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Experimental Analysis of Single Basin Solar Still with Internal Reflector and Sensible Heat Storage Medium

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Abstract : Pure drinking water is essential for the survival of human race. To overcome this shortage of pure drinking water, distillation method is used all over the world. During recent times, solar energy is used for this process. Solar stills are used for the purpose of conversion of saline to drinking water. But the efficiency level is very low. To increase the efficiency of solar stills, many types of modifications are made. In this experiment, conventional solar stills are modified by using multiple fins, spreading coal at the bottom of the still and radiation is increased by fitting a reflecting mirror at the bottom of the still, at Tamilnadu, India. Finally, experimental value was compared with theoretical value.
Keywords: Solar still, Coal, Multiple Fins, Reflecting mirror.

1. Introduction

Water is one of the gifts of nature. It is very essential for the existence of human beings. About 97 % of the water is salty and only 3 % of the earth's water is potable. Due to population growth and rapid growth in industries the need for fresh water increases day by day. Water scarcity is going to be a great problem in the future. The survival of human beings and animals depends upon the availability of fresh water .So necessary steps have to be taken to preserve the existing fresh water source. To meet the growing needs of the fresh water, it is necessary to convert saline water into pure water. So desalination is the best possible solution to the above problem. Many desalination techniques and methods are available. But these methods require large volume of fossil fuels. But the availability of the fossil fuel is limited in the world. Solar energy can be used for the desalination process. Solar stills are used all over the world in the desalination process but their productivity is very low. So we have to design techniques that will improve the productivity and efficiency of the solar stills. Different researchers have designed different techniques to improve the efficiency .In this work an attempt has been made to improve the efficiency.

The main objective of this work is to produce pure drinking water from hard water. To enhance the productivity experiments were carried out in the following combinations

1. Single basin solar still with fins
2. Single basin solar still with coal at the base
3. Single basin solar still with focussing mirror at the bottom
4. A combination of all these elements

2. Literature review

Murugavel et al.[1-2] studied the performance of single slope solar still with different types of wick materials in the basin such as cloth, coir mat sponge sheet black cotton cloth, jute, and waste cotton pieces. Among these, black cotton cloth was the most effective. El-Sebaii et al.[3] studied the performance of a single slope basin still with Phase Change Materials (PCM) as a storage medium and the daily efficiency of still produced 84.3% Sakthivel et al.[4] studied the regenerative solar still with energy storing material as jute cloth . The productivity of the still with jute cloth was 20 % higher than the conventional still. Abdallah et al.[5] used a suntracking device for rotating the solar still with the movement of the sun. The productivity of the still with suntracking device increased by 22 %. J.Prabahar et al.[6] compared the cumulative productivity per m^2 for simple still,still with collector, still with sponge and still with collector sponge combination. It was found that productivity increased by 14 % for collector, 10 % for sponge and 17 % for collector sponge combination on comparison with simple still. C. Tenthani et al.[7] compared the efficiency of improved solar still with conventional solar still. Efficiency increased by 6.9% in improved solar still[12]. It was found that distillate output improves by painting the internal surface of the walls of the still white. Hiroshi Tanaka et al.[8] theoretically predicted the productivity of distillate of a basin type still with internal and external reflectors. The distillate amount daily increases on an average by 48% by adding both the internal and external reflectors Sadineni et al.[9] studied the performance of weir type inclined solar still and found that the productivity of the weir type solar still was 20% higher than the convention solar basin still. Al-Karaghoulia et al.[10-11] studied the performances of single basin solar still and double basin solar stills. The double basin has higher productivity[17, 18]. They also observed that, insulation has a major effect on the output, mainly for the double basin type.

3. Experimental Setup

For the experimental work a solar basin was fabricated. The size of the solar basin was 77cmx57cm and the depth was 32cm. The basin was made up of 4 mm thick Galvanized iron [GI] which is readily available in the market. The top surface of the solar still was covered by a glass which was inclined by an angle of 11^0 that is latitude angle at Salem, Tamilnadu, India[14-16].

