Exergy analysis of double slope passive solar still

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Abstract. Solar still is processes that can be used to convert available water into clean water. To find out whether the exergy used in the evaporation process has been used optimally in terms of quality, the second law of thermodynamics is used or known as exergy analysis. The purpose of this study was to determine the magnitude of exergy and exergy efficiency of a double slope passive solar still. The results showed that the solar intensity, water temperature, and ambient temperature affected the magnitude of exergy and exergy efficiency. The higher the solar intensity and the temperature of the water, the higher exergy and efficiency of the exergy, and the higher the ambient temperature, the exergy of evaporation in the system will be lower. The daily exergy varies from 0.021 kWh to water temperature and average solar intensity 32.26 ^oC and 97.9 W/m^2 to 0.525 kWh for water temperature and average solar intensity 45.42 ^oC and 420.855 W/m^2 and exergy efficiency varies from 0.928% to 5.363%.

1. Introduction

Water is a natural resource that is very important for life on earth especially for humans, where water is one of the main needs. Humans need water not only for drinking but also for various other needs, such as washing, cooking, bathing, and so on. There are water sources that are obtained from springs, rivers, lakes and the sea. Water that is on land and at sea will evaporate by the sun's heat.

Humans are often faced with difficult situations, where freshwater sources are very limited and on the other hand there is an increase in needs. For people who live in coastal areas or on small islands, fresh water is a very important source of water. When the dry season begins to come, people living in coastal areas or small islands begin to lack water [1]. This condition can be prevented if humans can find other ways to produce clean water. According to study conducted by WHO, that in developed countries, everyone needs water between 60 to 120 liters / day. Daily demand for fresh water has increased from 75 to 100 L per day in the 20th century [2].

Desalinization generally means removing salt from sea water or salt water. To produce clean water from the desalination process, many researchers have done it. The production of water produced from the previous desalination process is still very low. The exergy used is also expensive because it uses a lot of conventional exergy such as using oil to carry out the process of producing clean water.

In remote areas where conventional exergy is not available or expensive. Conventional thermal desalination processes cause gas emissions to be harmful and toxic to the environment. One of the renewable exergy sources is solar exergy. Sub shine has the advantage of zero fuel costs but requires more space for its collection [3,4].

The most widely used exergy is solar exergy up to 57% [5]. It is estimated that in the future, distillation supported by solar exergy (called solar still), will be more popular. Even countries with large oil producers such as Saudi Arabia are increasing their use of solar exergy to power their distillation systems to develop a sustainable distillation system [1]. To find out whether the exergy used in the evaporation process has been used optimally in terms of quality, the second law of thermodynamics is used or known as exergy analysis. Kotas [6] defines exergy as part of exergy that can be converted into other forms of exergy. From this definition it can be interpreted that there is exergy that can be changed and some that cannot be changed into other forms. Exergy analysis and exergy efficiency in solar still devices have been investigated by many people, including A.K. Sethi and V.K. Dwivedi [7] in his study showed that the exergy efficiency that occurred varied between 0.26 to 1.34%. N. Rahbar, et al. [8] reported that the maximum exergy efficiency in the study conducted in Iran was 25%. Dwivedi and Tiwari [9] reported that double slope solar still provide higher distillation in the summer with low annual distillation, higher exergy efficiency compared to single slope solar still [10].

2. Method and Equipment

The measuring instrument used in this study is a thermocouple. Thermocouples are used to measure temperature at system points, where the tool works automatically and records the results of hourly measurements in the form of MS. Excel files. In this study, 6 thermocouples were used. To measure air temperature, wind speed, solar intensity and humidity, HOBO Micro Station Data Logger is used. The design parameters used in the calculation for the Double Slope Passive Solar Still are as follows:

Table 1. Design Parameters

Parameters	Value	Parameters	Value
α_g	0,05	A_b	1,932 m x 1 m
α_b	0,8	K_g	0,78 (W/m^{o}C)
α_w	0,6	L_g	0,003 m
ϵ_w	0,95	K_i	0,039 (W/m^{o}C)
ϵ_g	0,95	L_i	0,02 m
σ	5,67 x 10^{-8} (W/m^{2}K^4)	θ	15^o
A_{gE}	1 m x 1 m	x	0,2595
A_{gW}	1 m x 1 m	M_w	38,640 Kg

