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Design and Fabrication of Pyramidal-Hemispherical Solar Still

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A B S T R A C T

Adequate quality and reliability of drinking water is vital for all inhabitants' applications. Rapid increase in the world population leads to an increase in the demand of pure water. Many purification methods are available nowadays to make potable water from different resources. Solar desalination is one of the purification methods for getting potable water from brackish or waste in remote areas where there is scarcity of water as well as electricity. In recent years, attention has been focused on development of various designs of solar still to increase the productivity of water and to overcome limitations of single basin single slope solar still. In the present work, an attempt is made to develop a solar distillation device that produces fresh water using direct solar energy.

Keywords: Hemispherical Solar Still, Pyramidal Solar Still, Solar distillation, Solar energy, Water Purification

1. Introduction

Fresh water is the most essential of all natural resources. It is one of the fundamental elements for overall development of the human living such as domestic, industrial and agriculture purposes. The supply of freshwater is now less than the demand of the population. Although more than two-third of the earth's surface is covered with water, there is still an arisen crisis of water scarcity. Decrease in Water Sustainability Index (WSI) from 1992 to 2020 is a reflection that World's water resources are rapidly depleting and have been managed unsustainably. These situations will affect the world water supply and definitely will cause water shortage in future.

In Many countries of the world, women carry water from far places to fulfill the daily needs of the family. According to a UN survey, still two thirds of the people in the world are facing severe water problems. Global warming is also one of the causes for scarcity of water. Diminished flows in rivers and streams can increase concentration of harmful pollutants. Even though Water covers more than two-thirds of the earth's surface, available freshwater resource is only 2.7% and in that also only 1% of water is accessible. In some countries, sufficient freshwater is not available. In some countries, abundant freshwater is available, but it is expensive to use. Freshwater can also be obtained from seawater by the desalination process.

Groundwater is the most plentiful of all freshwater resources. As water percolates into the ground through layers of soil, clay, and rock, some of it adheres to the topmost layers to provide water to plants. But because of the continuous consumption, these resources are depleting. Though there are desalination plants available to convert saltwater into potable, it is very expensive. This water is in what is called the unsaturated, or vadose, zone. Most of the pores in the Vadose zone are filled with air, rather than water. Water quality can be impacted negatively by both natural and human causes: electrical conductivity, pH, temperature, phosphorus levels, dissolved oxygen levels, nitrogen levels and bacteria are tested as a measure of water quality. Water that runs off into the stream can naturally carry sediment, debris and pathogens. Turbidity, the measure of suspended sediment in a stream, is also a measure of water quality. The more turbid the water, the lower the water quality. Man-made contaminants such as gasoline, solvents, pesticides, and nitrogen from livestock can wash over the land and can leach into waterways, degrading the quality of nearby waters. The Clean Water

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Act in the United States protects the quality of the stream and issues fines to those contributing to the degradation in water quality. By protecting and conserving the water supply, there is a greater guarantee of future water resources for human use.

