Innovations

Increasing the Yield of Solar Still for Sea Water Using Nano Material with Thermocol Insulation of Solar Still Basin and Analyzing the Optimization Parameters for Improving the Efficiency of Conventional Desalination Plant

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Abstract: *The solar energy is utilized in the desalination process by collecting the sun's rays and stored in the form of heat energy. This solar energy is used to converting the sea water into good drinking water. Solar still is a device .which is used to collect and store the solar energy. The stored solar energy is used to evaporate the seawater. Then the evaporated sea water is condensed and collected as pure drinking water. When increasing the production rate of purifying sea water, using some heat energy absorbing materials in solar still and improve the performance of solar still. The solar still is fabricated with black lime stone (Cuddappa stone) and the solar still is covered with thermocol insulation. The production rate of the solar still is to be compared with different energy absorbing materials such as pebbles and nano-material. The nano material (Aluminum oxide) gave more yield rate than the rest of absorbing materials. The minimum day yield is 0.710L /m^2/day for without using any energy storage materials in the solar still and the minimum yield efficiency of solar still is 5%. The nano material gave maximum day yield of 2.130 L /m^2/day and the maximum yield efficiency of solar still is 16 %.*

Keywords: *Energy storage method; Nano material; Purification system; Solar still; Thermal insulation*

1. Introduction

The solar energy is no pollution and free renewable source of energy. So the solar energy is used in present and future energy needs of the world. The salty water is purified by using various methods. Desalination is one of the best methods of them. Sea water is purified as a good drinking water by the desalination process. Solar still is a device, used to convert sea water into good drinking water. Solar still is working under the principle of solar desalination process. Some energy storage materials are placed inside the solar still. The energy storage materials are used to store the more thermal energy and convert the salty sea water into drinking water. Various experiments had been conducted to increase the production rate of solar still. A. Bassam et al.[1] had conducted several experiments to improve the solar still performance. They proposed a modification to enhance the distillate production by placing sponge cubes over the water surface. The sponge cubes increased the surface area over which evaporation of water occurs hence caused the increase of yield. Shukla S.K. et al. [2] had conducted an experiments on both single slope and double slope solar still by keeping the jute cloth in horizontal position and immersed in the basin saline water. The daily yield during the summer was 2.0 kg/m^2 and for the double slope still it was increased to 2.5 kg/m^2. Elango et al. [3] analyzed the energy storage material like nano material to enhance the yield of single basin single slope solar still. They conducted experimentally with different nano fluids like iron oxide[Fe_2O_3], aluminium oxide[Al_2O_3], Tin oxide[SnO_2] and Zinc oxide [ZnO]. They found the aluminium oxide nano materials were enhanced the performance of solar still. The enhanced yield rate of aluminum oxide was 29.95% more than the other nano materials.. N.H.A. Rahim, [4] had suggested about the new method of horizontal solar still basin which was divided into two zones, one was evaporating and the other one was heat storage zone. They had proposed an approach in a conventional still to store excess energy during day time that could be used to continue evaporation at night.

A.S. Nafey, M. Abdelkader, A. Abdelmotalip, A.A. Mabrouk, [5] had conducted several experiments for improving the solar still productivity. They modified solar still by using black rubber sheet and black gravels as storage materials for absorbing and storing the more solar heat energy. They conducted many experiments for varying the sizes of gravel with different quantities of saline water in the solar still. Kalidasa Murugavel K, Srithar K [6] had suggested about the thin water level of solar still produced more yield and more water level produced less yield. Several experimental were conducted for improving the solar still production. The single basin double slope solar still with thin layer of water basin produced more yield rate.

