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EXPERIMENTAL INVESTIGATION ON ENHANCEMENT OF SINGLE BASIN DOUBLE SLOPE SOLAR STILL PRODUCTIVITY BY VARYING DIFFERENT OPERATIONAL PARAMETERS

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ABSTRACT
Energy and water are necessity of mankind that influences the development of any nation. The availability of drinking water is reducing day by day due to population growth and pollution caused by industrial waste whereas the requirement of drinking water is increasing rapidly. To overcome this problem there is a need for some sustainable source for the water distillation (purification). Solar energy technologies are rapidly growing industries because it is one of the most reliable and readily available energy sources in the enhancement of the productivity of the solar desalination system, in a certain location, could be attained by a proper modification. In this paper, experimental investigation on double slope single basin solar still has been done for climate condition of Bhopal, Madhya Pradesh, India (latitude23°2599′N; longitude77°4126′E) during full day, 06:00 a.m. to 06:00 p.m. This work aims to augment the distilled water productivity of a modified double slope single basin solar still by implementing various operational parameters. The performance of the solar still with various modification such as increasing free surface area of water by sponges, increasing water glass temperature difference, varying depth of water surface, incorporating different types of phase change materials(PCMs) in basin water has been observed, recorded, and compared with conventional still.

KEYWORDS: Energy, Water, Thermal, Solar, temperature, Productivity.

1. INTRODUCTION
Energy and water are necessity of mankind that influences the development of any nation. Today, the production of fresh drinking water is a serious problem. The scarcity of clean and pure drinking water is common in many developing countries. Water from various sources cannot be used for drinking purpose due to often brackish (i.e. contain dissolved salts) and/or contains harmful bacteria (Montgomery 2001). In addition, there are many coastal areas where seawater is abundant but potable water is not available in sufficient quantity. Pure water is not only used for drinking purpose but also useful for health and industrial purposes such as hospitals, schools and batteries etc. Almost 90 % of the health problems in rural areas is due to the contaminated drinking water (Myers 2000). Fresh water resources are becoming scarce due to population growth and pollution caused by industrial waste. Out of 40–50 litres per capita per day (lpcd) of water requirement for domestic consumption, only 2 lpcd is the drinking water. For drinking and cooking purposes amount of 5–10 lpcd water is needed and thus, it is only this quantity of water that needs to meet the stringent quality standards of potability prescribed by W.H.O. or other similar agencies, whereas the remaining amount of water needed for washing and cleaning can be of intermediate quality. Therefore, for economical and sustainable water management system, it is important to supply water at appropriate level of quality, which is suitable enough for the kind of use for which it is meant (Nafey 2002, Sarı A 2003, Shukla SK 2005). Over 1 billion people are without clean drinking water and approximately 2.3 billion people (41% of the world population) live in regions with water shortages (Service 2006). Desalination, a technology that converts saline water into clean water, offers one of the most important solutions to these problems (Gleick 2008). Fresh water is defined as containing less than 1000 mg/L of salts or total dissolved solids (TDS) (Sandia 2003). Presently, the total global desalination capacity is around 66.4 million m^3/d and it is expected to reach about 100 million m^3/d by 2015 (GWI 2009). The five world

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leading countries by desalination capacity are Saudi Arabia (17.4%), USA (16.2%), the United Arab Emirates (14.7%), Spain (6.4%), and Kuwait (5.8%) (Khawaji et al. 2008).

Solar stills can provide a solution for those areas where solar energy is available in plenty but water quality is not good and hence can be used for producing drinking water. Solar stills are cheap and having low maintenance cost but the problem of solar still is the low productivity (Duffle 1991). It can be used for low capacity and self - dependence water supplying systems because it produces drinking water by solar energy only, and do not need other energy sources such as fuel or electricity.

There are many methods for converting brackish water in to potable water (Sukhamte 1987). Some of the water distillation ways are described as: In desalination thermal energy is used to evaporate the brackish or saline water, and resulting steam is collected and condensed as final product. Vapour compression is the process of distillation in which water vapour from boiling water is compressed adiabatically and vapour gets superheated. This superheated vapour is first cooled to saturation temperature and then condensed at constant pressure and these pressures are derived by mechanical energy. Reverse osmosis is the process in which saline water is pushed at high pressure through a special membrane which allows water molecules to pass selectively and do not allow to pass dissolved salts. In electrolysis method, water is passed through a pair of special membranes, perpendicular to which there is an electric field. Water does not pass through the membranes while dissolved salts pass selectively.

