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DEVELOPMENT OF SEAWATER DISTILLER THAT USES ELECTRICAL ENERGY FOR SUSTAINABLE CLEAN WATER PRODUCTION

Riyanto Haribowo[1*] , Emma Yuliani[1], Andi Gora Prasetyo[1]

[1]*Department of Water Resources Engineering, Faculty of Engineering, Universitas Brawijaya, Malang 65145, Indonesia*

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ABSTRACT

This study aims to develop a seawater distiller that can be used to purify water by using electrical energy to power the heating elements used in the condensation phase of distillation. Varying numbers of water heating elements and water levels in the evaporator unit were analyzed to determine the ideal device configuration. The distillation device consisted of a container unit, a water level control unit, and an evaporation chamber unit. Distillation was conducted in two experiments, one with a water level of 8 cm and the other, 4 cm, in the evaporation unit. Each experiment comprised eight tests, in which 1–6 water heating elements were used in various configurations; identical configurations were used in both experiments. The seawater used was obtained from the Indian Ocean off Balekambang Beach, Malang Regency, Indonesia. The largest purified water volume obtained among the 16 experimental conditions was 3.94 L at a cost of IDR 790 per liter. The effectiveness percentage toward water quality improvement in terms of pH, electrical conductivity, TDS, and maximum salinity was 9.88%, 99.98%, 99.96%, and 100%, respectively. In the future, a full-scale experiment will be conducted on site. The use of this device will therefore benefit people in areas with water scarcity.

Keywords: Distillation; Fresh water; Seawater; Water heating element

1. INTRODUCTION

For providing freshwater or drinking water in vulnerable areas, various products such as mineral water or purified water are currently available (Marianna et al., 2016; Mathias et al., 2017). Reverse osmosis technology has also been widely introduced in such areas; reverse osmosis can be used to produce drinking water from impure water or seawater (Veera et al., 2016). However, this technology remains too expensive for most people, especially in developing countries (Sharma et al., 2009; Sitanggang, 2016). Therefore, an inexpensive and simple alternative technology is required.

The benefits of using water refining technologies, such as distillation, to obtain freshwater from seawater have long been recognized. The concept of distillation is simple and is similar to the hydrological cycle; specifically, seawater is evaporated by heating, and then, the resulting water vapor is condensed and collected in a container to obtain fresh water (Effendi, 2003; Zheng et al., 2014). The heat required can be produced using diverse energy sources, including oil, gas, electricity, and solar (Holfman, 1991).

In Indonesia, many studies have investigated seawater distillation using solar energy.

*Corresponding author's email: riyanto_haribowo@ub.ac.id, Tel. +62-341-562454, Fax. +62-341-562454
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Puslitbang (2004) developed a glass roof solar distiller with length, width, and height of 150, 100, and 60 cm, respectively. Their device could produce an average of 6.44 L of water in 8 h, making it suitable for coastal areas and areas lacking in clean water. Muannis (2009) developed a distiller that used solar energy and that could produce a maximum of 375 mL of water in 8 h. They found that the productivity of water in the solar distillation test equipment was affected by the solar intensity; specifically, the higher the solar intensity, the higher was the productivity of water. Hidayat (2011) found that a solar distiller having a heating chamber with dimensions of 220cm×140cm could produce an average of up to 3.2 L of fresh water. This study was conducted over 6 days, with the lowest amount of water obtained being 1.91 L on the first day; the weather was cloudy on the first day, resulting in nonoptimal solar intensity and, in turn, reduced water production.

The main problems faced in studies on seawater distillation using solar thermal energy are the variability of climate and weather. Indonesia is located in an equatorial region, and the daily duration of sunlight is ~12 h (Limantara, 2010). However, in cloudy weather conditions, the freshwater output of the distiller is reduced.

Previous studies have shown that distillation using solar heating is subject to fluctuations based on the tool dimensions, equipment placement, environmental conditions, and solar intensity. This study aims to overcome the problem of varying solar intensity by adding a water heating element to the distiller to generate heat to boil the water, so as to yield more consistent data about the quantity of fresh water produced from distillers.