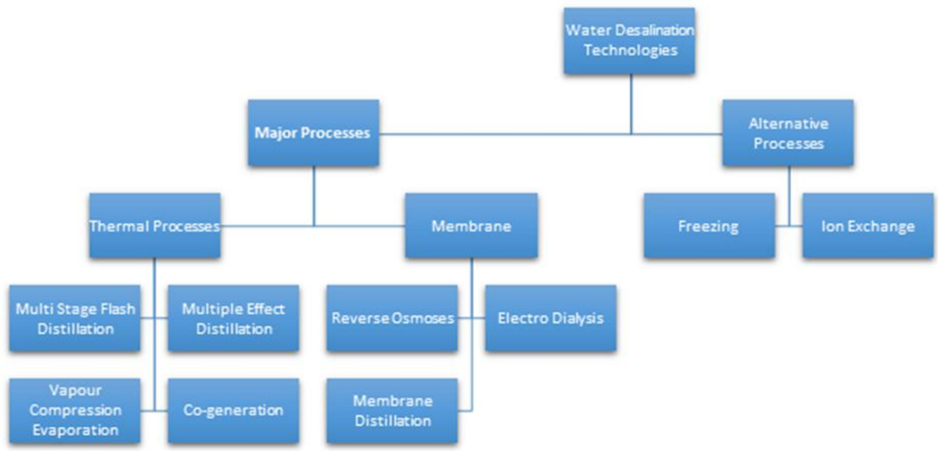

Fig 1: Flowchart of Methods to purify salt water

Desalination is an artificial process by which saline water (generally sea water) is converted to freshwater. The most common desalination processes are distillation and reverse osmosis. Currently there are two technologies with more desalination capacity in the world, distillation and reverse osmosis. But the disadvantage with this process is only one third of the water is converted to potable water and remaining is left waste.

Solar distillation is one of the purification methods where, water is heated up to evaporation temperature. After evaporation, the water vapor is condensed onto a cool surface. The condensed water is collected and used. This process is based on the natural evaporation cycle of water from sea to form clouds causing rain.

2. Literature Review

Ismail et,al.[1] designed a hemispherical solar still and performance was evaluated and the daily yield ranges from 2.8 to 5.7 lit/min. Mahian, et,al. [2] fabricated a solar still through mathematical calculation and studied the efficiency of the solar distillation process in various parts of the world. They have also reported the performance of the solar still when a small fan was utilized to enhance the daily productivity of freshwater. They tested the influence of forced convection induced by a fan, water depth, insulation thickness of the basin base, and wind velocity on the distillation process and compared their findings to the mathematical model. The findings suggest that using a low-cost, low-power fan to increase evaporation rate and hence freshwater production can be a cost-effective and cost-effective method. Arun Kumar et al.[3] simulated a hemispheric solar desalination process with and without water flowing over the cover.From the experimental study, they have observed that efficiency of the process was 34%, and can be increased to 42% with the top cover cooling effect. During field studies, diurnal fluctuations in a few key parameters such as water temperature, cover temperature, air temperature, ambient temperature, and distillate output were noted. Ali Kianifaret, al.[4] designed a pyramid-shaped solar purification system, and the exergy efficiency of conventional distillation and distillation assisted by a small fan to boost the evaporation rate was evaluated. When compared to a passive system, the test results from two seasons show that active systems provide better exergy efficiency at a lower cost. An energy, exergy, and thermo-economic analysis of a solar distillation was conducted by Ranjan et al [5]. The energy efficiency and productivity of typical solar stills was found to be low, ranging from 20–46% and less than 6 lit/m2/day, respectively. The exergetic efficiencies are estimated to be between 19% and 26% for a triple effect system, 17–20% for a double effect system, and less than 5% for a single effect system. They also stated that using single effect solar stills, the overall energy and exergy efficiency of the integrated systems rises to 62 percent and 8.5 percent, respectively. Also, study into previous research on the economic and thermo-economic analysis of solar stills. Ahsan et al.[6] investigated a number of numerical methods for estimating the amount of water produced by solar water distillation.Experiments were carried out under fifteen different sets of external conditions in order to determine the parameters of evaporation and condensation coefficients based on two alternative models. Finally, they discovered that among these six models, the chosen models have the smallest variation between estimated and observed values and can predict daily production flux. Arun Kumar et al.[7] modelled a solar still with a phase change material concentrator. They measured the temperature of water (Tw), temperature of PCM (TPCM), air temperature (Tair), and inner cover temperature (Tic) and outer cover temperature (Toc) in two modes: (1) single-slope solar still without the PCM effect, and (2) single-slope solar still with the PCM effect.And it was concluded that the productivity greatly increased 26% due to the still integrated with PCM. Ahsan et al.[8] investigated the creation of a low-cost solar-powered method for converting saline water to drinkable water. As a result, a triangle solar still was conceived and produced using low-cost, lightweight, locally available materials. They conducted a series of field experiments with an hourly time lag to assess the effects of solar radiation intensity, ambient air temperature, and the beginning water depth on water production. Finally, by altering the water depths with the climatic condition, a few key correlations were discovered.Muftah et al.[9] investigated parameters impacting basin type sun still productivity and analysed fresh water production, finding that ambient circumstances, operational conditions, and design conditions all had a substantial impact on solar still distillation productivity. The potential output of a basin type can still increase by around 70–100 percent. They also used a solar tracking system to improve their performance. The cost per litre of distilled water derived from a basin type solar still varied from 0.035 to 0.074$/liter, according to their research.Ajayraj S Solanket, et al.[10] investigated a hemispheric solar still with varying water depths and a constant ink proportion in the water. In this study, they discovered that adding 1.25 percent black ink boosted productivity by 1 percent to 20%, and adding 2 percent black ink raised productivity by 25%. Ravishankar et al.[11] created a triangular pyramidal solar still that they developed and built. They discovered the effect of water depth on the performance of the triangular pyramid solar still as a result of their research.The performance of a pyramid type concave basin solar still built by Vembathurajeshet, al.[12] was experimentally analysed. The solar still was tested in a concave basin under various conditions, including a water depth of 5 cm and the presence or absence of an absorbing substance.

