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A Performance study of a single basin double slope solar still with 45° of glass-cover slope angle in Indonesia

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Abstract. Solar energy is a clean energy, pollution free and available in abundance that can be used directly for heating. Utilization of solar heat in the supply of clean water through distillation is very suitable for use in remote coastal and swampy areas. In this study the performance test of a single basin type solar distillation system with a double slope cover that has 45° slope angle is operated in Cilegon-Indonesia. With rare rainy conditions the average solar distillation efficiency reaches 34.3%. The formation of condensate at night is almost five times greater than during the daytime, because temperature of water in the basin is higher than the inner surface temperature of the glass-cover. Thus the use of material as a thermal energy storage when the intensity of radiation is high and releasing it into the water at night will help a lot to increase condensate production.

1. Introduction

The lack of fresh water becoming a big problem in the world. Because water is a primary need not only for humans, but also a main need for all living things in this world. The surface of the earth is more covered by sea water than covered by land, about 71% of the earth's surface is covered by sea water [1]. However, not all water available on earth can be used for humans and other living things. A number of requirements are needed to maintain health and avoid the various disturbances stated in the water quality standards, among others; non-toxic, does not contain substances that cause health problems, does not contain excess chemicals.

Increasingly scarcity of clean water is getting worse given the limitations of water sources caused by the diminishing forest area as a supplier of natural water and the growing human population. To solve this problem water treatment efforts need to be done that can improve the quality of existing water to match the water quality needed by humans and other living things.

Desalination is one of the earliest forms of water treatment by humans to convert sea water into fresh water. Desalination methods are still widely used throughout the world today. Solar desalination utilizes heat energy from sunlight to evaporate pure water from sea water, then water vapor is condensed to obtain pure water and waste in the form of water with high salt content.

Utilization of solar energy in the distillation process can be direct or indirect. Direct solar distillation uses solar heat to produce distillates in the solar collector. Whereas the indirect method combines conventional distillation techniques with other systems such as vapor compression desalination (VC), multilevel flash desalination (MSF), membrane distillation (MD) and electrodialysis, Reverse Osmosis (RO) and the addition of solar collectors for heat generation. Direct solar distillation requires large land with relatively low productivity compared to indirect solar distillation [2].



Utilization of renewable energy sources is highly recommended for distillation systems, especially in remote areas. Geothermal energy is also effectively used in seawater desalination [3]. Direct solar distillation is considered the best solution for water production in small communities, remote area, where fresh water is not available. But the amount of fresh water produced per unit area is very low. Several attempts were made to increase the productivity of distilled water produced, including by adding phase change material as an thermal energy storage [4 -8].

Solar distillation is very effective in producing pure water, removing pathogenic elements, salts, heavy metals found in raw water. This is very beneficial for the user and avoids health problems contained in water.[9]

The position of the sun changes continuously throughout the day, so the intensity of solar radiation reaching the earth depends on the time and geographical position. Indonesia is located around the equator, so solar radiation can be obtained throughout the day. In this research, a double slope type solar distillation performance test was performed with a 45 degree slope angle.

2. Experimental Set Up

The study was conducted experimentally by using an equipment called solar distillation, which consists of a basin made of aluminum with a coat of black paint having a length of 106 cm and a width of 60 cm with a height of 30 cm. The outside wall and the bottom of the basin are placed insulating material (Styrofoam) to prevent heat leakage, and placed above a wood basin. Basin filled with raw water as deep as 10 cm. A double slope cover glass is mounted above the basin with a 45° tilt angle.

Transparent glass cover will allow solar radiation to enter towards the water in the basin. Solar radiation heats water until it starts to evaporate and collect at the bottom of the glass cover as a layer of dew. The dew layer moves along the surface of the glass toward the condensate channel.

Certain important parameters must be measured simultaneously among others is the temperature in some parts, global solar radiation and the condensate produced. Figure 1. Shows the test equipment accompanied by the position of the measuring instrument.

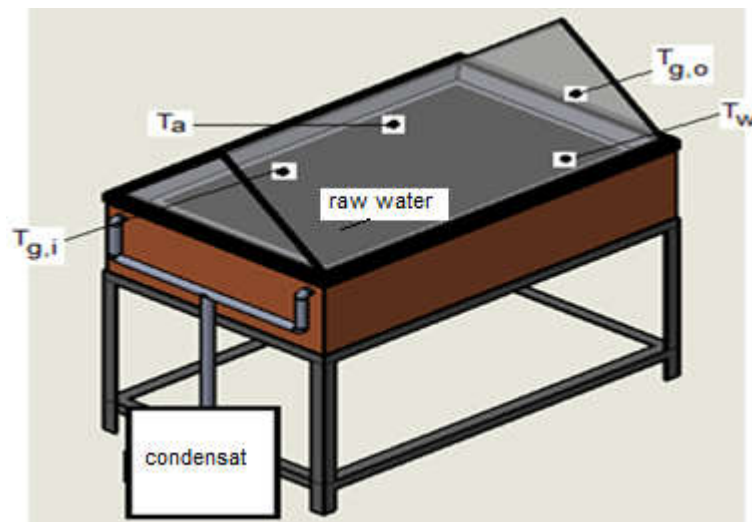


Figure 1. Arrangement of solar distillation testing instruments.