2. IDENTIFICATION OF PROBLEM

Solar still technology was first developed in 1872 by Carlos Wilson. In 1920, Kaush used metal concentrators to focus solar energy on brackish water to improve the performance of the still. An efficiency of 50% was achieved, and these results were later confirmed by Pasteur in 1928 (Sodha 1983). In 1930, Abbot used cylindrical parabolic reflectors for focusing solar energy onto tubes containing polluted water. The system worked with an efficiency of 80% (Daniels 1964). Lof, in 1961, investigated the performance of single basin stills with respect to variations in solar radiation, ambient temperature, area of cover, wind velocity, and water depth (Sodha et al. 1983) and his investigations revealed that productivity increased with increased solar radiation and that productivity also increased with increased ambient temperature. Direct variation between solar radiation and the performance of solar stills was later confirmed by Akinsete et al., in 1969 (Sodha et al. 1983). However, Akinsete et al., in their research of 1969, proposed that the effect of energy losses from the still is less significant at higher ambient temperatures. (Cooper 1969) studied the effect of water depth on productivity of solar stills and found out that productivity decreases with increased depth. This is in agreement with Lof's results of 1961. However, there is no mention of optimum depths needed for the still to function most efficiently. Bloemer investigated the effect of angle of inclination of the cover on still productivity in 1965 and found out that the still's performance was the same at inclinations of 10◦ and 45◦ (Alawi 1986). (Salam et al. 1986) reported that productivity of stills is much higher at low angles of inclination and that it decreases with increasing inclination.

Another method used to improve the productivity of solar stills is by using storage systems it can be in the form of either sensible or latent heat systems which utilizes the heat dissipated from the bottom of the still. The latent heat thermal energy storage systems have many advantages over sensible heat storage systems including a large energy storage capacity per unit volume and almost constant temperature for charging and discharging (Fath 1998). Recently, many researcher has given focus on concerning the use of PCM as storage media integrated with some solar-thermal energy systems; such as domestic hot water systems (Talmatsky 2008), solar cookers [Chen 2008 and Hussein 2008], and greenhouses (Najjar 2008) in order to fulfil the gap between supply and demand of solar energy.

(Radhwan 2004) presented a transient performance of a steeped solar still with the effect of thickness of paraffin wax as a PCM and mass flow rate of air on the system performance. His results indicated that decreasing the air flow rate has a significant influence on the still yield, while the green house heat load experiences a decrease. A total yield of about 4.6 L/m^2 with an efficiency of 57% has been obtained.

(Nijmeh et al.2005), experimentally studied a single basin solar still using various absorbing materials like violet dye, charcoal, potassium permanganate (KMnO4) and potassium dichromate (K2Cr2O7). The best result

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obtained by violet dye i.e. 29%. (Eman-Bellah 2007) carried out experiments to investigate a method to improve the thermal conductivity of paraffin wax by embedding aluminum powder (80 µm) in it. (Sebaii 2009) et al, studied the performance of solar still with and without the stearic acid as PCM on summer and winter days by computer simulation. Results reveals that after sunset, the stearic acid (PCM) as a heat source for the basin water until sun rise in the early morning hours of the next day. At lower masses of basin water PCM becomes more effective during the winter.

(Tabrizi et al. 2010) studied two cascade solar stills with latent heat thermal energy storage system (LHTESS) and without LHTESS. Both stills had the optimum inclination through the year for Zahedan, Iran.

(Hamadani et al. 2011) used lauric acid as phase change material (PCM) on a solar still and found that distillate productivity at night and on day without PCM was 30% to 35% and with PCM it increased by 127%. (Swetha 2011), used Lauric Acid as a phase change material on his study on a single slope single basin solar still and found 13% increment when it is used with sand as heat reservoir and 36% increment when used with Lauric Acid as PCM.

Several researchers used nano technology to increase the thermal conductivity of PCM material. (Jana et al 2007) investigated the thermal conductivity enhancement of single nanofluids containing CNTs, AuNPs and CuNPs added into water and hybrid nanofluids containing nanoparticles of CNT-AuNP and CNT-CuNP with water. Results reveal that nanofluid with CuNPs showed the 74% enhancement of thermal conductivity.