The efficiency of the concave basin pyramid type solar still is calculated based on the trial findings... Khan et al. [13] created a solar water treatment facility for residential use. They set up a solar water disinfection system to improve the microbiological purity of drinking water and obtained 14 litres of pure water in less than 240 minutes. Abhishek Saxena et,al.[14] developed a distillation unit for solar homes focusing on complete utilization of solar energy. They focused on a unique combination of solar dish cooker and solar water heater to produce distilled water with a high distillate and a high daily productivity. And obtained distilled water of 3.6 ltr/day of 7.7 pH and 21ppm values. Bakry et, al.[15] studied the performance of solar still with three stepped trays. The experiment was tested with two ways, a) brine feed being uninterrupted and b) with intermittent brine supply. And the yield recorded greater productivity (5.5 & 5.11 l/m2) than that of conventional pyramid solar still. Akteret,al.[16] fabricated a solar cooker for domestic purposes as well as performance analysis in order to evaluate its effectiveness. They adopted better techniques for construction with low maintenance through testing and graphed the result. In their analysis maximum temperature variation was found 36 degrees Celsius with efficiency 8.8%. Nayi et al.[17] reviewed a square pyramid solar still by applying various modifications and fabrication strategies which helps to increase productivity at low costs. Patel ShivangKantila [18] studied thermal performance of solar cooker by varying inclination angle. From the study, they have concluded that proper selection of inclination angle influences the performance of the solar stills. Varun et,al.[19] focused on design and fabrication a passive solar still system with different phase change materials and observed various parameters. They also studied variation of heat transfer coefficient with time. K.A.Porta Gandara et,al.[20] conducted experimental studies on single- slope solar still distillation enhancement through water surface perturbation in different regions in La Paz, BCS, Mexico. From the studies, it was identified that by introducing a simple intensification factor yield can be increased by 12%. Muthu Manohar et,al. [21] studied performance of pyramidal solar still by varying water depth with different insulating conditions. They found that the efficiency increases with insulation. Khaled M. Batainehet,al.[22] analyzed performance of single slope solar still integrated with internal reflectors and fins. Results show that adding reflectors and fins together increases both productivity and efficiency. Hassan et,al.[23] assessed parabolic trough solar collector assisted solar still at various saline water mediums via energy, exergy, exergoeconomic, and enviro economic approaches. Ashok Kumar Singh [24] developed a new designs of passive solar desalination systems to understand better, efficient and productive systems along with various solar desalting systems. Mohammed El Hadi Attia [27] et,al. They studied hemispherical solar still which achieves higher productivity with low expenses by comparing with reference distiller. S.S.tuly and colleagues[25] devised a solar water distillation system. By incorporating fins, nanofluids, solar collectors, phase change materials (PCMs), and energy-storing materials into the distillation system, they were able to identify distinct individual and combined parameters affecting the performance of the solar distillation system. In addition to vacuum technology, reflectors, condensers, heat pumps, the refrigeration cycle, the vibratory harmonic effect, and the cover cooling method are all regarded effective adaptations. PCM improves productivity, according to the company.Bachchan et al. [26] investigated the use of phase transition materials and water absorption materials to improve the productivity of solar stills. The usage of phase change materials, they claim, aids in increasing everyday production. From the above studies It was observed that pyramidal or hemispherical solar stills individual performance is less and coating of the collecting plate increases the absorption capacity of the collector. Insulation decreases the heat loss and increases the efficiency of the still. In the present work combination of pyramidal and hemispherical solar still is designed and fabricated with performance analysis.

