International Journal of Thermal Technologies

E-ISSN 2277 – 4114
Available at http://inpressco.com/category/ijtt/

Research Article

Solar Still Coupled with Evacuated Tube Collector with and without Porous Absorber: An Experimental Study

Munish Gupta*, **Jasbir Singh and Puneet Katyal**

Department of Mechanical Engineering , Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

Accepted 25 Nov 2015, Available online 20 Dec 2015, **Vol.5, No.4 (Dec 2015)**

Abstract

World population is increasing day by day at a very fast rate. There is a huge need of fresh water for mankind. There are many regions all around the world where people are forced to consume polluted water due to non-availability of fresh water. So there is a need to develop effective and cheap techniques to get pure water. In this research article, the performance of a active solar still (i.e. coupled with evacuated tube) is investigated. A single slope solar still (conventional still) integrated with evacuated tube collector was fabricated with a basin area of 0.49 m². The increase in temperature of the brackish water was more with the active solar still compared to the traditional solar still. This is due to the supplementary thermal energy added by ETC. The study was performed by varying the water depth (0.01m, 0.02m and 0.03m) in the still basin. The use of floating porous absorber in the basin of solar still was also studied. Results showed that the distillation yield increased by 19.48% with the decrease in water depth to 0.01m from 0.03m.The distillation yield further increased by 24% with porous material compared to water depth 0.03m.

Keywords: *solar desalination unit, solar still, floating porous absorber, evacuated tube collector.*

1. Introduction

Water is basic necessity for human mankind and is nature's gift available in abundant on our planet earth. But most of the accessible water is seawater or icebergs in polar region. This contributes to approximate 97% water which is salty and is not suitable for drinking purpose. Out of which only 1% fresh water is within reach of mankind. The requirement for fresh water is ever-increasing due to increase in population and rapid industrial growth while its availability is decreasing day by day. Due to non-availability of potable water, there are many health issues such as human disease, water borne diseases etc., 3.575 million deaths are recorded all around the world due to water borne diseases (Murugavel, *et al*, 2013). In the last few decades, scanty rainfall has increased the water salinity. Further increasing water pollution also affects the water quality. So there is a need to obtain fresh water from available salty water resources. There are many water treatment techniques which can be used to get fresh water from saline/brackish water. Desalination is one of the oldest technique used for water purification. Many techniques for desalination have harmful environmental affect because of their dependence on conventional source of energy (coal power plant, fossil fuels etc.). Conventional source of energy leads to increase in worldwide average temperatures, rising sea level and melting of glaciers etc. All these problems could be resolved by organized exploitation of renewable energy resources (solar energy, wind energy, geothermal energy etc). The energy from the sun is available at every place free of cost. Around 22 million m³ of freshwater is produced per day by desalination processes globally, out of which the contribution of solar energy is less than 1%. Hence the use of solar energy in the form of solar still is the best and economical solution for rural as well as for urban areas. Numerous researchers has performed experimental and numerical studies well organised in review articles (Velmurugan and Srithar, 2011), (Kabeel and El-Agouz,2011), (Xiao, *et al*, 2013), (Kaushal, 2010), (Sivakumar and Sundaram, 2013) on the design, performance, development, efficiency of solar still.

Many researchers used fins, sponge, jute cloth, wicks etc to increase the productivity and efficiency of solar still. (Samee, *et al*,2007) explained experimentally the performance of simple solar still. A simple solar still was tested at different condition. A distillate yield of 1.7 L/day for 0.54m² area was obtained. The efficiency calculated was 30.56%. (Rababa'h, *et al*,2003) studied the effect of adding sponge cubes to the basin of a solar still. They also studied the design factor for sponge cubes. There is 273% increment in the production of solar still. The optimum combination for sponge cubes was: 6cm sides with 20% sponge to

