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Experimental Investigation of Different Wick Materials to Enhance the Productivity of Single Slope Single Basin Solar Still

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ABSTRACT
The objective of this research work was to augment the productivity and efficiency of conventional single slope single basin solar still by adding various wick materials with brackish basin water. The wick materials enhanced the evaporation rate of water due to capillary action by raising the temperature distinction of basin water and inclined glass cover surface of the solar still. During the night session, the portion of daytime heat energy retained within the wick materials was liberated which causes an accumulation of a noticeable quantity of distillate water. Distillate output of conventional solar still (CSS) was 374 ml/day with a solar thermal efficiency of 11.47% at 2 cm optimum water depth which was modified with five distinct wick materials independently. Maximum enhancement in productivity was obtained 56.15% with an increase in solar thermal efficiency of 39.84% when CSS was modified with the black cotton as wick material.

Keywords: Solar desalination, Wick materials, Optimum water depth, Solar thermal efficiency.

1. Introduction

Water is essential for every living organism in the earth. It is one of the most significant gifts of Almighty God to the whole mankind. The worldwide fresh drinkable water demand is successively increasing due to climate change, drought, urbanization, industrial, agricultural and population growth etc. which has already been reached a severe condition in many corners of the world. It is forecasted that the worldwide drinkable water demand will grow 54 billion m^3/year by 2020 [1]. Enhancing the solar thermal efficiency of saline water sanctification technology to produce distillate fresh water is argued as one of the major challenges of the 21st century. Almost 71% of the earth's surface is encircled with water. Around 97% of this water is brackishly reserved in the oceans which is not suitable for drinking and cooking purposes. Only 3% of the total earth's water is potable which is contained in the ice poles, lakes, rivers, and groundwater satisfy most of the human and animal basic needs [2]. Today, most of the health problems are owing to the deficiency of pure drinkable water. The salinity of water is increased due to inadequate rainfall around the most part of the world. Due to various water-borne diseases, 3.575 million people accept premature death every year throughout the world [3]. For consumption purpose, water should be pure in terms of impurities and dissolved salts. The taste of water may be affected by the total amount of dissolved solids present in it. It is generally argued that salinity less than 500 ppm is compatible as drinkable water [4].
There are a large number of methods commonly used for brackish water purification: desalination, filtration, sedimentation, and disinfection, electrolysis, reverse osmosis etc. The technique commercially used for saltwater purification is reverse osmosis. The main drawback with this technique is it uses more electrical energy and produces less amount of fresh potable water. Hence, the solar desalination process would be a better option. It is considered the most compatible solutions to lessen water deficiency problem in remote and arid regions throughout the world especially Middle East, South Asia and North Africa [5]. Solar energy is regarded by most of the famous researchers to be the excellent substitute for a heating energy source because it is environmentally friendly as well as the use of solar energy to heat inlet brackish water complies to preserve fossil fuel energy.
CSS is used for sanctification (eliminating salts and other dissolved minerals) of saltwater for drinking purposes. It comprises of the inclined glass cover, basin, wooden frame, and distillate output collection jar etc. Solar desalination covers 3-4 steps: pumping of brackish water, pumped water pre-treatment (filtration, chemical addition), desalination process and distillate output post-treatment if required (in some cases, adding few minerals, measuring P^H value etc.) [4].
The major defects of the desalination system by solar still is its less productivity and efficiency. Generally, a CSS can supply 2.5–5 liter/m^2/day of fresh distillate output [5]. To amplify the solar thermal efficiency of CSS, renowned researchers have carried out a large number of experimental investigations modifying the CSS with various heat storage materials, phase change materials, nanoparticles, wick materials and integrated with solar collector, reflector, solar heater etc.

2. Objectives

1) To design and fabricate a desalination system with a solar heat source which will be cost effective.
2) To enhance the productivity and efficiency of CSS raising the temperature difference between basin water and glass cover surface adding wick materials with inlet brackish water inside the glass cover surface.

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3) To compare the efficiency enhancement of modified Solar Still (MSS) with various wick materials with respect to CSS.