2. METHODOLOGY

This study uses scale models. The modeling of seawater distillation (Figure 1) and the implementation of the research was conducted at the Basic Hydraulics Laboratory, Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya.

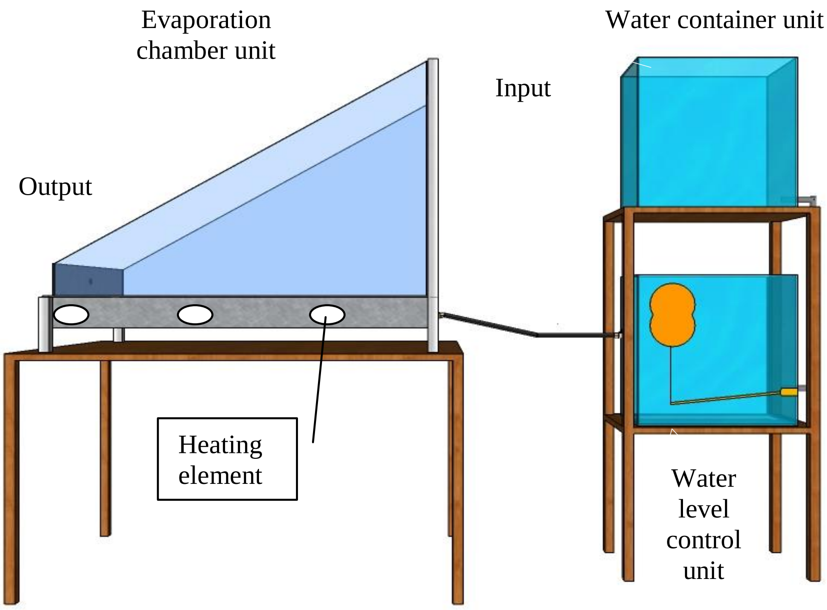

Figure 1 Design of seawater distiller

The seawater distiller models included a seawater container unit (0.50m×0.50m×0.30m), water level control unit (0.50m×0.50m×0.30m), and evaporation chamber unit (1.10m×0.90m×0.27m).

The research was conducted from October 16 through December 2, 2015. Sample testing was conducted at the Soil and Groundwater Laboratory, Water Resources Engineering Department. In this study, the water volume, turbidity, pH, electrical conductivity, total dissolved solids, and salinity were measured using a Horiba U-50 Multiparameter Water Quality Meter.

Water samples were taken from the Indian Ocean off Balekambang Beach in Malang, Indonesia, every day for 16 days using stainless steel buckets that were first washed with water at the sampling site. Water samples of various volumes were taken, with the largest one being 25 L, and the total volume of the water samples was 200 L. The water samples were tested before and after distillation. A total of 18 water quality datasets were obtained, with 2 and 16 datasets being obtained before and after distillation, respectively. In the experimental, the water level in the evaporation chamber and the number and position of water heating elements used were varied (Table 1), and the heating time was 360 min.

3. RESULTS AND DISCUSSION

3.1. Volume of Water Produced after Distillation

In Experiment 1, the seawater level was at 8 cm in the evaporation chamber for all eight tests. As shown in Figure 2, in test I, 410 mL of water was produced, which was the lowest volume among the eight tests. This was because only one heating element was used, and therefore, the water was heated very slowly.

Table 1 Variation of water level and number of water heating elements

Experiment I	Test number							
	I	II	III	IV	V	VI	VII	VIII
Water level (cm)	8	8	8	8	8	8	8	8
Number of water heating elements (unit)	1	2	2	2	4	4	4	6
Experiment II	**Test number**							
	I	II	III	IV	V	VI	VII	VIII
Water level (cm)	4	4	4	4	4	4	4	4
Number of water heating elements (unit)	1	2	2	2	4	4	4	6

In tests II–IV, much greater water volumes were produced: 860, 880, and 800 mL, respectively. This is because two heating elements were used, and therefore, the water heating rate was higher than in test I. The variation in the water volume produced was due to the heating element positions. The greatest water volume was produced in test III, in which the heating elements were positioned at the middle of the evaporator unit, thus affecting the heating process. The heating element position in test II was not as effective as that in test III but better than that in test IV. In test II, the heating element was positioned near the outlet of the evaporation chamber unit, where the distance between the water level and glass roof is lesser. In test IV, the heating element was positioned near the inlet of the evaporation chamber unit, where the distance between the water level and glass roof was the greatest.

