PERFORMANCE ENHANCEMENT OF SINGLE SLOPE SOLAR STILL USING NANO-PARTICLES MIXED BLACK PAINT

Manoj Kumar Sain, Godhraj Kumawat

Department of Mechanical Engineering
Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur

ABSTRACT

The present paper reports on an experiment to improve the productivity of solar still using nano-particles. Solar distillation is a relatively simple treatment of brackish or impure water. In this solar energy is used to evaporate water then this vapour is condensed as pure water. This process removes salts and other impurities. Latest trend to improve the efficiency of the solar still is use of nano-particles like metal oxides. These particles increase surface area of absorption to solar radiation. In this work the Al_2O_3 *nano-particles mixed black paint is used to enhance the productivity of solar still. The solar radiations are transmitted through the glass cover and captured by a black painted inner bottom surface of the solar still. Water absorbs the heat and is converted into vapour within the chamber of the solar still.Single slop solar still is used from past decades but in this study effect of nano-particles on productivity of solar still is analyzed. Experimental work is performed for the single slope solar still (SS-SS) under climatic conditions of Jaipur. The use of the nano-particles mixed with black paint increases the temperature of the solar still basin. The productivity and efficiency of solar still at water depth 0.01 m with nano-particles are 3.48 litre and 38.65% respectively which are maximum values compared to water depths 0.02 m and 0.03 m. Results of the study gives 38.09% increment in productivity and 12.18% increment in thermal efficiency when nano-particles of size 50 nm to 100 nm mixed black paint used at water depth .01 m. To check the significance of difference in productivity of solar still with and without nano-particle mixed black paint, a paired t-Test is performed which is conforms that the productivity enhancement due to nano-particle mixed black paint is significant at 95% confidence interval.*

KEYWORDS

Solar still, Distillation, Nano-particles, Productivity, TDS, PPM.

SYMBOLS USED

Symbol	**Brief description**
A	Area of basin (m^2)
c_p	Specific heat of water (kJ/kg ^oC)
dT	Change in temperature of water in basin for one hour (^oC)
dT'	Temperature difference between average temperature of water

	in one hour and initial temperature of water of two continues observations in one hour (^oC)
E_{evap}	Energy used to evaporate water (MJ)
E_i	Energy input, in MJ
E_o	Energy output, in MJ
$(E_{sensible})_1$	Energy for change in temperature of basin water (MJ)
$(E_{sensible})_2$	Energy for change in temperature of yield production before it evaporates(MJ)
h_{vap}	Latent heat of vaporization of water (kJ/kg)
I	Solar radiation on solar still (MJ/m^2)
ITS-90	International Temperature Scale of 1990
M	Condensed water mass per day (kg)
M_w	Mass of water in basin (kg)
PPM	Parts per million
TDS	Total dissolved solids
$T_{average}$	Average temperature(^oC)
T_w	Temperature of basin water (^oC)
η	Efficiency

1. INTRODUCTION

In the present scenario, the demand of fresh water is increasing continuously [1]. To meet this growing demand, ground water has been intensively exploited. Fresh water is required for drinking, and other domestic purposes [2]. Solar still is a simplest desalination device which uses solar energy for converting available impure or brackish water into distilled water. It is easy to fabricate and require no maintenance [3]. The productivity of single basin solar stills is very low [10], which must be increased with some modifications.