*Corresponding author: **Munish Gupta**

basin water volume ratio, 7cm basin water height. (Velmurugan, *et al*, 2008) studied the effect of adding fin to the basin of solar still. They also evaluated the performance of solar still with wicks, sponges, and fins. Theoretical analysis was also made by solving energy equation. Productivity increased by 45.5% when fins are used in still and got 2.8 $kgm^{-2}d^{-1}$ production rate. (Sakthivwl, *et al*,2010) 0explained the effect of adding a vertical jute cloth inside the basin which acts as an energy storage medium. Latent heat of condensation is utilized by placing jute cloth in the middle of solar still and one end at rear wall of solar still. Distillate yield of $4kg/m^2$ was recorded for 30 kg water in the basin. This improved the productivity and efficiency by 20% and 8% respectively. (Murugavel and Srithar,2011) explained effect of different wick material on the productivity of double slope solar still. They used black cotton cloth, jute cloth, sponge sheet and coir mate as wick material. A basin type double slope solar still (mild steel) was tested taking minimum mass of water and diverse wick materials. Solar still with aluminium rectangular fins arranged in different pattern and covered with different wicks were also studied. Still with rectangular aluminium fin covered with cotton cloth and arranged in lengthwise direction was found to be effective. Light black cotton cloth is effective which give 3.49 kgd^{-1} distillate yield. (Srivastava and Aggarawal,2013a) studied the effect of porous fins in the solar still. Porous fins made up of blackened old cotton rags were partially dipped in the basin water while rest of part was extended above the solar still basin water surface. Distillate output of 7.5 kg m^{-2} was obtained when black ended old cotton rags were to some extent dipped in the basin water of single sloped single basin solar still. Further they (Srivastava and Aggarawal ,2013b), (Srivastava and Aggarawal,2014)) explained the effect of floating porous absorber of black jute cloth on single slope single basin solar still. Nine floating absorber pieces were placed lengthwise in the solar still. A clearance was provided from basin sides. The edges of wick were immersed in basin water so that it remained wet due to capillary action. Distillate yield increased by 68% with the use of porous absorber.

The productivity of the still depends upon the temperature difference between the basin water and inner surface glass cover. In a conventional solar still, the glass cover is the only source of energy for raising the temperature. This leads to lower productivity of solar still. In order to improve the productivity, extra thermal energy is supplied by external source. For this purpose the solar still is coupled with external heat source i.e., flat plate collector, concentrated collector, heat pipe or evacuated tube collector (Sampathkumar , *et al*, 2010), (Abdullah, 2013).

(Rajaseenivasan, *et al*,2014) explained the effect of adding flat plate collector for heating of brine water and use of different material in basin. They made six small compartments in the basin. The projected space between these basin acts as extended surface. This resulted in an increase in the temperature of water. Distillate yield of 5.82 kgm^{-2} was obtained with 60% increase in comparison of simple solar still. (Shah and Fubra,2004) made a comparison of flat plate collector and evacuated tube collector. Distance between tubes, diameter of tubes and thermal performance of ETC were studied theoretical. It was found that ETC is best for solar radiation collection because it utilize the solar radiation from all direction. (Sampathkumar, *et al*, 2013a) studied experimentally the performance of solar still with ETC. The distilled yield of water increased by 129% in active solar still. It was concluded that distillate yield of 7.03 kg is obtained at water depth of 0.04m. (Reddy, *et al*, 2012) studied the performance of multi stage solar still with evacuated tube collector. They explained various parameters such as number of stages, gap between stages, supplied mass flow rate which comes 4,100mm, 55 kg/m^2d^{-1} respectively. Maximum distillate yield of 53.2 kg/m^2d^{-1} is obtained at acting pressure of 0.03bar. (Sampathkumar, et al,2013b) used thermal modelling for performance of the solar still with ETC in natural circulation mode. Average temperature of solar still obtained from solar still with ETC is 12°C higher than passive solar still maximum distillate yield of $7kg/m^2$ is obtained in the month of April. (Chow, *et al*, 2013) studied the performance of single phase and two phase evacuated tube solar water heater. Single phase solar water heater contains two tubes in which inner tube is coated with an absorbing material while two phase solar water heater contains evaporation and condensation zones. Two phase solar water heater was best for use. The ETC's are more efficient than flat plate collector. Keeping the above studies in consideration the objectives of the present work is to evaluate the solar still productivity by:

1- Coupling the Solar Still with Evacuated tube and evaluating its performance by varying the depth of water in the basin.
2- Using floating porous absorber inside the basin and to evaluate the solar still productivity To the best of author's knowledge no work has been performed using floating porous absorber in solar still coupled with evacuated tube collector.