The solar basin was placed inside the solar still. The outer cover still was made up of wood. The inner surface of the solar still was coated with black paint to absorb more solar radiation. The cross section of the solar still was (80cmx60cm) and its thickness was 1 cm. A slit of width 15 cm was made at the bottom of the solar still. A reflecting mirror was fitted at the bottom of the solar still so as to reflect solar radiation through the slit into the basin. The solar still was designed in such a way that it consisted of two parts - the lower and upper part. The upper part was removable. This enables to pour water into the solar basin [19,20].

To improve the efficiency of the solar still 5 rectangular fins of the size 37 mm height and 900 mm length and 1 mm breadth were fitted in the solar basin to increase the heat transfer rate. At the bottom of the basin 1 kg of coal was spreaded to produce high thermal conductivity. A collecting tank was fitted in the outer surface of the solar still to collect pure water [21,22].

Thermocouples are attached at the bottom of the basin and top surface of the still to measure temperature between evaporation and condensation process.

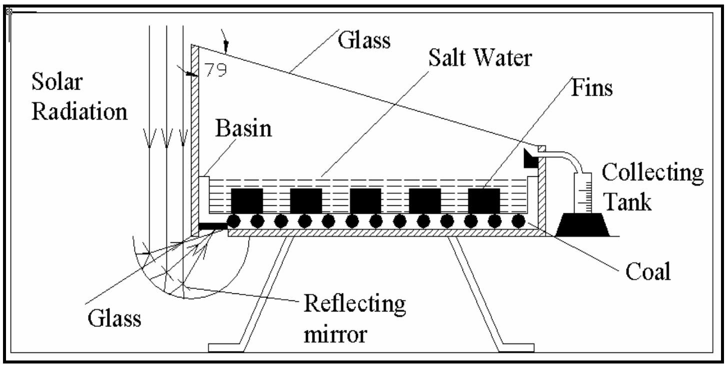


Fig 1: Schematic diagram

Solar still without any additional fittings [solar fins, coal layer and reflecting mirror] was kept in a sunny environment when sufficient sun rays fall on the equipment. 5 litres of hard water was poured into the still. The pure water collected at the end of the day was measured and recorded. Then solar fins were fitted into the solar still. The same amount of hard water was poured and the same environment maintained and readings recorded at the end of the day. To further increase the efficiency coal was spreaded at the bottom along with fins. Pure water collected was recorded. To further increase the efficiency solar radiation was focussed through mirrors at the bottom and pure water collected was recorded. Experiment was conducted in Salem, in the month of January2015 -March 2015 during 9.00a.m. to 5.00p.m at VSA school of Engineering, Salem.

Side view Top view Front view

Fig 2: Experiment Setup

4. Measurement of parameters calculation

The error analysis for various measuring instruments used in the experiments is shown in Table 5. The error is calculated for Anemometer, solarimeter, thermocouple, and collection tank. The least error occurred in given instrument is equal to the ratio between its least count and minimum value of the productivity calculated.

Table 1: Ranges of measuring instruments

Sl.no.	Instrument	Accuracy	Range	Error %
1	Thermocouple	± 1^0C	0–100°C	0.25
2	Solarimeter	± w/m^2	0–5000W/m^2	0.25
3	Collecting tank	±10ml	0-1000ml	10%
4	Anemometer	± 0.1m/s	0–15m/s	10%

5.Results and Discussion

The experiment was conducted under two circumstances - under low radiation i.e. when radiation was between 400-550 W/m^2 under high radiation i.e. when radiation was between 600-700 W/m^2, similar to [13]. solar fins were fitted into the solar still and experiment conducted during high radiation days and soft water collected was recorded after 8 hours. The maximum temperature attained by the water inside the solar still was 62^0C and temperature attained by glass was 59^0c As a result the soft water obtained was 2.25 litres. In other words the efficiency level attained was 45%. The same experiment was conducted during low radiation days. The maximum water temperature obtained was only 59^0C and the glass temperature was 52^0c. Output of pure water after 8 hours was only 1.8 litres. This shows an efficiency level of 36%. Now along with solar fins coal was spreaded at the bottom of the solar still. During high radiation days maximum water temperature reached was 64^0C and the glass temperature reached 60^0C. As a result pure water obtained increased from 2.25 to 2.55 litres.

