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Performance analysis of single slope solar still using sensible heat storage material

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Direct sunlight has been utilized long back for distillation of water. For supplying desalinated water to small communities nearby coastal remote areas solar distillation plants are used. Solar stills are easy to construct, can be done by rural people from locally available materials, simple in operation by unskilled personnel, no hard maintenance is required and almost no operation cost. In order to increase the efficiency of a solar still sensible heat storage materials such as marbles, pebbles, blue metal stone, basalt stone etc. We have used to improve the efficiency of solar still. While using the sensible heat storage material distillation process will continue in both day and night.

Keywords: Solar still, Solarimeter, Thermocouple, Galvanized iron

1 Introduction

Solar still is an eco-friendly, small scale, cheap equipment which utilizes the natural solar energy and it's the best solution to purify water, fresh water indispensable for the survival of humankind. Although water covers approximately 70 % of the world; more than 90 % of the water constitutes salt water that is not suitable for drinking. Apart from human consumption, water is also needed for industrial and agricultural purpose. With increases in population and industrial growth, the corresponding increase in fresh water consumption has inevitably led to a worldwide imbalance between demand and supply of fresh water. This is made worse by the fact that most of the available water is naturally impure or not drinkable and requires treatment.

A solar collector and a solar still integrated with each other are classified into active and passive still. Single and double basin stills are the different types of solar still named based on their construction. In single solar basin stills, only part of the solar intensity absorbed by the basin liner is used for distillation while the rest is lost to the environment. Places where there is an sample supply of both solar radiation and brackish water will allow the production of reasonable amount of potable water at economical costs via solar still that are easily constructed and relatively cheap. In Iran, the urgent need for fresh water is concentrated in the south regions, since the transportation of fresh water to these areas is difficult and not economic by the impact of the saltwater, distillation is one amongst the vital strategies of obtaining clean water from brackish and seawater using the free energy supply from the sun. Phase change material (PCM) which has high latent heat storage capacity and high diffusivity helps us in better productivity of desalinated water. The amount of desalinated water was more with Phase change material as compared to that without Phase change material. The percentage increase efficiency by using the Phase change material as energy storage material was found to be around 10%[1].Maximum output of single effect solar still is about 5 L/m^2. This output can be increase by using wick, sponge, jute cloth etc. up to 6.5 L/m^2. Day. Fins, pebbles, corrugations are another way to improve the productivity and performance of the solar stills Latent heat storage is additional engaging than wise heat storage.. In addition, nanoparticle with Phase change material is specially promising for heat storage[2].As temperature difference between basin liner and inner glass surface increases distilled output is increases. For best distilled output small frontal height between 50-70 mm is maximum suited[3]. Combined sensible latent heat TES configuration is performance wise more optimized and cost-competitive among the considered thermo cline storage prototypes for the same design requirements and operating conditions. However, more work is needed to explore the full potential of hybrid TES configuration for medium temperature applications[4]. The still was also modeled using fluent for high and low solar intensities and shows that for high

