Modern Environmental Science and Engineering (ISSN 2333-2581)
June 2021, Volume 7, No. 6, pp. 618-623
Doi: 10.15341/mese(2333-2581)/06.07.2021/012
Academic Star Publishing Company, 2021
www.academicstar.us

Efficiency of A Portable Solar Distiller With Condensation System Using Peltier Cells

Manuel Jesús Arjona Pérez, Blanca Laura Guillén Espinoza, Flavio Magallón Pulido, and Juan Manuel Guerrero Navarrete

Basic Sciences Department, Instituto Tecnologico de Jiquilpan, Mexico

Abstract: In this work, monitoring of a portable solar distiller design with Peltier cell-based condensation system is presented. The distiller was mostly constructed with three mm glass and 1 mm aluminum foil. Temperature records were recorded at different points inside and outside the distiller as well as the current and voltage of the Peltier cell and fan system. The monitoring period was 9 days and 5 h of solar radiation per day, in this period the yields obtained were 131.2 to 263.8 ml per day of monitoring, with levels of solar irradiation varying from 394 to 963.3 W/m^2 on the monitoring days. The efficiencies achieved range from a minimum and a maximum of 8.5% to 15.2% respectively.

Key words: peltier cells, solar distiller, efficiency, portable distiller, condensation, desalination

1. Introduction

According to UNICEF, in these days, 783 million people worldwide lack access to safe drinking water. From all these people, 200 million must walk or ride long journeys to access distant water sources. Even though there are technologies to purify contaminated water and seawater desalination, they usually require expensive infrastructure and a lot of energy which puts them out of reach for many communities[1].

Solar distillation is a process in which water contained in a container is evaporated and then condensed into some surface, resulting in a liquid with fewer impurities (salts, heavy metals and organic matter). There are a wide variety of solar distiller designs: their main classification is active and passive. In active solar distillers, additional energy is supplied for the solar either electrically or mechanically or a combination of both. Only solar energy is supplied for water evaporation in passive solar distillers.

There are a wide variety of distillers, but one way to classify them is to consider them as active or passive: Active uses some additional device such as collector, concentrator or photocells, while passive uses only solar radiation without any additional device for distillation [1].

Simultaneous thermal processes are presented in the solar distiller; Fig. 1 presents a simplified model described below: from the incident solar radiation on the solar distiller cover, one small part is absorbed and another part is reflected by the glass, much of it passes through the glass and is absorbed by water and material from the bottom of the distiller. The absorbed energy heats the water to be distilled and the bottom of the distiller, which transfers much of its energy in the form of heat to the water mass, which raises its temperature, thus increasing the movement of its molecules. This movement becomes more intense as the water temperature increases, causing a portion of the molecules to leave the water's surface by evaporation and increase moisture in the air near the water's surface,

Corresponding author: Manuel Jesús Arjona Pérez, Master; research area/interest: renewables energy. E-mail: manuel.ap@jiquilpan.tecnm.mx.

[1] Available online at: https://www.sciencemag.org/news/2019/06/new-solar-technology-could-produce-clean-drinking-water-millions-need.

generating convective currents within the distiller. The transfer of water vapour from the evaporator to the condenser is carried out by diffusion and by the convection of the wet air. The hot, humid air rises to the glass cover, where some of the water vapour condenses and slips into the collection channel, as well as distilled water. The following equations are presented through an energy balance.