(Wu et al. 2009) prepared Al_2O_3-H_2O nanofluids and found that by adding 0.2wt% Al_2O_3 nanoparticles into water, the maximum enhancement of thermal conductivity was increased by 10.5%. (Liu et al 2009) reported that TiO_2 nanoparticles dispersed into saturated $BaCl_2$ aqueous solution increased thermal conductivity considerably compared to the base material and in turn supply capacity and cool storage increased significantly.
From above discussed points, it is found that conventional solar distillation system reveals very low yield and it can be improved by controlling various operating parameters. Among various operating parameters, two major parameters that effects most in improving performance of double -slope solar still, namely (i) Complete utilization of solar radiation inside the water basin does not takes place because some solar radiation absorbed by the black painted vertical wall above the upper water surface and (ii) less temperature difference occurs between glass cover and basin water temperature. In the current experimental study, three major modifications has been done: (i) To increase solar reflectivity of solar radiation inside basin, walls of solar still have been coated with white paint (ii) Phase change material used in still to liberate heat to water during off sunshine hour and (iii) very thin water film is used on the glass cover to reduce the temperature between basin water and glass cover. Experimental comparison was done between both solar stills and results discussed with respect to various operating parameters and economic viability.

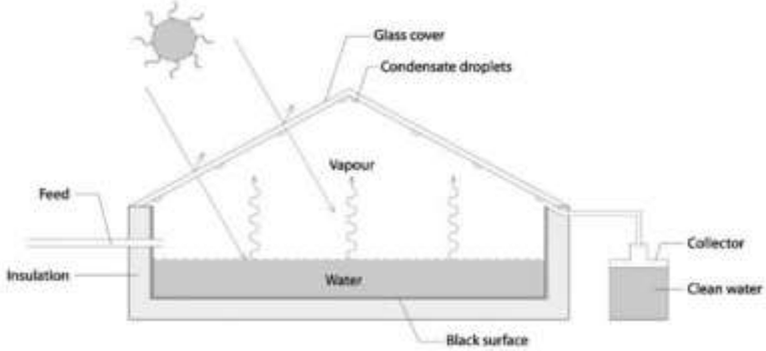

Figure 1: Double slope single basin solar still

3. MATERIAL AND METHODS

3.1 Experimental Setup

The schematic view of the experimental set up used is shown in Figure1. The stills designed and fabricated have single basin double slope solar still having basin area (100cm×100cm) with high side wall of 52.77cm and low side wall of 10cm. Galvanized steel sheet having a thickness of 1mm were used or fabrication purpose. To

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prevent heat loss from the basin to the outside environment, the basin and walls was insulated from outside and bottom by insulating material (rockwool) of thickness 4 cm. Envelop of basin over the insulating material is supported from outside by wooden sheet having a thickness of 3cm. In the conventional solar still, to increase the absorption of solar energy black coating was done on inner surfaces of bottom and side wall of the basin. The top of basin is covered with 5mm thick glass sheet inclined at nearly 23° with the horizontal. In the modified solar still, to increase absorptivity of bottom surface it is painted in black color, while vertical walls with white paint to increase the reflectivity of the wall. Water sprinkler was used to flow water over the glass surface. Solar still have been sealed by insulating and adhesive tape at the top to prevent vapour leakage from the basin to atmosphere. Condensate produced is collected in jar with the help of channel tubes attached at lower side of basin.

Figure 2: Image of working Solar Still

3.2 Experimental Procedure

The experiment has been performed in month of April, 2015 at Sagar Institute of Science, Technology & Engineering college, Bhopal (latitude 23° 25′ N; longitude 77° 41′ E) India. To receive maximum solar radiation experimental setup was kept facing in south direction. An image of experimental set up is shown in Figure 2. The experiments were performed during whole month of April 2015 but this paper analyses only data of a typical day with plenty of sunshine. The experiments were performed from 0900 to 1800 hours. Performance of modified solar still with incorporation of Phase change material paraffin wax and lauric acid in copper tube was compared with the conventional solar still. The sprinkler was used to flow water at ambient temperature over the glass surface from period of 0800 to 1600 hours with the flow rate of 0.0001kg/s. The flow rate was optimized by Somwanshi and Tiwari (2014). The depth of saline water is kept constant at 4cm for the all sets of experiments.