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intensity the difference in temperature region is more. Thus the modeling agreed with the experimental and theoretical results[5].Insulting the solar still box with the thermacoal and aluminum sheet also increases the evaporation process carried out under the solar still box. The black painting inside the solar still box also increases the efficiency by 5 %. When the overall efficiency of the solar still was calculated between the normal water and nanofluid there was 5 % increment in the nanofluid efficiency as compares to normal water[6].The efficiency of the double slope single basin solar still is increased when coupled with shallow solar pond. It has shown great potential in terms of higher distillate yield per unit area and its operation process is very steady. The maximum instantaneous efficiency of the solar still coupled with and without shallow solar pond was found to be 48 % and 65 %. The solar still can be used as a water purifier for domestic purposes by using solar energy in winter and summer seasons[7].The productivity of the still can be enhanced by varying the declination angle and it is observed that as the solar radiation increases the temperature in the still also increases and as a result the productivity increases remarkably[8].The effective temperature difference between water and glass improves the yield of solar still. Whereas analyzing the yield of solar still with energy storage the temperature distinction improves by 80 % as compared to the solar still with none heat storage[9].The maximum energy efficiency from conventional solar still at the same equivalent water mass of 20 kg is found as 5 %. With possible increase in the water mass, the energy efficiency from the solar still increases as there is an equivalent amount of energy stored by higher water mass which increases the yield and energy from solar still[10]. Semi permeable membrane and a solar pond enhance the productivity of a single slope single basin solar still with reflecting mirror. The payback period of the overall experimental setup was 200 days. By the combination of semi permeable membrane and mini solar pond reduce salt accumulation in solar still. Solar pond coupled with the still are experimentally investigated on a clear, partially cloudy and cloudy days and found that clear day has the maximum productivity[11].The daily yield of solar distillation system has a direct influence by the heat storage capacity and thermal conductivity of the phase change material Phase change material (Paraffin wax) which is reserved beneath the basin liner. Hence, solar still performance has been studied in terms of yield by using nano-composite phase change material (paraffin wax and Al_2O_3) and a considerable change was observed change in the yield increased[12]. The addition of heat storing materials improves the efficiency of the solar still compared to without the heat storing materials Absorbing materials like black rubber mat, black ink and black dye enhances the productivity by 38 %, 45 %, and 60 %. While increasing the free surface area of water with baffle suspended absorber plate the productivity increased from 18.5 to 20 %[13].Solar still continues to produce the fresh water by converting mud water. The distillate production is said to be increased to 10-25 % with Phase change material. The energy storage materials within the still store hefty quantity of warmth throughout noon hours and release the stored heat to the basin water in the late afternoon hours when radiation is low, and are found to influence the temperature of the solar still components considerably[14].The use of Phase change material as storage material in solar still results in increased distilled water output of about 2 % with 1.5 cm of water depth and 1.96 % for 2 cm water depth[15]. Solar still productivity also increases by use of reflectors, Black Pebbles & Phase change material[16].The copper solar still is modified with black paint coating, pebbles, fins, and finally with vacuum. Black paint coating, pebbles, and fins were used and the output of the still is increased significantly[17].Sensible energy storage mediums (Al turning) of different masses (3 kg and 5 kg) were used in basin of single slope solar still to increase the daily productivity of the still[18].A single slope passive solar still with heat reservoir was fabricated which could be used during night time also. With Phase change material as heat storage material, an improvement of 28 % in the distillate production is obtained compared to normal solar still[19].The solar still with Al basin material was found to show the highest freshwater production[20].As temperature difference between Basin liner and Inner Glass Surface increases distilled output is increases[21]. The role of solid, sensible heat storage materials in the still improves productivity by 84% than conventional still[22]. Observed that the productivity of the wick type solar stills can be improved by integrating the solar stills with fins by enhancing the heat transfer coefficients to around 53 %. The daily yield of the distilled water can be increased by around 14 % to 34 % by using various inclination angles and reflectors in the solar stills[23].The presence of phase change material negatively affects the daytime freshwater productivity with a significant increment in the overall freshwater yield of the still[24].

2 Experimental Setup and Materials used

2.1 Experimental setup

The experimental setup is shown below in Fig.1 in which solar still is made up of galvanized iron sheet of required size that is made into six steps of same size. The top of the basin is covered with transparent 5 mm window glass for condensation purpose inclined by nearly 23°-30° angles which is equal to the latitude of the location. The dimensions of solar stills are 49.5cm inner length, 43.5 cm inner width, and 58cm outer length, 58cm outer width as shown in table no.1. The whole setup is insulated by using glass wool of thermal conductivity 0.038 W/m K to minimize heat losses. The absorbing plate is painted with black colour so it will be better to absorb the maximum amount of solar radiation falling on them and convert it in to the heat. Solar radiation intensity and ambient temperature have been measured with solar radiation monitor and digital thermometer. The experiments were conducted at Coimbatore Institute of Engineering and Technology Coimbatore. The entire assembly is placed on a stand structure made up of cast iron. A pipe with storage container is fixed for outlet. To change the water in stills provisions are made. The experiment was carried out with water depth of 1, 2.3 cm each day. During the experiment the solar radiation at the still plane, ambient temperature and water temperature and portable water generated were also measured at a time interval of 60 min from 8 AM to 5 PM. A cross section pipe of diameter 6 cm of length 1.5 m is used to carry down the pure condenses water from the solar stills to the collecting container which is provided outside the solar still.

Table 1 — Dimension of Solar Still.