Where :

T_w = Water temperature in the basin ($^{\circ}\text{C}$)

$T_{g,i}$ = Lower surface temperature of cover glass ($^{\circ}\text{C}$)

$T_{g,o}$ = Upper surface temperature of cover glass ($^{\circ}\text{C}$)

T_a = Air temperature in the test equipment ($^{\circ}\text{C}$)

I_R = Intensity of global radiation (klx - kilolux)

Q_c = Volume of condensate produced (ml)

3. Methodology

The experiment was carried out 5 times with the observation time between 8:00 and 17:00. Whereas the condensate produced is observed until 8:00 the next day considering that condensate production also occurs at night. Tests carried out in May 2019 during the dry season. This site is 6° 0' 56" South, 106° 3' 11" East. The climate is non-semi-arid and is characterized by bright sunlight and high annual rainfall during the rainy season.

The performance of solar distillation is expressed in terms of efficiency which is the ratio of heat to vaporizing water to the total heat of radiation received by the surface of the solar distillation device which can be expressed in (1).

$$\eta = \frac{m_c \cdot h_{fg}}{A_c \cdot I_R \cdot t} \times 100 \% \quad (1)$$

Where :

- η = solar distillation efficiency (%)
- m_c = condensate mass (kg)
- h_{fg} = latent heat of evaporation (kJ/kg)
- A_c = heat absorbent area (m^2)
- I_R = radiation Intensity (kW)
- t = radiation time (s)

Radiation time in one day is expressed as a time of high enough sunlight from 8.00 to 17.00. While the condensate mass is determined from the volume of condensate produced in one day from 08.00 to 08.00 the next day.

$$m_c = Q_c \cdot \rho_w \quad (2)$$

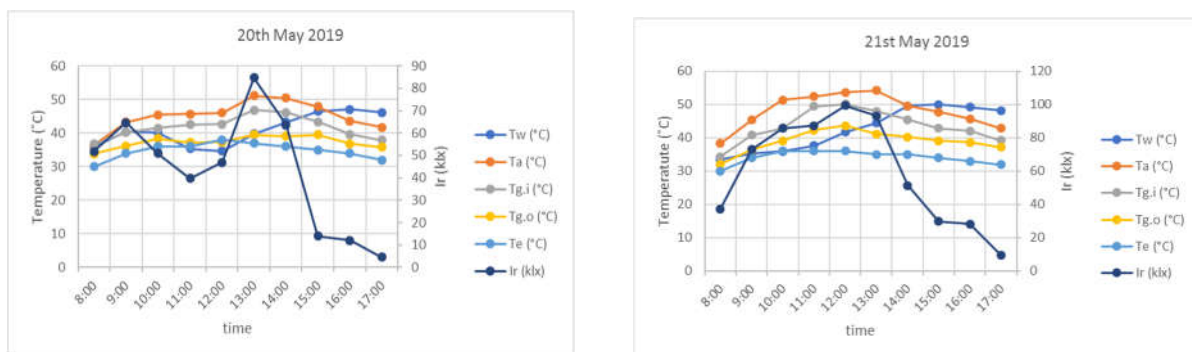
Where :

- ρ_w = water density (1000 kg/m^3)

4. Results and Discussion

4.1 Temperature Distribution and Intensity of Solar Radiation.

Temperature distribution in the solar water distillation system and global intensity of solar radiation for 5 repetition of data collection shown in Figure 2.