In tests V–VII, the water volume produced increased relative to that in the previous tests to 2,240, 2,280, and 2,300 ml, respectively. In these tests, four heating elements were used, and therefore, the water heating rate was even higher than that in the previous tests. The greatest water volume was produced in test VII, because the heating elements were positioned near the outlet and centrally on the edge of the evaporator unit. In test VI, the heating elements were positioned near the inlet and centrally on the edge of the evaporator unit, where the distance between the water level and glass roof was greater. In test V, in which the least water volume was obtained among this group of three tests, the heating elements were positioned on both sides of the edge of the evaporator unit; therefore, the heat was spread out and was not concentrated at one location.

Test VIII yielded the greatest water volume among all tests, with 3,440 mL. This is because six heating elements were used, thereby achieving the maximum heating level among all tests. The heating elements dispersed heat over almost the entire bottom of the tank, ensuring that no sides were left unaffected.

However, different results were obtained in Experiment 2, in which the seawater level in the evaporation chamber was reduced to 4 cm, although the heating element positions were kept the same as in each corresponding test. The fresh water volume produced by distillation in tests I–VIII increased to 470, 980, 1,010, 950, 2,570, 2,620, 2,645, and 3,940 mL, respectively. This demonstrates that a lower fresh water volume in the evaporator chamber results in the production of a greater fresh water volume by distillation.

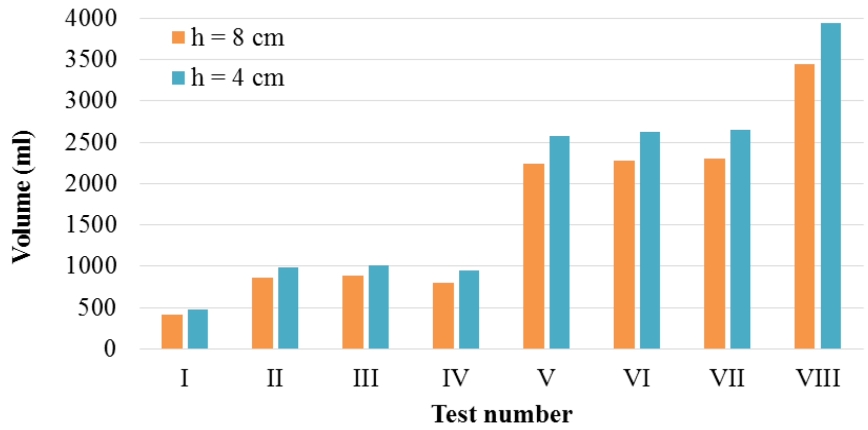

Figure 2 Water volume produced by distiller

3.2. Analysis of Turbidity after Distillation

The turbidity in the initial seawater sample before distillation was 0 NTU, and it did not change after distillation. The distillation process does not introduce turbidity.

3.3. Distillation Effectiveness in Terms of pH

Distillation effectiveness refers to the percent change in a parameter from the inlet to the outlet. In test I in Experiment I, the resulting pH of distilled water was 6.44; this was the lowest pH value among the eight tests, because the salt that typically accumulates during seawater evaporation had not yet built up.

In tests II–IV, the pH values were 6.61, 6.53, and 6.79, respectively. This was due to the accumulation of the salt remaining after evaporation. However, although tests II–IV were conducted sequentially, the pH values did not increase continuously. This is because of the different heating element positions. Test III showed the lowest pH value among these three tests, because the heating elements were positioned in the middle of the evaporator unit.

In tests V–VII, the pH values increased to 6.96, 6.90, and 6.98, respectively. This was also caused by the accumulation of the salt remaining after evaporation. In test VIII, the pH value was 7.14.

