Solar distillation using heat pipes and heat exchanger

B Vijayasarathy¹, Dinesh Kumar¹, K Vijayakrishnan¹, Ajith Kumar¹ and Vinod Kotebavi²

¹,² Department of Mechanical engineering,
Amrita School of Engineering, Bangalore
Amrita Vishwa Vidyapeetham, India.

Abstract. This project focuses on obtaining distilled water using solar power. A non conventional design was given to the solar distillation by eliminating the basin and replacing it with a small tank with lid which has an outlet for evaporated steam. The arrangement consists of a tank of volume of 7.4 litres which is filled with water which is heated with the help of heat pipe placed inside evacuated tubes. The complete arrangement was made and experiment was conducted at Amrita school of engineering, Bangalore (Latitude: 12.97°N and Longitude: 77.59°E). The performance study was conducted i) Without compound parabolic concentrator ii) With compound parabolic concentrator. The maximum distilled water output obtained was of 560 ml without the use of compound parabolic concentrator with overall efficiency of 23.31%. The output was found to be increased to 680 ml with the use of compound parabolic concentrator which gave an overall efficiency of 27.23%. The hardness of the distilled water was 19ppm which was obtained by distilling brackish water of 390ppm.

1. INTRODUCTION

Safe and potable water is essential to lead a healthy life for humans and animals. Water covers 71% of earth’s crust. Almost 97% of the available water on the planet is found in the form of oceans and seas which is salty or brackish. Only 2.5 % of the available water is fresh [11], out of which 68.9% are locked up as icebergs in glaciers and 30.8% is groundwater [12]. Ponds, lakes and rivers contain only 0.3% of fresh water. Water supply is getting worse day by day. 30% of population in the developing world is without safe and reliable source of water supply.80% of communicable diseases are water borne and approximately 3.1% deaths occur due to water with poor quality [9]. Water is polluted by organic wastes, infectious microbes and many other inorganic chemicals and salts.

There is an urgent need to convert salty water into pure water. Solar Distillation process is one of the solutions for converting sea water into pure water. Solar energy has the greatest potential of all available sources of energy. The power received from the sun at earth’s surface is 10¹⁷ watts [10]. Especially in India which is closer to the equator, the exposure to the sun is almost available most of the time in a year. Solar energy is the best potential source of energy which should be made use of. This method is effective in areas where there is no reliable power supply in order to use reverse osmosis (RO) for purifying water. It is also cost effective and provides the advantage of one time
installment and least maintenance. The process requires no moving parts and is very simple to use. The arrangement is easy to manufacture and can be used at anyplace where solar energy is available.