M. Sakthivel, S. Shanmugasundaram [7] had conducted several experiments about the various energy storage materials in the solar still. They had conducted the experiments with black granite gravel size of 6 mm as an energy storage medium kept in the basin of a single slope solar still with different depth. The different depths of gravel layer with optimized quantity of saline water in the modified regenerative solar still produced more solar desalination yield.Mathematical model had been developed to validate the experimental observations. Samee et al. [8] suggested that the productivity of solar stills was improved by different types of methods. The solar still effectiveness was increased by the various design of solar still. The passive and active solar stills were improving the productivity of the solar desalination process.. Abhat.A, et al.[9]had suggested about the solar heat absorbing material increased the production rate of solar still. M. Lacroix, [10] had evaluated about the heat transfer behavior of a latent heat thermal energy storage materials. The Numerical simulation of a shell-and-tube latent heat thermal energy storage solar still and the finned tube solar still are increased the solar still production. N.H.A. Rahim [11] had suggested that the more solar heat energy increased the solar yield. The new approach is proposed to store the excess heat energy in horizontal solar stills during daytime for the continuation of the process at night and improve the effectiveness of solar still. Salah Abdallaha et al. [12] analyzed the some gripping materials like stringy sponges and black rock to increase the performance of solar still. The coated silver stringy sponges and black rock gave 28% the yield of solar still and the uncoated silver stringy sponges and black rock gave the yield of solar still of 43%. Manoj Kumar Sain, Mahendra Singh Rajpoot, Vishnu Kr. Sharma [13] had designed an inverted absorber and single slope solar still for increase the solar energy absorption.. Hitesh Panchal [14] analyzed with new design of single basin double slope solar still with various levels of basin water depth. He used to color dyes for mixed with basin water and check the yield of solar still. The decreased depth of water and black dye will increase the solar still yield. Khaled M.S. Eldalil [15] had suggested that vibrating solar still increase the yield of solar still. The efficiency of the solar still was increased by using the vibratory harmonic effect. Rahul Dev, G.N. Tiwari [16] had conducted several experiments about the various design parameters of the solar still. The passive solar still was evaluated about the effect of different inclination angle of glass cover of solar still and also found that comparisons of instantaneous gain and loss efficiencies at 0.01 and 0.04 m water depths for a 15° inclination angle had also been made to show the effect of water depth on the performance of solar stills. B. I. Ismail [17] had evaluated that the design of the solar still in the solar desalination process. The Design of a transportable hemispherical solar still improved the performance of the soar still. T. Arunkumar, R. Jayaprakash, D. Denkenberger et al [18] had suggested that the new design of hemispherical solar still increased the production rate. Fath.MES, K. Fahmyc, and A. Hassaboud [19] had designed a solar still with thermal economical method and analysis for thermal-economic parameters and comparison between pyramid-shaped solar still. Mona et al. [20] suggested the non conventional solar stills with energy storage element of solar desalination process. They designed a simple solar still with phase change materials such as paraffin wax and paraffin oil as the energy storage media to make use of its latent heat of fusion for storing the excess solar energy at noon. This stored energy could be used to evaporate the water during off sunshine hours in the evening and night. The result was achieved the average daily still yield of 2.5 kg/m^2 with 15% improvement in the production.They conducted the experiments by using charcoal particles as heat absorption medium and charcoal acted as wick to provide more surface area to increase the rate of evaporation of the solar still and it increased the solar still effectiveness.A. El-Sebaii [21] had conducted many experiments about the solar still's performance for improving the solar still yield. The triple-basin solar still was designed and evaluated about the thermal performance and comparing the performance of triple-basin solar still with single basin solar still.

2. Construction details of solar still

The single basin and single slope glass cover solar still had been fabricated with black lime stone (Cuddappa stone). The basin contains sea water. This is enclosed in a completely air tight envelope and a transparent white glass cover at top. The basin absorbs the maximum part of the transmitted radiation through the glass cover. The glass cover is a single inclined type. The glass cover thickness is 4 mm and its inclination is 30^0. The effective depth of the water level in solar still is 20mm.The figure 1 shows that the construction details the single basin and single slope glass cover solar still.