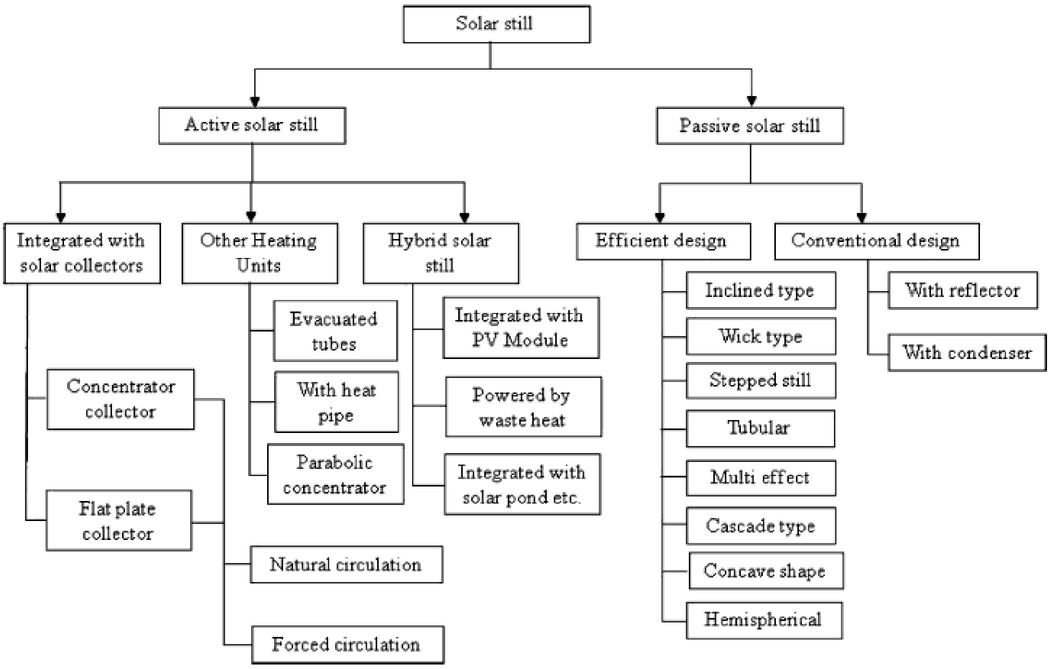


Fig. 1 General classification of solar distillers, Machanda and Kumar [1].

$$q_c' = q_{rw} + q_{cw} + q_e + \alpha g * I_T - (q_{rv} + q_{cv}) \quad (1)$$

$$q_a' = I_T*(1-\alpha g)(1-\alpha a)-(q_{rw}+q_{cw}+q_e+q_c) \quad (2)$$

Where:

q_c' = heat stored on deck $\left(\frac{W}{m^2}\right)$

q_{rw} = lost heat by water radiation $\left(\frac{W}{m^2}\right)$

q_{cw} = lost heat by water convection $\left(\frac{W}{m^2}\right)$

q_e = lost heat by evaporation $\left(\frac{W}{m^2}\right)$

I_T = Direct ratiation over the inclined surface $\left(\frac{W}{m^2}\right)$

αg = Radiation reflection factor

q_{rv} = lost heat by radiation from the glass $\left(\frac{W}{m^2}\right)$

q_{cv} = lost heat by glass convection $\left(\frac{W}{m^2}\right)$

q_a' = heat stored by watter $\left(\frac{W}{m^2}\right)$

αa = coefficient that includes the reflection and absortion of the solar radiation considering the water and distiller

q_c = lost heat by conduction $\left(\frac{W}{m^2}\right)$

On the other hand, in 1834 Jean Peltier discovers that the passage of an electric current through the union of two different conductors in a certain direction produces a cooling effect. Angels [3] mentions that a Peltier cell is composed of semiconductor materials in general has a similar configuration presented in Fig. 3. The Semiconductor Junction Composites Type N with 75% Bi_2Te_3 (Telurium Bismuth) with 25 Bi_2 Se_3 (Selenium Bismuth), while the type P semiconductor with 25% Bi_2Te_3 (Telurium Bismuto) with 75% Sb_2 Te_3 (Telurium Antimony). Fig. 3 shows the physical connection of semiconductors.