2. Experimental Setup

A water desalination unit was designed and fabricated at Department of Mechanical Engineering, GJUS&T, Hisar *(Latitude 29° 10′ N Longitude 75° 43′ E)* and experiments were performed from January to July, 2015. A simple conventional solar still was fabricated and coupled with evacuated tubes. Nine evacuated tubes were used.

The solar still was made of galvanized iron sheet and was insulated from the environment with the help of glass wool. The basin area of the solar still is 0.49 m^2 (0.49 m width × 1 m Length). High-side wall depth is 438 mm and the low-side wall height is 150 mm. A schematic diagram of the setup is shown in Fig 1 Basin of solar still is coated with black paint for better absorptivity. Evacuated tubes are coupled with solar still with the help of gaskets.

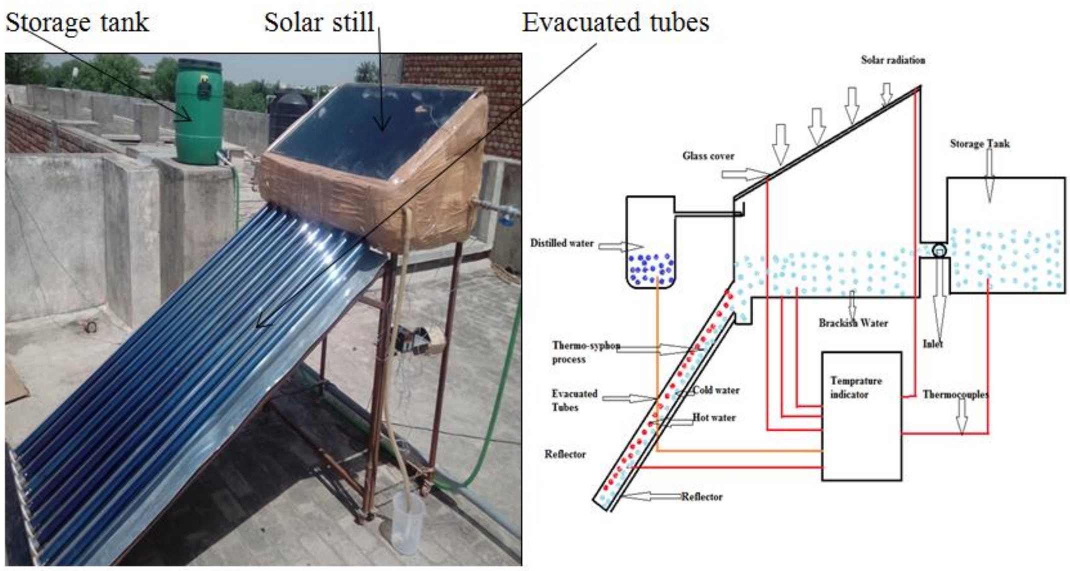

Fig 1: Schematic diagram of experimental setup

A seal is also provided in order to prevent leakages and dust. A reflective sheet is used below the tubes for better reflection. Solar still is covered with a glass cover fitted in a frame tilted at 30º angle. Evacuated tubes were also tilted at angle of 30º. Solar still coupled with evacuated tube was placed on movable iron stand. Supply of brackish water was given to the solar still through inlet port. A float valve was used inside the solar still for maintain different heights. A channel was attached at low side of solar still so that water vapours slide on glass cover and after condensation could be collected in channel. This distillation yield was collected in the measuring jar with the help of pipe through provided outlet. Floating porous absorber was also placed inside the basin of solar still to study the effect on the distillate yield and various parameters. Firstly basin and evacuated tubes were filled with brackish water up to the required water depth. Continuous flow inside the basin of solar still was maintained with the help of float valve. The Evacuated tubes consist of two concentrating borosilicate glass tube with evacuated space between them. The water inside inner tube gets heated and moves toward the basin and cold water comes inside the tube. Due to this thermo-syphon process water in solar still gets heated and evaporation rate in solar still get increased. The main advantage of evacuated tube over other collector is zero convective loss and no requirement of tracking system. The details are given in Table 1 (a and b).