3. Methodology

Solar water distillers or solar stills are usually used in remote areas where there is limited access to freshwater. The basic principles of solar water distillation are simple, yet effective, as distillation replicates the way nature makes rain. A solar still works on two scientific principles: evaporation and condensation. The salts and minerals do not evaporate with the water. For example, table salt does not turn into vapour until it gets to a temperature over 1400ºC. However, it still does take a certain amount of energy for water to turn into water vapour. While a certain amount of energy is needed to raise the temperature of a kilogram of water from 0ºC to 100ºC, it takes five and one-half times that much to change it from water at 100ºC to water vapour at 100ºC. Practically all this energy, however, is given back when the water vapour condenses.

Fig 2: Flow chart on process of solar distillation

Solar still is an uncommonly used method of water distillation process used to produce drinkable water in efficient and minimal cost method. This method is more efficient because of its low cost even very hard water can also be converted into drinkable water in easy way. However, the amount of water vaporized and condensed is minimum for the operating period of the still. Even though it‘s a better method of water distillation process due to no need of fossil fuels and its use only solar energy which is easily and hugely available at everywhere for the water distillation process Most stills are simple black bottomed vessels filled with water and topped with clear glass or plastic. Sunlight that is absorbed by the black material speeds the rate of evaporation. The evaporation is then trapped by the clear topping and funneled away. Most pollutants do not evaporate, so they are left behind. Multiple solar distillation systems are required to produce a large quantity of distilled water.

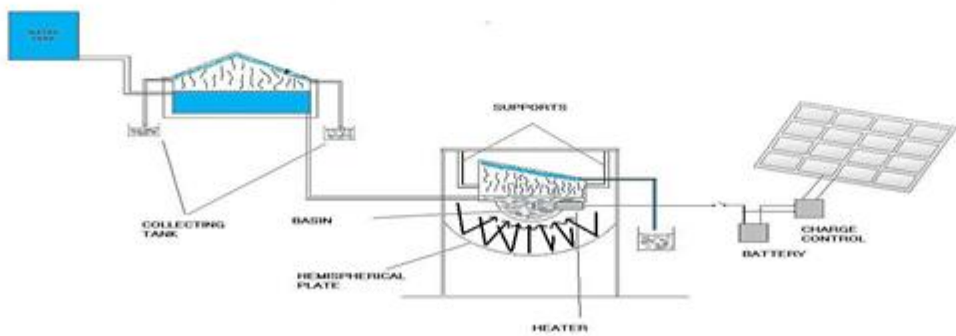

Fig 3: Proposed Model

4. Components of Proposed Model

4.1 Pyramid Solar Still:

a. Still basin: It is the part of the system in which the water to be distilled is kept. It is therefore essential that it must absorb solar energy. Hence it is necessary that the material have high absorption or very less reflectivity and very less transmittable. Kinds of the basin materials that can be used are as follows:

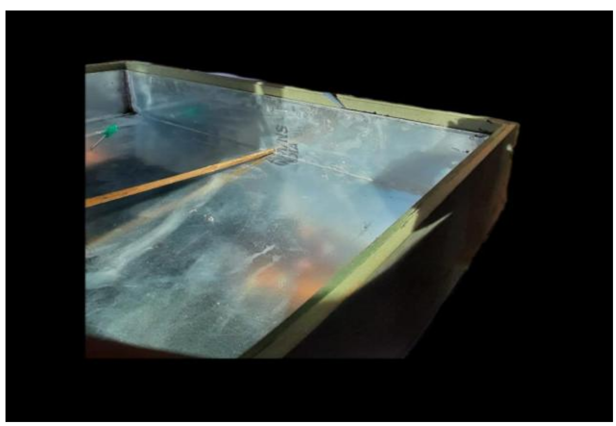

Fig 4: Still Basin enclosed with wooden box

- Leather sheet
- Ge silicon
- Mild steel
- RPF(Reinforced plastic)
- G.I(galvanized iron)
- Iron sheet of 24 gauge has been used.

b. Side Walls: It generally provides rigidness to the still. But technically it provides thermal resistance to the heat transfer that takes place from the system to the surrounding. So it must be made from the material that is having low value of thermal conductivity and should be rigid enough to sustain its own weight and the weight of the top cover

Different kinds of materials that can be used are:

- Wood
- Insulation
- RPF (reinforced plastic).
- For better insulation wood of ¾ inch size with 1 sq.m has been used.

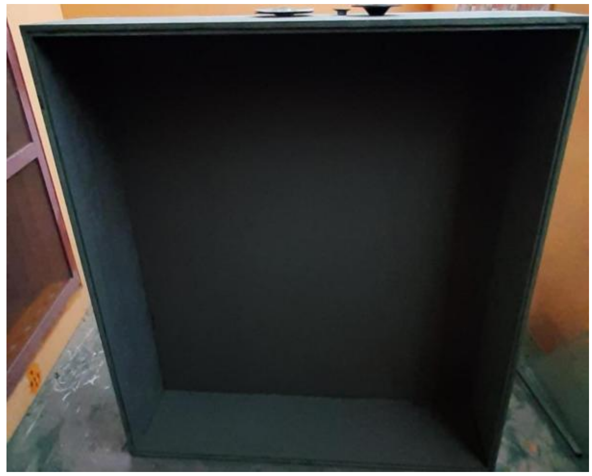

Fig 5: wooden box

c. Top Cover: The passage from where irradiation occurs on the surface of the basin is top cover. Also it is the surface where condensate collects. So the features of the top cover are:

Transparent to solar radiation

Nonabsorbent and non-adsorbent of water

Clean and smooth surface.

The materials that can be used are:

- Glass
- Polythene

Glass of 5mm thickness and angle of 45degrees has been used.

Fig 6: Solar still glass with cover

d. Channel: The condensate that is formed slides over the inclined top cover and falls in the passage, this passage which fetches out the pure water is called channel. The materials that can be used are:

1) P.V.C

2) G.I.

3) RPFW

P.V.C channel of C section has been used.

4.2 Hemispherical Solar Still:

a. Concentrating lens: The disc is coated with black paint as well as a silver reflecting film is stick upon the surface of the dish as shown in figure , which helps in concentrating solar energy to a focal point of 45cm of dish area 0.6sq.m.

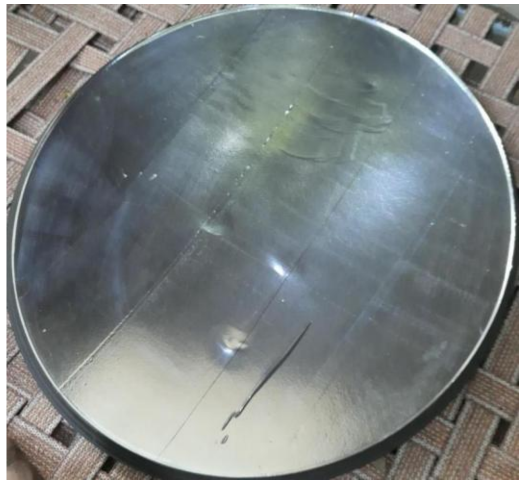

Fig 7: Dish coated with black paint

b. Absorbing tank : Tank is made of glass with 20sq.m base, 25cm and 15 cm on other sides. One inlet and one outlet holes are drilled for water flow. It is placed at the focal point so that it receives heat from the solar energy . Design is made so that the condensation is collected at one side.

