

Efficiency Analysis of Modified Double Basin Pyramid Shaped Solar Still – An Experimental Study

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Abstract— A model of solar still is prepared using the least possible material and several experiments were performed on that still to analyze the various factors that have influence on the productivity of the solar still. Experiment was conducted in the month of July, 2016 between 6th July to 25th July, on 4 random days for continuous 5 hours and observations were taken at intervals of 1 hour. Result concluded that the pyramid shaped double basin solar still of water depth and surface area exposed to solar radiation as 2 mm and 2.25 sq. ft, respectively, can produce a distillate of 226.37 ml/ft² or 2.437 l/m² in 5 hours at an atmospheric temperature of 27.5o C and ambient temperature of 34.5o C.

Key words: Productivity, Solar Still, Exposed area to solar radiations, Double Basin

I. INTRODUCTION

A. General Theory of Solar Still:

Energy given to the water raises its temperature from 0o to 100o Celsius (C), and by maintaining that very same energy level, water get vaporized from 100o C of water to vapour at 100o C. Ordinary table salt,, does not turn into vapour until it gets over a temperature of 1400o C, similarly other salts & minerals do not evaporate along with water. This is the way we get fresh water in the clouds and then as precipitation, from the oceans. Solar distillation system is similar to the phenomenon involved in hydrological cycle, just the surroundings can be controlled and conditions can be altered.

- A wide, shallow, baked black painted pan makes an ideal vessel for the water. Baking in the sun for a while before use helps to free the paint from any volatile toxicants, which might otherwise evaporate and condense along with the drinking water. The pan is painted black (or some other dark colour) to maximize the amount of solar energy absorbed. It should also be wide and shallow to increase the surface area, assuming the availability of a substance with good solar absorbing properties and durability in heated salt water.
- To capture and condense the evaporated water, raw water vessel is equipped with some kind of surface close like glass-top or polyethene cover to the heat salt water, which is several degrees cooler than the water. The cover of clear glass sheet or translucent plastic is used to allow sunlight penetration through it, so as to reach the water, is tilted to a slight angle to let the fresh water that condenses on its underside trickle down to a collecting trough. The glass creates a cavity and also holds the heat inside.

B. Process of Solar Distillation:

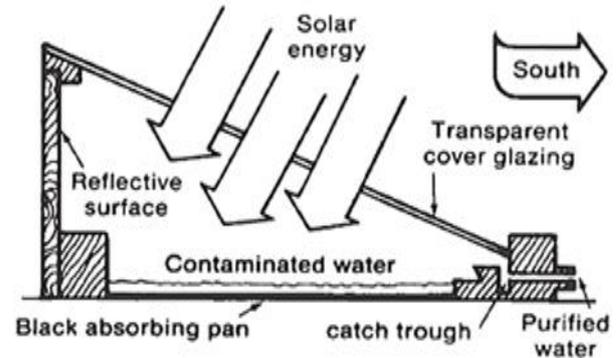


Fig. 1: Design of a Simple Solar Still

Fig.1. shows the solar distillation process, where solar energy/ heat reaches the vessel filled with contaminated water, after passing through a glass cover. Solar energy heats up the brine or contaminated water in a pan and causes the water to vaporize. The vapour rises and condenses on the underside of the cover and runs down into distillate troughs. A technical description of solar still is as follows:

- 1) The sun's energy is in the form of short electromagnetic waves that passes through a clear glazing surface such as glass or polyethene cover. Upon striking a dark surface, this energy changes wavelength and becomes long waves of heat which gets added to the water in a shallow basin below the glazing. As the water heats up, it begins to evaporate.
- 2) The warmed vapour rises to a cooler area. Almost all impurities are left behind in the basin.
- 3) The vapour condenses onto the underside of the cooler glazing and accumulates into water droplets or sheets of water.
- 4) The combination of gravity and the tilted glazing surface allows the water to run down the cover a collection trough, and into where it is channelled into storage.

C. Types of Solar Still:

Solar distillation systems are broadly classified into two groups in terms of energy supply:

Passive Solar Stills : The passive solar still systems are conventional solar still systems that use solar energy as the only source of thermal energy for their operation.

Active Solar Stills : In active solar stills systems, extra thermal energy is supplied to the passive solar still system for enhanced evaporation.

II. HISTORICAL REVIEW

Sharshir, Yang, Peng and Kabeel [1] studied the factors affecting solar still production (climatic conditions, operations and design parameters) and enhancement techniques (wicks, internal and external condensers, internal

and external reflectors, phase change materials, Stepped solar still and a new method improved the solar still yield by using nano particles) has been argued. He analysed that use of sponge cubes in the basin water causes a significant enhancement in solar still production (up to 273%) whereas use of cuprous oxide nanoparticles increases the distilled yield by 133.64 % and 93.87 % with and without the fan respectively.

M.R. Karimi Estahbanati, Amimul Ahsan, Mehrzad Feilizadeh, Khosrow Jafarpur, Seyedeh-Saba Ashrafmansouri and Mansoor Feilizadeh [2] presented a theoretical and experimental model, to observe the effects of internal reflectors in solar still performance. He found that the distillate production can be increased upto 34% by making use of internal reflectors yearly. However, cloud factor can decrease the results significantly.