Figure 1. Double Slope Solar Still

This study was carried out at the Sustainable Exergy and Biomaterial Centre of Excellent, Faculty of Engineering, University of Sumatera Utara. The study was conducted from 08.00 to 18.00 local time. Seawater that has been filled in the water tank, is flowed to the evaporator by opening the tap water until the water level in the evaporator reaches 2 cm. This height can be seen from the control glass in the evaporator. Data obtained from study is calculated using MS. Excel 2010.

Double slope passive solar still assembled consists of an evaporator, a glass cover, a sea water tank, a pipeline from the tank to the evaporator and a pipe for condensation results. Seawater that experiences condensation in the evaporator will evaporate and condensate water will stick to the glass. The Inclination of glass cover used in this study is 15^o so that the water vapor attached to the glass will go down to the reservoir on the glass until it finally exits through a hose of water to the water reservoir.

Heat transfer in solar still, mainly classified into internal and external heat transfer.

2.1. Internal heat transfer

Internal heat transfer occurs inside the solar still from the surface of the water (T_w) to the inner surface of the glass cover (T_{gi}), which mainly consists of evaporation, convection and radiation. Convective and evaporative heat transfer takes place simultaneously and is independent of radiation heat transfer.

2.1.1. Radiation heat transfer

Radiation heat transfer coefficient between water to glass h_{rwg} (W/m^2 ^{o}C) is given as follows [9]:

$$h_{rwg} = \varepsilon_{eff}\,\sigma\left[(T_w+273)^2+(T_{gi}+273)^2\right](T_w+T_{gi}+546) \quad (1)$$

Where the effective transmit power between water to the cover glass ε_{eff} is given as follows:

$$\frac{1}{\varepsilon_{eff}} = \frac{1}{\varepsilon_w}+\frac{1}{\varepsilon_g}-1 \quad (2)$$

and σ is the number of the Stefan – Boltzman coefficient is: 5,67 x 10^{-8} W/m^{2}K^4, ε_w is emissivity of the fluid and ε_g is emissivity of condensing cover.

2.1.2. Convection heat transfer

Natural convection occurs in moist air in the basin due to differences in temperature between the surfaces of the water to the inner surface of the glass cover. The convective heat transfer coefficient h_{cwg} (W/m^2 ^{o}C) is given as follows [9]:

$$h_{cwg} = 0.884\left[\left(T_w - T_{gi}\right) + \frac{\left(P_w - P_{gi}\right)\left(T_w + 273\right)}{2.689\,x10^5 - P_w}\right]^{1/3} \tag{3}$$

Where,

$$P_w = \exp\left[25.317 - \left(\frac{5144}{273 + T_w}\right)\right] \tag{4}$$

$$P_{gi} = \exp\left[25.317 - \left(\frac{5144}{273 + T_{gi}}\right)\right] \tag{5}$$

2.1.3. Evaporation heat transfer

The performance of solar still depends on the evaporative and convective heat transfer coefficients. Various scientists developed a mathematical relationship to evaluate evaporative and convective heat transfer coefficients. Evaporation takes place inside the solar still by adding heat to the water through solar radiation. The evaporative heat transfer coefficient h_{ewg} (W/m^2 ^{o}C) and total heat transfer coefficient from the water surface to east side glass cover h_{1w} (W/m^2 ^{o}C) is given as follows [9]:

$$h_{ewg} = 0.016273\,h_{cwg}\left(\frac{P_w - P_{gi}}{T_w - T_{gi}}\right) \tag{6}$$