3.3 Measuring Instruments

Various measuring instruments were used to determine various parameters of solar still. The measurement of temperatures at various points of the still, such as outer glass surface, inner glass surface, basin water region, vapor region and ambient temperature, have been measured by using k type thermocouple. Thermocouples were attached to digital temperature indicator which indicates different temperatures. The distillate output was measured by jar engraved with marking having capacity of 1,000 ml with least count of 10ml. The intensity of solar radiation was measured on glass cover with the help of solar power meter range 0–2,000W/m^2 with least count 0.1W/m^2.

4. RESULT AND DISCUSSIONS

The readings of variable parameters, such as vapor temperature, ambient temperature, glass temperature, water temperature, solar radiation intensity on the glass surface and distillate output, have been recorded hourly at constant water depth. The experimental study for performance evaluation has been done by modifying solar still.

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4.1 Climatological Conditions

The hourly profile of ambient temperature and solar radiation for a hot sunny day are shown in Figure 3. The daily solar radiation received is in the range of 0–850 W/m^2 and the ambient temperature is found during the project varying 26–38°C. The highest temperature and solar radiation occurs in between 12:00 and14:00 hours as depicted from the Figure 3. Result reveals the increment in solar radiation profile in the morning time and obtains maximum value nearly about mid-day. After the mid-day, solar radiation profile shows declination. The ambient temperature profile also shows similar to solar radiation profile.

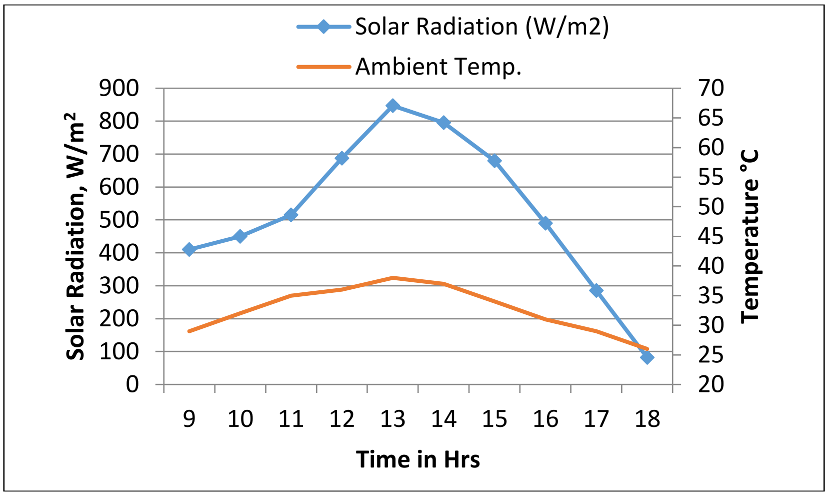

Figure 3: Hourly profile of solar radiation and ambient temperature with time

4.2 Effect on Performance of Various Temperatures with respect to Solar Radiation

Figure 4 & 5 shows the hourly variation of solar radiation, basin water temperature, and inner glass temperature and outer glass temperature with time for modified and conventional solar still. The temperature at various points in still, such as vapour temperature, water temperature, outer glass and inner glass temperature, varies with the solar radiation. In the morning time, the temperatures profile increases with solar radiation and obtained peak values during period 12:00–14:00 hours. Due to white coated wall in modified solar still, solar rays get reflected inside the basin and as a result availability of solar energy in still increases to a large extent. Vapor being a green house gas traps more and more of it and makes evaporation faster. From Figure 4, it is observed that the vapour temperature curve is above all till mid-day and after that the water temperature obtained higher value. Water film from sprinkler flow over the glass surface from 08:00 to 16:00 hours reduces the temperature of glass cover and increases condensation simultaneously. PCM present in water basin increases latent heat storage capacity. During off sunshine period, solar radiation as well as ambient temperature decreases. PCM maintains evaporation by releasing stored latent heat to water during off sun shine hours. In conventional solar still with black painted side walls, availability of energy to basin water enhances but absence of PCM reduces rate of evaporation. Absence of sprinkler further reduces the condensation and as a cumulative result productivity of modified still has been better.