2. LITERATURE REVIEW

Shobha.B.S, Vilas Watwe and Rajesh .A.M[1] have evaluated the performance of a solar distillation still coupled to a solar water heater of evacuated tube collector type. They had constructed a double slope single basin still having base which was square in shape coupled to ETC solar water heater. The basin was constructed using plywood and was insulated on sides with the help of glass wool. The glass and body were sealed using silicone rubber sealant. They reported that the productivity of the solar still increased to 59% from 39 when coupled with solar water heater of evacuated tube collector type. They conclude that there is drop in efficiency of the plant with increase in water depth. Harikrishnan S and Vinod Kotebavi[2] have studied the performance of solar heat pipes by varying the working fluids in the heat pipes along with variation of fill ratios and different inclination angles. The heat pipes were made using two different copper tubes of specific dimensions and brazing them together. A water basin of 200ml was made for the study and condenser section of heat pipe was placed to heat the water in the basin. Methanol, acetone and water were used as working fluids with different fill ratios, i.e. 25%,50%,75% and 100%. The study consisted of two methods i)placing the heat pipe inside evacuated tube collector ii)usage of parabolic concentrator to reflect radiation onto heat pipes. It is reported that acetone and methanol inside the heat pipe show better results as working fluids than water. The heat pipe showed maximum efficiency when the filled volume of the working fluid was about 25% of the total evaporator volume. It is also stated that the solar heat pipe is sensitive to the change in angle of inclination. Andrew Stonebraker, Joel Newmeyer and Mark Branner[3] used a parabolic concentrator to concentrate solar energy onto a water pipe made of copper. The setup was made up of a channel in which water is heated with help of concentrated solar radiation from reflector and the water moves onto cooler region of channel kept in shade and inverted V- shaped lid is used to distill and collect the evaporated water. In their research they state that a device at Florida Solar Energy centre could produce drinking water of an amount up to 660 gallons per day, using a 92 square foot parabolic trough concentrator which is similar to their model. Ganesh A and Vinod M Kotebavi[4] constructed pyramid type solar still which was made of GI sheet basin insulated from atmosphere using saw dust. The pyramid lid was made using four triangular glasses and sealed using sealant. Pebbles which were painted black were added to the basin. They report that the output of a pyramid lid type solar distillation still increased to 4 litres/day from 2.1 litres/day when heat pipes were inserted in evacuated tubes. The overall efficiency of the solar distillation unit increased from 23% to 28% with coupling the evacuated tube. The salt(CaCO$_3$) content of the distilled water from the solar still reduced by 98.6%. Ken Toms Pothen, Nevin Saju Varghese, Nidhish Thomas Jacob, Sachin Mathew and Nikhil Ninan[5] in their project work, have fabricated a solar distillation unit which uses a parabolic type concentrator to focus solar radiation into a water tube of copper. The setup uses flat plate collector in order to heat the brine which is passed through a copper pipe which has parabolic reflector, the copper tube acts as passage for water between flat plate collector and cooling tank in which the water condenses to give pure water. The efficiency of the plant was calculated to be 32.97%. Abuhamed, A.J., Adam, N. M., Hairuddin, A. A. and Kareem, H. K.[6] had constructed a shell and tube heat exchanger which would be used for water distiller system. In their experimental result, they established that the condenser produced an amount of 3.8 litre/hour of distilled water from vapour which was at 99.7°C of inlet temperature and vapour flow rate of 4 litre/hour, when condenser coolant water was flowing at rate 130 litre/hour. The heat efficiency of the condenser can be increased by means of reducing the tube’s thickness and reducing inlet vapor pressure. J.V Dinesh Raju, T.L.V Vaibhav, Ch. Sai Chaitanya and Vinod Kotebavi [7] experimented using hemispherical basin in 4 different modes. They had constructed both hemispherical basin and solar still made up of aluminium metal and brazed it together. Arrangement consisted of a glass lid sloped at 15°. The arrangement used two heat pipes along with evacuated tubes inclined at 20°. They report that integrating evacuated tubes and heat pipes
with solar still having hemispherical basin raises the temperature of the water and distilled water output. Addition of paraboloid concentrator to the existing increased the thermal efficiency. Pramod B V N, Prudhvi Raj J, Hari Krishnan S S and Vinod Kotebavi [8], fabricated a rectangular basin pyramid solar still which had fillings of saw dust as insulation. A folded GI sheet having a shape of U was used to collect distilled water and was fixed at bottom side of still. In their study they concluded that the pyramid type solar distillation still attached with evacuated tubes and heat pipes had a better performance than normal pyramid type solar distillation still. The distillate water obtained with attaching heat pipes and evacuated tube with the solar still was 28% more than solar still attached with evacuated tubes and 43% more than that of only the pyramid type solar still. The key objective of this project is to enhance performance of the simple solar still. To achieve the objective certain modification were done to the simple solar distillation system and experimental and theoretical parametric studies are performed.

3. EXPERIMENTAL SETUP

The complete setup was made and experiment was conducted at Amrita school of engineering, Bangalore. The experiments are carried out during the month of April 2018 from 8:00 to 17:00 hr. The main parts of the experiments are heat pipes inserted in evacuated tube, water channel (tank), condenser and compound parabolic concentrator (CPC). A channel of volume 7344cc (90 * 10.2 * 8) is painted in black colour which absorbs the maximum amount of Incident solar radiation. It is tightly sealed to prevent escaping of steam from the chamber. Channel is made up of Mild steel. The provisions for PVC pipes used for holding heat tubes are of diameter 1.25”. Heat pipes are coupled with evacuated tubes in order to increase the temperature inside the channel. Heat pipes are made 25% Fill ratio of acetone. The evacuated tubes are placed on a metal frame and it is connected to the arrangement at an angle of 15° with respect to the base to receive maximum solar radiation. Counter flow heat exchanger is used in the experimental setup. The steam collecting pipe of diameter 2.25” is placed at an angle of 35˚. Condenser inlet is connected to overhead tank outlet, to gain the pressure head. Condenser cooling water outlet is connected to one way valve. Compound Parabolic concentrators are used for all combinations separately and proper mounting space has been provided in the frame.