In other wards efficiency increased from 45 to 51%.When experiment was conducted during low radiation days. The maximum water temperature attained was 61^0c and glass temperature obtained was 54^0c. Pure water obtained was 1.9 litres after 8 hours i.e. efficiency increased from 36 to 38 % Then to the solar still solar fins were fitted and additional radiation was given by fitting a reflecting mirror at the bottom. As a result the maximum water temperature reached increased to 69^0C and glass reached a value of 62^0c. The pure water obtained increased to 2.25 litres. This shows that efficiency has increased to 51%. The same experiment was conducted during low radiation days. The maximum water temperature reached was only 62^0c and glass temperature was 56^0c. Pure water obtained was only 2.1 litres. The efficiency is only 42 %. In the next stage solar fins were added to the solar still and coal was spreaded at the bottom and additional radiation was given by fitting a mirror at the bottom As a result the maximum water temperature increased to 71^0c and glass temperature to 68^0c. The collection of pure water was 2.8 litres and efficiency level attained was 56 %.During low radiation days the maximum water temperature reached was only 64^0c and the corresponding glass temperature was 59^0c. Pure water collected was 2.3 litres. Efficiency level attained was 46 %. From the above analysis it is clear that efficiency level of the solar still without any modification was very low. As we do additional modifications efficiency increases. To further increase the efficiency few more modifications have to be done. The results are tabulated in table 2, 3 and 4.

Table 2: Efficiency on solar still with various modifications during high and low radiation days.

Sl. no.	Modification	During high radiation ($600–720 W/m^2$)				During low radiation ($400–550 W/m^2$)			
		Date	Input water 5 litres	Output pure water 8 H/ D	Daily efficiency (%)	Date	Input water 5 litres	Output pure water 8 H/ D	Daily efficiency (%)
1	Fin type still	25.02.15	5	2.25	45	21.02.15	5	1.8	36
2	Fin type still with coal	26.04.15	5	2.35	47	22.01.15	5	1.9	38
3	Fin type still with curved shape reflecting	04.03.15	5	2.55	51	14.03.15	5	2.1	42
4	Fin type still with coal, curved shape reflecting mirror	22.03.15	5	2.8	56	20.03.15	5	2.3	46

Table 3: water and glass temperature recorded for various solar still modifications during high radiation days

Sl. no.	Modifications	During high radiation($600–720 W/m^2$)				
		Date	Water temperature (°C)	Glass temperature (°C)	Increase in productivity (%)	Daily efficiency (%)
1	Fin type still	25.02.15	62	59	12	45
2	Fin type still with coal	26.04.15	64	60	14	47
3	Fin type still with curved shape reflecting	04.03.15	69	62	18	51
4	Fin type still with coal, curved shape reflecting	22.03.15	71	68	23	56

Table 4: water and glass temperature recorded for various solar still modification during low radiation days

Sl. no.	Modification	During Low Radiation(400–550W/m^2)				
		Date	Water temperature (°C)	Glass temperature (°C)	Increase in productivity (%)	Daily efficiency (%)
1.	Fin type still	25.02.15	59	52	3	36
2.	Fin type still with coal	26.04.15	61	54	5	38
3.	Fin type still with curved shape reflecting	04.03.15	62	56	9	42
4.	Fin type still with coal, curved shape reflecting mirror	22.03.15	64	59	13	46

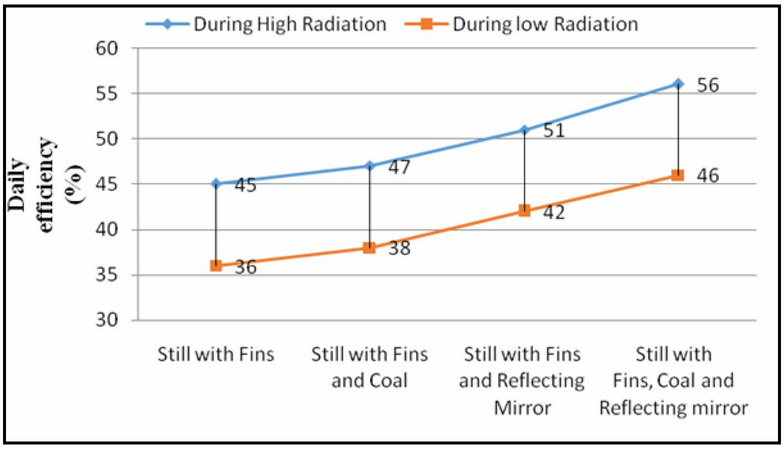


Fig 3: comparison of daily efficiency with various solar still modifications during high low radiation days

