Investigation and Performance Analysis of Triple-Effect Solar Still Coupled with Evacuated Tubes

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Abstract: **- Drinkable water is one of the most essential requirements for humanity, and the rise in human population growth has to lead to water pollution to the river and underground water reservoirs. To overcome the demand concerning about potable water, many researchers from all around the world have tried various new technologies. Solar distillation is the simple and cost-effective technology for changing of contaminated water to potable water. In this present research work, efforts are applied to make solar still with enhanced distillate output with the help of attachment of Evacuated tubes. Hence, triple effect solar still has been fabricated and tested to see its performance. Experiments on the present solar still have been carried out for three days in climate conditions of Patan, Gujarat. From the research work, it has been evaluated that, the increment of distillate water production and energy payback time found 700% and 72 days only. It has also found that the present solar still is capable of producing 20 litres of distillate production of water from saline or brackish water. Hence, it is the best solar still for potable water requirement.**

***Keywords*: Triple effect solar still, Evacuated tubes, output**

I. INTRODUCTION

As we all know that, the prime requirement for survival for the human being is Water. The faster economic growth and pressure on value and amount of water reservoirs, mainly in developing country shows the urgent requirement of safe and fresh drinking water. Rapid industrialization is one of the significant causes of contamination of water bodies due to direct discharge of untreated sewage and wastewater into the rivers and lakes. Drinkable water availability is becoming a primary issue in many areas of the world. Use of emerging technologies for the treatment of contaminated water is essential. At in present rising scenario, solar distillation is one of the promising technology have made possible way to gain potable water. In the natural distillation process, solar radiation falls on the water bodies and the water get enough heat to evaporate. Evaporated water to rise high above the surface of the earth and this vapour once cooled then, it results in condensation. Hence, evaporation and condensation are two primary processes responsible for the production of potable water. [1-6].

Solar still is one of cheapest material by which we can get clean water by the process of solar distillation. In other words, merely solar distillation used the heat means (the solar radiation which directly comes from the sun) in equipment to treat and purified the water. This apparatus is called as a solar still, the structure of solar still is elementary, it consists of two things one is shallow basin and a thin glass cover. When solar radiation falls on the water which is present in a basin it heats the water; the water gets evaporated by the evaporation process. [7-10].

The vapours raise (in the form of moisture) it collects and condenses on the glass cover, and these vapours are collected. All the inorganic and organic contaminant including microorganisms are left in the basin. The process of manufacturing a solar still is a cost-effective method and also the cheapest way to get clean water. Solar still is one of the long-lasting techniques to purify contaminated water, by merely built the solar still we can get filtered water in a low cost if it is manufactured and maintained carefully. The operation process of solar still is very easy. Hence no new workforce is required. [11-12].

Solar still is a single basin solar still this is a famous device which is used in solar distillation and desalination for the conversion of available blackish water or wastewater into potable water **[12]. Panchal et al. [13]** found improvement in efficiency and productivity many materials were used like-coupling with reflectors has been used. Parameters can play the vital role in location, solar radiation intensity, and wind velocity, water depth in the basin, solar angle, wind, inclination and most significant heat capacity of still. Whereas active solar still requires the different type of mechanical support for maximum output by making the essential improvement to get the better rate of heat transfer we can obtain enhancement in the distilled production. **Abdel-Rahim and Lasheen [14]** proved that coupling of solar still with parabolic through collector focal pipe heat collector increases the production of solar still 18%. **Rai and Tiwari [15]** have worked on the solar still integrated with flat plate and concentrating collector to improve the efficiency around 24% compared with conventional solar still. **Tiris et al. [16]** proved that coupling of flat plate collector with single basin increases the efficiency 51% compare with single basin. The effect of coupling a flat-plate collector on the solar still productivity in desalination, work was investigated by **Barden et al. [17].** They found enhancement of around 29%

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compared with conventional solar still. **Velmurgan and Srithar [18]** integrated solar pond with conventional solar still to enhance water temperature inside basin. They found 26.6% increment of distillate output compared with conventional solar still. They have also carried out theoretical analysis and compared with experimental study and found impressive similarity in results. **Dimri et al. [19]** evaluated that, the integration of flat plate collector with higher thermal conductivity materials improve the distilled output compare with the single slope solar still. To reduce inner glass cover temperature was determined by **Kumar and Bai [20]** gained that 30% improvement in distillate output compared with conventional solar still. Integration of black wire helical springs have used by **Khaled and Eldalil, [21]** and found 32% increment.