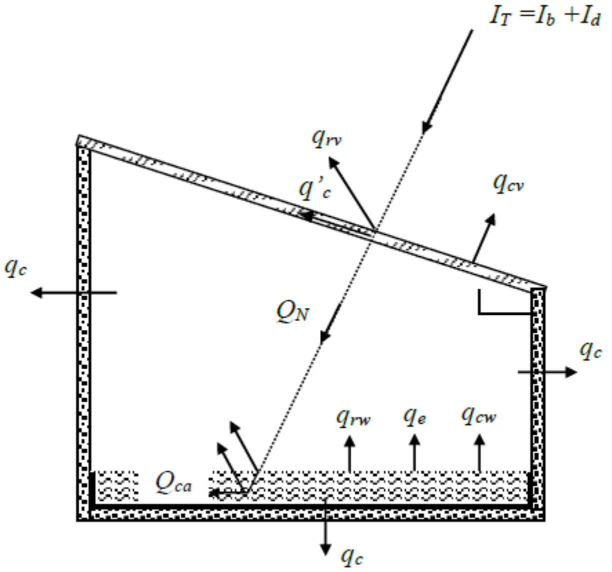


Fig. 2 Energy balance in a distiller [2].

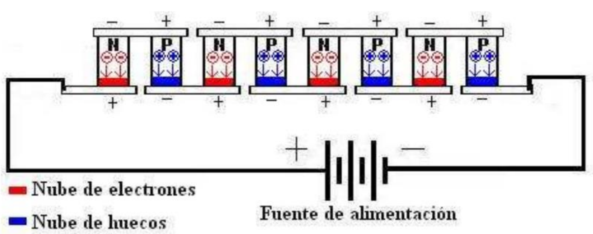


Fig. 3 Understanding and rareening load carriers near the semiconductor metal junction in a Peltier cell [4].

In the operation of a Peltier cell several phenomena happen simultaneously: Peltier effect, Thomson effect, Joule effect and thermal conduction; below are the simplified equations reported by Platero [5].

Applying a potential difference over the cell will result in a heat transfer per unit of time on the hot face Q_{PC} equal to:

$$Q_{PC} = \alpha T_C I \quad (3)$$

Where α is the Seebeck coeficient, T_C is the temperature of the hot face, I is the current circulating in the cell.

For the same purpose, the heat absorption per unit of time on the cold face Q_{PF} will be:

$$Q_{PF} = \alpha T_F I \quad (4)$$

Where α is the Seebeck coeficient, T_F is the temperature of the cold face, I is the current circulating in the cell.

Considering the Joule-effect pereds Q_J which are supposed to be distributed half for each face, they shall be expressed by:

$$Q_J = \frac{1}{2} I^2 R \quad (5)$$

Where R is the electrical resistance of the Peltier cell, I is the current circulating through the cell.

The diference of temperatures between both sides will produce a thermal conduction effect Q_{CT} between the hot face and the cold face that is determined as:

$$Q_{CT} = \frac{T_C - T_F}{R_{TH}} \quad (6)$$

Where R_{TH} represents the thermal resistance between the hot face and the cold face.

The calorific net flow absorbed by the cold face Q_F, will be making the energy balance to:

$$Q_F = Q_{PF} - Q_J - Q_{CT} = \alpha T_F I - \frac{1}{2} I^2 R - \frac{T_C - T_F}{R_{TH}} \quad (7)$$

While the heat yielded and it should dissipate through the hot face Q_C will be equal to:

$$Q_C = Q_{PC} - Q_J - Q_{CT} = \alpha T_C I + \frac{1}{2} I^2 R - \frac{T_C - T_F}{R_{TH}} \quad (8)$$

By applying the energy balance, it will turn out that the electrical power P_{and} supplied will be the difference between the calorific dissipation and absorption flows, i.e.:

$$P_e = Q_C - Q_F = \alpha \left(T_c - T_f\right) I + I^2 R = \alpha \Delta T I + I^2 R \quad (9)$$

If the Thomson effect is considered negligible and considering only the average values of heat transport properties. Seebeck coefficient, electrical resistivity and thermal conductivity will vary with temperature. It has been verified that for the temperature range of practices, these can be considered constant.