	Length (cm)	Width (cm)
Inner	49.5	43.5
Outer	58	58

Fig. 1 — Experimental setup of single slope solar still.

2.2 Sensible heat storage materials used

The still which have sensible heat storage material gives higher efficiency when compared to conventional still because the sensible heat storage materials emits the heat when the solar intensity is low. So the still works for a long period of time. Sensible heat storage material used here are pebbles, blue metal stone, kadappa stone, bricks, granite, marbles as shown in Fig. 2.

2.3 Selection of sensible heat storage materials

The materials are selected by using following parameters

2.3.1 Size of material

The size of materials is varied for optimization purpose. Each material are made into four different sizes of 5 mm, 10 mm, 15 mm and 20 mm.

Fig. 2 — Sensible heat storage material.

2.3.2 Quantity of material

There are four different quantities of material used. Each material is collected in four different quantities such as 500 g, 1000 g, 1500 g and 2000 g.

3 Results and Discussion

3.1 Optimum experiment condition with yield

Design of experiment consists of set of experiments which is the setting of several products or process parameters to be studied that are changed from one experiment to another. Design of experiments is also called matrix experiments. Parameters are called factors and parameters settings are also called levels. The important technique in conducting matrix experiment is orthogonal array. It offers additional reliable estimates of issue effects with fewer numbers of experiments when put next with the standard ways like one issue at a time experiments. Taguchi methodology involves the determination of enormous variety of experimental state of affairs, described as orthogonal array, to reduce errors and enhance the efficiency and reproducibility of experiments.

The columns of an orthogonal array are wise orthogonal that is for every pair of column, all combination of factor levels occur at an equal numbers of times.

The columns of an orthogonal array represent factors to be studied and the rows represent individual experiments. This study is associated with five factors with each at four levels. The orthogonal array used to find the effects of four parameters namely the water quantity, depth of water, size of the material quantity of the material. Orthogonal array used to design experiments with five parameters at four levels, L-16.

The variation of glass temperature, vapour temperature, water temperature, side wall temperature and base plate temperature of time versus temperature for different heat storage materials have been graphically represented in Figs 3-20. Figures 21-23 represent water collected with sensible storage materials per day at different water level.

3.2 Effect of water depth

By using Taguchi method it has been found that the water depth of 10 mm gives the optimal output, this is because of the fact that at lower depth the evaporation rate of water will be high. Surface area between water and sensible heat materials is high so the evaporation rate is also high.