Panchal et al. [22] proved that coupling of flat plate collector with single basin increases the 29%. Single sloped solar still using Lauric acid (PCM) increases the output 36% proved by **Voropoulus et al. [23].** Solar still integration with evacuated tube collector increases the output 40% solar still. An experimental investigation on single basin solar still the improvement with evacuated pipes have used by **Sampathkumar [24].** He found 49.7% increment in the production of water compared with conventional solar still.

From the literature review, it has been found that the distillate output improvement is required in solar still. Many researchers have introduced various devices like flat plat collector, Evacuated tubes, parabolic trough collector etc. But the design of solar still requires attention along with the use of above tools with it. Hence, the primary aim of the present research work is to fabricate triple effect solar still with Evacuated tubes and tested in climate conditions of Patan to see its performance and increase distillate output.

II. OPERATING PRINCIPLES

During day time solar radiation falling on the solar still as well as evacuated tubes. Lower basin of solar still supplies cold water into the evacuated tubes, hence it will undergo hot water from the evacuated pipes and hot water would go to the lower basin. This process will be continuing for producing hot water in the lower basin.

Lower basin water evaporated into water vapour and condensed in the lower stacked tray and produces potable water. Latent heat of lower basin will evaporate water inside the middle basin, and water vapour of central basin condenses on the lower portion of the upper stacked tray. Some amount of latent heat will evaporate water inside the upper basin, in which solar rays are also entrapped for producing steam and potable water. In all basins, raw water quantity remains same all time. Hence, distillate output is obtained from all three basins.

2.1 Experimental Procedure

During starting of research work on solar still, water is filled in the storage tank after that basin is filled up to 3 cm of height on night time through the inlet pipe which is directly connected to the upper basin. The glass, which covers the top basin, is cleaned daily in the morning for removal of extra dust and particles which is deposited on the upper surface of glass before stating the setup. The experiment setup was set in the November and March month from 10 to 24 November 2015 and 10 to 30 March in 2016. The reading was recorded and taken from morning 9 am to evening 6 pm. The important variables in present research work like basins water temperature (Tw), the upper surface temperature of glass (To), evacuated tube outside temperature(Teo), ambient temperature (Ta) and solar radiation on the still (Ig) and output.

Fig. 1. Pictorial view of experimental setup

2.2 Experimental Structure

The experimental structure was assembled in the Solar energy laboratory developed by Government Engineering College Patan, Gujarat. Primary elements mandatory for the experimental structure are triple effect solar still with evacuated pipes. Fig.1 exhibits the Pictorial view of triple basin solar still with evacuated tubes. The water in the solar still is gained heat by two kinds of heat causes. One cause is the Evacuated tubes attached to lower side of solar still with dimensions of Φ0.1 m ×1.88 m, and the other is the black colour paint coating on the upper surface of the top stacked tray which can absorb the sunlight and heat the water. An insulation of glass wool is provided at the outer side of the basin to prevent the heat loss as it is good to control loss of heat. Distilled water inner and outer side was condensed by glass cover with 4 mm thickness, and the glass cover was toughened by black colour silicon tap with solar still to prevent the heat loss by the sides of solar still. Condensed distilled output was collected in the collecting tanks. Which is represented by extracted output 1, purified output 2 and distilled output 3. Total 3 holes are made in three basins for the thermocouples. Here, 25 evacuated tubes are coupled in the lower basin. Plastic cone cups are used to attach the

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evacuated tubes with stand. Range, accuracy and percentage of errors of measuring instruments are taken from reference [26].

III. RESULT AND DISCUSSION

An experimental setup was set in the month of November 10/11/2015 to 24/11/2015 and in March 20/03/2016 to 30/03/2016. The observation was monitored and analyzed on daily basis Daily Total by 15 days regular monitoring in November show that the maximum distilled output was recorded 15, 16 and 17 November, 2015. The main reason for choosing of three days is that; the average global solar radiations are found nearly same during above said three days. 10 days routine monitoring in March shows that the maximum distilled output was recorded in 23, 24 and 25 March. Therefore, for further study, these three days in November consider for detail study.