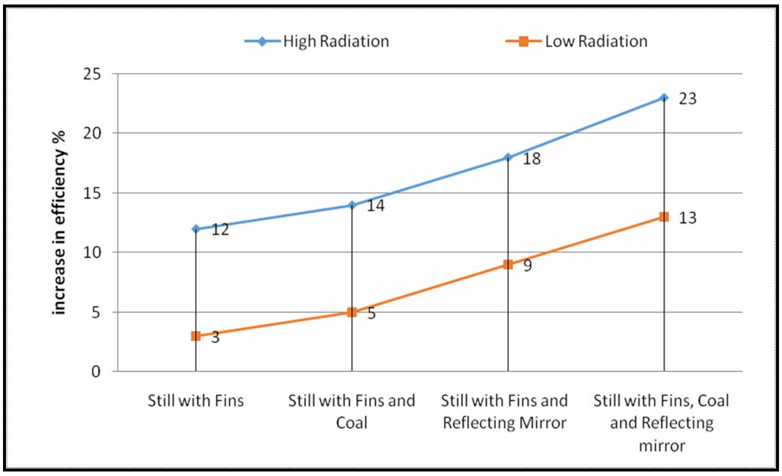


Fig 4: comparison of increase in efficiency with various solar still modification during high low radiation days.

5.1 Daily efficiency

$$\eta_d = \frac{output}{input} = \frac{\Sigma m_e h_{fg}}{\Sigma AI(t)}$$

It is defined as the ratio of energy output to the energy input. The energy output is obtained by summation of the hourly condensate production **m** with multiplied by the latent heat of vaporization h_{fg} and Energy input of still by daily solar radiation I(t) with whole area (A). theoretical calculations of daily efficiency was done using the above formula for solar still with all modifications are shown in table 3.

5.2 Increasing in Productivity

$$\% \text{ increase in productivity} = \frac{(m_{Output} - m_{without\ any\ modification\ still})}{(m_{without\ any\ modification\ still})} \times 100$$

It is defined as the ratio of difference in productivity between (with and without modifications) and without modifications. the efficiency obtained with different modifications are shown in table 4.

5.3 Effect of solar intensity on productivity

Experiments were conducted from February 2015 to April 2015. At a constant wind velocity of 0.7 m/s, data was recorded for various days to evaluate the effect of solar intensity on productivity as a solar radiation increases the productivity increases this is given fig.5.

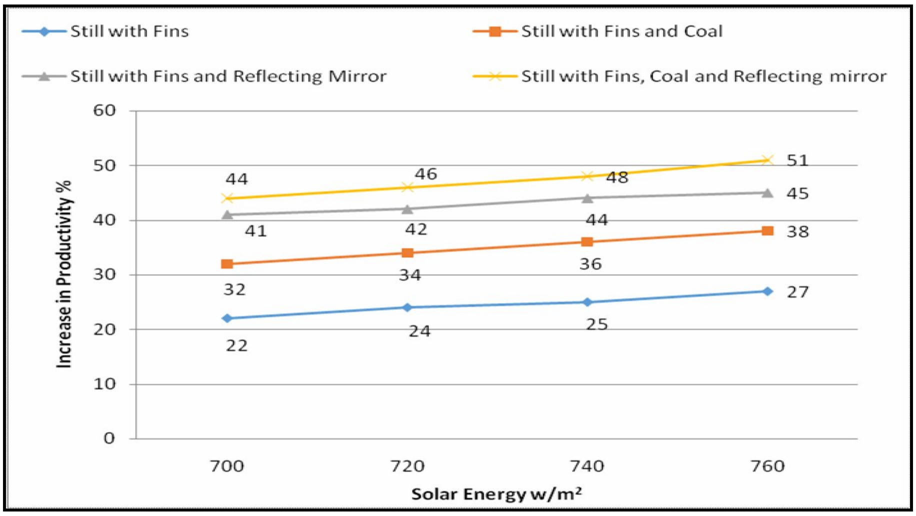


Fig 5: Effect of solar energy on increases in productivity.