The temperatures were measured using thermocouples (±1°C) and they were linked to a digital temperature indicator. The ambient temperature was also measured. The solar radiation intensity was measured by solarimeter of *WACO 206 series* having range up to 1999W/m^2 with resolution of 1W/m^2. The flask of total capacity 2 l with an accuracy of 5 ml was used to measure the hourly yield.

Table 1(a): Design Parameter of Solar still Unit

Solar Still	
Area of basin	0.49m^2
Material	Galvanized Iron
Thickness	0.002m
High side : low side	2.92:1
Glass Cover	
Thickness	0.004m
Inclination	30º
Insulation	
Material	Glass Wool
Thickness	0.050m

Table 1(b): Design Parameter of Evacuated tube collector

Evacuated Tube	
Outer diameter	58mm
Inner diameter	47mm
Length	1800mm
Number of tubes	9
Inclination	30
Centre to centre spacing	100mm
Aperture area of solar still	0.94 m^2

The solar radiations, ambient temperature, temperature of the basin, brackish water, glass cover and distilled water temperatures were measured after every 1 h. All measurements were performed to find the performance of the solar still with ETC under the outdoor condition of Hisar City conditions.

3. Result and Discussion

The experiments were performed at Department of Mechanical Engineering, GJUS&T, Hisar (Latitude 29° 10' N Longitude 75° 43' E) from January to July, 2015.

The temperature at different points of desalination unit is measured after every 1 hour time interval during day time from 7:00 to 19:00. For various parametric study two cases are studied which is discussed below

Case 1: Solar Still coupled with Evacuated Tube Collector for different water depth.

a) Temperature distribution for different water depth

The experiments were performed for different water depth in the solar still. Experiments for water depth at 0.01m, 0.02 and 0.03 was performed on 19/5/2015, 20/5/1015 and 21/5/2015 respectively. The Figures (2,3&4) show the distribution ETC temperature, basin temperature, outer surface of glass covers temperature, inner surface of glass cover temperature, basin water temperature, ambient temperature, inlet water temperature, distillate yield temperature and solar intensity at solar still and ETC. It can be observed that the maximum solar intensity was observed at 12:00 hours and maximum basin water temperature between 15:00 to 16:00 hours. Maximum inner surface of glass cover temperature and outer surface of glass cover temperature was recorded between 14:00 and 14:30 hours. Maximum ambient temperature was recorded between 14:00 and 14:30. Inlet water temperature and distillate water temperature have maximum value between 15:00 and 15:30 hours.

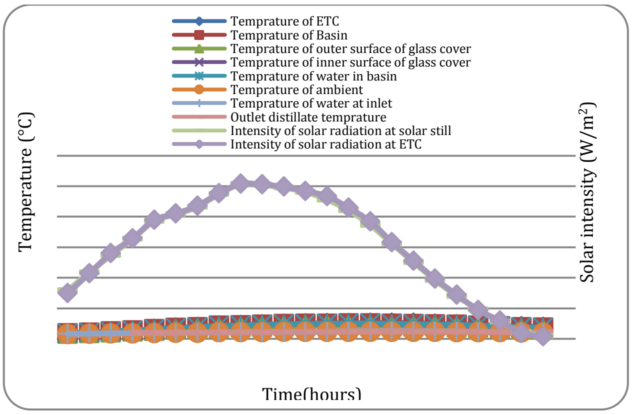

Fig 2: Distribution of different Temperature and Solar Intensity at 0.01 m water depth

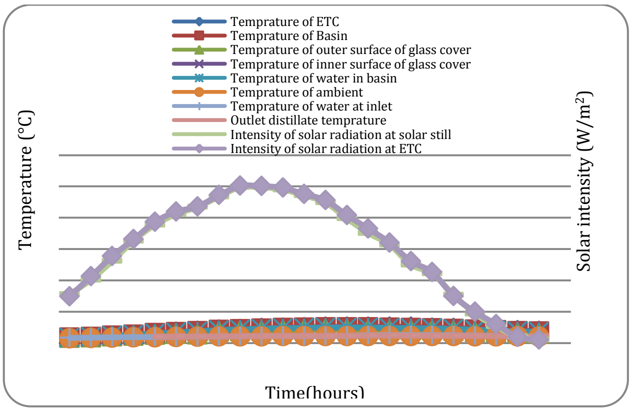

Fig 3: Distribution of different Temperature and Solar Intensity at 0.02 m water depth