3. Basic principles of CSS

CSS uses solar energy to sanctify salt water instead of other heating sources: fossil fuels to achieve the energy required for desalination and works based on two scientific principles:

3.1 Evaporation

Firstly, the brackish water which is to be sanctified is provided inside the solar still basin. Then the solar still is settled upon under the sun which permits the solar still to absorb solar energy by means of solar radiation. When the energy is absorbed remarkably, the water in the basin is heated gradually. As a result, the liquid water is converted into vapor and evaporated towards the glass cover ceiling surface.

3.2 Condensation

This water vapor strikes the ceiling of the glass cover with high vapor pressure and slowly condenses along the glass cover inner surface causing pure water droplets. As the glass cover surface is angled down towards the collecting jar, pure water droplets slide down into the collecting jar. The water droplets collected into the jar are simply sanctified because none of the minerals, bacteria are capable to evaporate with pure water which is now used for drinking and cooking purposes.

4. Factors impacting the productivity of solar still

There are a large number of factors influencing the daily productivity and efficiency of solar still. Amongst them, intensity of solar radiation, wind velocity and ambient air temperature are the meteorological parameters which may not be controlled. The other factors may be controlled to amplify the solar still productivity and solar thermal efficiency. The following several factors which have generally been controlled:

- The temperature distinction between inclined glass cover surface and basin water
- Temperature and depth of inlet brackish water
- The inclination angle of the glass cover surface
- Thickness of inclined glass cover surface
- Absorber plate and surface coating etc.

5. Methods used to enhance the productivity and efficiency of CSS

Special design, the addition of various heat energy storage materials (ESM), phase change materials (PCM), fins and corrugated absorber, nanoparticles, usage of various wick materials, vacuum technique and integration of solar reflector, condenser, collector, combined solar still with solar pond and modified stepped solar still can amplify the distillate output and solar thermal efficiency of CSS.

5.1 Wick materials

Inlet water surface exposure area can be enhanced by adding appropriate wick materials inside the solar still basin. Generally, various wick materials: black cotton cloth (BCC), white sponge sheet (WSS), black sponge sheet (BSS), brown jute sheet (BJS), jute sheet (JS), cotton mate (CM), coconut mate etc. are added with inlet brackish water. The intensity of solar radiation incident on the inclined glass surface is dispatched to the wick material surface. A portion of incident solar energy is used for heating brackish water which is streaming through the wick surface because of capillary action. Hence, the brackish water gets heated and evaporated into vapor rapidly. This saturated vapor starts to condense along the inner surface of inclined glass cover after liberating latent heat of vaporization of water. Then the condensed pure water droplets slide down along the glass surface due to gravity and stored in the collecting jar. There are two heat transfer modes in the solar desalination system: external and internal modes. The external mode takes place outside the solar still due to convection and radiation. Contrariwise, internal mode takes place within the solar still due to radiation, convection, and evaporation. Following are the different notable wick type solar still designs:

- Basin wick type solar still
- Multi-wick type solar still
- Floating wick type solar still
- Concave wick type solar still etc.


Cotton cloth


Jute sheet


Sponge sheet


Coconut mate


Velvet sheet

Fig.1 Wick materials used with inlet brackish water.

6. Design & fabrication of experimental set-up

6.1 Methodology

The following methodologies were applied during the experimental investigations:

1) A simple conventional single slope single basin solar still was designed and fabricated. For three different inlet water depth (1cm, 2cm, 3cm), total fresh distillate output accumulated was measured conventionally. According to the fresh output, optimum water depth (2 cm) had been established.
2) The CSS had been modified adding wick materials (heat storage materials) with inlet brackish water.
3) Detailed experimental investigations had been conducted to measure the distillate yield of the solar

still for the effect of adding black cotton sheet, jute sheet, black sponge sheet, black velvet sheet and coconut mate respectively. The percentage of productivity enhancement was calculated.

4) Finally, the percentage of productivity and solar thermal efficiency enhancement in case of MSS were compared with the CSS at optimum water depth.

6.2 Theoretical approaches

The analysis had been conducted with the following considerations:

- ❖ The CSS was made in such a way that it must be vapor tight.
- ❖ Wick materials, solar still basin wall, and glass cover were at the almost identical temperature.
- ❖ Under almost identical thermal conditions, the solar still with and without wick materials were experimented.
- ❖ The motion of the raised vapor from the evaporating surface to the condensing surface was predominantly under natural convection.