Fig 8: Absorbing tank

5. Fabrication of Pyramid and Hemispherical Solar Still

As stated in our titular name, we have proposed a solar still distillation that comprises of both pyramidal and hemispherical stills combined together as one system. A pyramid type solar still is designed and constructed for the purpose of experimental work. Figure 9 shows the pyramidal solar still fabricated with plain basin of square aperture of 1m x 1m. It is fabricated from galvanized iron steel of 24 gauge. The basin surface is coated with black materials such as black silicone gel, black paint or black ink to absorb maximum solar radiation. The four sides of glass cover are of ordinary window glass of 5 mm thickness with a tilt angle of 45 degrees to the horizontal surface. The distillate water is collected by a PVC channel fixed on the one side at the lower end of the glass cover and is taken out through pipe. The whole system is made vapor tight using silicone rubber as a sealant to prevent any vapor leakage.

The experimental setup is suitably instrumented to measure the amount of distillate. The amount of distillate collected can be read in the distillate collecting slight canes which are graduated in ml. The still is fabricated from galvanized iron and normal window glass the basin and square aperture of stills base is made by means of welding the glasses are dimensional and cut for the required shape of triangular to get a pyramid shape of condensing surface, the four glasses are cut like the glasses are in same dimension and shape to produce the pyramid shape, then the four glasses are assembled together in pyramid shape using the adhesive materials. After assembling the glasses in pyramid shape, the distillate collecting channels are prepared to collect the distillate drawn from condensing surface, the collecting channels are made of plastic pipes, cut into C-section, which locate in bottom of pyramid shape glass assembly, the channels assembled in square shape by using silicon gel the collecting surface of still is mounted into the condensing surface by using the adhesive materials then the joining surface of the glasses and the collecting channels are made vapor tight by using the silicone gel as a sealant in the outer side of the collecting channels. The square aperture of the still is surrounded by the wood of thickness 6 mm and the bottom of the still also surrounded by the wood, the woods which are surrounds the square aperture and bottom of still are joined by the adhesives. The square aperture of the still and the glass and collecting channel assembly are mounted together. The assembly is made vapor tight by using the silicone gel as sealant.

Fig 9: Pyramidal solar still at condensing stage.

A hemispherical type solar still is designed and constructed as shown in Figure 10. A lens that has a focal point of 45cm is fabricated to a wide-frame like setup, which also supports the absorb tank to rest as shown in the figure below. The lens is made up of a Steel dish that is used for TV-antenna painted black and then a layer of reflecting surface is placed upon the face of the dish. It is painted black so as to increase the heat absorption process. The Absorb tank is made of a normal glass of 5mm thick. Absorb tank is a closed system whose glasses are stick glued together by the aid of a transparent silicon adhesive. It has a base of 20cm x 20cm, elevated to 15cm on one side and 25cm on the other. The water that needs to be distilled is sent through an inlet into the absorb tank. Due to heat generation, the water gets evaporated and the condensate tries to escape. Therefore, a glass is setup in such a way that the distilled water is collected through an outlet hole on the absorb tank through pipes.

Fig 10: hemispherical solar still.

6. Fabrication Procedure:

6.1 Solar still without absorbing material:

The solar still is fabricated as discussed above and then the still is placed where the sun's radiation can reach into the still without any trouble. The still is filled with water to a depth of 5 cm, and allowed to get heated and evaporated. The still is filled with salty water and allowed to evaporate; the evaporatedwater gets condensed into water droplets and the condensed water droplets are drawn into the plastic distillate collecting channels. The collected distillate in the channels is flow into the holes provided in the collecting channels, and then the condensed water is collected in the slight canes which are graduated in ml.

6.2 Solar still with Black paint as absorbing material for water depth of 5 cm:

In this setup the stills basin and the square aperture are coated with the black paint as absorbing material to improve the radiation absorption of the solar still. The still is filled with the water of depth 5 cm height, for this height of water the still occupies 12.4 liters of water. The 5 cm depth of water is allowed to get heated and evaporated, the readings observed variation of the distillate output.