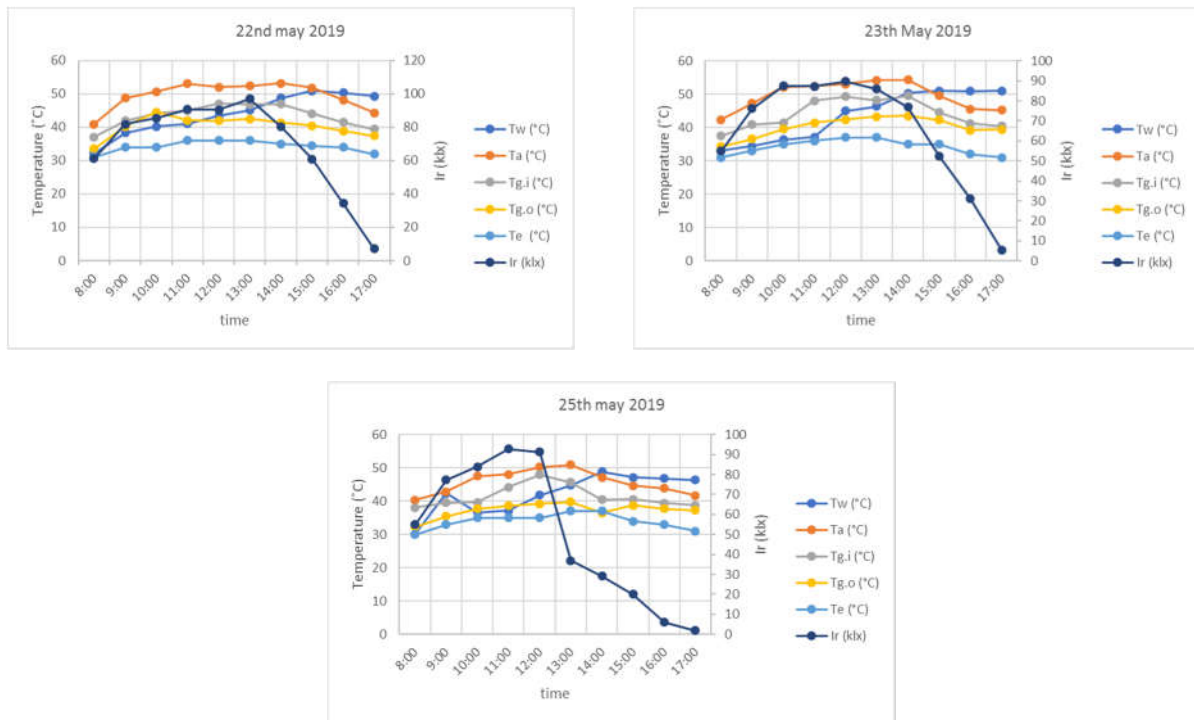


Figure 2. Temperature distributions and global intensity of solar radiation

From observations when the intensity of solar radiation is high, the air temperature in the solar distillation chamber (T_a) has the highest value, while the environmental temperature (T_e) has the lowest value. This is due to heat leakage from the system to the environment is very low. All radiant heat received is used to optimally heat the distillation system parts. Furthermore, when there is a decrease in the intensity of solar radiation, the temperature of the water in the basin seems to continue to increase some time before it goes down, this is due to the heat obtained from the constituent material of the basin which is coated with Styrofoam as an insulator that is quite effective in resisting heat leakage.

4.2 Distillate Production

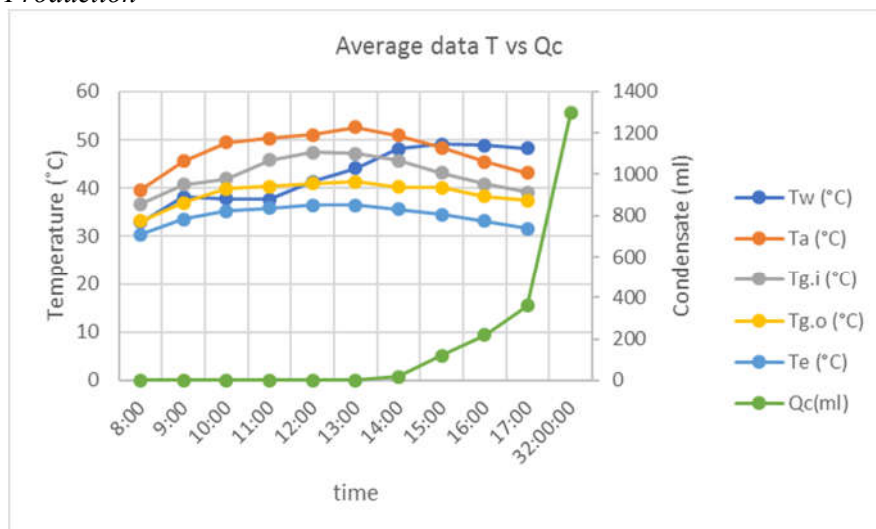


Figure 3. The average temperature distribution and condensate production

From 5 times the test data obtained the average value of the temperature distribution on the solar distillation test equipment. Figure 3 shows the average temperature: water in the basin (T_w), air temperature above the water basin (T_a), surface temperature in the glass cover ($T_{g, i}$), average environmental temperature (T_e) and the production of distillate water produced up to 8:00 the next day (in table 32:00:00).