6.3 Experimental set-up

Firstly, the 3D model of the (CSS) was designed using SOLIDWORKS software. The solar still was 30 inches long and 18 inches wide. The glass cover slope angle was 11 degree with horizontal. The height of the solar still was 5.50 inch (front side) and 9.00 inch (back side). To fabricate the desired solar still system, at first the rectangular tray type basin of the solar still having a height of 4 inches was made by using 2 mm galvanized steel sheets welded with 10 number size electrode in which the brackish water was provided. The length of the basin was 29 inch and width was 17 inch. This manufactured basin was contained inside a wooden frame fabricated from our Mechanical workshops. The size of the wooden frame was slightly higher than the solar still basin for smooth operation having 0.5-inch thickness. It had provided sufficient space for adjusting glass cover at the upper surface. A glass plate of 3 mm thickness was used for roofing the top surface of the wooden frame. At the upper back side of the frame, a 0.75-inch hole was shaped at where elbow joint was fixed for supplying brackish water into the solar still basin. And at the front side, a distillate water collection tube (PVC pipe) was adjusted for collecting the condensed distillate water which slide down along the inclined glass surface. This pipe was cut at the inner side as like as U shape with an appropriate dimension. Silicon gum was used for sealing the wooden frame at every corner properly before holding the solar still basin into the wooden frame in order to eliminate the heat and vapor loss and get the maximum possible water vapor. The glass cover was adjusted on the wooden frame and it was also sealed with the pipe using superior silicon sealants completely. The PVC pipe was 34 inches long which was slightly bigger than the wooden frame because a water tap was provided at one end and the other end of the pipe was sealed. By using a stainless steel scale, the basin was calibrated for the interval of 1 cm from the bottom of the basin up to 5cm.

Fig.2 The fabricated conventional single slope single basin solar still.

Fig.3 MSS with black sponge sheet.

6.4 Data collection method

Experimental data were taken during the clear sunshiny days during the month of October at the roof of our Electrical and Mechanical Engineering (EME) building, CUET. The experiment was started at 9:00 am of the local time when brackish water was provided into the solar still basin. At 9:00 am, ambient air and inlet water temperature were measured using a thermometer. Amount of the incident solar intensity on the glass surface was measured using a Daystar meter at the interval of 60 minutes and wind velocity was measured using a digital anemometer. At 10:00 am, the temperature of the basin water and inclined glass cover were measured. As the solar intensity was increasing gradually, the temperature of the basin water and glass cover were enough high. At 11:00 am evaporation and condensation rate was increased gradually and the quantity of distillate water stored in the jar was increased than 10:00 am. At noon, the solar intensity was maximum and the amount of potable water accumulated was high with the time being passed. On the other hand, the solar intensity was reduced gradually at afternoon which reduce the amount of distillate water gradually. In the same manner, the data was collected until 5:00 pm. After 5:00 pm, the heat energy retained by the wick surface was radiated which causes a remarkable evaporation and condensation rate of brackish water during the night period. The amount of fresh water stored during this session was measured at 8:00 am of the following day. From 8:00 am-9:00 am, the set-up was made ready for the following experimentation. This same procedure was repeated when different wick materials were added with the CSS.

6.5 Addition of wick materials with brackish water

When these enlisted wick materials were entirely dipped under inlet brackish water, other parameters were kept almost identical as that for CSS.

Table 1 Details information of various wick materials.

SI. No.	Various wick materials	Mass Kg	Thickness mm	Specific heat KJ/Kg-K
01	Black cotton cloth	0.2	3	0.8
02	Brown jute sheet	1.5	8	1.4
03	Black sponge sheet	0.15	10	-----
04	Black velvet sheet	0.2	3	-----
05	Coconut mate	2.0	18	0.4

6.6 Governing equation

Solar thermal efficiency, [1]

$$\eta = \frac{\sum m_d \times h_{fg}}{\sum A_{eff} \times I(t)} \times 100\% \qquad (1)$$