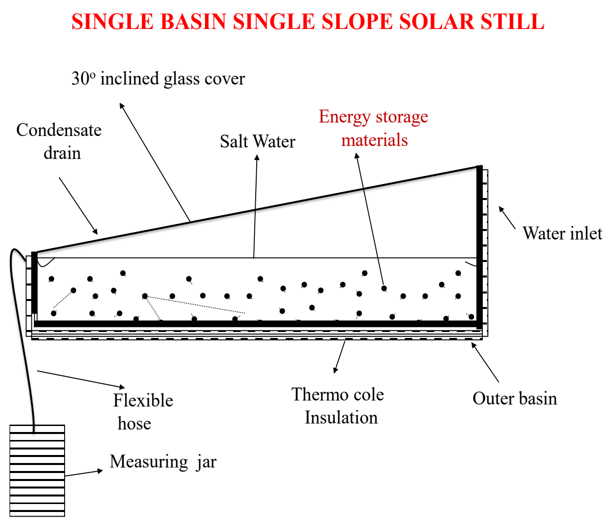

Fig. 1 Constructional details about the single basin and single slope solar still

2.1 Design of solar still

A single basinsingle glass solar still is designed with the dimension of 1.060m x 0.725 m x 0.275 m and it had a fabricated with black lime stone. Figure 2 shows that the orthographic view of black lime stone. Black lime stone is quite impervious, hard and block in colour. Figure 3 shows that the experimental set up view of the solar still.. Many parameters are considered for improving the effectiveness of the solar still. They are, effective level of water depth in solar still basin, increasing the absorption of the solar energy using various energy absorbing materials such as pebbles and nano materials.

The maximum production rate of solar still is achieved at an inclination of glass cover angle at 30°. The insulating material thermocol is used to reduce heat loss from solar still to atmosphere.

Fig. 2.Orthographic view of black lime stone

Fig 3.Experimental set -up of solar still

2.2 Physical properties of black lime stone

Table 1 show that the physical properties of black lime stone. Black lime stone is compact and fine grained calcareous rocks of sedimentary nature

Table 1.Physical properties of black lime stone

Hardness	3 to 4 on Moh's Scale
Density	2.5 to 2.65 Kg/m3
Compressive Strength	1800 to 2100 Kg/cm2
Water Absorption	Less than 1%
Porosity	Quite low
Weather Impact	Resistant

2.3 Chemical properties of black lime stone

Table 2 shows that the chemical properties of black lime stone. Black lime stone is siliceous calcium carbonate rocks.

Table 2. Chemical properties of black lime stone

Lime (CaO)	38-42%
Silica (SiO2)	20-25%
Alumina (Al2O3)	2-4%
Other Oxides like Na, Mg	1.5 to 2.5%

3. Experimental Measurements

The experimental set up was done and all the measurements were taken at Vasudevanallur, Tamilnadu, India (south) (9°11' N 77^{0}52' E) during March 2023 to October 2023 (8 months). The observations are taken from 9.00 am to 6.00 pm. The atmospheric temperatures, solar still basin water temperatures, solar still basin water vapor temperatures, condensed water temperatures and diffused radiation readings are noted every one hour. The temperatures and solar radiations are recorded by thermometers and sun meter.

Table 3, 4 and 5 shows that the experimental day yield readings for sea water with various energy materials.

Table 3 Hourly production rates for sea water with thermocol insulation

Sl .No	Time hours	Solar intensity W/m²	Ambient Temp 0℃	Basin water Temp 0℃	Basin water vapour Temp 0℃	Condensate water Temp 0℃	Cumulative day yield liters	Wind velocity mph
1	9.00 AM	330	25	27	29	25	-	1.4
2	10.00 AM	470	26	29	32	26	0.020	1.3
3	11.00 AM	590	27	32	34	28	0.070	1.2
4	12.00 AM	740	28	33	38	30	0.180	1.1
5	1.00 PM	880	29	37	41	32	0.340	1
6	2.00 PM	900	30	40	45	33	0.530	1.1
7	3.00 PM	780	28	37	40	30	0.630	0.8
8	4.00 PM	630	26	30	33	29	0.680	1.2
9	5.00 PM	340	25	27	30	25	0.700	1.3
10	6.00 PM	190	24	26	28	24	0.710	1.5

