DEVELOPMENT OF BRACKISH WATER DISTILLER USING EVACUATED TUBE FOR SUB-SAHARAN COUNTRIES

A. Tecle and Y. Nakajo
Division of Renewable Energy and Environmental Engineering, Ashikaga University, Ashikaga City, Tochigi Prefecture, JAPAN
E-mail: abtec3@gmail.com

Abstract
Nowadays the Sub-Saharan countries are suffering of two crises, the crises of lack of clean energy and fresh water. To resolve these crises many researches on renewable energy and resource of fresh water had been done and still undergoing. The researchers predict promising results. In this work, an experiment is done to resolve these two problems at a time. By using solar energy, a passive water distillation is demonstrated. A solar evacuated tube with a parabolic trough reflector and stainless tube condenser is used. The solar evacuated tube absorbs and converts the solar energy to heat and vaporize the brackish water and the condenser condenses the vapour in to clean water. To increase the performance, the water is filled into the tube thus it has a direct contact with the absorber. The tube is inclined at 36 degree which is the latitude of the site (Ashikaga, Japan) where the experiment is done, to accelerate the bubble formation and vaporization. In addition to this, the inclination helps the vapour to rise up, as water vapour is less dense, and minimises the vapour loss. 0.33kg/sqm.h rate of production and 27.1 percent efficiency is obtained. With the results obtained, the solar evacuated tube distiller is effective for the Sub-Saharan countries.

Key words: Evacuated tube, parabolic trough, passive water distillation, condenser, efficiency, rate of production.

1.0 Introduction
Water is an indispensable resource for any form of life. In particular potable water is more indispensable to human beings. Most part of the globe’s water is unpotable. More than two-thirds of earth’s surface is covered with water of which around 97% is salty, 2.6% is present as icebergs and only less than 1% of fresh water is accessible. Due to its scarcity; water has become a political issue as equal as the politics for oil in particular in arid and semi-arid regions. Several methods have been developed to supply fresh water such as reverse osmosis, distillation and electro-dialysis are amongst the common technologies. These technologies require a vast amount of energy mainly from fossil fuels. Fossil fuels have an adverse impact on the environment and are expensive. To avoid environmental pollution and take advantage of cost-free energy, water distillation assisted with renewable energy is a better option. The most common renewable energy used in distillation is thermal solar energy. The arid and semi-arid regions are endowed with abundant solar irradiance thus solar distillation is a suitable technology.

Different solar distillation technologies have been devised by different researchers based on simple stills and evacuated tubes or a combination of both. Solar distillation works on the principle of natural precipitation. Water in the basin vaporizes by the solar energy and condenses on by temperature difference between the surface the vapour in contact and the ambient temperature. In this experiment the evacuated tube as a basin and a stainless steel cylinder as a condenser is employed. The evacuated tube heats and vaporizes the water by absorbing the solar radiation and the vapour rises up and condenses on the stainless steel by exchanging the heat to the environment. The distillate output is dependent on the intensity of the solar radiation, optical efficiency(reflectance of reflector, receiver
absorbance and glass transmittance, and interception factor), latitude, ambient air temperature, wind speed and set-up configuration (inclination, water depth and condenser performance).

2.1 Experimental Setup and Procedures
The experiments were conducted in Ashikaga University, Ashikaga, Japan 36° 20’ N latitude, 139° 26’ longitude at an altitude of 96.7 m above sea level. The experiments were conducted on May 2018 from 9:00 to 15:00 hours, measurement was taken 10 minutes. The set up consists of an evacuated tube, parabolic concentrator and condenser. The evacuated tube is a double layer of borosilicate glass, with an evacuated between the layers which serves as thermal insulator. The external surface of the inner tube is coated with a selective coating to absorb the solar radiation. The tube is fixed at 36° which is the latitude of the place of experiment, this helps to increase the upward velocity of bubbles by buoyancy, thus the rate of production increases, etc. has an internal diameter of 55 mm, and external diameter of 70 mm, and with a length of 475 mm. In order to maximize the production of distillate a parabolic trough concentrator is used. The parabolic trough concentrates the sun direct beams in to a line at the focal line. It is made with an aluminum frame and aluminum foil reflector. The trough is fixed in such a way that its focal axis line aligns to the longitudinal axis of the vacuum tube. And has an aperture area of 0.21 m². The condenser exchanges heat between the vapour and the ambient air, thus the vapour cools and condenses on the wall and flows down. It is made from stainless-steel 430 with a thickness of 0.4mm and has a diameter of 100 mm and 540mm length. The condenser is fitted in to the evacuated tube with a ring gasket. The condenser collects the condensate at the bottom end channel and drains out through a hole in to a collection bottle.

The evacuated tube was filled with water in order to get higher solar heat gain. Since the water has a direct contact with the absorber the heat loss is minimized as much as possible. Its level is made in such a way it will not overflow the tube during boiling. The volume of water at this level is approximated to be 900ml. The set up was made to track the sun manually, thus maximum solar heat gain is obtained.
2.2 Instrumentation

Different instruments were used to measure the physical quantities of the experimental results. Sato Shoujo SPM-SD pyranometer was used to measure the solar radiation with accuracy \( \pm 10 \text{w/m}^2 \) and resolution 0.1w/m². K-type thermocouple was used to measure the temperature and read by Mastech S838 multi-meter with an accuracy \( \pm 20\% \) of reading and resolution of \( 1^\circ \text{C} \). CS-2000S was used to measure weight of the distillate water with a resolution of 1gm.
3.0 Thermal Analysis

The thermal analysis is based on the following equations.