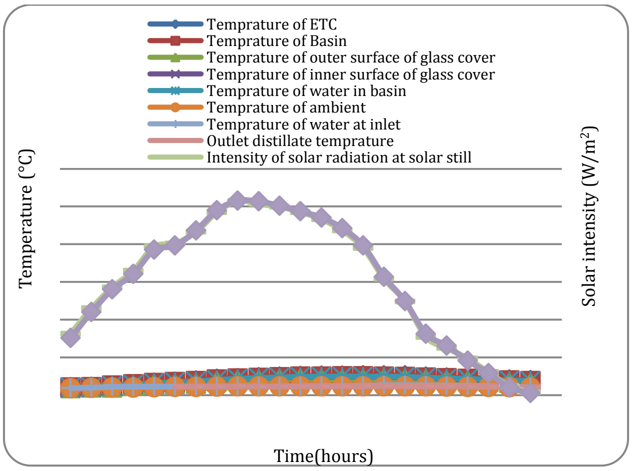

Fig 4: Distribution of different Temperature and Solar Intensity at 0.03 m water depth

b) Variation of distillate yield for different water depth

Measurement of distillate yield is measured at the interval of 30 minutes for 0.01m, 0.02m and water depth experiment. Variation in distillate yield for different water depth is shown in Fig 5. The yield obtained for coupled system at 0.01m, 0.02m and 0.03m water depth are 3.919 kg, 3.611 kg and3.284 kg respectively from 8:00 to 19:00. Maximum hourly distillate yield obtained for 0.01m, 0.02m and 0.03m is 0.794 kg, 0.695 kg and 0.595 kg respectively between 15:00 to 16:00 hours. It is concluded that as the depth of water inside the basin of solar still decrease there is an increase in distillate yield. Thus system have maximum distillate yield at 0.01m water depth. Distillate yield is directly affected by solar intensity but there is time lag between the maximum solar intensity and maximum yield. This time lag is due to the process of evaporation and condensation of water in the system.

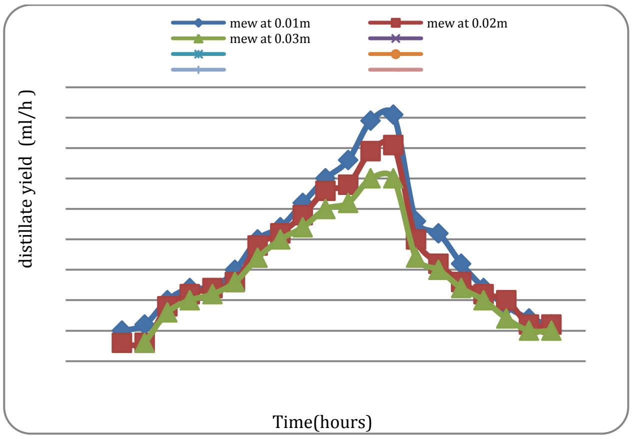

Fig 5: Variation in Distillate Yield for different water depth

There is production of distillate yield at the night due to the heat stored by water inside the basin. Higher water depth inside the basin gives high yield during the night period. Higher depth increases the water quantity inside the basin which result high energy storage. At night time glass cover temperature reduces which increase the evaporation and condensation process. This result the production of distillate yield at night time. Amount of distillate yield during night time from 19:00 hours to 8:00 hours in next day for water depth 0.01m, 0.02m and 0.03m was 0.298kg, 0.396kg and 0.496 kg respectively.