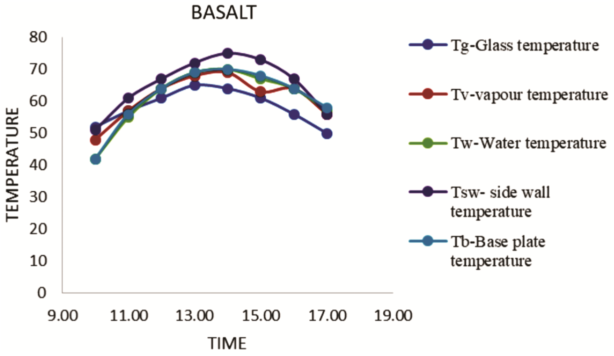

Fig. 3 — Graphical representation of basalt stone with 10 mm water level

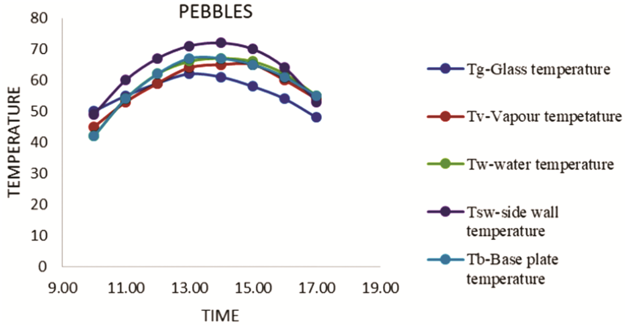

Fig. 4 — Graphical representation of pebbles stone with 10 mm water level

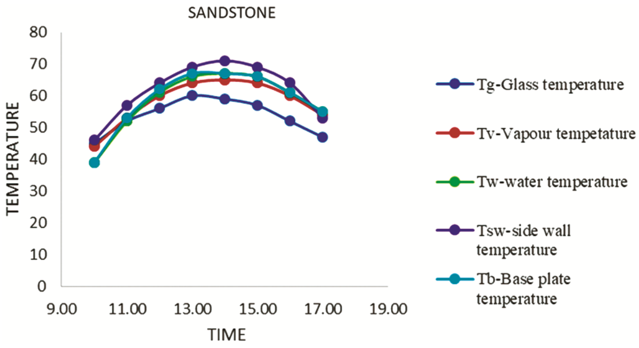

Fig. 5 — Graphical representation of granite stone with 10 mm water level

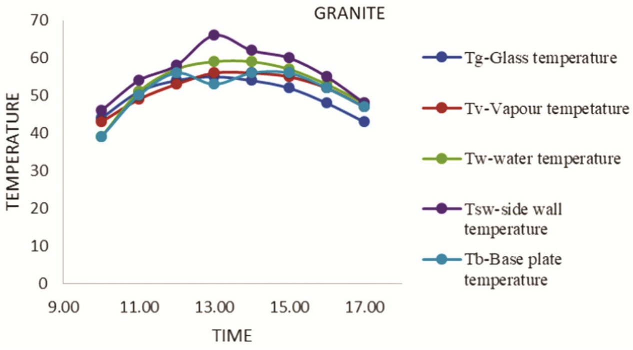

Fig. 6 — Graphical representation of sand stone with 10 mm water level

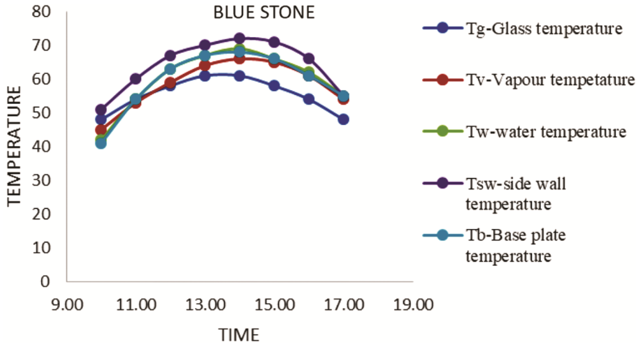

Fig. 7 — Graphical representation of blue stone with 10 mm water Level

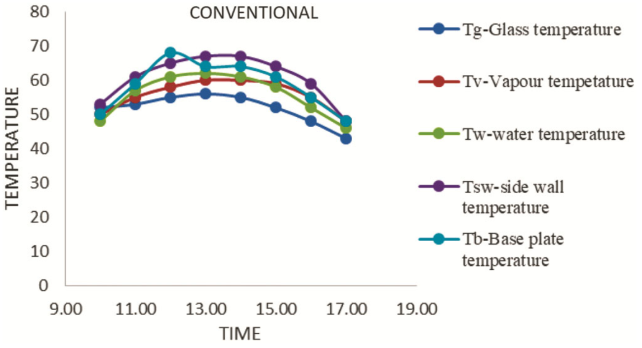

Fig. 8 — Graphical representation of conventional with 10 mm water level

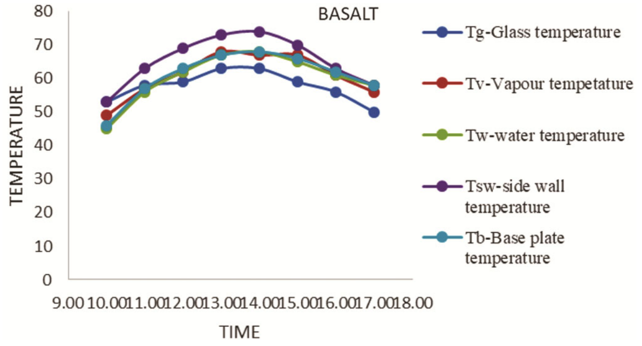

Fig. 9 — Graphical representation of basalt with 20 mm water level

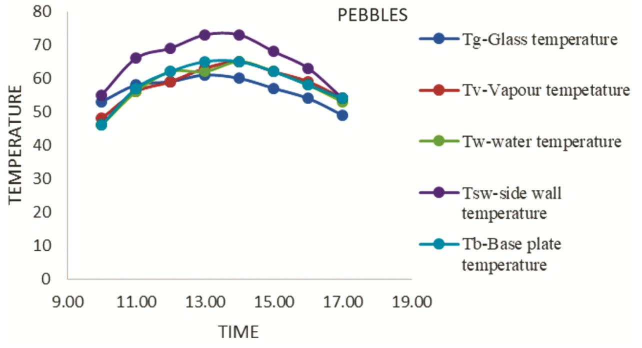

Fig. 10 — Graphical representation of pebbles with 20 mm water level

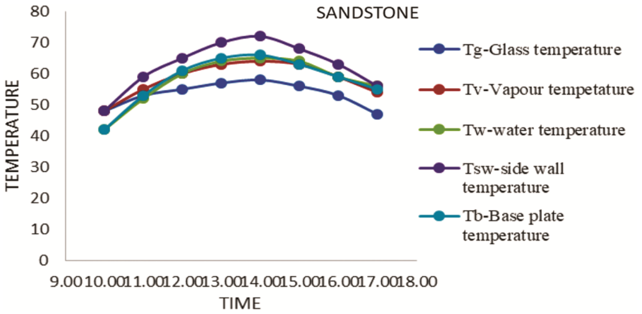

Fig. 11 — Graphical representation of granite with 20 mm water level

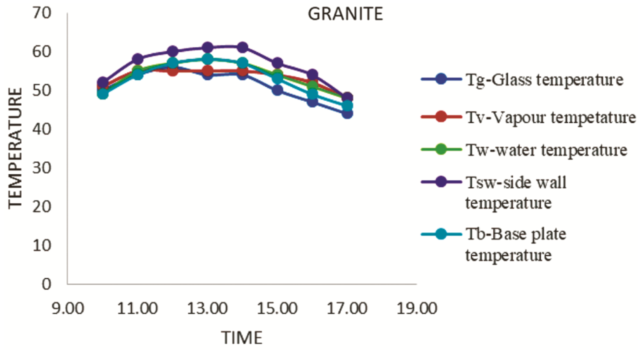

Fig. 12 — Graphical representation of sandstone with 20 mm water level

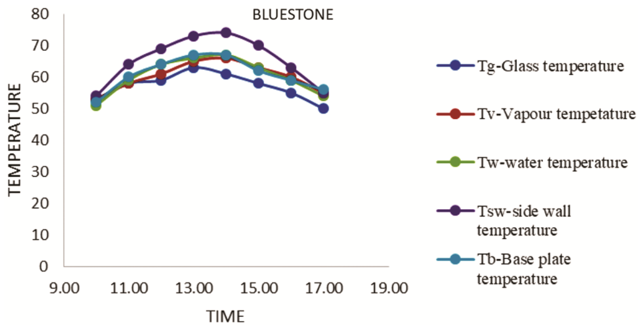