3.1 Effect of Ambient temperature and solar intensity with time on triple basin solar still.

Solar still distilled output is directly depending upon the weather condition of that place and time. The ambient temperature and solar intensity play a key role in the distillation process. Figure 2

The basin temperature was recorded maximum at 12 pm to 3 pm. The solar radiation gradually increases from early morning to 1 pm due to brilliant sun and then cut back towards evening due to low sunshine. It gets to maximum value of 900 W/m^2 on 17/11/2015 at 1:00 pm. But the variation in ambient temperature was found as its minimum 17°C at early 9 am morning in 17/11/2015 and gained the maximum of 25 °C at 2pm on 16/11/2015 and 26 °C on 17/11/2015, but on 15/11/2015 the ambient temperature was maximum at 1:00 pm found 27 °C.

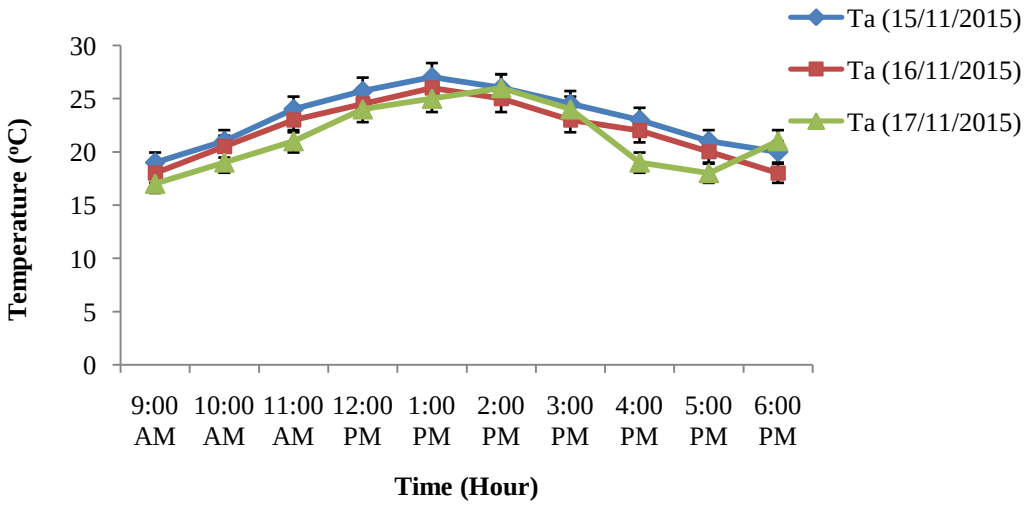

Fig.2 Variation of ambient temperature with time

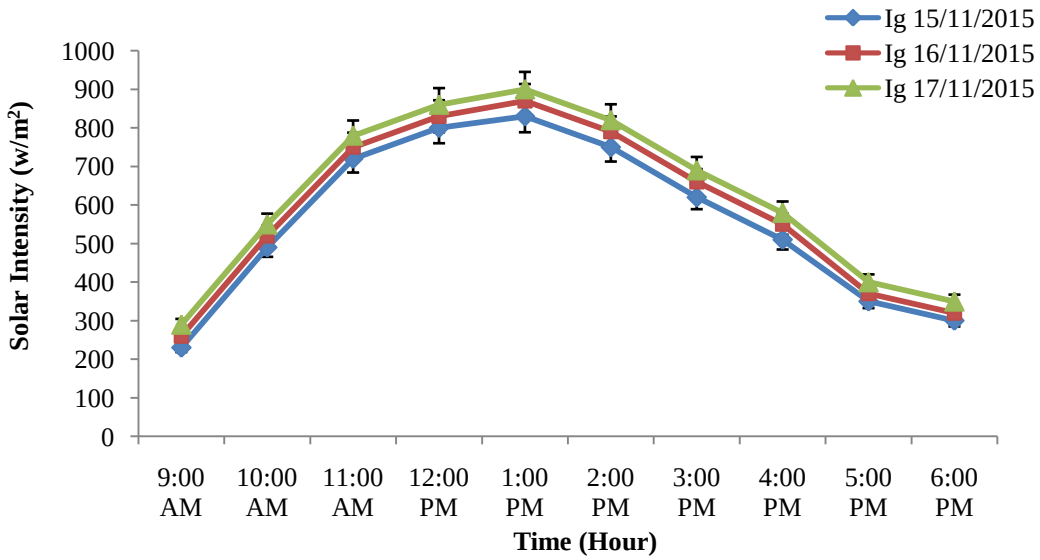

Fig.3 Variation of solar radiation with time

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3.2 Enhancement in the of distilled output coupling with evacuated tubes.