CASE 2 Solar Still with Floating Porous Absorber in Basin Coupled with Evacuated Tube Collector

a) Temperature distribution of solar still with floating porous absorber in basin coupled with ETC

Firstly porous absorber was placed in the basin of solar still at water depth 0.02m. Due to the presence of floating porous absorber inside the basin height of water increase in the basin. Now float valve is set at the increased height so that water remains at the height of 0.02m. After this setting measurement of temperatures and solar intensity was performed. The reason for taking 0.02m depth of water was the formation of dry spot occur during working of system at water depth 0.01m inside the basin and capillary action do not work smoothly due to the less quantity of water.

On 22-5-2015 reading of various temperature and solar intensity was taken at the interval of 30 minutes from 8:00 to 19:00. All the reading was taken with floating porous absorber inside the basin of solar still. Distribution of different parameter such as ETC temperature, floating porous absorber temperature, basin temperature, outer surface of glass covers temperature, inner surface of glass cover temperature, basin water temperature, ambient temperature, inlet water temperature, distillate yield temperature and solar intensity at solar still and ETC are presented in Fig 6.

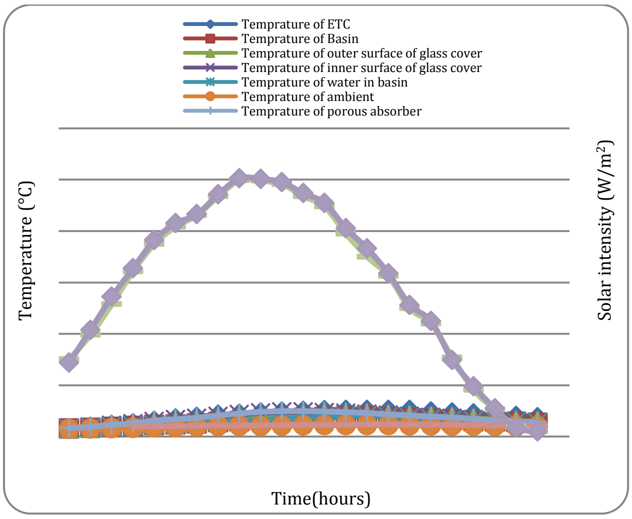

Fig 6: Distribution of different Temperature and Solar Intensity for solar still with floating porous absorber inside the basin coupled with evacuated tube collector

It is observed that highest solar intensity was recorded at 12:00. Maximum ETC, basin, Distillate water and basin water temperatures were recorded at 15:00. Maximum floating porous absorber temperature of was recorded at 13:00 hours. Maximum inner surface of glass cover temperature and outer surface of glass cover temperature was recorded at 13:00 and 14:00 respectively. Maximum ambient temperature was recorded at 14:00.

It is seen that floating porous absorber attains its maximum temperature at 13:00 hours while in simple solar still with ETC maximum temperature was attained at 15:00 or 15:30 hours. This shows the quicker action of porous absorber as compared to without porous medium. This fastens up the distillation process or process of formation of fresh water. There is less time consumption in evaporation and condensation process as compared to simple solar still with ETC. The basin water and basin temperature was very low as compared to porous absorber temperature. This may be attributed to the presence of floating porous absorber in the basin of solar still. Temperature graph shows the behaviour of floating porous absorber which heats up and cool down very quickly

b) Distillate yield variation of experimental setup with and without floating porous absorber in the basin

The yield obtained for coupled system with floating porous absorber inside the basin was 4.068 kg from 8:00 to 19:00. Distillate yield is directly affected by solar intensity but there is time lag between the maximum solar intensity and maximum yield. The presence of floating porous absorber increases the surface area for evaporation which leads to high evaporation rate and the time lag is due to the process of evaporation and condensation of water in the system is reduced. Due to less time lags between the maximum solar intensity and maximum yield with floating porous absorber the distillation yield is higher.