- ❖ Latent heat of vaporization of water: 2230 KJ/Kg.
- ❖ Net effective area of the solar still basin: 493 inch^2 = 0.3181 m^2.
- ❖ Time interval of data entry: 1 hour = 3600 s.
- ❖ Mass of 1 ml of distillate water: 1 gm.
- ❖ Inlet water temperature: 25-27 ℃.
- ❖ Atmospheric air temperature: 30-34 ℃.
- ❖ Glass cover temperature: 48-55 ℃.
- ❖ Basin water temperature: 53-62 ℃.
- ❖ Wind velocity: 1.2-1.9 m/s.
- ❖ The intensity of solar radiation during the night period due to radiation: 15 W/m^2 approx.
- ❖ At 7:00 am, the intensity of solar radiation: 250 W/m^2 approx.
- ❖ At 8:00 am, the intensity of solar radiation at 8:00 am: 460 W/m^2 approx.
- ❖ During 5:00 pm-8:00 am, the average intensity of solar radiation per hour: 60 W/m^2 approx.

Table 2 Comparison of production rate and solar thermal efficiency of CSS for various inlet water depth.

SI. No.	Inlet water depth, cm	The volume of brackish water (approx.), L	Distillate output production rate, ml/day	Solar thermal efficiency, %
01	1	3.0	393	12.05
02	2	6.0	374 (reference)	11.47 (reference)
03	3	9.0	319	9.78

✓ Considering 2 cm as the optimum water depth:

Table 3 Comparison of production rate and solar thermal efficiency for the MSS with various wick materials at 2 cm inlet water depth.

SI. No.	Various wick materials used	Distillate output production rate, ml/day	Increase in production rate, %	Solar thermal efficiency, %	Increase in efficiency, %
01	Cotton cloth	584	56.15	16.04	39.84
02	Jute sheet	539	44.12	14.56	26.94
03	Sponge sheet	498	33.16	14.17	23.54
04	Velvet sheet	436	16.58	12.09	5.41
05	Coconut mate	469	25.40	12.77	11.33

7. Results & Discussion

Fig.4 shows the variation of the intensity of solar radiation with time. The intensity was maximum between 12.00 pm to 2.00 pm and then it dropped significantly in the afternoon.

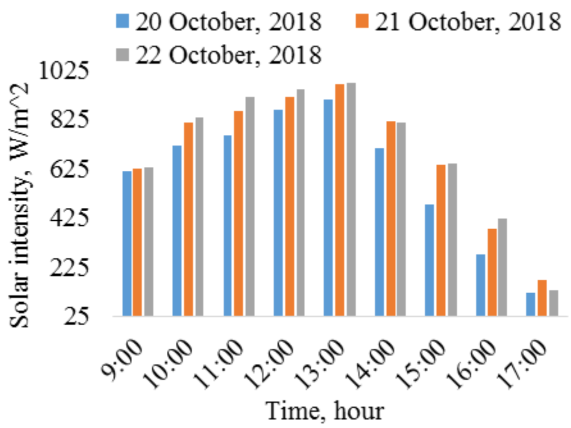

Fig.4 Variation of the intensity of solar radiation during three experimental days with time.

Fig.5 shows the variation of wind velocity during six different experimentation days. There is an inverse relation of wind velocity with the total daily distillate output of the solar still.

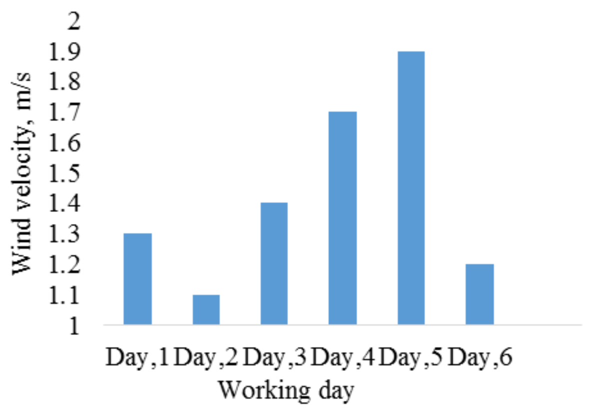

Fig.5 Variation of wind velocity with the working day.

Fig.6 shows the actual hourly variation of fresh distillate output of CSS for three different inlet water depth (1cm, 2cm and 3cm). The maximum was output obtained at 1.00 pm for the three different cases.

