Solar Evaporation System Using Spray Pipe Method

Srie Muljani[1*], *Ketut* Sumada[2], *Caecilia* Pujiastuti[3]

[1,2,3] Chemical Engineering Department., Engineering Faculty, UPN Veteran East Java

Abstract. Evaporation of water using a spray pipe is required to expand the contact between hot air and water surface so that the rate of evaporation of water becomes faster. Salt production in the case of solar evaporation may take weeks to obtain salt. This study aims to observe the correlation of flow rate and evaporation time on salinity by considering several potential factors. The experiment was carried out in two stages, the first stage on a small scale where spray evaporation was carried out in an evaporation pond with an area of 1x2 m^2, seawater rate 0.8 – 2.0 L/min, seawater volume 100 L. The second stage of spray evaporation is carried out on an evaporation pond of 3x15 m, a flow rate of 0.3-0.6 L/s, and a seawater volume of 220 L. Observation of the evaporation time for 30 h at an evaporation rate of 0.6 L/s obtained a salinity of 22.6 Be while at a rate of 2L/min it could reach a degree of salinity 23.8Be within 90 h.

Keywords: Evaporation Rate, Nozzle, Salt, Salinity, Spray Evaporation

1 Introduction

Salt production in the case of solar evaporation may take weeks to obtain salt. Generally, evaporation in pond plots is carried out until the degree of salinity reaches 22-24 Be where the seawater is ready for the crystallization process. Several studies have reported various evaporation methods for salt production from seawater [1;2;3]. El-Agouz et al [1] designed a system to increase the evaporation rate by spraying water at low temperatures but it is rarely found that tries to measure the evaporation rate due to the influence of complex environmental factors. The technology used in the manufacture of salt varies according to geographic area and locally available resources. The production capacity desired by salt farmers may also influence the choice of salt production method. Whatever the method, the final step in salt production always requires evaporation of water from the seawater to precipitate the salt crystals. Evaporation using solar heat is still considered in order to save energy [4;5]. Spray flash evaporation technology is a promising way for efficient low-temperature desalination that can utilize solar energy as heat source [6;9]. Solar-driven evaporation of water is a cost-effective and environmentally friendly method [4;10;13]. This study developed an solar evaporation process using a spray pipe to increase the salinity of seawater to at least 23 Be. Several factors were observed related to its effect on salinity, including: nozzle size and number, wind speed, seawater flow rate, humidity, evaporation pond area, and evaporation time. Amirkalae et.al [7] investigated the effects of injection pressure, nozzle outlet diameter, nozzle type, and relative humidity inside the chamber in both upward and downward injection directions. The direction of the spraying of seawater in the chamber is one of the effective parameters in elevating the discharged rate of vapor in solar desalination systems. The flow rate has a different effect on the evaporation rate depending on whether spray or jet flash evaporation is taking place [8]. The spray direction in this study was upwards by considering the distance between the nozzles. Salt production experiments using sprays can provide insight into the intricacies of the spray evaporation process as well as how to control potential variables. Experimental results can be relevant according to the scenario under study even if there are several other evaporation conditions that have not been tested. This research still relies on solar energy for the evaporation process. One of the main advantages of the solar evaporation process is that the rate of water removal is only slightly affected by the salinity of the water source [5;15]. This research was conducted from May to October in the city of Surabaya, East Java, considering the weather data from the Surabaya Central Statistics Agency. The windiest month of the year in Surabaya is August, with an hourly average wind speed of 14.0 Km/h. The period of calmer winds throughout the year lasts 7.4 months, from mid-October to late May. The windy time of year lasts 4.6 months, from late May to mid-October, with average wind speeds of more than 11.2 Km/h. Throughout the year in the Surabaya area, the temperature usually varies from 24°C to 34°C. Humidity ranges from 42-95%, average 68-74% (BPS, 2019).

* Corresponding author: sriemuljani.tk@upnvjatim.ac.id

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

https://doi.org/10.1051/matecconf/202237209003

2 Material and Method

The experiment was carried out in two stages, the first stage on a laboratory scale where spray evaporation was carried out in an evaporation pond with an area of 2 m^2, seawater rate 0.8; 1.1; 1,4; 1.7 and 2 L/min, seawater volume 100 L and observation time of evaporation and salinity for 30 h. This study was carried out in an open space but using a net cover on top. The second stage of spray evaporation is carried out in a 3x15 m tub covered with a geomembrane. In this tub there is a U-shaped pipe with a diameter of 5 cm supporting 8 distributor pipes with a diameter of 2.5 cm. Each distributor pipe has nozzles with a diameter of 5 mm, a flow rate of 0.3; 0.4; 0.5 and 0.6 L/s, seawater volume of 220 L and an observation of time evaporation and salinity for 30 h. Measurement of salinity was carried out in a holding tank until it reached 23-24 Be. In addition, measurements of wind speed, ambient temperature, spray height from the spray pipe, and humidity were also carried out. Wind speed was measured with an Anemometer Digital Thermometer, salinity was measured with Digital Salinometers EB-158P and humidity was measured with a Themo-Hygrometer TAOT-250-U.