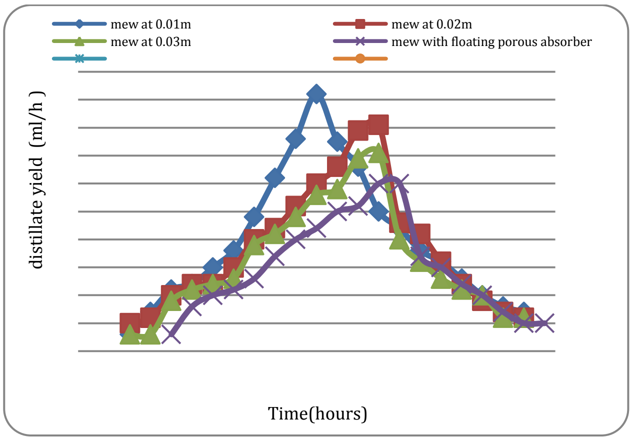

Fig 7: Variation in Distillate Yield

There is production of distillate yield at the night due to the heat stored by water inside the basin. Only 0.248 kg of water is produced during night period which is very less as compare to simple solar still with evacuated tube collector. Fig shows a comparison between different distillate yields at different conditions. The maximum distillate yield is obtained in case of floating porous absorber.

4. Uncertainty Analysis

The accuracy of measured data obtained through experimental study is very important which is dependent on the measuring instrument. Uncertainty analysis is performed to prove the extent of accuracy of experimental results. Uncertainty dependent on measuring instrument cannot be removed by number of measurements. The expression for uncertainty in the measured value by an instrument is given by (Beckwith, *et al*, 2007).

$$\mu = \frac{a}{b_{max}} \times 100$$

where a corresponds to the accuracy of the instrument and b_{max} is the maximum measured value of parameter by an instrument. The uncertainty analysis of measured values of parameters are performed and listed in Table. 2

Table 2: Uncertainty analysis of measured data

Name of instrument	Variable measured	Least division of measuring instrument	Max. values measured in experiment	Uncertainty %
Thermocouple	Temperature of ETC	0.1°C	103.6°C	0.096
Solar power meter	Intensity of solar radiations at ETC	10W/m^2	1031 W/m^2	0.969

Conclusion

Water desalination unit is established by coupling single slope single basin solar still with evacuated tube. Natural flow of water occurs through tube due to thermo-syphon principle. Major finding of this work is

- Thermo-syphon principle work successfully for heating of water inside the desalination unit and is helpful in increasing the temperature of water during working of system.
- Integration of evacuated tubes helps in increasing the water temperature up to 99ºC inside the basin and 103.6ºC inside the evacuated tubes.
- Maximum yield of 3.919 kg is obtained at 0.01m water depth in simple solar still coupled with ETC for 0.49m^2 basin area.
- Distillate yield is inversely affected by water depth inside the basin of system. As water depth increase distillate yield decrease. The distillation yield increased by 19.48% with the reduction in water depth from 0.03m from 0.01m
- Heat transfer coefficients are also affected by water depth. For low water depth heat transfer coefficients have higher value.
- Addition of floating porous absorber in the solar still increases the efficiency and distillate output of solar system. The addition of floating porous absorber reduces the time lag between maximum solar intensity and maximum distillate yield. Thus it fastens up the process of evaporation and condensation. A distillate yield of 4.068 kg is obtained for solar still with floating porous absorber in solar still. The distillation yield increased by 24% with porous material compared to water depth 0.03m without porous material. Further Basin water temperature is very low as compare to floating porous absorber. Thus basin water has low energy which reduces the bottom losses from basin of water to ambient.

Future Directions

More work has to be performed on solar still from research point of view for meeting demands of society. Some important work have to be done in future is listed below

- Research should be carried out for reducing the cost and to minimize thermal losses in order to make desalination unit more efficient.
- Research should be carried out in developing highly efficient hybrid water desalination unit so that it could give water uninterruptedly during the cloudy or rainy season and to increase the distillate output of the system.

These are the probable areas of interest on which work can be carried out in future for making the system more efficient, easy to handle, available at low cost and commercially viable for each and every household. In brief the upcoming area is of renewable energy resources and solar energy is one of them.

References

Murugavel, K. K., Anburaj, P., Hanson, R. S., & Elango, T. (2013). Progresses in inclined type solar stills. *Renewable and Sustainable Energy Reviews*, *20*, pp 364-377.

Velmurugan, V., & Srithar, K. (2011). Performance analysis of solar stills based on various factors affecting the productivity—A review. *Renewable and Sustainable Energy Reviews*, 15(2), pp 1294-1304.