5.4 Effect of wind velocity on productivity

With a constant solar intensity of 720w/m^2 data was recorded for various wind velocity for different solar still modifications when wind velocity increased from 0.6 to 0.7 m/s the productivity decreased. Increase in wind velocity increases the convective heat losses at the top surface of the glass and thus the efficiency has decreased the fig.5

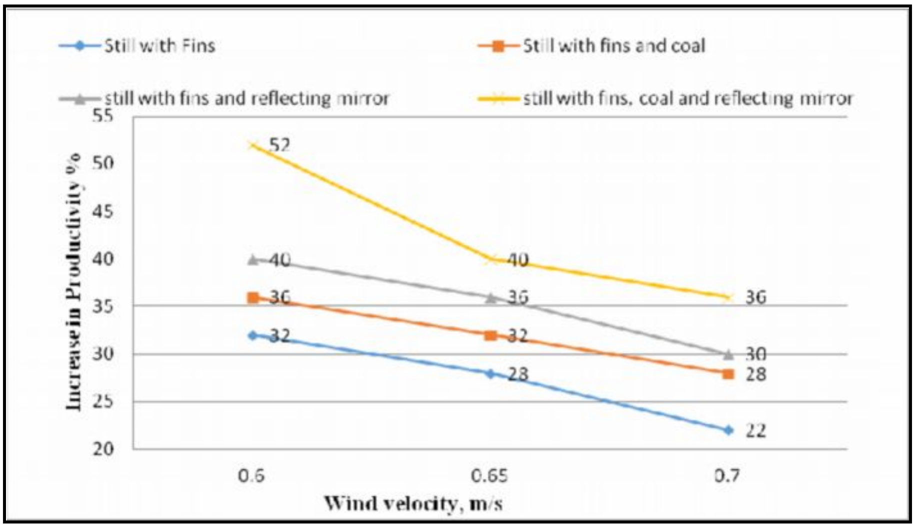


Fig 6: Effect of wind velocity on increase in productivity

5.5 Theoretical Calculation

Theoretical investigation was done to find the temperature of single basin solar still, the evaporation rate and glass temperature at each moment.

5.5.1 Single basin solar still

The energy balance equation for the single basin plate can be written as

Energy absorbed by solar still basin

Energy absorbed by the basin plate = (Energy gained by the basin plate) + (Energy lost by convective heat transfer between basin and water $Q_{c,b-w}$) + (Side losses Q_{loss})

Absorbtivity of water α_b is 0.95.

Mass of basin, (m_b) is taken as 3.5 kg

$$I(t)A_b\alpha_b = [mc_p\,[dT/dt]]_b + Q_{c,b-w} + Q_{loss} \quad (1)$$

Energy received by salt water

The energy gained by the salt water in the solar still = (Energy gained by the salty water) + (Energy lost by convection between water and glass $Q_{c,w-g}$) + (Energy lost by radiation between water and glass $Q_{r,w-g}$) + (Energy lost by evaporative heat transfer between water and glass $Q_{e,w-g}$)

Absorbtivity of the water α_w is 0.05.

mass of water, (m_w) is taken as 3.8 kg.

$$I(t)\alpha_w A_w + Q_{c,b-w} = [mc_p[dT/\,dt]]_w \;\; Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} \quad (2)$$

Energy received by glass cover

Energy gained by the glass cover due to convection, radiation and evaporation + heat transfer through water to glass=(Energy lost by radiative heat transfer between glass and sky $Q_{r,g-sky}$)+ (Energy lost by convective heat transfer between glass and sky $Q_{c,g-sky}$) +(Energy gained by glass)

Absorbtivity of the glass, α_g, is 0.0475.

$$I(t)\,\alpha_g A_g + Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} = Q_{r,g-sky} + Q_{c,g-sky} + [m_g c_p[dT/dt]]_g \quad (3)$$

Total condensation are given as

$$(dm_e /dt) = h_{e,w-g}[Tw - Tg]/h_{fg} \qquad (4)$$

At the initial stage, water temperature, glass temperature and basin temperature are kept at ambient temperature. The change in temperature of water due to solar energy received by the still of the basin is solved by solving equation (2),(3) (4) with mathematical calculation. The values for $Q_{c,b-w}$, Q_{loss}, $Q_{c,w-g}$, $Q_{r,w-g}$, $Q_{e,w-g}$, $Q_{r,g-sky}$, $Q_{c,g-sky}$ are taken from [19]. Ambient temperature, wind velocity and solar radiation values are measured hourly during the experimental dates. The values are substituted the above said equation. And theoretical result obtained.