7. Result and Discussion:

The distillate output is collected during the day time. We get an output of up to 6 – 6.4 liters in an active sunny day and the water quality analysis has been done to make sure the water production from the Solar still is safe to drink. The test results shown in the table above showed that the water will be usable and safe to drink.

Table 1: Test results of water sample

S.No	Test Parameter	Acceptable limits (10500-2012)	Test Results of Raw Sample Water	Test results of Purified water
1.	Appearance	-	Clear	Clear
2.	Odor	Unobjectionable	Unobjectionable	Unobjectionable
3.	Turbidity	1.0	1.2	1.2
4.	pH Value	6.5-8.5	7.58	7.1
5.	Total Dissolved Solids	500mg/l	615mg/l	510mg/l
6.	Total Hardness	200mg/l	372mg/l	214mg/l
7.	Chlorides as Cl	250mg/l	154mg/l	112mg/l
8.	Iron as Fe	0.3mg/l	0.4mg/l	0.2mg/l
9.	Manganese	0.1mg/l	ND	ND
10.	Total Solids	-	620mg/l	524mg/l
11.	Suspended Solids	-	12mg/l	10mg/l
12.	Total Alkalinity	200mg/l	320mg/l	208mg/l
13.	Total Acidity	-	4mg/l	4mg/l
14.	Total Fixed Solids	-	610mg/l	510mg/l
15.	Volatile Solids	-	10mg/l	10mg/l

Amount of total solar radiation incident on the still surface depends on the time of the day. The solar radiation varies along the hours after sunrise till a maximum value at mid- day then decreases.

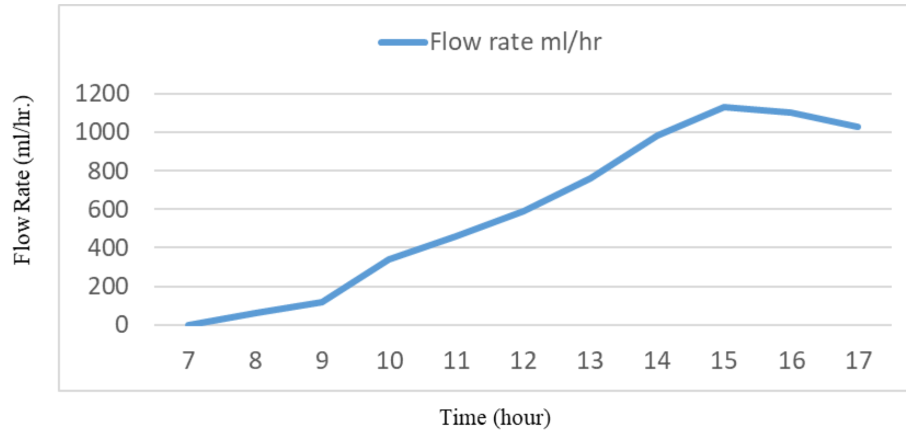

Fig. 11. Variation of distillate output

8. Conclusion

In this work, a plain basin Pyramid type solar still and Hemispherical solar still were designed, fabricated and experimentally tested during daytime for four days under outdoors of summer climatic conditions. It was found that, the daily distillate water produced from the still ranged from approximately 380ml to 540 ml for seven hours per day in pyramid and 400 to 460ml in hemispherical. The daily efficiency of the pyramid still varies for different absorbing materials. The efficiency of solar still for without absorbing material for water depth about 5 cm is 33%, with black paint as absorbing material for water depth about 5 cm is 38%. The experimental results indicated that the still with black paint as absorbing material has the highest efficiency of 38% than the other absorbing materials for the water depth of 5 cm. The effect of saline water depth on the still efficiency was also studied. It was found that the efficiency of the still decreases as the water depth increases in pyramid and finding the right focal distance increases the efficiency in hemispherical still.

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