Kabeel, A. E., & El-Agouz, S. A. (2011). Review of researches and developments on solar stills. *Desalination*, 276(1), pp 1-12.

Xiao, G., Wang, X., Ni, M., Wang, F., Zhu, W., Luo, Z., & Cen, K. (2013). A review on solar stills for brine desalination. *Applied Energy*, 103, pp 642-652.

Kaushal, A. (2010). Solar stills: A review. *Renewable and Sustainable Energy Reviews*, 14(1), pp 446-453.

Sivakumar, V., & Sundaram, E. G. (2013). Improvement techniques of solar still efficiency: A review. *Renewable and Sustainable Energy Reviews*, 28, pp 246-264.

Samee, M. A., Mirza, U. K., Majeed, T., & Ahmad, N. (2007). Design and performance of a simple single basin solar still. *Renewable and Sustainable Energy Reviews*, *11*(3), pp 543-549.

Rababa'h, H. M. (2003). Experimental study of a solar still with sponge cubes in basin. *Energy conversion and Management*, *44*(9), pp 1411-1418.

Velmurugan, V., Gopalakrishnan, M., Raghu, R., & Srithar, K. (2008). Single basin solar still with fin for enhancing productivity. *Energy Conversion and Management*, *49*(10), pp 2602-2608.

Sakthivel, M., Shanmugasundaram, S., & Alwarsamy, T. (2010). An experimental study on a regenerative solar still with energy storage medium—Jute cloth. *Desalination*, *264*(1), pp 24-31.

Kalidasa Murugavel, K., & Srithar, K. (2011). Performance study on basin type double slope solar still with different wick materials and minimum mass of water. *Renewable energy*, , 36(2), pp 612-620.

Srivastava, P. K., & Agrawal, S. K. (2013a). Winter and summer performance of single sloped basin type solar still integrated with extended porous fins. *Desalination*, *319*, pp 73-78.

Srivastava, P. K., & Agrawal, S. K. (2013b). Experimental and theoretical analysis of single sloped basin type solar still consisting of multiple low thermal inertia floating porous absorbers. *Desalination*, 311, pp 198-205.

Srivastava, P. K., & Agrawal, S. K. (2014). Multiple floating porous absorbers type solar still: annual performance evaluation. *International Journal of Renewable Energy Technology*, *5*(2), pp 159-175.

Sampathkumar, K., Arjunan, T. V., Pitchandi, P., & Senthilkumar, P. (2010). Active solar distillation—a detailed review. *Renewable and Sustainable Energy Reviews*, 14(6), pp 1503-1526.

Abdullah, A. S. (2013). Improving the performance of stepped solar still. *Desalination*, *319*, pp 60-65.

Rajaseenivasan, T., Raja, P. N., & Srithar, K. (2014). An experimental investigation on a solar still with an integrated flat plate collector. *Desalination*,*347*, pp 131-137.

Shah, L. J., & Furbo, S. (2004). Vertical evacuated tubular-collectors utilizing solar radiation from all directions. *Applied energy*, *78*(4), pp 371-395.

Sampathkumar, K., Arjunan, T. V., & Senthilkumar, P. (2013). The experimental investigation of a solar still coupled with an evacuated tube collector. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *35*(3), pp 261-270.

Reddy, K. S., Kumar, K. R., O'Donovan, T. S., & Mallick, T. K. (2012). Performance analysis of an evacuated multi-stage solar water desalination system. *Desalination*, *288*, pp 80-92.

Sampathkumar, K., Arjunan, T. V., Eswaramoorthy, M., & Senthilkumar, P. (2013). Thermal Modeling of a Solar Still Coupled with Evacuated Tube Collector under Natural Circulation Mode—An Experimental Validation. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 35(15), pp 1441-1455.

Chow, T. T., Bai, Y., Dong, Z., & Fong, K. F. (2013). Selection between single-phase and two-phase evacuated-tube solar water heaters in different climate zones of China. *Solar Energy*, 98, pp 265-274.

Beckwith, T. G., Marangoni, R. D., & Lienhard, J. H. (2007). Mechanical measurements. Upper Saddle River, NJ: Pearson Prentice Hall.