Figure 1. CAD model of Designed channel
Table 1: Specification of setup.

| Components                        | Specification            |
|-----------------------------------|--------------------------|
| Basin material                    | Mild Steel              |
| Thermal conductivity of MS sheet  | 46W/mK                  |
| Channel volume                    | 7.34Litres              |
| Thickness of sheet                | 2mm                     |
| Inner shell - Copper (Condenser)  | 1 inch                  |
| Outer shell - PVC (Condenser)     | 3 inch                  |
| Thermal conductivity of Copper metal | 385W/mK              |
| Adhesive used for fixing and密封ing | M-seal, Silica gel   |
| Inclination of Heat pipes         | $15^\circ$              |
| Length of evacuated tube          | 1.5m                    |
| Material of the evacuated tubes    | Borosilicate            |
| Inside and outside diameter of Evacuated tube | .037m & .047m |

Figure 2. Fabricated setup

Table 2: Measuring Instruments.

| Parameter          | Device          | Range                  |
|--------------------|-----------------|------------------------|
| Temperature        | Thermocouple    | -272$^\circ$C to 1260$^\circ$C |
| Length             | Measuring Tape  | 0 to 2.5m              |
| Solar Intensity    | Pyranometer     | 0 to 1200W/m$^2$       |
| Volume of water    | Measuring jar   | 0 to 2000ml            |
| Hardness           | Hardness meter  | 0 to 999ppm            |
The water inside the channel heats up and the vapors escape through the outlet provided at top of the channel. It contains a 35° bend which is inlet to the condenser and which is a heat exchanges. Due to the cooling effect, the vapors condense and are collected at outlet which flows to the outlet of condenser. The outlet is connected to a container and is made air tight in order to prevent the escape of vapors. The edges and the bends are sealed with silicone sealant so that there is no water leakage.

The key factor in this project is that the feeble part which is glass has been replaced with a lid. The lid is sealed using a gasket and can be removed for periodic maintenance to remove scale and deposition. The size has been reduced by a larger margin making it portable.

4. RESULTS

The experiment was carried in two modes and the results obtained are as follows:-

4.1.1. Without Compound Parabolic Concentrator

In this mode, only the evacuated tube coupled with heat pipe was used in order to raise the temperature of water in the channel.

\[ \eta = \frac{(m \cdot L) + (m \cdot cp \cdot \Delta T)}{I \cdot A \cdot t} \]  

Water output = 560ml, Weight of water
\[ m = 0.560 Kg. \]
Average Intensity of solar radiation = 797.7 W/m²
Average water temperature \( T_{avg} \) = 53° C
Latent heat of water at \( T_{avg} \) = 2605.65 KJ/Kg
Projected area of the heat pipe = 0.3768 m²
Time Duration, \( t = 36000s \). From the obtained data, 23.31% was found to be the efficiency of heat pipes.
4.1.2. With Compound Parabolic Concentrator

The setup with the help of Compound parabolic Concentrator showed higher efficiency and output compared to the previous. Output of 680 ml distilled water was obtained using this setup.

The efficiency was found using

\[ \eta = \frac{(m \cdot L) + (m \cdot \text{cp} \cdot \Delta T)}{I \cdot A \cdot t} \]  

Water output = 680ml, Weight of water \( m = 0.68 \) Kg,
Average Intensity of solar radiation =829W/m²
Average water temperature \( T_{\text{avg}}=53^\circ\text{C} \)
Latent heat of water at \( T_{\text{avg}}=2605.65 \) KJ/Kg
Projected area of the heat pipe = 0.3768 m²
Time Duration, \( t = 36000\)s. From the obtained data, 27.23% was found to be the efficiency of the heat pipes.