The distillate water increases from 2 pm to 5 pm. It reaches a maximum value of distillate water 1670 mL during 5 pm on 15/11/2015 and the minimum amount of 843 mL during 3 pm on 17/11/2015. The maximum value of water was found on 16/11/2015, and the minimum value of water was found on 17/11/2015.

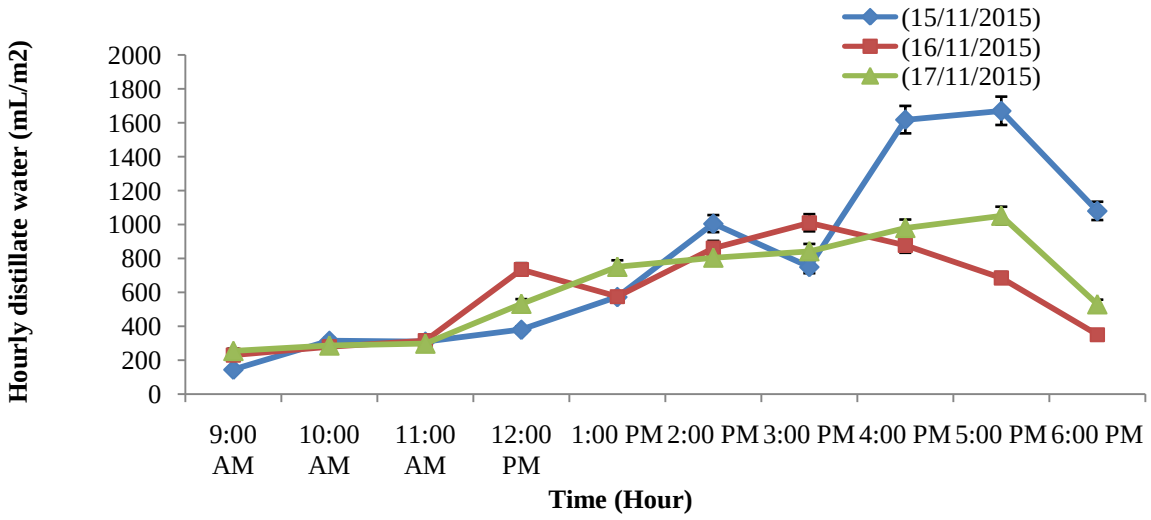

Fig. 4. Hourly variation of distilled output with time

3.3 Total (Day & Night) Distilled water output

The slight variation of distilled output in sun-shine and off-sunshine hours was recorded on 15/11/2015, but in 16/11/2015 and 17/11/2015, the extracted output was maximum at night time

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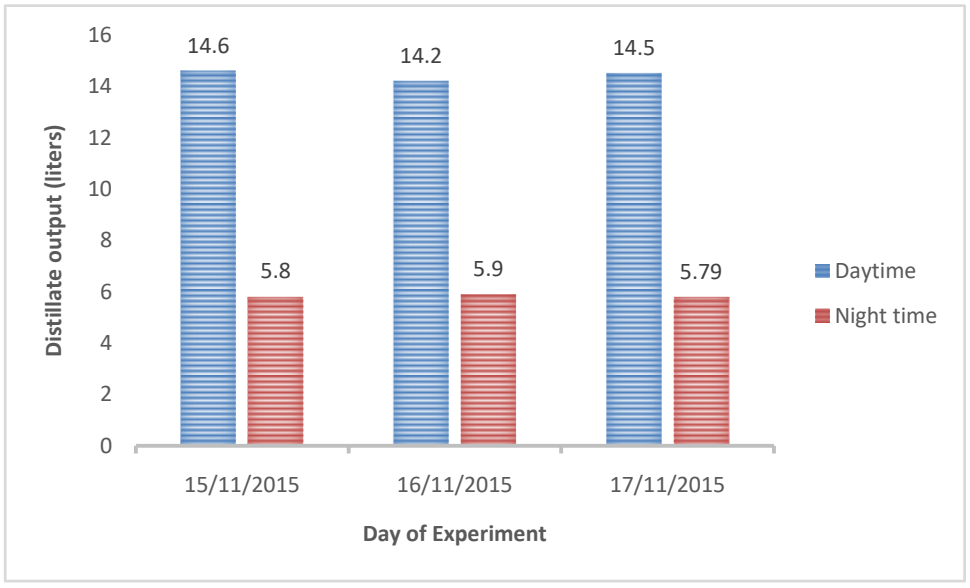