As seen in Figure 3, there were no significant differences in the pH values between the eight tests in Experiments I and II. The pH values in tests I–VIII in Experiment II were 6.51, 6.54, 6.57, 6.75, 6.86, 6.80, 6.98, and 7.02, respectively.

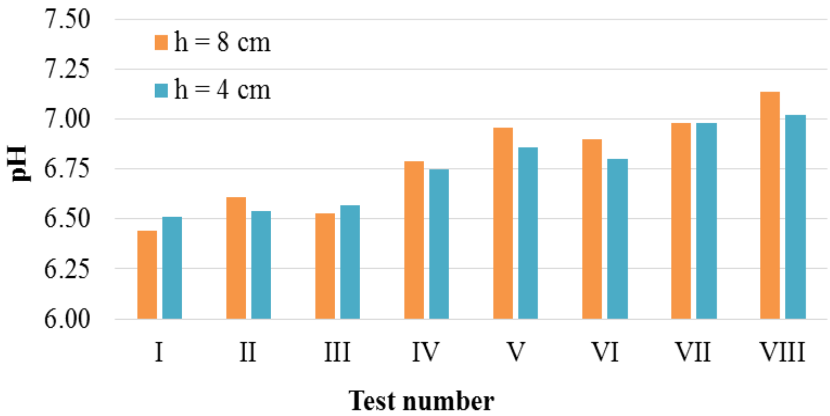

Figure 3 Results of pH values after distillation

The results showed that the pH values of the water samples ranged between 6.44 and 7.14, with the lowest value obtained in test I in Experiment I and the highest value, in test VIII in Experiment I. After excluding the results of test I, the pH value of the water samples was in the range 6.51–7.14; this satisfies the drinking water quality requirements set by the Ministry of Health in Indonesia (Ministry of Health, 2010). Based on the distillation effectiveness in terms of the pH value (Table 2), it is seen that the water level in the evaporator unit can affect the pH value.

Table 2 Distillation effectiveness in terms of pH value

Test number	Effectiveness (%)	
	h = 8 cm	h = 4 cm
I	21.84	21.00
II	19.78	20.63
III	20.75	20.27
IV	17.60	18.08
V	15.53	16.75
VI	16.26	17.48
VII	15.29	15.29
VIII	13.35	14.81

3.4. Distillation Effectiveness in Terms of Electrical Conductivity

The electrical conductivity of all distilled water samples in Experiments I and II was measured to be 0.0110–0.750 mS/cm (Figure 4). The electrical conductivity of the distilled water samples (aquades) is under 1 S/cm, whereas that of naturally occurring freshwater is 20–1,500 mS/cm. Across both experiments, the electrical conductivity value was the highest in test III and second highest in test VI.

Based on the distillation effectiveness in terms of the electrical conductivity (Table 3), it is seen that the water level in the evaporator unit only slightly affected the electrical conductivity value. Between Experiments I and II, the effectiveness values differed by only 0.01%–0.03% across all tests. The results of both experiments showed that the seawater distiller very effectively reduced the electrical conductivity by 99.94% on average, and this effectiveness was not influenced by the number of heating elements used.

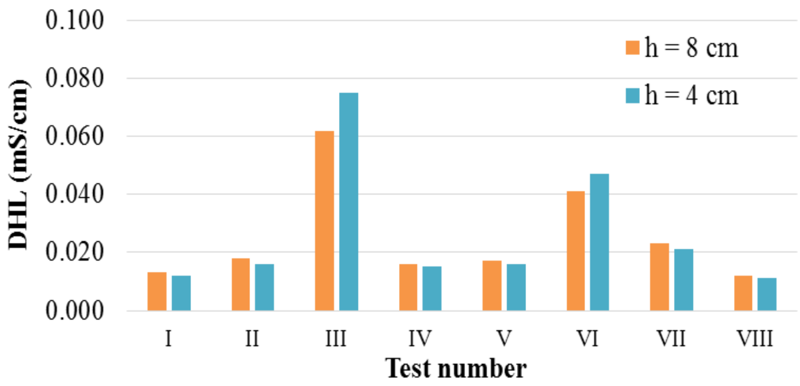

Figure 4 Results of electrical conductivity

Table 3 Distillation effectiveness in terms of electrical conductivity

Test number	Effectiveness (%)	
	h = 8 cm	h = 4 cm
I	99.97	99.97
II	99.96	99.96
III	99.86	99.83
IV	99.97	99.97
V	99.96	99.96
VI	99.91	99.89
VII	99.95	99.95
VIII	99.97	99.98