5. CONCLUSION

This setup without the use of compound parabolic concentrator gave a distilled water output of 560ml. The distilled water output increased by 17% with the use of compound parabolic concentrator; the net output was 680ml. The thermal efficiency of the setup was found to be 23.31% without the use of compound parabolic concentrator which increased to 27.23% with inclusion of compound parabolic concentrator. This non conventional setup reduces the space and cost compared to pyramid type solar distillation still. The hardness of the distilled water was 19ppm which was obtained by distilling brackish water of 390ppm.
6. REFERENCES

[1] Shobha.B.S, Vilas Watwe and Rajesh .A.M, “Performance Evaluation of A Solar Still Coupled to an Evacuated Tube Collector type Solar Water Heater”, Int. J. Innov. Engr. Technol. (IJIET), June 2012, ISSN: 2319 – 1058

[2] S. S. Harikrishnan and Vinod Kotebavi, “Performance Study of Solar Heat Pipe with Different Working Fluids and Fill Ratios,” Proc. IOP Conf. Series: Materials Science and Engineering, September 2016, IOP Publishing, Vol. 149, Issue 1, pages 012224.

[3] Andrew Stonebraker, Joel Newmeyer and Mark Branner,” Parabolic Solar Water Distillation”, a senior project Interim report, pp. 1–45, 2008

[4] Vinod M Kotebavi and A Ganesh,” Pyramid Type Solar Still Coupled with Evacuated”, Power and Energy Systems: Towards Sustainable Energy (PESTSE), 2016 Proc. Biennial Int. Conf., 2016/1/21 IEEE, pp. 2–6.

[5] Ken Toms Pothen, Nevin Saju Varghese, Nidhish Thomas Jacob, Sachin Mathew and Nikhil Ninan,”Solar Distillation”, Int. J. Eng. Technol. Sci. Res. (IJETSR), March 2015, Vol. 2 Issue 3, ISSN 2394 – 3386

[6] Abdulhamed, A.J., Adam, N. M., Hairuddin, A. A. and Kareem, H. K,” Design and fabrication of a heat exchanger for portable solar water distiller system”, J. Int. Food Res. 23(Suppl): S15 - S22 (December 2016).

[7] J.V Dinesh Raju, T.L.V Vaibhav, Ch. Sai Chaitanya and Vinod Kotebavi,” An Experimental investigation on Hemispherical Basin Solar Still coupled with Heat Pipes, Evacuated Tubes & Paraboloid Concentrator”, Proc. IOP Conf. Series: Materials Science and Engineering 225, (ICMAEM-2017), 012056, doi:10.1088/1757-899X/225/1/012056.

[8] Pramod B V N, Prudhvi Raj J, Hari Krishnan S S and Vinod Kotebavi,” Performance analysis of a solar still coupled with evacuated heat pipes”, Proc. IOP Conf. Series: Materials Science and Engineering 310 (IConAMMA-2017), doi:10.1088/1757-899X/310/1/012149.

[9] Mehtab Haseena, Muhammad Faheem Malik, Asma Javed, Sidra Arshad, Nayab Asif, Sharon Zulfiqar and Jaweria Hanif. “Water pollution and Human health”, Review article -Environmental Risk Assessment and Remediation(2017), volume 1, issue 3.

[10] G.D. Rai, “Non Conventional Sources of Energy”, a textbook for engineering students, Khanna Publishers, 5th edition, Delhi, ISBN no. :978-81-7409-073-8, pp1-908.

[11] R. K. Mishra and S.C. Dubey, “Fresh water availability and it’s local challenge”, Int. J. Engr. Sci. Invention Res. Dev.; Vol. 2 Issue 6 December 2015 www.ijesird.com e-ISSN: 2349-6185

[12] Jie Liu, Amarbayasgalan Dorjerem, Jinhua Fu, Xiaohui Lei ,Huajie Liu, Darryl Macer, Qingju Qiao, Amy Sun, Keisuke Tachiyama, Lilin Yu, Yi Zheng, “Water Ethics and Water Resource Management”, Project Working Group 14 Report on Ethics and Climate Change in Asia and the Pacific (ECCAP), Published by UNESCO Bangkok, 2011, ISBN 978-92-9223-358-7.