To determine instantaneous efficiency based on distillate production, the Rahbar equation [6] was used:

$$\eta = \frac{\dot{m} h_{fg}}{I_s * A + \dot{W}_{TEC}} \quad (9)$$

$\dot{m}$ = distilled water production kg/s

h_{fg} = Vaporization latent heat (2300 kJ/kg)

3. Materials and Method

The built device is located at coordinates 19-58'59.2"N, 102-42'22.4"W at the interior of the Jiquilpan's Technological Institute. A geometric model such as the one shown in the following figure was used in the construction. Fig. 4 shows the dimensions used in its construction with a tilt angle of 35 degrees on the glass front and 55 degrees on the aluminium back. Feilizadeh [7] makes some recommendations regarding geometries of solar distillers that have better performance and, in this regard, a rectangular geometry at the base was of better performance and was taken into consideration in the geometry presented.

The materials used in its construction were basically 3 mm glass and 1 mm aluminum joined with silicone. At the bottom was used extruded polystyrene insulation 1 in thickness and aluminum foil. The water depth inside ranged from 2 to 4 mm. Table 1 shows the materials generally used.

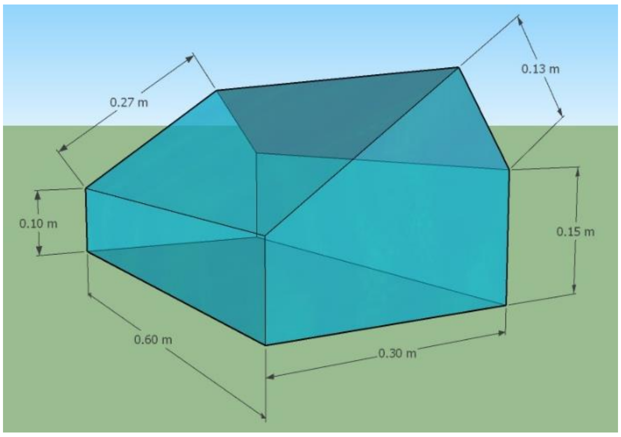


Fig. 4 Geometric model used in the construction of the solar distiller.

Table 1 Materials used in the construction of the distiller.

Materials
3 mm thick glass
Peltier CELL TEC1-12706
Tube silicone
12 V fan
Voltage source 12V to 15A
Aluminum channel
Extruded polystyrene insulator 2.54 cm thick
Aluminum foil 1 mm thick

Thermocouples, voltmeter and ammeter were used for the monitoring of a TRUPER MUT-39 brand digital multimeter. Specified in the Table 2.

The construction was carried out considering the mentioned materials and the Solar's distiller geometry presented, its final version can be seen in the following Fig. 5.

Table 2 Magnitudes measured in the multimeter used.

Magnitude		Range	Precision
Temperature	Type K	-40 a 1000 C	±3%+10
DC current		2 mA to 20 A	±0.8%+1
Voltage		200 mV 1000 V	±0.5%+1

Fig. 5 Built solar distiller.

Fig. 6 Peltier cell installation detail.

4. Results

For solar radiation data used in distiller performance calculations, the weather cloud page [8] was consulted with the coordinate data 20°40′0″ N, 103°19′32″ O; at an elevation of 1560.1 m location that corresponds to the Guadalajara's interior of the city.

Monitoring of the portable solar distiller was carried out over a 9-day period (11/5/20, 12/5/20, 13/5/20, 29/5/20, 5/6/20, 8/6/20, 29/6/20, 3/7/20 and 14/7/20) and on each day at a time from 9:30 am to 2:30 pm, i.e., 5 h per day. The volumes obtained during this period can be summarized in Fig. 7, the volume oscillated between 131.2 and 256.1 ml; It should be mentioned that as reported by Rahbar [6] in his work reports a production of distilled water that oscillated between 225 and 500 ml, with irradiation levels 20,500 to 25,500 which shows a discrepancy regarding to the obtained results, mainly due to exposure times and intensities of solar radiation, mainly J/m^2.

The amount of solar energy received according to the level of global irradiance referenced to a weather station located 20°40′0″ N, 103°19′32″ O at 1560 m of elevation, location corresponding to the Guadalajara's city interior. the monitoring days can be summarized in the following Fig. 8, ranging from a minimum to a maximum 394 to 963.3 W/m^2.