The solar energy absorbed by the evacuated tube is

\[ Q_{in} = I_N A_R \]  

(1)

The latent heat of energy

\[ Q_{out} = m h_{fg} \]  

(2)

The efficiency of the system

\[ \eta = \frac{Q_{in}}{Q_{out}} = \frac{m h_{fg}}{I_N A_R} \]  

(3)

The geometric factor \( R_b \), the ratio of normal beam radiation on the tilted surface to that on a horizontal surface at any time.

\[ R_b = \frac{\cos \theta}{\cos \theta_z} \]  

(4)

Where \( \cos \theta = \cos \delta \cos \phi \cos \omega + \sin \delta \sin \phi \)  

\[ \cos \delta z = \cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta \]

Where

- \( I_N \) Normal solar radiation
- \( A_R \) aperture area
- \( m \) mass of the distillate water
- \( h_{fg} \) the latent heat of evaporation
- \( \eta \) Efficiency
- \( R_b \) Geometric ratio
- \( \theta \) Angle of incidence
- \( \theta_z \) Zenith angle
- \( \delta \) Declination
- \( \beta \) Tilt angle
- \( \gamma \) Surface azimuth angle
- \( \gamma_s \) Solar azimuth angle
- \( \phi \) Latitude
4.0 Results and Discussion
To adapt the final setup a series of experimental developments were undergone under similar conditions (solar radiation 500-850 W/m$^2$ and ambience temperature 27°C). Originally, the experiment begun to distillate water using only evacuated tube, in the next experiment a concentrator (parabolic trough) was fitted to the setup and put in a fixed direction. At last the setup with concentrator was made to track the sun.

4.1 Water Distillation without Parabolic Trough
In this experiment the water took three and half hours to boil and the distillation rate was very slow, since the solar heat gain was very small due to small absorber projected area of absorber. In addition to that, the ratio of water volume in the tube to the total surface area of absorber is big compared to the standard evacuated tubes (Φ47mm, 1.8m long.), as a result a very small distillate was obtained. For the whole day experiment (9:00-17:00) 50 ml distillate was obtained.

4.2 Water Distillation Using Parabolic Trough in Fixed Direction
In the second experiment, the aim was to see the effect of a concentrator in fixed direction, thus a concentrator was fixed into the setup. The setup was made to face to the south direction. During the early hours the water boiled and started to vaporize in less than three and half hours. Though it is not considerable, the concentrator improved the result by 100% increase in distillate output. An average of 100 ml of distillate water was collected during the experiment.

4.3 Water Distillation Using Parabolic Trough and Tracking
In this experiment the distiller was made to track the sun manually every ten minutes, thus better solar heat gain is obtained. The water boiled in an hour and fifteen minutes. The distillation reached at its maximum rate when direct sun rays become normal with the evacuated tube. As it can be observed from the fig.1 at the beginning hours the water boils and the production of distillate starts after an hour and quarter. The distillate production increases gradually 55, 65, 80 ml for each hour between 11:00 and 13:00 respectively. At 11:40 the normal solar flux attains its peak value (817 w/m$^2$), yet only 65 ml of distillate is collected. A maximum distillate is obtained (120 ml) at around 14:00 o’clock, as the solar flux becomes normal to the evacuated tube and the concentrator (36°) and altitude of the sun (54°). After 14:00 the distillate production decreases for following reasons. Both the solar flux and the depth of water level in the evacuated tube are decreasing. The level of water decreases because of vaporization. As the water level decreases the rate of vaporization also decreases, at the same time the vapour temperature gets high because the absorber transfers the heat to the vapour (not water), thus the heat dissipation at the condenser takes time for condensation. It is absorbed that that there was heat loss due to radiation, convection and vapour loss. It was found that a vapour loss of 105ml. It is observed that the effect of the concentrator and the tracking has a significant result in the production of distillate. During the experiment period an average 485 ml of distillate was collected and, which is 870% increase in production compared to the tube only. In addition to this, a vapour loss of 105 ml occurred. In the fig.2&3 at 14:00 a maximum thermal efficiency and production rate of 46.5% and 0.57kg/h.m$^2$ respectively are obtained. The overall efficiency and production rate of the setup is found to be 27.1% and a production rate of 0.33kg/h.m$^2$ respectively.
Fig. 3 Distillate production and Solar radiation with respect to time

Fig. 4 Efficiency and Solar radiation with respect to time
Fig. 5 Production rate and Solar radiation with respect to time

5.0 Conclusion
Solar distillation using an evacuated tube is demonstrated. It is developed from a simple evacuated tube only into a better setup. In order to optimize the solar heat gain and production rate a concentrator was fixed and made to track the sun. The result considerably increased by 870%. It is observed that a maximum efficiency and production rate of 46.5% and 0.57 Kg/h.m² respectively obtained at 14:00 hour, in which the solar radiation becomes normal to the tube. It is also observed that there was vapour loss. An average of 105 ml vapour loss occurred. All in all, this set up can be used effectively in Sub Saharan countries.
References