Fig. 13 — Graphical representation of blue stone with 20 mm water level

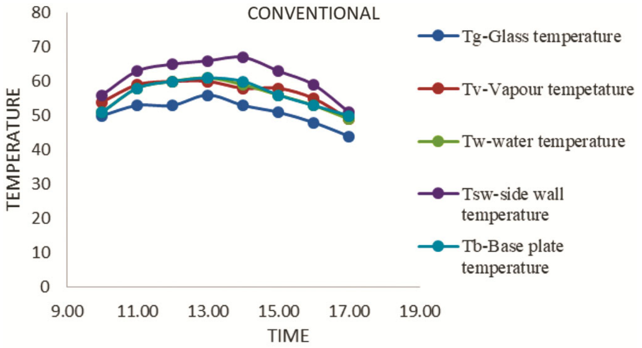

Fig. 14 — Graphical representation of conventional with 20 mm water level

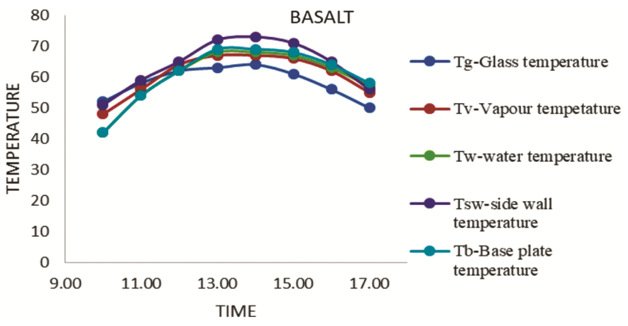

Fig. 15 — Graphical representation of basalt with 30 mm water level

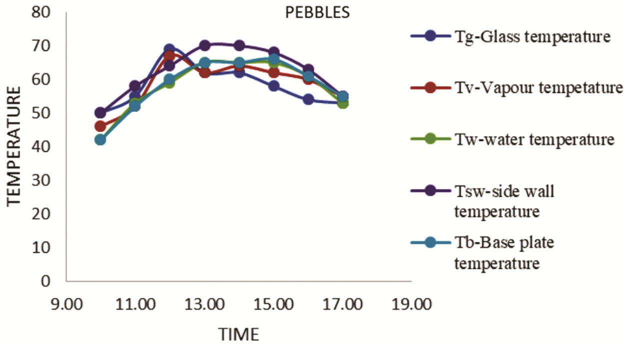

Fig. 16 — Graphical representation of pebbles with 30 mm water level

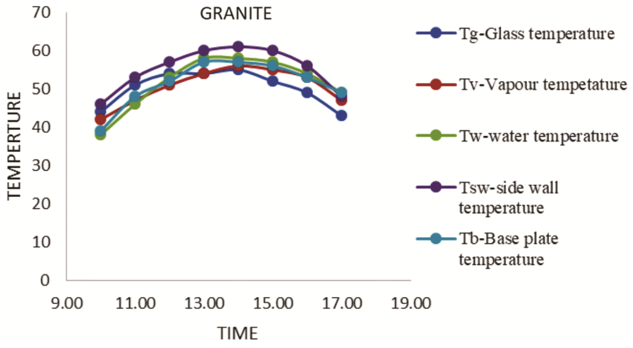

Fig. 17 — Graphical representation of granite with 30 mm water level

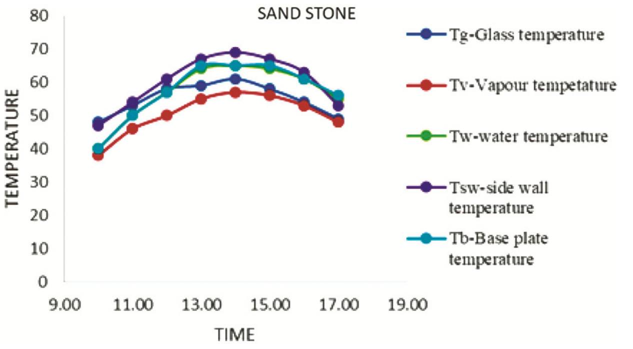

Fig. 18 — Graphical representation of sandstone with 30 mm water level

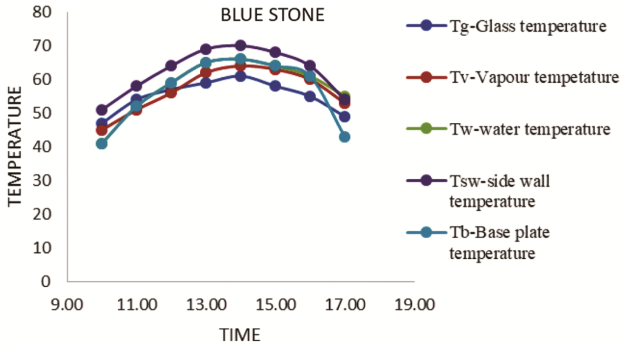

Fig. 19 — Graphical representation of bluestone with 30 mm water level

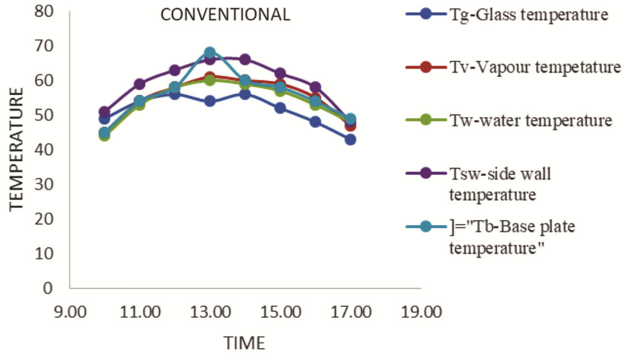

Fig. 20 — Graphical representation of conventional with 30 mm water level

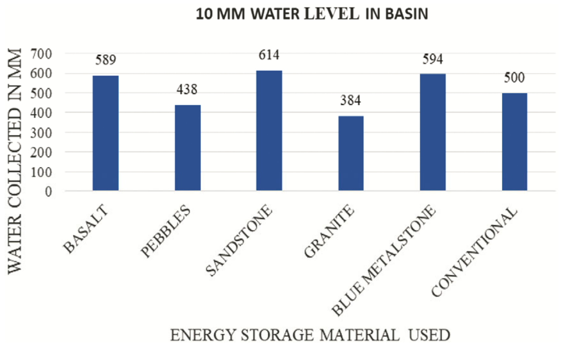

Fig. 21 — Water collected with sensible storage material per day with 10 mm

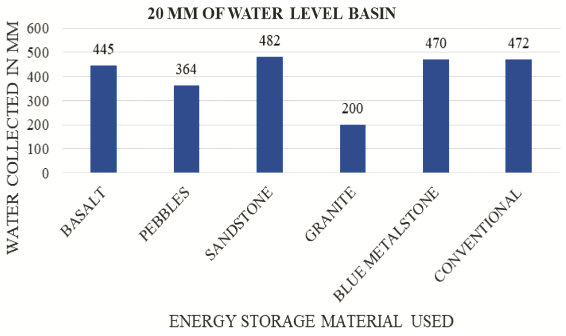

Fig. 22 — Water collected with sensible storage material per day with 20 mm

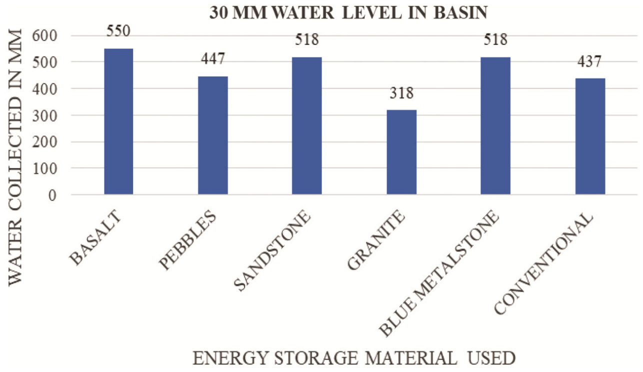

Fig. 23 — Water collected with sensible storage material per day with 30 mm