An inverted absorber solar still is a combination of a simple single slope solar still and a curved reflector under its basin which gives additional heat to basin.. in this way the solar still takes an advantage of double sided heating of basin i.e. from top as well as bottom which increases the temperature of basin, which results in increased productivity [4]. Latest trends to improve the efficiency of the solar still is, use of nano-particles like metal oxides, coupling of other solar energy devices like solar air heater, solar pond etc, thermal storage tank. Previous study shows that use of Nano-particles demonstrate better results for solar collecting devices. In domestic buildings lots of heat is used by occupants it can be very useful for distillation process. Mathematical modeling of solar still is done by lots of researchers and this can be helpful for present study [5]. For small or remote communities where there is lack of water but also of electrical grid the only solution is the use of renewable energies, as solar, wind etc., in connection either to small capacity conventional desalination units but better to use solar energy with solar stills. Conventional thermal desalination methods, as Multi-Stage-Flash, Multiple-Effect Diffusion (MED) [9] and minor Thermal and/or Mechanical Vapor Compression found application for large capacity installations. Reverse Osmosis, a membrane operating method which functions by electricity, is used as well in small or large capacity plants. All these methods found application worldwide, but especially in places with a total lack of fresh water and more or less dense population. They are operated by conventional energy sources as fuels[6].

1.1. Objectives of Present Study

Objectives of present study are to show results of single slope solar distillation device which is used to purify raw water in Indian desert region. Al_2O_3 nano-particles of size 50 nm to 100 nm mixed with black paint is used at absorber surface (basin) for increasing the efficiency of solar still.

2. SOLAR STILL WORKING PRINCIPLE

The main features are the same for all type of solar stills. In the present solar still solar radiations transmitted through the glass cover and absorbed by nano particles mixed black painted surface at the basin of the solar still. This energy is used to convert water into vapor within the chamber of the solar still. The vapor is condensd on the glass cover of the solar still, which is at a lower temperature because it is in contact with the ambient air and also the convection is takes place at this layer. The condensed water goes down into a channel from where it is fed to a storage tank for distilled water.

3. DESIGN OF SINGLE SLOPE SOLAR STILL

Single slop solar still is a commom device which is used from past decades. In this study the effect of Al_2O_3 nano-particle on productivity of sinle slope solar still is analyzed. Figure 1 shows the isometric view of solar still used for study.

The height, length and width of the solar still are shown in Figure 1. The area of basin of still is 1 m^2. Solar still is made by GI sheet and cover of solar still is made by clear glass. All sides of solar still are insulated with thermocol of thickness 50 mm. Al_2O_3 nano-particles mixed black paint is painted on basin to increase the radiation absorption.

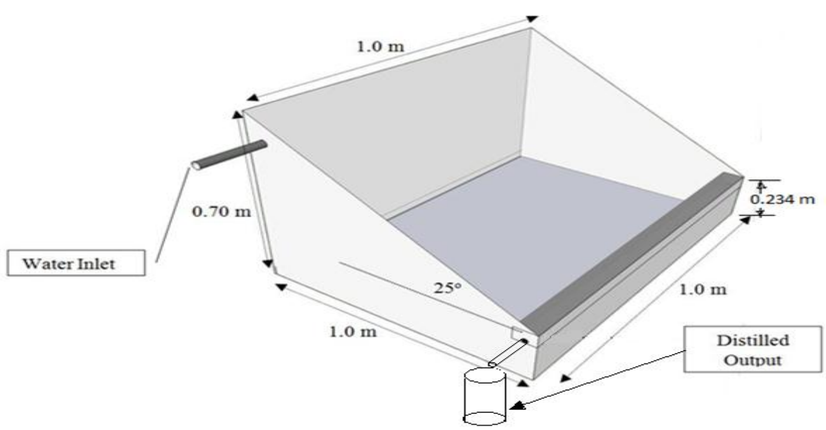

Figure 1: Isometric view of solar still

The solar radiations partially reach to the water surface directly after transmission through the glass cover, the water surface receives the rest of the radiations after the reflection from reflector. The water also partially reflects and partially absorbs the total solar radiations falling on the water surface and the rest are absorbed by the absorber painted with nano-particles mixed black paint. Most of the solar radiations are used by water after absorption, which gets heated and vaporization is started. Due to wind some heat is transferred to the atmosphere through outer layer of glass cover and then condensation is started. This condensed water is collected through the channel. Figure 2 shows actual view of setup which is used for experimentation.

