Hybrid Photovoltaic-Thermal Solar System for Brackish Water Reverse Osmosis

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Abstract. In this paper, a hybrid combination of solar thermal collector and photovoltaic (PV) solar system was applied to reverse osmosis (RO) desalination plant to increase the energy efficiency and its sustainability. An experimental study was performed on 75 GPD small scale RO plant using processed brackish/saline groundwater in Kenjeran area. It shows that increasing in temperature of feed raw water results a decrease in pump pressure and the consumption of electrical power. The smallest result of pump pressure which is 40 psi and the smallest electrical power consumption which is 1.68 W were obtained when the temperature is at 40 °C. However, the quality of the product, the amount of water, and the ability of the membrane to recover salt are decreasing when the temperature of the feed water is raised. The best result was obtained at 31 °C with a TDS water product quality of 105 ppm, the amount of produced water was 36.5 L, and a salt rejection ability was 95.9%. The electrical power consumption of whole system for one day was 914.63 Watt-hours and requires six units of 155 Watt-peak capacity of PV panels.

1. Introduction
Conventionally, reverse osmosis systems process untreated raw saline water at its raw temperature. However, a pre-treatment is very important in the RO process, which is useful to prevent and reduce salt accumulation and the growth of marine life on the membrane [1]. The temperature increase in raw water has a positive impact on reverse osmosis performance. The flow rate through the semipermeable membrane increases with increasing raw water temperature. Increasing the raw water temperature causes the viscosity of the raw water to decrease and the diffusion coefficient through the membrane is higher [2]. The increase in temperature of desalinated raw water also has a positive effect on the resistance of the reverse osmosis membrane. When the raw water temperature is increased, the reverse osmosis membrane becomes lower in resistance. This will affect the reverse osmosis productivity. This reduction in resistance will reduce the energy consumption of the desalination system [2]. Based on experimental studies, Akhatov et al. [3] recommend use of solar thermal converters for a significant reduction in power consumption and for enhancing plant productivity. Goujdi et al. [4] also reported that preheating of the RO feed water had different effects on the production of fresh water at various concentrations.

According to the Indonesia Water Investment Roadmap 2011-2014, it is stated that only 47.71% of the total population in Indonesia has access to clean water sources. Especially in critical water resources areas, such as in a remote coastal area and saline groundwater area, where difficult to have supply of clean water. Those such regions have sometimes also lack of electric energy supply, therefore a solar energy is the most candidate as the renewable energy sources in that areas. In this work, the authors...
made an experimental studies of hybrid solar collector and PV solar system to provide an effective brackish water RO (BWRO) desalination system by saving energy of the system. Studies were made on a 75 GPD RO membrane for saline/brackish water using flat plate serpentine pipe solar collector and a simulated PV power using RETScreen® Expert simulation software [5].

2. Materials and methods

![Schematic drawing of experimental apparatus](image)

Solar collector as a water preheater for RO desalination system has dimension of 1500 mm × 1000 mm × 150 mm and consists of \( \frac{1}{2} \) inch copper tube in serpentine row. The collector was inclined 30° to receive solar irradiation intensity of 899.3 W/m². The reverse osmosis system applies concentrate recirculation method with a two-stage configuration with capacity of 75 GPD brackish water RO membrane. The RO circuit uses two semipermeable membranes with a spiral wound membrane type. The purpose of using this method is to increase the amount of clean water product by flowing the brine water produced by the first membrane to the inlet of the second membrane. Meanwhile, the brine water produced by the second membrane is recirculated to the inlet of the reverse osmosis pump [7]. The freshwater results of reverse osmosis then will be filtered using a ceramic membrane to kill the bacteria in the water [8]. The RO system used processed saline water and was varied at three temperature condition: 31 °C, 35 °C, and 40 °C. Water has TDS value of 2200 ppm with a salinity level of 0.07% to meet the standard requirement of brackish water. Bulk of data of solar collector and fluid temperatures, pressures, salt rejection, and freshwater production debit were also derived. The energy balance in solar collector and the average fluid temperature were calculated using equation (1) and (2).

\[
Q_u = A_c \left[ S - U_L (T_{pm} - T_o) \right]
\]

\[
T_{fn} = T_{fi} + \frac{A_c}{F_{RL}} \left( 1 - F^i \right)
\]

3. Results and discussion

3.1. Analysis of solar collector

Analysis of the solar collector based on the data derived from the experiments. The results are related with analysis of useful energy and the loss of energy of the system. The output temperature of the water was also obtained. The authors used 40 °C feed water temperature experimental data to perform the analysis because it has a constant temperature rise in solar collector for one hour running of system.
Based on the results of the analysis there is a difference in the results of the average fluid temperature. In the solar collector test, the average fluid temperature was 37.3 °C, while the formula analysis obtained an average value of 47.6 °C. There are several factors that allow other heat loss to occur in the solar collector so that the results between the analysis and testing are different. In addition, there are small gaps on some sides of the solar collector which allows for heat loss.

![Figure 2](image1.png)

**Figure 2.** The effect of feed water temperature on TDS of product water (experiment 1).

![Figure 3](image2.png)

**Figure 3.** The effect of feed water temperature on TDS of product water (experiment 2).

### 3.2. **RO system performance analysis**

#### 3.2.1. **The effect of temperature variations on the TDS of water products.**

RO analysis was performed based on the results from two iteration running of experiments. Retrieval of product water TDS data in the experiments was carried out in every 5 minutes. There is an increase in the TDS content of product water when the raw feed water temperature increases. The highest amount of product water TDS content of 366 ppm was produced in the experiment with temperature variations of 40 °C. Meanwhile, the lowest TDS level of 144 ppm was obtained in the experiment with a temperature variation of 31 °C.