3.5. Distillation Effectiveness in Terms of Total Dissolved Solids (TDS)

The TDS test results showed that the distiller very effectively reduced the TDS values relative to those of the initial samples. The seawater samples had TDS values of 26,000–28,000 mg/L, whereas those of the distilled water samples were 10–47 mg/L. The decrease in the TDS value was influenced by the electrical conductivity and turbidity values. Furthermore, the low TDS were directly proportional to the electrical conductivity and turbidity values.

The varying TDS values across tests in this experiment resulted from several types of specific minerals that were transported during evaporation. Though the results show some variance, the TDS values in all 16 tests are still below the maximum levels allowed under the drinking water quality standards in Indonesia (Ministry of Health, 2010).

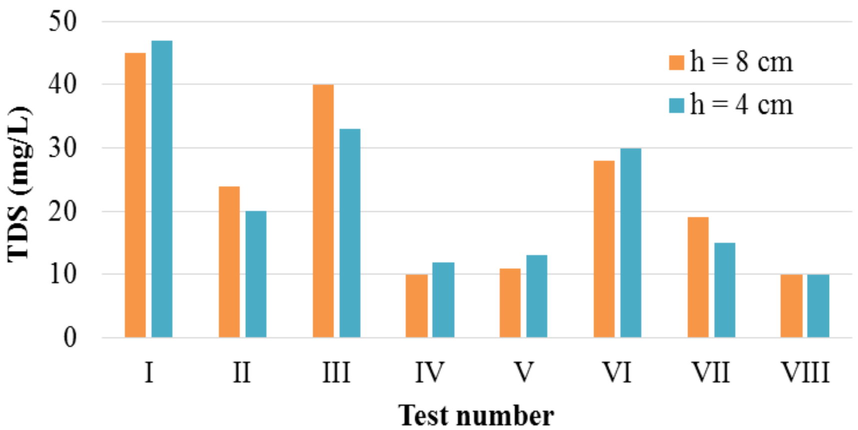

Figure 5 Results of TDS

Figure 5 shows the results of the TDS parameter tests, from which the effectiveness percentage is determined by calculating the differences between the values of TDS samples before (input) and after (output) distillation. Based on the calculation of distillation effectiveness in terms of TDS (Table 4), it is seen that the water level in the evaporator unit only slightly affects the TDS value between Experiments I and II. The effectiveness values differed by only 0.01%–0.02% across all tests. Overall, it is clear that the seawater distiller very effectively reduces the amount of TDS.

Table 4 Distillation effectiveness in terms of TDS

Test number	Effectiveness (%)	
	h = 8 cm	h = 4 cm
I	99.84	99.82
II	99.91	99.92
III	99.86	99.87
IV	99.96	99.95
V	99.96	99.95
VI	99.90	99.88
VII	99.93	99.94
VIII	99.96	99.96

3.6. Distillation Effectiveness in Terms of Salinity

Post-distillation salinity measurements showed a 100% decrease in salinity across all tests in both experiments. This means that all the salt in the seawater was removed, and the purified water did not contain any salt. During water evaporation, water changes from a liquid into a gas, and this automatically changes the density of water. During distillation, the solvent (water) evaporates, and the solute remains in the tank because the various impurities contained in it (such as metals, salts, and solids) have a density greater than the density of vapor. The lighter vapor rises and condenses to form a clean water equivalent of aquades with salinity of 0% (0 ppt).

The distiller's effectiveness in terms of salinity for both water levels was 100% in all tests. Therefore, it is clear that the water level in the evaporator unit does not affect the distiller's ability to reduce salinity, making this seawater distiller a feasible means for treating seawater.

3.7. Analysis of Electrical Cost

It is important to measure the distiller's operating cost to determine whether its benefits outweigh its costs. An electrical cost calculation is performed to determine the cost of obtaining 1 L of clean water from the seawater distiller.