Figure 2: Final stage photograph of solar still

4. THERMAL EFFICIENCY OF SOLAR STILL

Efficiency of the solar still is calculated using the input and output energies. Input energy (E_i) is the solar radiation; solar radiation for location of Jaipur is taken from Indian Metrological Department.

Output energy (E_o) of the solar still is in three parts.

(i) Distillate output

Distillate output (in terms of energy):

$$E_{vap} = M \times h_{vap} \quad \text{.....(i)}$$

Where

M is yield production of solar still in kg/h and h_{vap} is latent heat of water.

(ii) $(E_{sensible})_1$ Energy for change in temperature of basin water.

$$(E_{sensible})_1 = M_w \times c_p dT \quad \text{.......(ii)}$$

Where,

M_w is water mass in basin remaining after vaporization for one hour.
c_p is specific heat of water and $c_p = 4.187$ kJ/kg °C.
dT is change in temperature of water remain in basin for one hour.

(iii) $(E_{sensible})_2$ Energy for change in temperature of yield production before it evaporate.
Water is evaporating at different temperatures in the period of one hour between two continuous observations. So, calculation of energy take temperature difference between average temperature of water in one hour and initial temperature of water of two continioue observations in one hour.

$$(E_{sensible})_2 = M \times c_p dT' \quad \text{.......(iii)}$$

Where,

dT' is temperature difference between average temperature of water in one hour and initial temperature of water of two continioue observations in one hour.

Thermal efficiency is calculated by following equations

Energy input $$E_i = \sum_{7AM}^{7PM} I \times A \quad \text{.......(iv)}$$

Energy output $$E_o = E_{vap} + (E_{sensible})_1 + (E_{sensible})_2 \quad \text{.......(v)}$$

Put the values of E_{vap}, $(E_{sensible})_1$ and $(E_{sensible})_2$ from equation (i), (ii) and (iii) in equation (v) then.

$$E_o = M \times h_{vap} + M_w \times c_p dT + M \times c_p dT' \quad \text{.......(vi)}$$

The value of h_{vap} is taken as

$$h_{vap} = 2503.3 - 2.398 \times T \text{ kJ/kg [22]} \quad \text{.......(vii)}$$

In above equation T is take as average temperature of basin water.

Energy used to change temperature of water

$$E_{sensible} = (E_{sensible})_1 + (E_{sensible})_2$$
$$E_{sensible} = M_w \times c_p dT + M \times c_p dT' \quad \text{.......(viii)}$$

Output energy $$E_o = E_{vap} + E_{sensible} \quad \text{.......(ix)}$$

Overall efficiency $$\eta = \frac{E_o}{E_i} \times 100\% \quad \text{.......(x)}$$

Where A = Area of basin = 1.0 m^2
M = Mass of water evaporated in one day in kg.

5. RESULT AND DISCUSSION

Parameters which are analyzed in this study are following:

5.1 Full day yield production

In this part of study full day water distillation done by solar still is analyzed which is shown in Table 1. Loss of heat from solar still is also considered, so that thermal efficiency of solar still can be improved. Here 0.01 m water depth will be used for analysis because maximum yield production was observed at 0.01 m depth.

5.2 Effect of water mass

Efficiency of solar still depends on level of raw water or in other way water mass is an important parameter for solar still efficiency. In this study different depth of water has been taken to find the change in thermal efficiency. Three different depths of water have been recorded which are 0.01 m, 0.02 m and 0.03 m respectively.

5.3 Effect of Al_2O_3 nano-particles mixed black paint

Use of nano-particles mixed black paint can improve thermal efficiency of any heat transfer device [5], because area of heat absorbing surface is increased. Very few studies show application of nano-particles in solar thermal engineering, so in this study effect of nano-particles mixed black paint has been analyzed. Al_2O_3 has been used as material for nano-particles. The size of nano-particles used is 50 nm to 100 nm.