2.2. External heat transfer

External heat transfer in solar still is mainly governed by convection and radiation processes, which are independent of each other. Heat is lost from the outer surface of the glass to the atmosphere through convection and radiation. Glass (T_{go}) and atmospheric (T_a) temperatures are directly related to the performance of solar still. The radiation heat transfer coefficient between glass to the atmosphere h_{rga} (W/m^2 ^{o}C) is given as follows [11, 12]:

$$h_{rga} = \frac{\varepsilon_g\,\sigma\left[\left(T_{gi} + 273\right)^4 - \left(T_{sky} + 273\right)^4\right]}{T_{go} - T_a} \tag{7}$$

where,

$$T_{sky} = T_a - 6 \tag{8}$$

2.3. Exergy Analysis

Exergy can be evaluated using the concept of entropy derived from the second law of thermodynamics. The exergy efficiency of the desalination system can be defined as the ratio of exergy output associated with the product (fresh water) to exergy input (radiation exergy), and expressed as follows [11, 8, and 15]:

$$\eta_{Ex} = \frac{E_{x\,output}}{E_{x\,input}} \tag{9}$$

$$E_{x\,input} = E_{x\,sun} = \left[\left(A_{gE} I_{SE}(t)\right) + \left(A_{gW} I_{SW}(t)\right)\right]\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \tag{10}$$

Where Ts is the sun's temperature 6000 K, whereas for exergy output can be written as follows [11, 13, 14, 15]:

$$E_{x\,output} = E_{x\,evap} = h_{ewg}\frac{A_b}{2}\left[\left(T_w - T_{gi}\right) - \left(T_a + 273\right)\ln\left(\frac{T_w + 273}{T_{gi} + 273}\right)\right] \tag{11}$$

3. Results and Discussion

Figure 2. shows the variation in the average solar intensity (*I*). Based on the study that has been done, the lowest solar intensity data is obtained on the second day with an average intensity of 97.9 W/m^2 and the highest on the fifth day with an average intensity of 420.855 W/m^2. Figure 3. shows the variation in ambient temperature. From the study, the lowest ambient temperature is on the second day with an average temperature of 27.708 ^{o}C and the highest on the fifth day with an average temperature of 32.995 ^{o}C. The highest average temperature between water and glass is found on the fifth day of testing. Water and glass cover temperatures at the fifth day of testing are at 1:00 pm., while the lowest temperature is at 8:00 a.m.

The exergy value is determined by solar intensity, evaporation coefficient, water temperature, ambient temperature and watershed. The higher the evaporation coefficient and water temperature and the wider the basin, the higher the exergy value. The exergy value also depends on the ambient temperature, the lower the ambient temperature, the higher the exergy value.

The lowest exergy evaporation on the second day at 8:00 am and the highest at 16:00 pm. The exergy produced on the second day was 0.0209 kWh. The exergy on the second day is the lowest exergy produced by the system.