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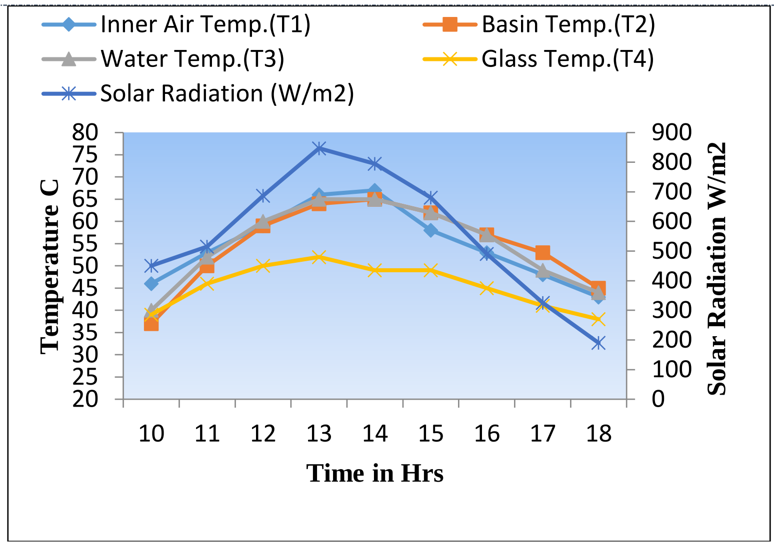

Figure 4: Hourly profile of solar radiation with various temperatures of Modified solar still

4.3 Distillate Productivity

Figure 6 shows the productivity curve for conventional and modified solar still with respect to solar radiation and time duration. It shows that productivity of both still is zero till 1000 a.m. The curve shows increase in productivity after 10:00 a.m. but productivity curve in modified still started earlier than conventional still. The productivity increases till afternoon as it observe maximum solar radiation and then reduces with reduction in solar radiation. PCM's used in still liberate heat to water during off sunshine hour while using of water sprinkler which allows water to flow on the glass cover reduces temperature of glass cover. As a result, temperature difference occurs and condensation as well as productivity improved in modified still.

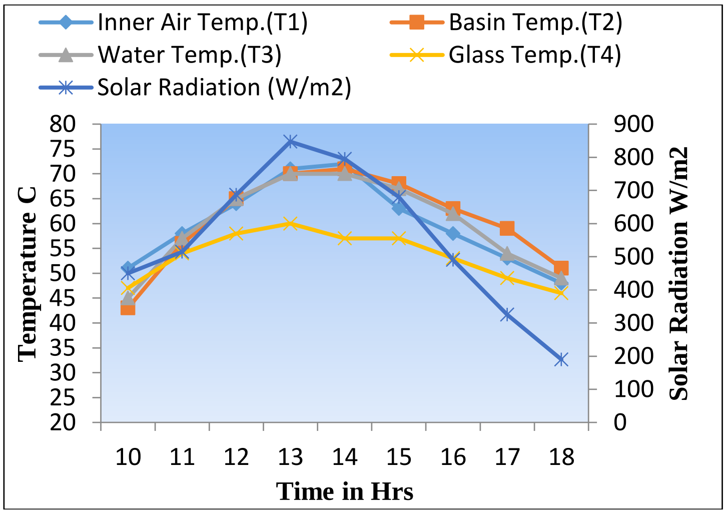

Figure 5: Hourly profile of solar radiation with various temperatures of Conventional solar still

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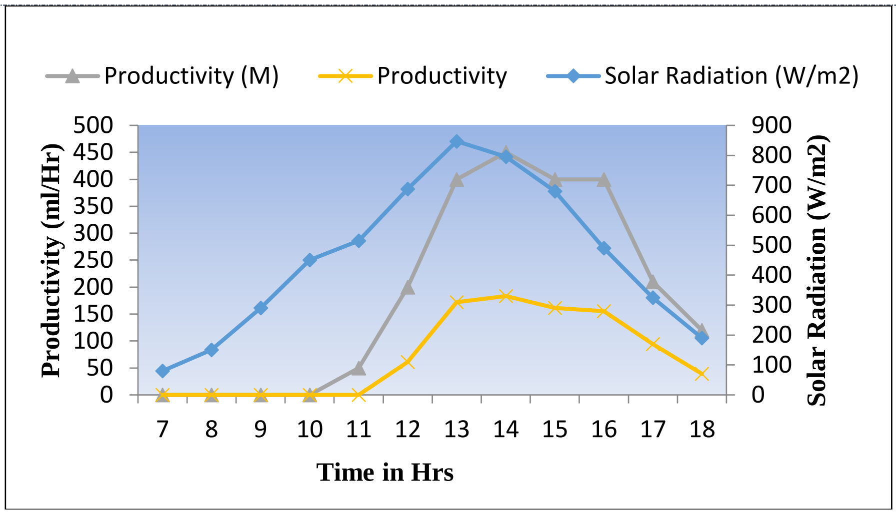