Mohamed Asbik, Omar Ansari, Abdellah Bah, Nadia Zari, Abdelaziz Mimmet and Hamdy El-Ghetany[3] combined solar distillation still with the heat storage system, using a phase change material (PCM). He used paraffin wax as the PCM to store/retrieve energy in the process of changing the aggregate state from solid to liquid. He highlighted effects of influencing parameters like thickness of PCM medium, ambient air velocity, depth of brackish water, etc on energy destruction. He also suggested the methods to minimize highly destructed energy during sunshine due to presence of absorbers.

A.E. Kabeel, Mohamed Abdelgaied and M. Mahgoub[4] investigated solar air coupled with modified solar still with PCM and carried out comparison between modified still with conventional still. He established that the freshwater productivity for the modified still reached 109% compared to conventional still.

S. Rashidi, M. Bovand and J. Abolfazli Esfahani[5] installed partitions into the still basin to increase number of small sized vortices, that leads to provide sufficient pathway to heat exchange in the still. He observed that there is a rapid change in temperature near the glass cover and the water surface.

Mohammed Shadi S. Abujazar, S. Fatihah, A.R. Rakmi and M.Z. Shahrom[6] enlightened effects of environment, design and operation on the performance of solar still. He analysed that several design parameters can be improved to increase productivity of solar still, like stepped solar stills has increased productivity due to availability of enlarged area for evaporation. Also, if high thermal conductivity material is used for designing still, workability and productivity can be considerably increased. He studied various designs of stills, to analyse the best design.

III. OBJECTIVE OF STUDY

The major objective of the dissertation is to develop a model of Solar still of optimum size, to produce maximum potable water of desired water quality parameters, by varying the input raw water depth over a period of 10 days with temperature records. The major findings of the project would be:

- Identifying the quantity of water obtained
- Identifying the quality of water obtained
- Identifying the change of varying water depths on output water

- Identifying the change in output due to change in temperature
- Identifying the raise in inside temperature of still on hours of exposure under the sun

IV. METHODOLOGY

The aim of the project is to install a water distiller based on solar energy and to study its efficiency at different daytime temperatures during 5 hours of sunlight in the month of July which is cloudy and rainy most of the time. The study also includes the temperature measurement of inside still that enhances the productivity of still because on continuous exposure to sunlight, the temperature and humidity inside the solar still is found to be raised as compared to the outer atmosphere. Water distillation is the oldest known method for water purification and hence, the Betwa river water taken for test is examined for quality parameters before and after distillation to check the efficiency of the project on water purification. The water quality parameters that have been studied under this project are general colour and odour, pH, total solids, total dissolved solids, total suspended solids.

A. Material Used:

- Filter: A gravity rapid sand filter with filtration rate of 20 l/hr is installed before the solar still feed. The filter is composed of layers of coarse aggregate on the top, followed by fine aggregate (sand), wooden coal and cotton at the bottom. The filter takes off the impurities of larger size, objectionable content and particles imparting turbidity to much extent, and allows comparatively clearer water to the solar still.
- Inlet: An inlet is a connecting pipe between container having filtrate and the inner basin of solar still, which can be regulated by a tap. Tap ensures the entry of controlled quantity of water, so as to vary depth of feed water to test productivity of solar still on different depths of water. The inlet is arranged in such a way that it feeds the water into the inner basin, without hindering operations of outer basin. Fig. Shows the location of the inlet provided in the solar still.
- Solar Still Basin : A double basin solar still vessel made up of G.I. sheet of 22 Standard Wire Gauge (0.711 mm) and dimension of 0.6 m x 0.6 m x 0.15 m (or 2 ft x 2 ft x 0.5 ft), which has solid base and top opened to sky was used. The use of G.I sheet is justifiable because it stores energy within in the form of heat, which is beneficial in raising the temperature of the still and the stored heat can also be utilized during shades The basin is named as double basin, because it has two basins, one in another, separated by a wall of G.I. sheet. The inner basin is filled with raw water feed which is to be distilled and the water after evaporation and condensation inside the pyramid shaped plastic cover, runs to the sides and get collected into the outer basin and then through the outer basin to the collector plastic bottle by a outlet hole. The edges of the basin were folded inwards to support the cover of the still and hence to direct condensed water droplets inside the vessel. The Inner basin is preferably painted black with some non-volatile and water resistant paint, to absorb maximum solar radiations and maintain high inner temperature. But, we have used red coloured plastic bag for making the container leak proof. Although the

productivity will get adversely affected by making use of red coloured base, but due to lack of availability of black coloured plastic, we could not use it. Fig. Shows the line diagram of the double basin base of the solar still. The outer basin is left unpainted, because G.I. sheet itself is light/ heat reflecting in nature that is advantageous in working of productive solar still.