5.5.2 Efficiency of Solar Still

The theoretically obtained amount of portable water = 3.2 litre

The practically obtained amount of pure water = 2.8 litre.

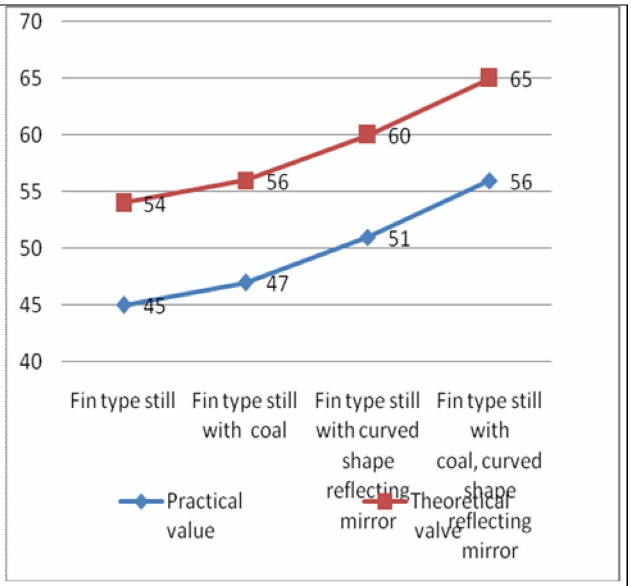
$$\text{Efficiency} = \frac{\text{actual amount of pure water}}{\text{theoretical amount of pure water}} \text{x100}$$

$$= \frac{2.8}{3.3}\text{x100}$$

$$= 84\%$$

Table 5: Comparison between experimental and theoretical efficiency

Sl.no.	modifications	Solar intensity> 600w/m^2	
		Practical	Theoretical
		Daily Efficiency	Daily Efficiency
1	Fin type still	45	54
2	Fin type still with coal	47	56
3	Fin type still with curved shape reflecting mirror	51	60
4	Fin type still with coal, curved shape reflecting mirror	56	65



Comparison between experimental and theoretical efficiency for various solar still modifications are shown in table 5.

6. Conclusion

A simple basin solar still was modified by using fins, spreading coal at the bottom and increasing radiation by fitting a reflecting mirror. To examine the productivity various experiments were conducted at low radiation atmosphere and high radiation atmosphere.

1. In low radiation atmosphere fins single basin solar still alone produced daily efficiency of 36%. The daily efficiency increased upto 46% when the still was modified.
2. In high radiation atmosphere the daily efficiency of the single basin solar still increased from 45% to 56% when modified.

3. During high radiation days there was an increase in efficiency up to 23% with modified solar still compare to the efficiency of solar still without modification.
4. It was found that the modifications made in the simple solar still increased the productivity considerably. To further increase the efficiency few more modifications have to be done.

Symbols			
English letters		**Greeks**	
A	Area, m^2	α	Absorptivity
c_p	Specific heat, J/kgk	b	collector surface inclination
I(t)	Solar flux on inclined collector, W/m^2	e	emissivity
Q	Heat transfer, W	η_d	Daily efficiency (%)
°C	Temperature	S	Stefan–Boltzmann constant
dt	Time interval,	Subscripts	
dT	Change in temperature,	a	Ambient
h_{fg}	Enthalpy, J/kg	K	Thermal conductivity, W/mk

