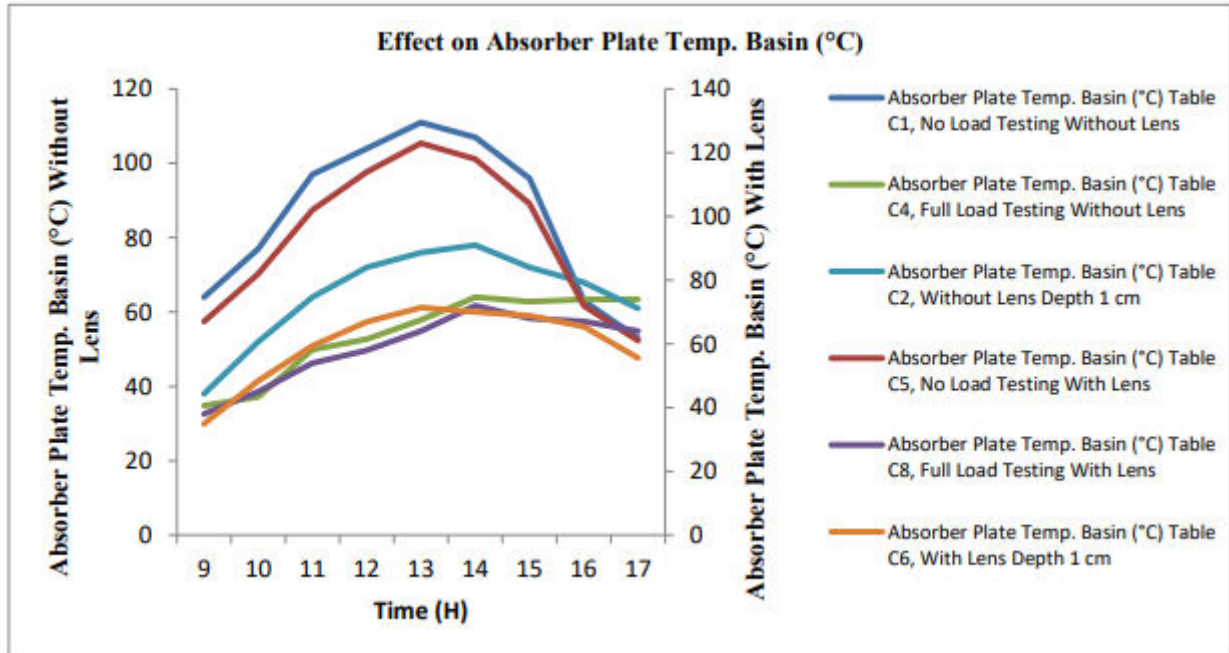


taken in the month of may 2022.

PM.

It was found that in no load maximum temperature of 123°C and 111°C with and without Fresnel lens respectively occurred at 1.00 P.M. In testing process, the solar still is loaded to its full capacity of 24 liters. It was found that in full load maximum temperature of 72°C and 64°C with and without Fresnel lens respectively occurred at the water outlet at 2 P.M. The maximum volume of distilled water obtained was 220 ml with efficiency of the distillation tank 10.86 % at an average yield of .9 l/m²/day and the maximum volume of distilled water obtained was 294 ml with efficiency 13.50 % at an average yield of 1.2 l/m²/day with and without Fresnel lens respectively at full load. It was found that maximum yield of 2.56 kg/m²/day and 2 kg/m²/day respectively with and without Fresnel lens and maximum yield of 625 ml and 490 ml with and without Fresnel lens respectively occurred at 1 cm. It was found that maximum efficiency of 39.7 % and 24.48 % respectively with and without Fresnel lens occurred at 1 cm. Yield varies from 240 ml (full load) to 490 ml (1 cm) without lens and 294 ml (full load) to 625 ml (1 cm) with lens efficiency varies from (10.7% to 24.47%) without lens and (13.5% to 39.7%) with lens. Percentage change in efficiency is 62% at (1 cm) and 26% at (full load). Distilled water output yield (0.9 - 2 kg) without lens and (1.2 - 2.56 kg) and percentage change in still efficiency is very from 27 to 33%. It was found that TDS varies from (10 to 30 ppm) and (110 to 140 ppm) with and without Fresnel lens and percentage change 96% and 66% with and without Fresnel lens respectively. % maximum change in efficiency at 1 cm is 62%







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