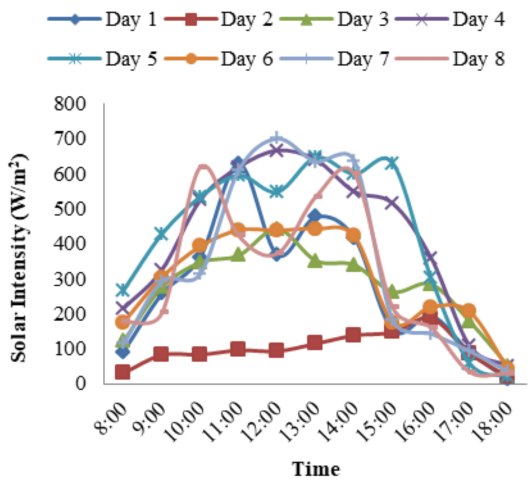

Figure 2. Hourly variation of solar intensity

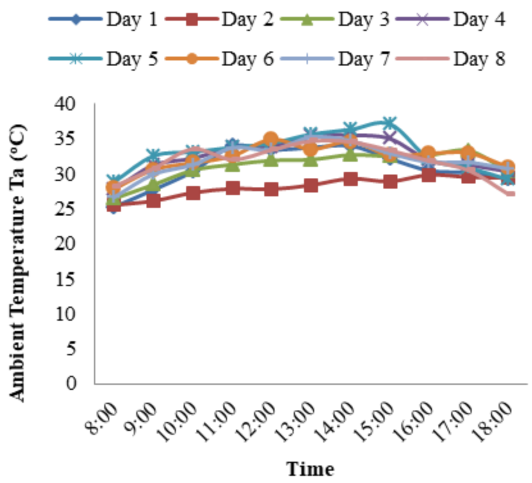

Figure 3. Hourly variation of ambient temperature

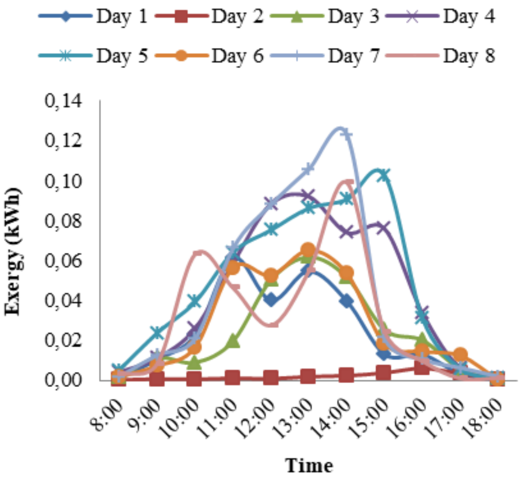

Figure 4. Exergy of evaporation

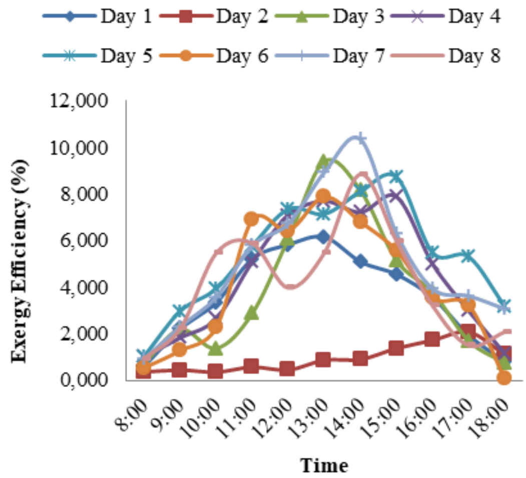

Figure 5. Exergy Efficiency

On the second day, the state of the desalination system in the basin is almost the same as the situation in the ambient or close to the dead state when the exergy value is close to zero. This situation is because on the second day the solar intensity is at the lowest position compared to the study of other days, so the water temperature, temperature in the glass, and ambient temperature are low. The lowest exergy for evaporation on the fifth day at 18:00 pm and the highest at 3:00 pm. Variations in the value of exergy evaporation can be observed from Figure 4. The exergy generated by the system on the fifth day is the largest evaporator exergy which is equal to 0.5248 kWh. After observing Figure 5. the lowest exergy efficiency data was obtained on the second day at 10:00 am and the highest at 17:00 pm. On the second day, exergy efficiency is the lowest efficiency compared to other days, which is equal to 0.928% or the exergy that can be converted into work is 0,0002 kWh. The lowest efficiency of exergy on the fifth day is 08.00 am and the highest is at 3:00 pm. On the fifth day, exergy efficiency is the highest efficiency compared to other days, which is equal to 5.363%. The size of the exergy efficiency shows that the exergy that can be changed into work 0.03 kWh. Exergy efficiency is influenced by the area of glass, the solar intensity, the coefficient of evaporation, water temperature, ambient temperature and area of the basin. The wider the surface of the glass, the smaller the exergy efficiency, the higher the solar intensity, the higher the exergy efficiency, the greater the area of the basin, the greater the efficiency of the evaporation coefficient, the greater the exergy efficiency, the higher the water efficiency exergy produced, and the higher the ambient temperature the lower the exergy efficiency produced.

4. Conclusions

Based on the results of study and calculations as described, related to the magnitude of exergy and efficiency of exergy of double slope passive solar still, it can be concluded that the exergy produced in the double slope passive solar still is different every day. The daily exergy varies from 0.021 kWh to 0.525 kWh and exergy efficiency varies from 0.928% to 5.363%.This difference is caused by the solar intensity and water temperature. The higher the solar intensity and the water temperature, the higher the exergy of evaporation in the system, but the higher the temperature of the environment, the exergy of evaporation in the system will be lower.

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