5.4 Cost analysis

In this work by using nano-particles there is an increase of Rs. 1500 in the cost of solar still. But increases productivity by 38.09% (0.96 litre per day) so increased cost recovered by the solar still in 104 days because market price of branded potable water is Rs. 15 per litre. Rs. 0.96 × 15 = 14.4/- per day increased (increased cost recovered by the solar still in 1500/14.4 = 104 days) and very less cost appear in maintenance

5.5 Summary of results

Experimental work was performed for the single slope solar still (SS-SS) under desert climatic conditions of Rajasthan (Jaipur). When the water depth was increased from 0.01 m to 0.03 m, it was observed that the productivity decreased by 6.34%. These results show that the water level has an intense effect on the productivity of the solar stil.

After the use of Al_2O_3 nano-particles it was observed that the solar still productivity increased by 38.09%. The use of the nano-particle mixed paint increases the temperature of the solar still basin, such an increase in the temperature is because of the increase in the absorption of the solar radiation at basin of the still.

Table 1: Summary of parameters of study

S. No.	Study parameter	Total quantity of raw water (kg)	TDS of sample water(PPM)	Total collected water (kg)	TDS of collected water(PPM)	Efficiency
1	Depth = 0.01 m	10	463	2.52	14	26.47%
2	Depth = 0.02 m	20	496	2.4	16	31.62%
3	Depth = 0.03 m	30	520	2.36	15	38.16%
4	Depth = 0.01 m, nano- particles use	10	414	3.48	14	38.65%

Table 1 shows the results that solar still achieves more than 98.4% (less than 16 PPM) pure water

5.6 Comparison of solar radiation and day time production in graphical form

Comparative study of global solar radiation intensity and day time production are shown in graphical form in figures 3, 4, 5 and 6 recorded at 0.01 m water depth, 0.02 m water depth, 0.03 m water depth and 0.01 m water depth with nano-particles respectively.

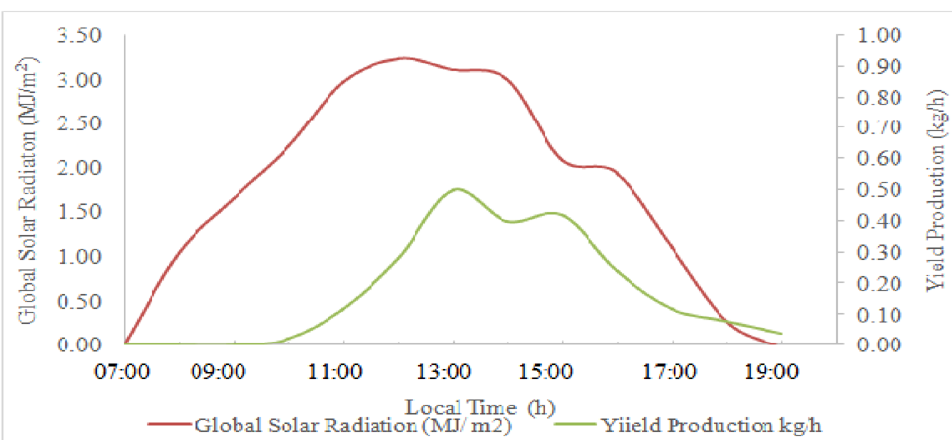

Figure 3: Global solar radiation and production at 0.01 m water depth on 31March 2014 [7]