Table 4.Hourly production rates for sea water and pebbles with thermocol insulation

Sl.No	Time hours	Solar intensity W/m²	Ambient Temp 0℃	Basin water Temp 0℃	Basin water vapour Temp 0℃	Condensate water Temp 0℃	Cumulative day yield liters	Wind velocity mph
1	9.00 AM	330	23	25	30	24	-	1.3
2	10.00 AM	480	24	33	44	25	0.050	1.2
3	11.00 AM	590	25	41	55	27	0.160	1.2
4	12.00	750	26	48	59	29	0.330	1.1

	AM							
5	1.00 PM	880	27	53	65	30	0.560	1.1
6	2.00 PM	910	27	58	69	33	0.860	1.2
7	3.00 PM	790	26	55	67	31	1.120	0.9
8	4.00 PM	640	25	50	60	27	1.300	1.2
9	5.00 PM	340	24	47	49	25	1.420	1.3
10	6.00 PM	180	23	38	41	24	1.480	1.4

Table 5.Hourly production rates for sea water and nano materials with thermocol insulation

Sl.No	Time hours	Solar intensity W/m^2	Ambient Temp 0℃	Basin water Temp 0℃	Basin water vapour Temp 0℃	Condensate water Temp 0℃	Cumulative day yield liters	Wind velocity mph
1	9.00AM	340	26	29	35	27	-	1.4
2	10.00 AM	480	27	36	45	29	0.090	1.3
3	11.00 AM	600	28	45	54	31	0.250	1.2
4	12.00 AM	760	29	53	62	33	0.480	1.1
5	1.00PM	880	30	58	69	34	0.790	1
6	2.00 PM	910	31	62	71	35	1.210	0.9
7	3.00 PM	790	29	60	70	32	1.560	0.8
8	4.00 PM	650	27	55	61	29	1.840	1.2
9	5.00 PM	350	25	49	54	27	2.020	1.4
10	6.00 PM	190	24	41	40	25	2.130	1.5

4. Result analysis

The figure 4 shows that the cumulative day yield of the solar still from 9.00 am to 6.00 pm of the day. The cumulative day of the solar still is measured by the conical flask with milliliter measurements, Cumulative values for the sea water at start 9 am is 0 ml and the evening 6 pm is 710 ml, and for sea water with pebbles 0 ml to 1480 ml and sea water with nano materials is 0 ml to 2130 ml.

The yield increased from 9.00 am to mid-day (1.00 pm to 2.00pm) due to reason of solar intensity at 9 am solar intensity is 330 W/m^2 to increased maximum intensity of 910 W/m^2 at 2 pm and also decreased from 2.00 pm to 6.00pm. solar intensity at 2 pm solar intensity is 910 W/m2 to decreased to 190 W/m2 at 6 pm The intensity is more in mid-day time 1.00 pm to 2.00 pm. so the intensity also more in mid-day time

The monthly solar radiation is taken from March 2023 to October 2023. The solar radiation is increased from March to June and also decreased from June to October 2023 The solar radiation is more in the month of June 2023. The solar radiation is minimum at in the month of October 2023.