Fig.5. Day and night collection of distilled water

3.4 Comparison of output efficiency of present research work

Before current solar still in the market, the comparison study is required. It gives the idea of present work compared with other researchers work. Table 1 shows the comparison of various researchers works compared to present research work in terms of increase in distillate output of water. For comparison with other researchers work, average distillate output of conventional solar still is take as 3 liters.

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Sr. No.	References	Experiment work Type of Augmentation with solar still	Increase in distillate water (%)
1	Rai *et al*., 1983	Single basin Solar still coupled with Flat plate collector	18
2	Adbel-Rehim *et al.*, 2007	Experimental and Therotical Analysis solar still Augmented with Parabolic collector	24
3.	Velmurgan and Srithar, 2007	Solar still Integrated with a Mini Solar Pond ,	26.6
4	Badran *et al*., 2005	The effect of coupling a flat-plate collector on the solar still productivity. Desalination	29
5	Kumar and Bai, 2008	Solar still condensation	30
6	Srithar, 2010	Solar still coupled with activated carbon and methanol with sponge and sand	32.32
7	Panchal, 2013	Actual performance analysis of flat plate collector coupled with passive solar still with Flat plate collector	36
8	Sampathkumar, 2013	An experimental study on single basin solar still augmented with evacuated tubes	49.7
9	Panchal *et al*., 2014	Enhancement of distillate output of double basin solar still with vacuum tubes	266.67
10	**Present work**	**Triple basin solar still with Evacuated tube collector**	**700**

Table 1 : Comparison of various researchers work on solar still in terms of percentage of distillate output

IV. ECONOMIC ANALYSIS OF THE SOLAR STILL

Payback period of triple basin solar still coupled with evacuated tubes depends on the various cost like- cost of fabrication, cost of feed water maintains and operating cost and also the financial subsidy are offered by the Government. Table 2 Shows the economic analysis of solar still.

₹1 USD	INR. 63 (Assume)
Cost of Fabrication	₹-19640
Cost of Operation	₹-5/day
Cost of Maintenance	₹-5/day
Feed water cost	₹-1
Cost of distilled water	₹12/Litre
Cost of water produced / day	₹-264/day
Subsidized cost given by government	4% = ₹-785
Net profit = (Cost of water produced / day) –Cost of Operation – Cost of Maintenance - Cost of feed water	₹253.
Payback period = (Investment - Subsidized cost) / Net profit	74 Days

Table 2 : Economic analysis of solar still

V. CONCLUSION

In the growing realization of relationship between human wellbeing and water pollution, it is necessary to undertake regular monitoring and surveillance of chief ecosystem to control the pollution. Among the number of treatment technology solar distillation is the best, environmental friendly, reliable and cost-effective way for treatment of contaminated water. Present research work shows design, fabrication and analysis of a new solar still with enhanced condensation surface, which applies the corrugated shape structure to decrease the condensation resistance and increase the freshwater yield and treat the contaminated water from solar energy. From the research work, following points are concluded:

- Design and development of solar still with modified three basins increase the output.
- The present solar still can generate freshwater not only in the daytime but also in the night, with maximum freshwater yield amounting to 20 liter.
- Present solar still is not only producing the distillate water from the lower basin but also from top and middle basin. Hence, distillate output will be remains higher as compared with conventional solar still.
- Evacuated tubes coupled with lower basin, hence lower basin temperature always remain higher compared with middle and upper basin. It provides thermal force to transfer heat from lower basin to middle and top basin to get higher distillate output.
- Presence of maximum amount of solar intensity and ambient temperature increases the distilled output.

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- Present solar still increased distillate output around 700% compared with conventional solar still distillate output.
- Temperature of water is not only remains higher during sunshine hours but also in night time. Hence, present solar still provides continuous supply of fresh water from day to night.
- After the experiment this distilled water can be utilized as potable water.
- This technology can be referred as environmental friendly and low cost technology for water purification

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