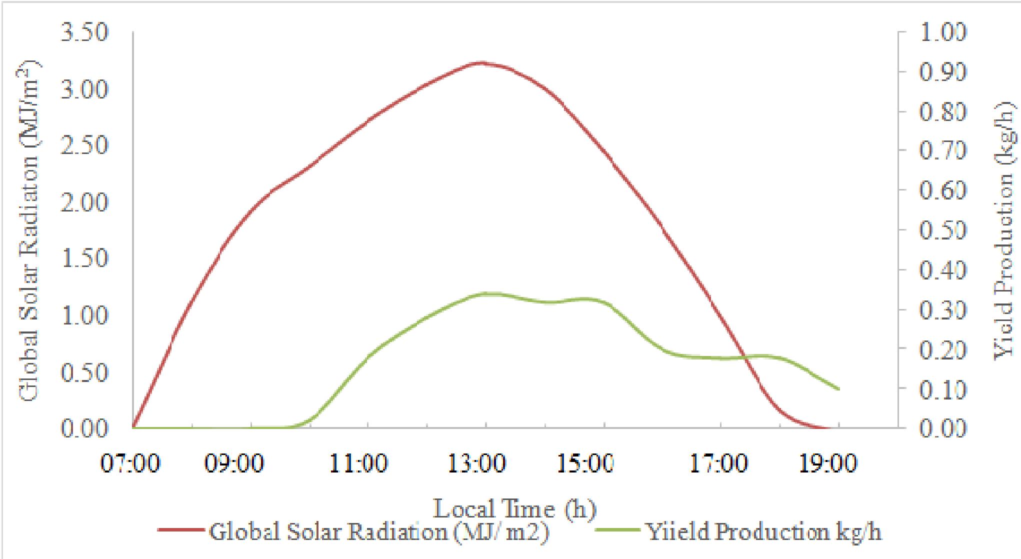

Figure 4: Global solar radiation and production at 0.02 m water depth on 01 April 2014 [7]

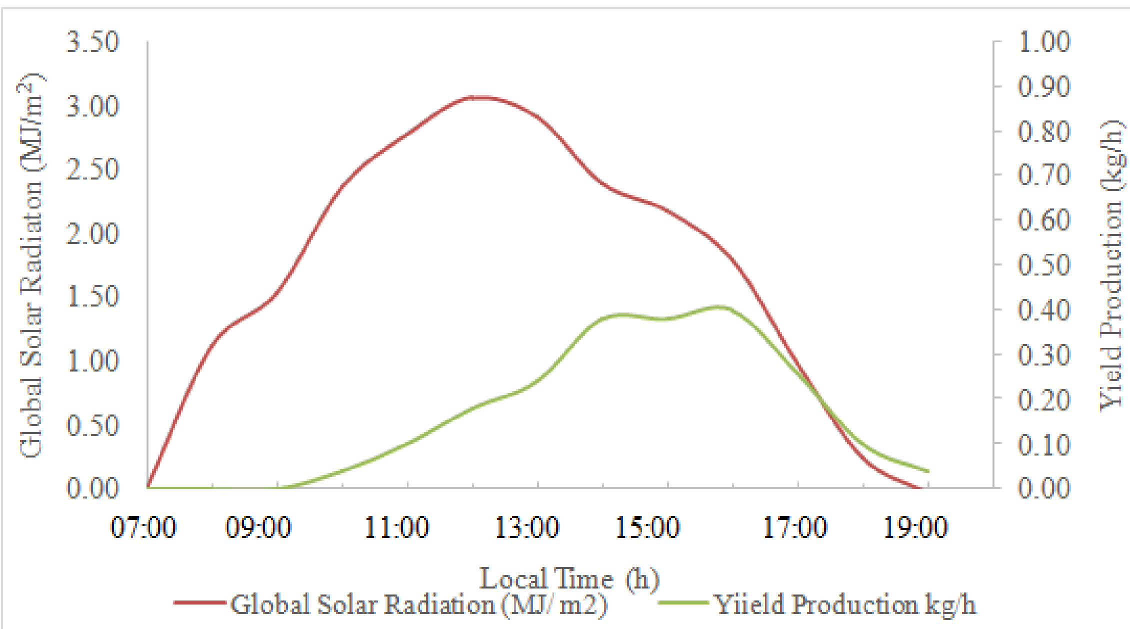

Figure 5: Global solar radiation and production at 0.03 m water depth on 02 April 2014 [7]