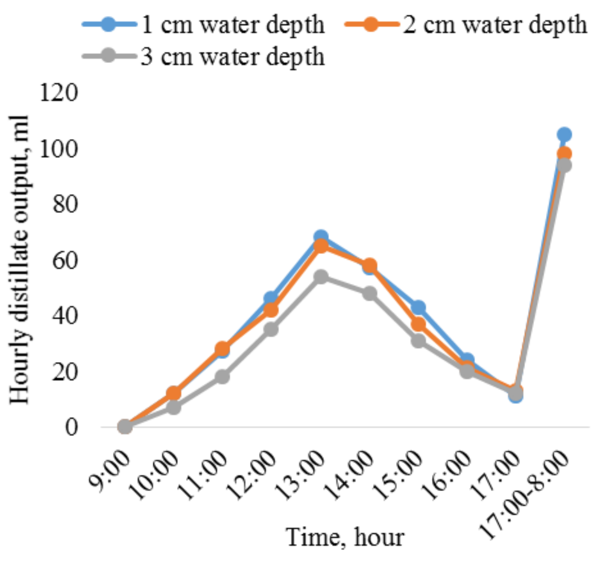

Fig.6 Hourly variation of the fresh distillate output of CSS for different inlet water depth.

Fig.7 shows the actual variation of accumulated fresh distillate output of CSS for different water depth (1cm, 2cm and 3cm). From the output of CSS for different inlet water depth, it was found that 2 cm was the optimum water depth. The amount of accumulated distillate output for 1cm water depth was high because of the high evaporation rate but inlet water had to be provided repeatedly which causes temperature variation with previous brackish water. On the other hand, the evaporation rate was low because of the deep layer at 3 cm water depth.

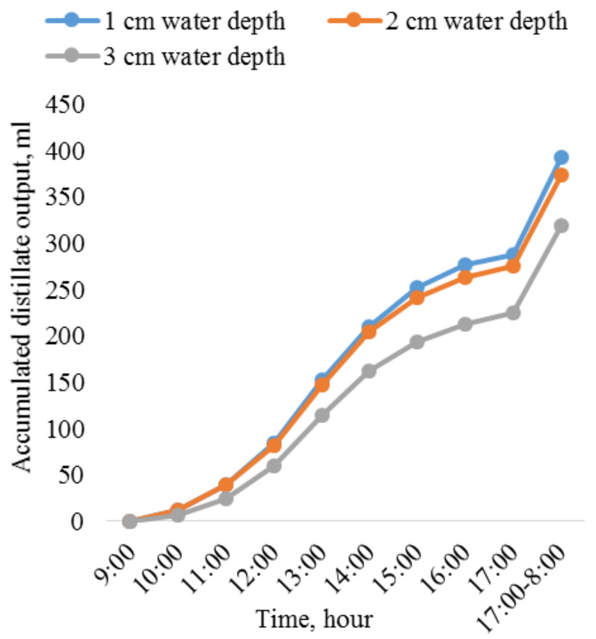

Fig.7 Variation of the accumulated fresh output of CSS for different inlet water depth.

Fig.8 shows the variation of the actual overall distillate output for five different wick materials used inside the solar still basin for modifying the CSS. Among these, the black cotton cloth is more effective than other wick materials followed by the jute sheet, black sponge sheet, coconut mate and black velvet sheet respectively.

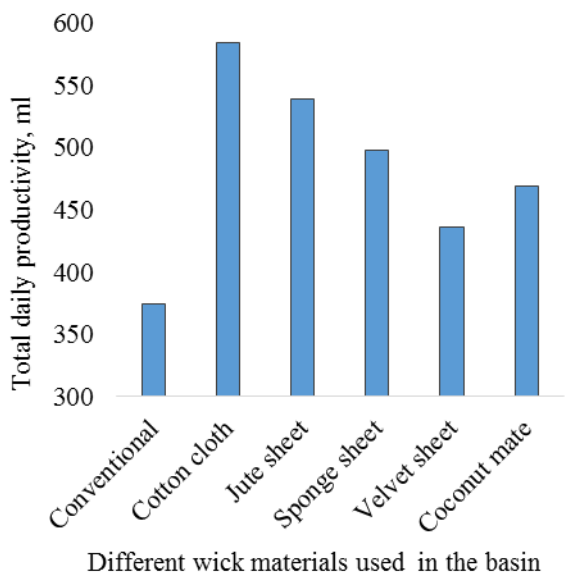

Fig.8 Variation of total daily productivity for various wick materials with CSS (2cm water depth).