References

1. Vinoth KK, Bai RK. Performance study on solar still wit enhanced condensation. Desalination 2008; 230(1–3):51–61.
2. K.Kalidasa Murugavel, K.Srithar, Performance study on basin type double slope solar still with different wick materials and minimum mass of water, Renewable Energy. 36(2) (2011) 612-20.
3. A. A. El-Sebaii, Al-Ghamdi, F. S Al-Hazmi, S. Faidah Adel, Thermal performance of a single basin solar still with PCM as a storage medium, Applied Energy. 86(7-8) (2009) 1187-95.
4. M. Sakthivel, S.Shanmugasundaram, T. Alwarsamy, An experimental study on a regenerative solar still with energy storage medium–jute cloth, Desalination. 264(1-2) (2010) 24.
5. S. Abdallah, O.O.Badran, Suntracking system for productivity enhancement of solar still, Desalination.220 (1-3) (2008) 669-76.
6. Prabahar, Dr.T.Balusamy, Varghese, M John. Enhancement of Productivity on Double Slope Single Basin Solar Still by Flat Plate Collector and Sponge Applied Mechanics and Materials Vols. 813-814 (2015) pp 690-694.
7. C. Tenthani, A. Madhlopa, Z. Kimambo Improved Solar Still for Water Purification Journal of Sustainable Energy & Environment 3 (2012) 111-113.
8. Hiroshi Tanaka, Yasuhito Nakatake .Theoretical analysis of a basin type solar still with internal and external reflectors Desalination 197 (2006) 205-216.
9. B. Sadineni, R. Hurt, C.K. Halford, R.F. Boehm, Theory and experimental investigation of a weir type inclined solar still, Energy Conversion and Management. 33 (2008) 71-80.
10. A.A. Al-Karaghoulia, W.E. Alnaserb, Experimental comparative study of the performances of single and double basin solar-stills, Appl. Energy 77 (2004) 317–325.
11. A.A. Al-Karaghoulia, W.E. Alnaserb, Performances of single and double basin solar-stills, Appl. Energy 78 (2004) 347–354.
12. P. Rajendra Prasad, Padma Pujitha, B., G. Venkata Rajeev and K.Vikky, Energy efficient Solar Water Still, International Journal of ChemTech Research, Vol.3, No.4, pp 1781-1787, Oct-Dec 2011.
13. G. Mageshwaran, S. Ramachandran, G. Iyappan & R.B. Durairaj (2016): Experimental investigation on surface radiation properties' degradation of solar collector receiver tube material, International Journal of Ambient Energy, DOI: 10.1080/01430750.2016.1202139.
14. Pankaj K. Srivastava, S.K. Agrawal, Abhay Agrawal, Effect Of Absorber Material On The Performance Of Basin Type Solar Still With Multiple Floating Porous Absorbers, International Journal of ChemTech Research, Vol.5, No.2, pp 1046-1053, April-June 2013`
15. M. Edwin1, S. Joseph Sekhar, Performance and Chemical Analysis of Distilled Saline Water Production Using Solar Distillation System, International Journal of ChemTech Research, Vol.8, No.4, pp 1632-1637, 2015.
16. Dhananjay Singh, Durgesh Pratap, Sunita Maurya and D.P. Maurya, Hygiene Promotion & Sanitation through Solar Distillation for Safe Drinking Water in Rural India. International Journal of ChemTech Research, Vol.3, No.1, pp 51-57, Jan-Mar 2011.

17. A.Jesu1, L.Prabudoss Kumar, K.Sneka Latha, Ignatius Navis Karthika, Utilization Of Solar Energy For The Treatment Of Sugar And Distilleries Effluent, International Journal of ChemTech Research, Vol.5, No.3, pp 1195-1204, April-June 2013.
18. Dayal Singh Rajput, K. Sudhakar, Effect Of Dust On The Performance Of Solar PV Panel, International Journal of ChemTech Research, Vol.5, No.2, pp 1083-1086, April-June 2013.
19. Akshat Agrawal, Solar Energy For Domestic Drinking Water – A Pilot Study, International Journal of ChemTech Research, Vol.5, No.2, pp 811-814, April-June 2013.
20. Pranay Vijayvargiya, Combating India's Power Deficit Using Solar Thermal Power, International Journal of ChemTech Research, Vol.5, No.2, pp 1087-1093, April-June 2013.
21. Adit Gaur, Mayank Bhayana , S.K. Agarwal, An Experimental Investigation Of A Novel Design Of A Double Pass Solar Air Heater, International Journal of ChemTech Research, Vol.5, No.2, pp 1036-1040, April-June 2013.
22. M. Edwin, S. Joseph Sekhar, Performance and Chemical Analysis of Distilled Saline Water Production Using Solar Distillation System, International Journal of ChemTech Research, Vol.8, No.4, pp 1632-1637, 2015.

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