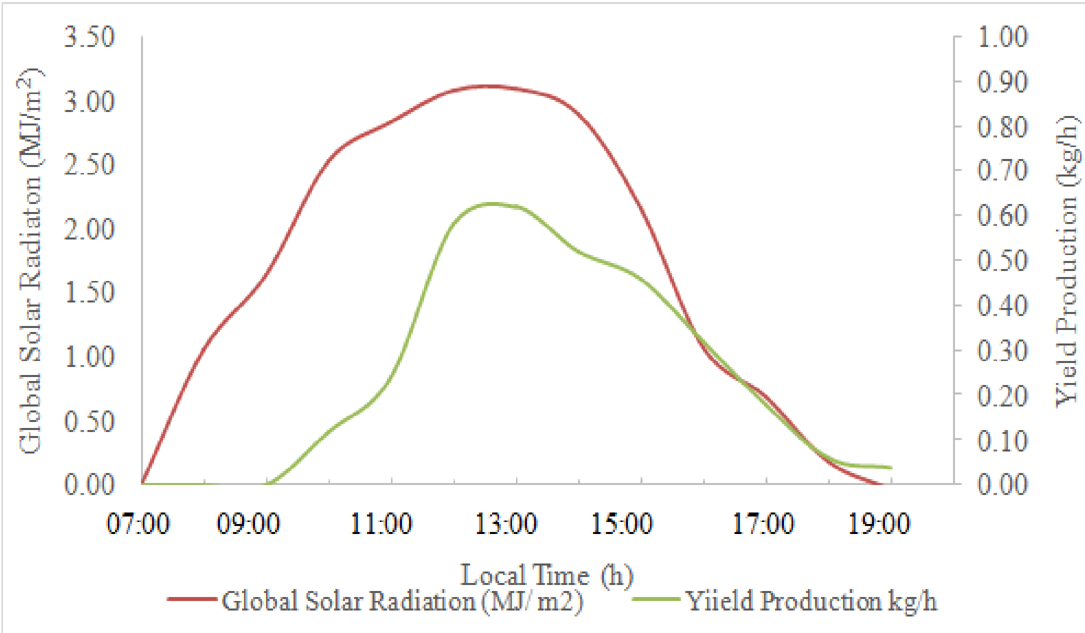

Figure 6: Global solar radiation and production at 0.01 m water depth (nano-particles mixed black paint) on 06 April 2014 [7]

5.7 Effect of nano-particles on production at different water levels

Comparison of production of distilled water (kg/hour) in graphical form is shown in Figure 7.