Figure 6: Hourly profile of productivity with solar radiation for modified and conventional solar still

4.4 Efficiency of the Solar Stills

The efficiencies of conventional and modified solar still are shown in Figure 7. The efficiency profile curve of modified solar still varies from zero value at the time nearly 10:00 hours and achieve higher value after mid-day around 15:00 hours. But, in conventional solar still, the efficiency profile was zero value around 11:00 hours and achieved a higher value after 15:00 hours. Significant value of efficiency is shown during 10:00–16:00 hours. Solar still takes times to reach steady-state condition from start to 1000 hours. The daily thermal efficiency (Eq. 1) of solar still is calculated by:

$$\eta \text{ still} = \frac{\sum Mw \times L}{\sum I \times A \times 3{,}600} \qquad (1)$$

Where, Mw = hourly distillate output (kg),
L = latent heat of vaporization (kJ/kg)
L = 2260 kJ/kg (5)
Ig = daily average radiation (W/m^2)
A = area of glass cover (m^2).

The above equation to calculate the efficiency (Tiwari et al., 2009)

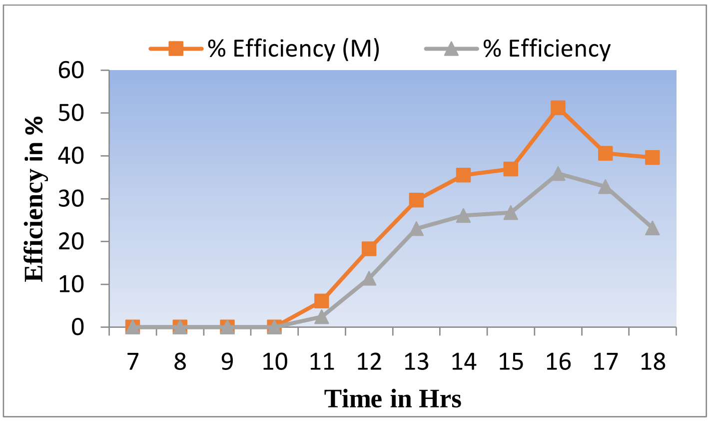

Figure 7: Hourly efficiency curve modified solar still and conventional solar still

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5. CONCLUSION

Solar stills inherent simplicity, ability to supply fresh water to remote areas where no fresh water is available, and its environmental friendliness makes it a technology that is ripe for much wider use. The following conclusions have been drawn after three major modifications in conventional solar still: (i) increasing free surface area of water, (ii) sprinklers attachment with water flow rate of 0.0001 kg/s and (iii) using Parafin wax and Lauric acid as phase change material in the basin water.

- The productivity of modified solar still has been found increased using combined effect of Parafin wax and Lauric acid as phase change material, water sprinkler attachment on the glass surface, and increasing free surface area of water of the modified solar still.
- Computed daily yield for modified solar sill is 3600 ml/(m^2- day) and conventional solar still is 2,300 ml/(m^2-day).
- The water productivity increased by 56.5%. These results show better performance of modified solar still in this study.
- The maximum efficiency of modified solar still obtained was 51.25% and conventional solar still was 35.87%. Therefore, the increase in hourly maximum efficiency with design modifications was 42.8%.

It can be concluded that the use of solar water distillation promises to enhance the quality of life and to improve health standards in arid areas near Bhopal.

NOMENCLATURE	
Lpcd	Litres per capita per day
PCM	Phase Change Material
Ta	Ambient temperature(°C)
T_1	Inner air temperature(°C)
T_2	Basin temperature(°C)
T_3	Water temperature(°C)
T_4	Glass temperature(°C)
A	Area of glass cover (m^2)
L	Latent heat of vaporization
m	Distillate output(ml)
M	Modified
ηs	Daily efficiency
Ig	Global solar radiation(W/m^2)
G.I.	Galvanized iron

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