As for the efficiency of the solar distiller in the monitoring period, they ranged from 8.5% to 15.2%, can be seen in Fig. 9.

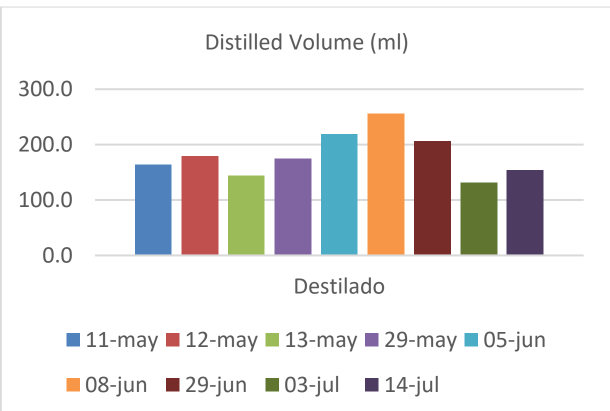


Fig. 7 Daily distillate volume in ml during monitoring days.

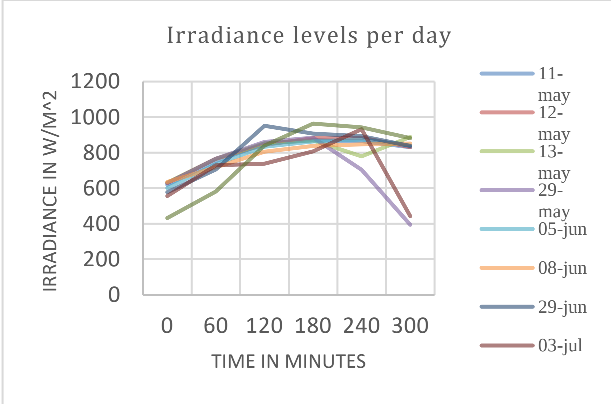


Fig. 8 Radiation levels per day from 9:30 a.m. to 14:30 p.m.

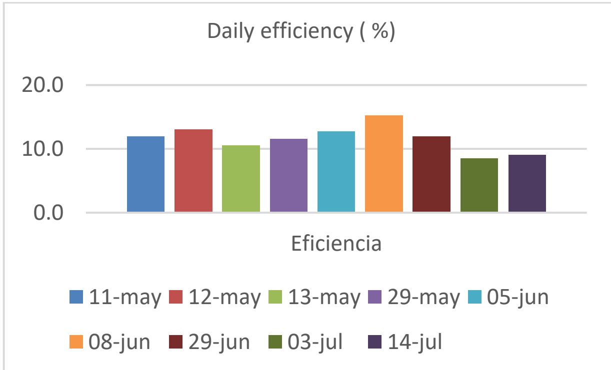
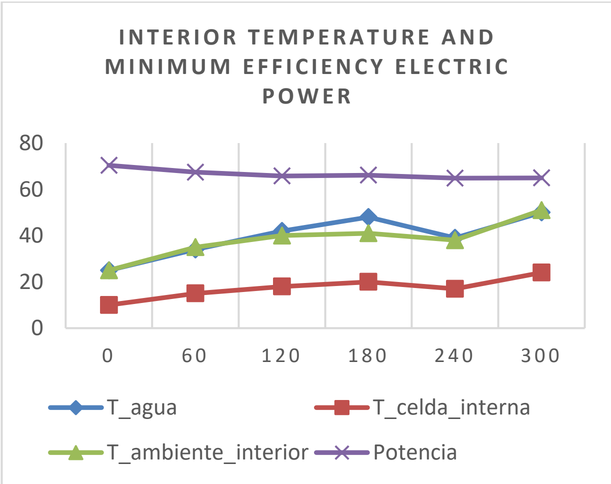