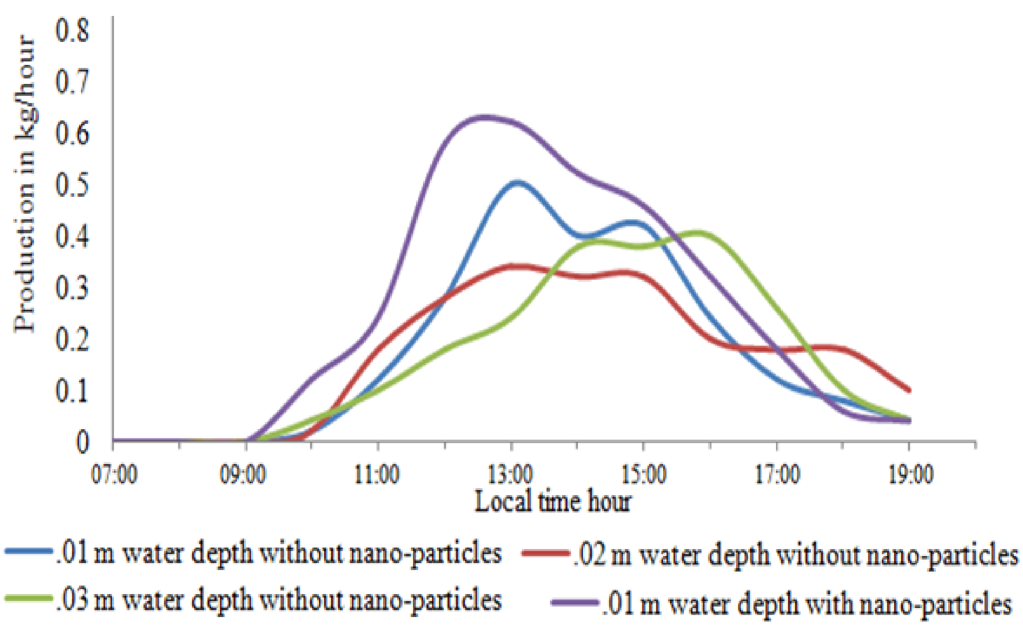

Figure 7: Effect of nano-particles on production

6. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

From the study it can be concluded that the production and efficiency of solar still at water depth 0.01 m with nano-particles are 3.48 litres and 38.65% respectively. 38.09% increment in production and 12.18% increment in thermal efficiency was achieved when nano-particles mixed black paint is used. These results show that the water level and nano-particles mixed black paint has an intense effect on the distillate output of the solar still. The PPM of raw water is more than the PPM of distilled water given by the solar still is the proof of quality of distilled water.

6.2 Future scope

Distilled water is very useful for industries and laboratories. It be can use for drinking by adding a certain percentage of normal water. Solar still is very useful in desert or rural areas where no connection of electricity is available to run modern RO (Reverse Osmosis) systems. So this work will be useful for providing this facility in the villages which have not electricity connection. Ordinary people can setup small solar still on the roof of the building and get distilled water continuously. This work will also provide growth of the small scale industries which produce distilled water in India. In the setup small investment is required initially and its maintenance is very little. The technology involved in the fabrication of solar still is very simple and can be maintained at the village level itself.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. N. K. Banthiya, Professor and Head, Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur for his valuable suggestions and guidance during the work.

REFERENCES

[1] Boubekria, M., and Chakerb A., (2011) "Yield of an Improved Solar Still: Numerical Approach" Energy Procedia , Vol. 6, pp. 610-617.

[2] Arunkumar, T., Jayaprakash, R., Denkenberger, D.. Ahsan, A., Okundamiya, M.S., and Kumar, S., (2011) "An Experimental Study on a Hemispherical Solar Still" Desalination, Vol. 286, pp. 1-7.

[3] Kalidasa, M.K. and Srithar, K., (2011) "Performance Study on Basin Type Double Slope Solar Still with Different Wick Materials and Minimum mass of Water". Renewable Energy, Vol. 36, pp. 612-620.

[4] Dev, R., Wahab, S.A.A., and Tiwari, G. N., (2011) "Performance Study of the Inverted Absorber Solar Still with Water Depth and Total Dissolved Solid." Applied Energy, Vol. 88, pp. 252-264

[5] Koilraj, G.M., Senthil Kumar, P., Rajakumar, S. and Syed Yousuf., M. H., (2011) "Effect of Nano-Fluids in a Vaccum Single Basin Solar Still" International Journal of Advanced Engineering Research and Studies Vol. I, pp. 171-177

[6] Khaoula, H., Slama, R.B. and Gabsi, S., (2010) "Hybrid Solar Still by Heat Pump Compression." Desalination Vol. 250, pp. 444-449.

[7] Indian Metrologocal Department, AWS LAB PUNE http://www.imdaws.com/ViewRadiationData.aspx (accessed on 9 April 2014)

[8] Amimul, A., Shafiul Islam, K. M., Teruyuki, F., and Abdul, H.G., (2010) "Experimental Study on Evaporation, Condensation and Production Of A New Tubular Solar Still." Desalination, Vol. 260, pp. 172–179.
[9] Huang,,B., Chong, T., Po-HsienWu, Han-YiDai, and Kao, Y., (2015) “Spiral Multiple-Effect Diffusion Solar Still Coupled with Vacuum-Tube Collector and Heat Pipe” Desalination, Vol. 362, pp. 74–83
[10] El-Sebaii, A.A., Ramadan, M.R.I., Aboul-Enein, S. M. and El-Naggar, (2015) “Effect of Fin Configuration Parameters on Single Basin Solar Still Performance” Desalination, Vol. 365, pp. 15-24