- Clear Plastic Cover : A cover of clearly transparent plastic sheet is used as a medium that passes solar radiations into the basin and traps it to raise basin temperature. It also maintains a difference in temperature between inside of solar still and the outer atmosphere. This plastic sheet also allows the water vapours to rest over it and then condenses and directs distilled water droplet to the outlet. The frame of cover is made up of aluminium angle shaped stripes, joined together with a grass frame to support the plastic of the cover. The pyramid shape of plastic is made rigid by using a wooden stick that lies on the basin and supports polyethene cover vertically at an angle of 30o.
- Outlet : An outlet is provided on the base of the outer basin that accommodates distilled water. Outlet hole is attached to a small pipe that takes water from the basin to the collector water bottle. The whole arrangement of solar still is tilted such that the whole of the distilled water gets directed towards the outlet, for better working of the system. Outlet is an important part, because if the water remains in the outer basin for long, it will absorb some amount of heat within the solar still and starts getting evaporated along with the raw feed water. Hence, lowering the efficiency of the still. So it's better to take out distilled water as soon as possible.
- Miscellaneous : There are many other items that are required to fix the assembly altogether, like tape, water tight sealant (M-seal), water sealing tape, silicone gel, etc.

B. Preparation of Model:

- Step – 1: Deciding Location for Installation.
- Step – 2: Preparation of Filter Media.
- Step -3: Fixing Up Inlet.
- Step – 5: Fixing up the cover over basin.
- Step – 6: Gap filling of setup.

V. OBSERVATIONS

Water Quality Parameters	Before Distillation	After Distillation
General Appearance	Muddy, odorous, highly turbid water	Crystal clear water with no odour or turbidity
pH	5 (Acidic)	7 (Neutral)
Total Solid	710 mg/L	7 mg/L
Total Suspended Solid	440 mg/L	0 mg/L
Total Dissolved Solid	390 mg/L	7 mg/L

Table 1: Observation of Water Quality Parameters of Feed water and Distillate Water

Date	Specifications	1st hour	2nd hour	3rd hour	4th hour	5th hour	Total Water	Total Water
6-7-2016	Time	10:	11:	12:	1:3	2:3	206 ml/ft ²	824 ml = 0.824 l
	Outside Temp.	24 0C	26 0C	30 0C	32 0C	27 0C		
	Inside Temp.	27	29	34	39	35		
	Water Product	0 ml/	25 ml/	40 ml/	62 ml/	79 ml/		
14-7-2016	Time	12:	1:1	2:1	3:0	4:0	196 ml/ft ²	784 ml = 0.784 l
	Outside Temp.	29 0C	24 0C	26 0C	29 0C	25 0C		
	Inside Temp.	32 0C	35 0C	37 0C	38 0C	34 0C		
	Water Product	0 ml/	32 ml/	47 ml/	55 ml/	62 ml/		
23-7-2016	Time	12:	1:1	2:3	3:1	4:3	249 ml/ft ²	996 ml = 0.996 l
	Outside Temp.	29 0C	30 0C	28 0C	29 0C	27 0C		
	Inside Temp.	34	37	42	45	39		
	Water Product	0 ml/	49 ml/	67 ml/	72 ml/	61 ml/		
25-7-2016	Time	10:	11:	12:	1:1	2:4	344 ml/ft ²	1,376 ml = 1.376 l
	Outside Temp.	27 0C	30 0C	32 0C	32 0C	31 0C		
	Inside Temp.	36	41	47	49	46		
	Water Product	0 ml/	58 ml/	89 ml/	10 ml/	96 ml/		

Table 2: Comparison between inner and outer temperature; and Amount of Distillate Produced

VI. ANALYSIS AND CONCLUSION

Distillation is known from years to purify contaminated water or saline water at places where availability of fresh water is limited or lacking. The system is the only feasible option of water purification in this modern world that promotes sustainable development by employing no other energy source for its operation. Since the system uses only the energy radiations of Sun as the source of energy utilized for the purification process, it has few limitations over all its advantages. To study advantages, efficiency and limitations of double basin pyramid shaped solar still in the month of July, experiment was conducted on solar still and following are the findings:

- 1) At an average atmospheric temperature of 27.50C, the productivity of a solar still is 226.37 ml/ft² or 2.437 l/m² in 5 hours.
- 2) At an average atmospheric temperature of 27.50C approximately, the observed raise in temperature of the still is 34.50C.
- 3) The distilled water obtained from the solar still is the purest form that can be obtained by any other mean, because all the foreign particles that were imparting colour, taste, acidity and other objectionable characteristics to the water.

4) The Productivity of solar still

$$= \frac{\text{Avg. Distilled Water Obtained}}{\text{Amount of Water Feed}} \times 100$$

[Amount of feed water = 5 l/ 4 ft²; Avg. Distilled water obtained =0.906 l/4 ft²]

The productivity of solar still with surface area having maximum exposure to the solar radiations is 4 sq. Foot and depth of feed water 2 mm at avg. ambient temperature 34.50C and avg. atmospheric temperature 27.50C is 18.12% in the month of July. Low efficiency or productivity is due to low temperature in the month of July and dense cloud cover because of monsoon.

Hence, the designed solar still is suitable for domestic use, especially in the places where the availability of fresh water is low and temperatures are elevated throughout maximum duration of the year. The surface area of the solar still can be increased to gain more efficiency and thus the productivity.

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