The figure 4 shows that the Cumulative day yield of the solar still for sea water with various energy absorbing materials

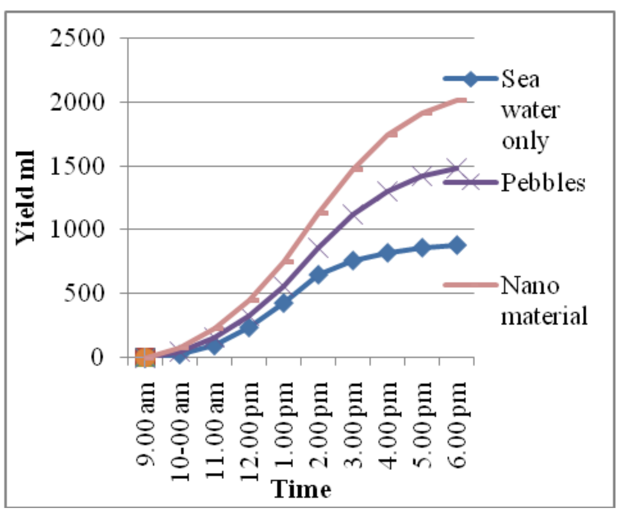

Fig.4. Cumulative yield for sea water with various energy absorbing materials

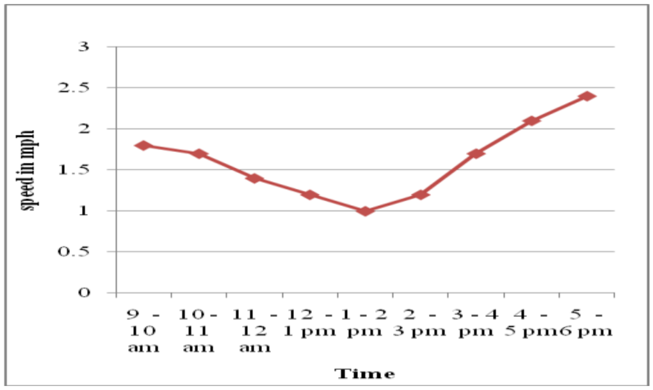

Fig. 5 Day variation of wind speed

Figure 5 shows that the variation of wind speed with respect to local time during the experimental days the wind speed is low in mid-day time and more in the evening time.

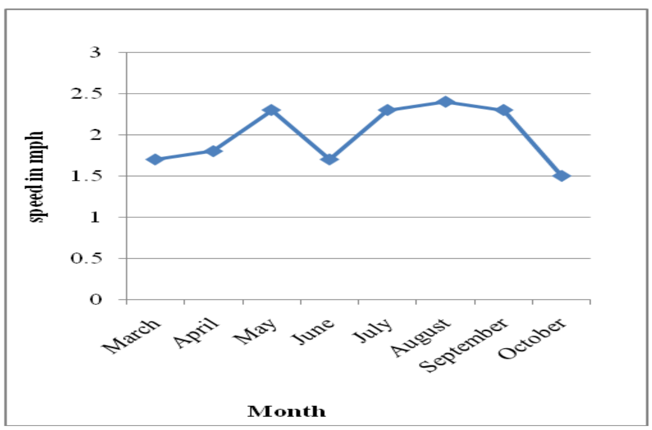

Fig 6 Monthly variation of wind speed

Figure 6 shows that the variation of wind speed with respect to local time during the experimental days the wind speed is less in the month of June mid-and more in the month of October.

5. Mathematical Calculations and Analyzing

5.1 Performance of Nano particle

The performance of nano particles is calculated from the expression. The Nano particles played more important role in the solar still. The solar still absorbed more solar radiation and stored nano material. So total number of increased nano particles in absorbed more solar radiation.

$$N = \frac{m}{4 \pi r^3/3 \times \rho_n} \quad (1)$$

Where

N is total number of nano particles, m is mass of nano powder in Kg, r is radius of nano particles in m and ρ_n is density of nano particles.

From the above formula, the total number of Nano particles is 1.114×10^{18}

5.2 Total Spherical area of Nano particle

The total nano materials spherical surface areas conduct solar heat.Since this area is large as tha calculation below shows,more heat is conducted and stored in nano materials.This increase the yield and efficiencu of the slar still.

The total spherical area of nano particles is calculated from the expression.

$$A_n = 4 \pi r^2 \times N \quad (2)$$

Where,

A_n is spherical area of the nano particle

From the above formula the total spherical area of nano particles is $12592 m^2$.