3.3 Effect of type of material

It has been proved that basalt stone material gives higher efficiency as a sensible heat storage material this is due to the high thermal energy storage property. Since the material has high quick response property sensible heat is high.

3.4 Effect of size of the material

As per taguchi method, 15 mm size of the material is considerably more optimum. This is because of the optimal surface contact between sensible heat storage material and water. Size of the material influence the surface area contact between the water, so we need to use optimal size.

3.5 Effect of quantity of material

As per Taguchi method, 500 g of sensible heat storage material gives higher yield, this is because of the fact that lower the materials quantity higher the volume of water in the still. Total maximum quantity of material stores the maximum thermal energy for constant water depth area of still, it gives higher efficiency.

Eventually the output of the solar still is increased by hour by hour in the mid period of 12:00 a.m. to 3:00 p.m.From about 3:00 p.m., water temperature start decreasing due to the decreasing of solar radiation. It may be noted that the basin temperature gets nearer to the water temperature, being continual contact between them that results in heat equilibrium. Because the glass temperature is far below the vapour temperature, it causes condensation of vapour on the glass. Increase in the solar intensity in the early morning until it reaches the maximum at around 12:00 to 2:00 p.m., and then decreases in the late afternoon. The solar still productivity has an important effect on the solar intensity. The productivity increases due to the increase as the solar intensity increases increase in heat gain for water vaporization inside the still.

4 Conclusions

The present study gives the performance of solar stills using different sensible heat storage materials. A maximum yield of 550 ml was obtained using basalt stone material at 30 mm water depth, 1000 g of material quantity. The parameters are optimized by using Min tab software (Taguchi method).In order to get higher efficiency the following parameters need to be followed. The water depth of 10 mm, sand stone material, 15 mm size and 1000 g quantity of material. These parameters help in higher output at reduced cost and energy usage.

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