Figure 2 and 3 show an increase in the TDS content of product water when the feed water temperature increases. From experiment 2, the highest TDS content of product water was produced in the experiment with a temperature variation of 40 °C with a value of 290 ppm. Meanwhile, the lowest TDS level was obtained in the experiment with a temperature variation of 31 °C with a value of 105 ppm. However, in the experiment between the temperature variations of 35 °C and 40 °C, the TDS values were almost the same. The increase in TDS levels was due to an increase in TDS in raw feed water after heating process in the solar collector.

#### 3.2.2. **The effect of temperature variations on pump pressure.**

Data were collected every 5 minutes at each temperature variation. In figure 4, the temperature difference affects the required pump pressure to penetrate the reverse osmosis membrane. The lowest pressure at 40 psi was derived from experiment with a feed water temperature of 40 °C. In the experiment 1, the measurement results are almost the same due to decrease in the need for pump pressure to penetrate the membrane. From experiment 2, the highest pressure at 70 psi occurs in the experiment by feed water temperature of 31 °C and the lowest pressure at 60 psi occurs in an experiment by temperature variation of 40 °C. The decrease in pressure occurs because of lowering viscosity of the feed water due to increase in temperature. This makes it easier for the feed water to penetrate the reverse osmosis membrane at a lower pressure.

#### 3.2.3. **The effect of temperature variations on pump power.**

Data were also collected every 5 minutes at each temperature variation. In figure 5, it can be seen the RO pump power consumption from each temperature variation. The highest pump power consumption of 3.6 W and 3.84 W were obtained at the temperature variation of 31 °C from experiment 1 and 2, respectively. The lowest pump power of 1.68
W was obtained at feed water temperature variation of 40 °C from experiment 1. The experiments show a decrease in the power consumption of RO pump by the increase in feed water temperature, which is induced by decreasing of pump pressure. The decrease in pump pressure results in lighter pump work so that the pump power consumption also decreases.

3.2.4. The effect of temperature variations on salt rejection. In figure 6 and 7, it can be seen the difference in the ability of salt rejection of the membrane due to the increase in feed water temperature. The increase in feed raw water temperature results in decreased rejection ability of the reverse osmosis membrane. Meanwhile, from experiment 1 in figure 6, the lowest ability of the membrane to reflect salt water was at a temperature variation of 40 °C with a rejection of 85.70%. In figure 7, there was a difference in the results where the salt rejection at the temperature variation of 40 °C was more than at 35 °C. However, the lowest ability of the membrane to reflect salt water was at a temperature variation of 40 °C with a rejection of 88.62%. From both experiments, the highest salt rejection was 95.9 %, which was made at 31 °C temperature variation.

3.2.5. The effect of temperature variations on RO capacity. Based on the experimental data, an increase in temperature of feed water will reduce the amount of water production. The highest RO capacity of water production occurred in the experiment was 36.5 L with a temperature variation of 31 °C. While the production of water at temperature variation of 40 °C was 29.07 L. Lower temperature of feed water produces more clean water because of TDS content is lower.
3.3. Analysis of PV cell using RETScreen® Expert software

Power requirement of the BWRO plant includes power of RO pump, a circulation pump, and a supply pump to the ceramic membrane. Calculations were made by simulation of RETScreen® Expert software to determine the type and number of PV or solar cells based on total required power. Table 1 shows the result of calculation of power requirements based on experimental data.

In the selection of PV cells, data of power requirement for 1 day will be used. The overall power requirements that must be met are 914.63 Watt-hours, which is based on experimental data of the highest total power loads. In the RETScreen® Expert software, the authors chose SW 155W model, which is a monocrystalline silicon or mono-Si PV cell. Figure 8 shows the specification of PV panels or cells. To meet the power requirements of the entire reverse osmosis system, it requires 6 units of PV cells with total power generated is 930 Watt-peak. The tilt angle of the photovoltaic cell is 7°. The photovoltaic cell has an efficiency of 11.89%. The area for the photovoltaic cell to meet the overall power requirements for 1 day is 7.8 m².

Table 1. Calculation of power requirements for each experiment

| Temp. variable | Total of power req. (W) | Total of power req. (1 day) (Wh) |
|----------------|-------------------------|---------------------------------|
|                | Non-Circ. pump | Circulating pump |                                |
| 31°C (1)       | 61.52          | 61.48             | 895.35                          |
| 31°C (2)       | 61.48          | 61.48             | 894.82                          |
| 35°C (1)       | 60.16          | 82.66             | 900.04                          |
| 35°C (2)       | 57.31          | 79.86             | 899.26                          |
| 40°C (1)       | 55.72          | 100.72            | 914.63                          |
| 40°C (2)       | 46.02          | 113.52            |                                |

Figure 8. Specifications of a Photovoltaic Cell in RETScreen® Expert
4. Conclusions
A desalination RO system had been experimentally studied using hybrid solar collector and PV solar system. The flat plate solar collector performed as a preheater for increasing the feed raw water temperature before entrance the RO membrane. The increasing temperature of feed water affects several performance of RO systems, i.e.: the decrease in the viscosity of water; the reduce of pump pressure and the power consumption of the pump; the ability of salt rejection, which is inversely proportional to the increase in temperature; the increase in TDS content of product water, and the reduce of RO water production capacity.

To meet the power requirements of the system, a mono-Si - SW 155W model of PV cell was applied in the system, based on the RETScreen® Expert simulation. This photovoltaic model has a capacity of 155 Watt-peak per unit, and it takes 6 units with an area of 7.8 m².

5. References
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Acknowledgments
Authors wishing to acknowledge the funding support of Marine Engineering Department – ITS Research Grant 2020 and special work by students on the final project.