The increased surface area for solar heat transfer helps to raise the efficiency of the system. The increases in yield of distilled water in nano material filled still is due to the increase in heat transfer area compared with plain solar still. The nano materials absorb sunlight and heat transfer the heat to the saline water efficiently.

5.3 Solar still efficiency calculation

When increased the effective area of solar still, the yield rate also increased and the performance of solar still is calculated from the expression.

$$\eta = \frac{Mh_{fg}}{A_{st}\varepsilon I} \qquad (3)$$

Where,

M is mass of yield in kg/day, h_{fg} is latent heat of water in kJ/kg , εI is solar radiation intensity in $W/m^2/day$,A_{st} is Effective Area of still in m^2.

From the above formula, the efficiency of solar desalination systems with the present experiment shows

that efficiency of 16% is achieved by using nano material.

5.4 The inlet and exit face pressure variance

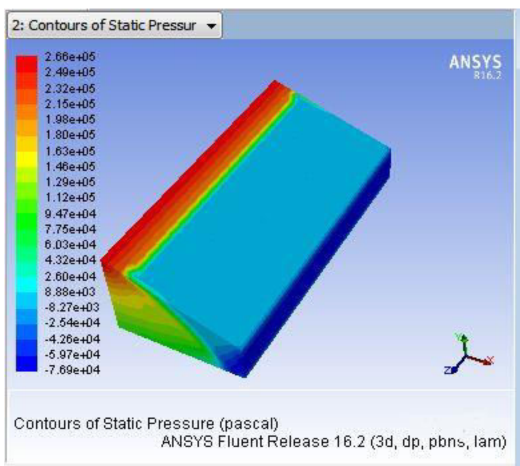

Fig 7 The inlet and exit face pressure variance

The inlet and exit face pressure variance are appeared in fig 7. Inlet contour temperature pressure inputs are 110 MPa and varying pressure values are 131 MPa. Ansys workbench 16.2 version with help of done to complete the pressure variance range of solar still.

5.5 The wall temperature variance

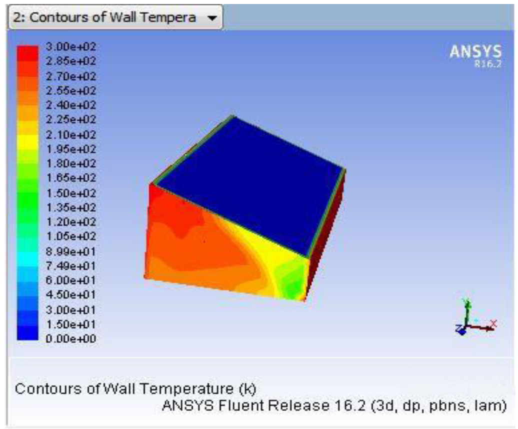

Fig 8 The wall temperature variance

Constant wall temperature results are appeared with of Ansys CFD process and changing atmospheric temperature. Ansys workbench 16.2 version with help of done to complete the temperature variance range of solar still. In this method to analyzed basic of normally passing pressure and velocity controls. Increase wall temperature results are shown in the figure 8.

6. Conclusion

The evaporation rate is increased by the various solar heat absorber materials such as Pebbles and nano materials (Aluminum oxide>60nm). The nano material (aluminium oxide) has higher solar absorption co- efficient than salty sea water .So more solar radiation is converted in to thermal heat and the basin water rises in temperature quickly. The nano material is giving the more yield of pure water than the other solar heat absorber materials. The best slope of glass cover is $30^0$and the water depth of still is 20mm. The optimization result of the yield is in the mid-day time (1.00 to 2.00 pm).The maximum day yield of seawater for the mid-day time is 0.380 L /m^2/day. The maximum day yield for sea water with nano material is 2.130 L /m^2/day. The maximum efficiency of the solar still with nano material is 16%.

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Conflicts of interest: The authors declare no competing financial interest.

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request

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