Fig.9 shows the actual hourly variation of distillate fresh output for different wick materials used inside the basin. The maximum output was obtained at 1.00 p.m.

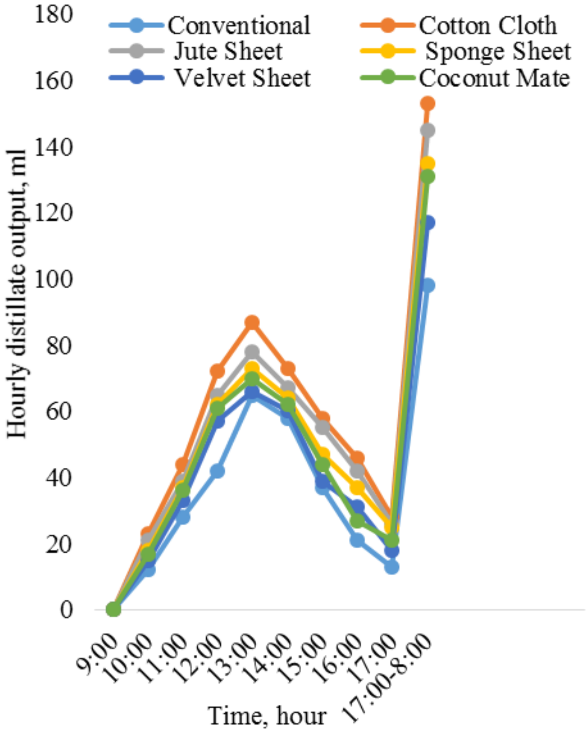

Fig.9 Hourly variation of distillate output for various wick materials with CSS (2cm water depth).

Fig.10 shows the variation of accumulated distillate output for various wick materials. Cotton cloth yielded maximum accumulated output among them.

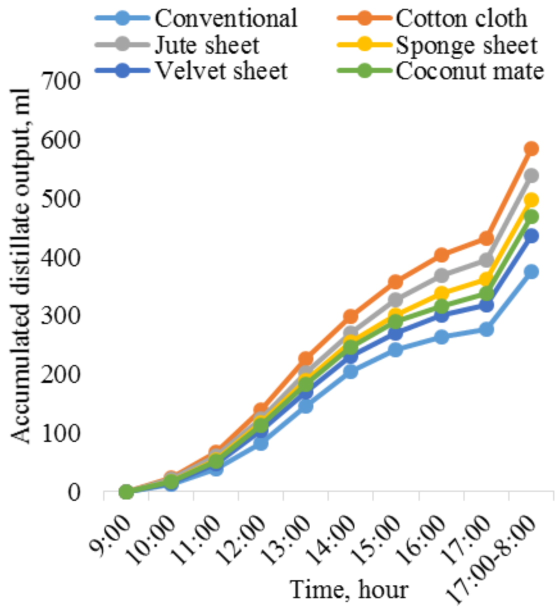

Fig.10 Hourly variation of accumulated distillate output for various wick materials with CSS (2cm water depth).

8. Conclusion

In this present research work, the distillate output production rate and solar thermal efficiency for different water depth were investigated. From the output of this study, 2 cm was considered as the optimum water depth where the distillate output production rate was 373 ml/day and solar thermal efficiency was 11.47% which was considered as the reference. Then the solar still was modified using various wick materials. Among these, the black cotton cloth was the highest efficient produced maximum distillate output per day having 56.15% production rate enhancement followed by the jute sheet 44.12%, black sponge sheet 33.16%, coconut mate 25.40% and black velvet sheet 16.58% respectively with respect to reference production rate.

9. Scope for future work

In this present research work, impure brackish water from the tap was used for experimentation. In the future, it may be possible to produce distillate water from industrial effluents with more modifications such as to use integration method: internal reflector, flat plate collector in the basin along with the energy storage mediums.

NOMENCLATURE

η : Solar thermal efficiency, %
m_d : Mass of distillate water, Kg
h_{fg} : Latent heat of vaporization of water, KJ/Kg
A_{eff} : Net effective area of the solar still basin, m^2
I : The intensity of solar radiation, W/m^2
t : Time interval of data entry, s
CSS : Conventional Solar Still
MSS : Modified Solar Still

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