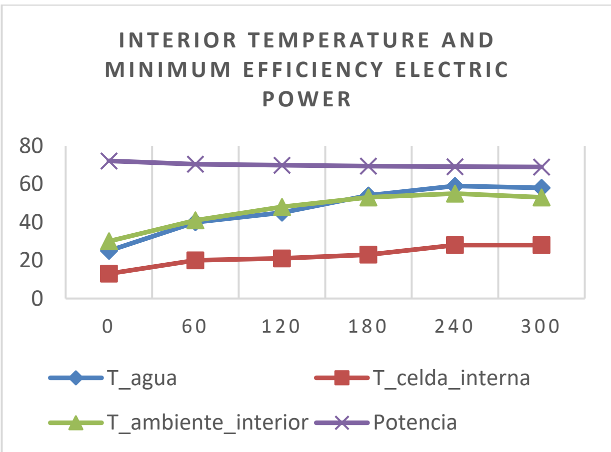
Fig. 9 Daily efficiency estimated in % during the monitoring period.

This efficiency is similar to other reported works such as those of Esfahani [9] in whose design of solar distiller with Peltier cells reported that the maximum production of 1.7 L/m^2 in a test time of 7 h with an irradiance level of 728 W/m^2, with an efficiency of approximately 3% to 13%, with an absorbing area of 0.024 m^2. On the other hand, Kaviti [10] reported in his work concerning to inclined solar distillers (active and passive distillers) that the productivity of such design's ranges from 2.5 to 9 l/m^2 day and an efficiency between 34% and 87%, regarding this work it does present significant discrepancies, this is due to differences in areas of the absorber and energy consumption.

The temperatures inside the distiller corresponding to the water temperature, interior temperature of the distiller and the inner temperature of the cell were monitored, as well as the power of the condensation system (Peltier cells, fans and exchangers). In Fig. 10, you can see that the power (W) was practically



(a)



(b)

Fig. 10 Graph of indoor temperatures, the power of the condensation system on the lowest performance day (a) and the highest performance (b).

maintained throughout the test on average 67 W. The water temperature (C) and the indoor temperature (C) practically go simultaneously and the inner temperature of the cell remains an appreciable difference from the two mentioned.

5. Conclusion

With this work's experience which is not conclusive, performance monitoring per day and the daily efficiency of a portable solar distiller using Peltier cells were presented. In the monitoring period distillates were obtained with a minimum of 131.2 ml and a maximum of 256.1 ml; as well as daily efficiency between 8.5% and 15.2%. These results showed similarities to other works, which is indicative that using Peltier cells as an alternative in solar distillers; it is imminent to carry out more monitoring days and with sufficient information continue to improve the design to increase distillate production, decrease energy consumption, analyze the quality of the distillate and propose possible end use.

References

[1] Machanda and Kumar, A comprehensive decade review and analysis on designs and performance parameters of passive solar still, *Renewables: Wind, Water and Solar* 2 (2015) 17

[2] Saint James, Experimental evaluation of a single slope solarstill, *Techscience* 12 (2017) (22) 61-71.

[3] R. Angels and J. Marquez, study of the characteristics of thermoelectric systems and their application in refrigeration, national polytechnic institute, professional unit Azcapotzalco, 2005.

[4] A. P. Sandoval, E. Espinosa and J. L. Barahona, Peltier Cells: an alternative for semiconductor-based cooling systems, in: *11th State Forum for Scientific and Technological Research*, 2008, pp. 158-161.

[5] Platero Carlos (2000), Classical and modern control over Peltier cells in a didactic environment, XXI Automatic Days, Seville.

[6] Rahbar Nader, An experimental investigation on productivity and performance of a new improved design portable asymmetrical solar still utilizing thermoelectric modules, *Energy Conversion and Management* 118 (2016) 55-62.

[7] Feilizadeh Mehrzad, Optimization of geometrical dimensions of single-slope basin-type solar stills, *Desalination* 424 (2017) 159-168.

[8] Available online at: https://app.weathercloud.net/.

[9] J. A. Esfahani, Utilization of thermoelectric cooling in a portable active solar still — An experimental study on winter days, *Desalination* 269 (2011) 198-205.

[10] A. K. Kaviti, Inclined solar still: A review, *Renewable and Sustainable Energy Reviews* 54 (2016) 429-451.