Distillate production on average began to appear at 14:00 with an amount of 18 ml and until 08.00 the next day the production of distillates reached 1296 ml. Distillate production begins to be detected when the temperature of the bottom cover glass begins to decrease, this makes it easier for water vapor contained in the air above the basin to condense when touching the surface of the cover glass. Distillate production, Q_c , at 32:00:00 states that distillate production until 08.00 the next day.

The distillate production in double slope solar distillation with 45 degree slope of the cover glass is as follows.

- Average of distillate production : 1296 ml/day
- Distillate production during the day (08.00 - 16.00) : 220 ml
- Average nighttime distillate production (16.00 - 08.00 the next day) : 1076 ml.

Distillate production to the global solar radiation intensity is shown in Figure 4. From 5 times observations, the highest average solar radiation intensity was 83,560 lux at 12.00. While the average value of the intensity of solar radiation from 8:00 to 16:00 is 62,898 lux.

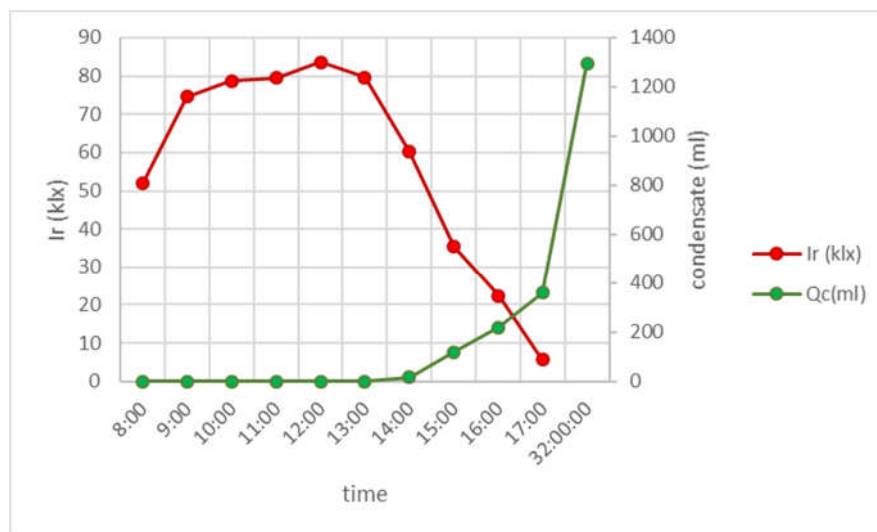


Figure 4. Average of distillate production and global solar radiation intensity.

4.3 Solar Distillation Efficiency

For an average water temperature of 40 °C, then :

- value of latent heat for water evaporated, $h_{fg} = 2406.8$ kJ / kg
- water density , ρ , = 1000 kg / m³

distillate production :

$$Q_c = 1296 \text{ ml}$$

$$m_c = 1.296 \text{ kg}$$

Average of global solar radiation intensity for eight hours (08.00-16.00) :

$$I_R = 62,898 \text{ lx} = 496.8942 \text{ W/m}^2.$$

Basin Surface area :

$$A_c = 106 \text{ cm} \times 60 \text{ cm} = 0.636 \text{ m}^2$$

So the average solar distillation efficiency for a double slope with a slope angle of 45° is :

$$\varepsilon = \frac{1.296 \text{ kg} \times 2406.8 \text{ kJ/kg}}{0.636 \text{ m}^2 \times 496.8942 \text{ W/m}^2 \times 8 \text{ h}} = \frac{3,119,212.8 \text{ J}}{9,101,511.68 \text{ J}} = 34,3 \%$$

5. Conclusions

The purpose of this experiment is to evaluate of effectivity double slope solar distillation with 45° slope angles, operated in Indonesia with semi-arid weather.

Based on experiments and discussions conducted, the following conclusions can be drawn :

1. The temperature of the water in the basin and the air temperature above it does not necessarily decrease following the decrease in the intensity of global solar radiation, due to the lack of heat leakage out of the system.
2. Condensate starts to be produced when the water temperature in the basin is higher than the inner surface temperature of the glass cover.
3. The formation of condensate at night is almost five times greater than during the daytime. So the difference between the temperature of the basin water and the temperature of the glass cover plays an important role. For this reason, needs to be carried out to maintain the temperature of the basin water higher than the inner surface of the glass cover, for example by adding heat energy storage material in the basin.
4. The results of performance tests on double slope solar distillation with a 45 degree slope of the cover glass that is operated in rare rain conditions in Indonesia shows an efficiency value of 34.3 %.

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