A crucial factor in determining the operational plan for the electrical power system is forecasting or estimating the load that will be experienced by the relevant electrical power systems. To obtain 1 L of water, the equipment was operated for 6 h. The electricity cost per kWh is Indonesian Rupiah (IDR) 445 (Ministry of Energy and Mineral Resources, 2014). The electrical cost is incurred for the use of the heating element, and electrical costs are calculated by first determining the electrical power expended to operate one heating element that consumes 190 W of power (Table 5).

The production cost per liter is obtained from the total operational cost of the distiller divided by the water volume produced. Table 5 shows the water price per liter calculation from the production results of the distiller for each water level and number of heating elements.

Table 5 Calculation of electrical cost

Test number	Number of heating elements	Power (W)	Electrical load (kWh)	Electrical cost (IDR)	h = 8 cm		h = 4 cm	
					Volume of water produced (mL)	Water price per liter	Volume of water produced (mL)	Water price per liter
I	1	190	1.14	519	410.0	1,265	470.0	1,104
II	2	380	2.28	1,037	860.0	1,206	980.0	1,059
III	2	380	2.28	1,037	880.0	1,179	1,010.0	1,027
IV	2	380	2.28	1,037	800.0	1,297	950.0	1,092
V	4	760	4.56	2,075	2,240.0	926	2,570.0	807
VI	4	760	4.56	2,075	2,280.0	910	2,620.0	792
VII	4	760	4.56	2,075	2,300.0	902	2,645.0	784
VIII	6	1,140	6.84	3,112	3,440.0	905	3,940.0	790

Experiment I showed the lowest electrical costs; test VII showed the lowest water price of IDR 902, and test I showed the highest one of IDR 1,265. In Experiment II, test VII showed the lowest water price of IDR 784, and test I showed the highest one of IDR 1,104.

3.8. Determination of Effectiveness of Seawater Distiller

Based on the water quality test results, all water samples, after excluding the results of test I, meet the requirements for drinking water quality in Indonesia (Ministry of Health, 2010), and therefore, the overall effectiveness can be determined by only reviewing the clean water volume produced and the cost per liter. Table 5 shows that the lowest water price per liter, IDR 784, was achieved in test VII, Experiment II. However, from the viewpoint of amount of production, test VIII, Experiment II, was the most optimum, with 3,940 mL produced at a cost per liter of IDR 790.

The results showed that the seawater distiller can produce fresh water at a maximum rate of 3.94 L in 6 h, which is lower than the value of 6.44 L in 8 h reported by Puslitbang (2004) but higher than the values of 0.375 L in 8 h reported by Muannis (2009) and 3.2 L in 6 h reported by Hidayat (2011). The differences in the fresh water volume produced from various distillers occurred because the conditions and variables used in the studies differed. The result of the evaporation process is easily influenced by many variables, include temperature of device and environment, area of heating chamber, depth of water in heating chamber, water intake in heating chamber, characteristics of seawater, and placement of distiller. If even only one variable is different, then the results can be different.

4. CONCLUSION

This analysis showed that the optimum design for producing clean water is the design used in test VIII, Experiment 2, with water at a height of 4 cm in the evaporation chamber and six heating elements. The maximum quantity of fresh water volume produced during 6 h of operation was 3,940 mL, at a cost of IDR 790 per liter. The effectiveness percentage of this particular seawater distiller toward water quality improvement as viewed in terms of the pH, electrical conductivity, TDS, and maximum salinity was 9.88%, 99.98%, 99.96%, and 100%, respectively.

The advantage of this model compared to a seawater distillation model that uses solar energy is its ability to consistently produce clean water. This distillation model is much more effective in producing clean water compared with previously reported distillers because it can operate for 24 h a day without depending on solar energy. In certain regions, such as small islands, fresh water can become very scarce in the dry season. Therefore, distillation is a solution that is worth considering for use in coastal areas, remote islands, or other areas where it is difficult to obtain clean water. In the future, energy obtained from a solar power plant will be used to reduce the operational costs.

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