3 Results and Discussions

Several factors that are an important part in determining salinity, in addition to flow rate and evaporation time in this experiment were also measured: humidity, wind speed and ambient temperature as listed in Table 1. During the experiment period in several days, the wind speed was about 6-12 Km/h, the average humidity is around 48%, and the weather conditions were sunny. The evaporation cycle was stopped before sunset at 5pm and restarts at 7am.

Table 1. Observation and measurement data of spray evaporation experiments

Evap time (h)	Days to	T (°C)	Humidity (%)	Wind avg (km/h)	Salinity (Be)	Remaining Volume (L)
Rate = 0.6L/s						
3	First day	29.3	54	9	6.5	101.5
6		31.6	49	9	8.1	81.8
9		32.3	47	11	10.3	64.0
12	The second day	31.5	42	8	12.5	52.8
15		31.6	40	10	15.3	43.0
18	The third day	32.8	46	10	17.8	37.0
21		32.6	50	12	19.2	34.4
24		32.9	45	12	21.6	30.5
27	The fourth day	32.1	46	11	22.0	30.0
30		32.9	51	11	22.6	29.0
Rate = 0.5L/s						
3	First day	31.6	56	8	5.3	124.5
6		32.2	45	10	6.5	101.5
9		32.7	38	10	9.8	67.3
12	The second day	29.3	48	8	11.7	56.4
15		31.8	50	12	14.3	46.2
18	The third day	32.6	42	12	16.43	40.2
21		31.1	39	11	17.87	37.0
24		31.0	51	11	20.00	33.0
27	The fourth day	32.5	40	10	20.73	31.8
30		32.5	46	11	21.07	31.3
Rate = 0.4L/s						
3	First day	29.4	38	6	5.1	129
6		33.4	49	8	6.9	95.6
9		34.2	58	11	9.3	71
12	The second day	29.7	42	11	10.9	60.5
15		34.3	53	10	12.3	53.6
18	The third day	32.2	57	8	13.07	50.5
21		33.4	46	10	16.53	40
24	The fourth day	28.5	42	9	17.4	38
27		30.1	51	11	17.67	37.4
30		32.5	45	12	19.03	34.7
Rate = 0.3L/s						
3	First day	28.8	48	9	4.9	134.7
6		30.1	37	11	6.3	104.8

9	The second day	32.8	44	11	8.8	75
12		33.4	47	12	10.1	65.5
15		31.4	49	11	12.3	53.7
18	The third day	31	50	10	12.7	52
21		34.6	52	12	14.2	46.5
24		33.8	49	12	16.1	41
27	The fourth day	32	48	10	18.2	36
30		33.5	48	10	19.2	34.4

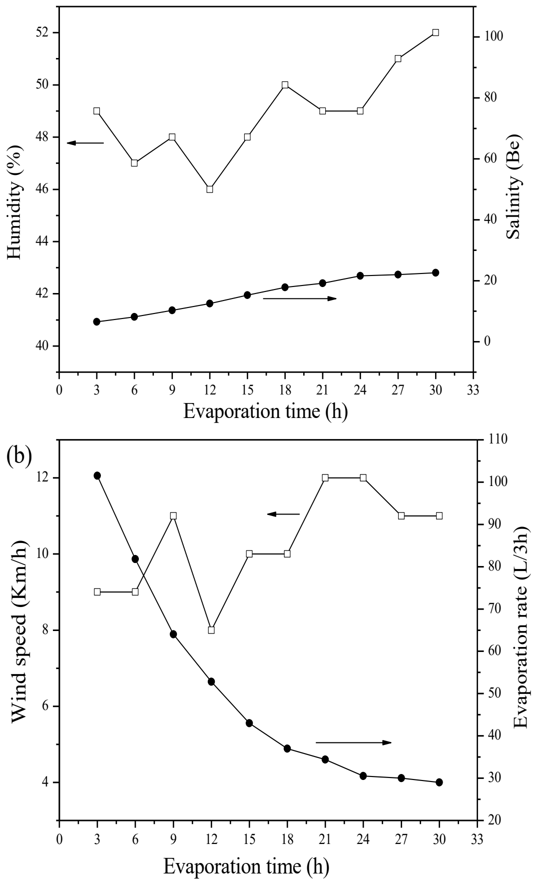

Fig. 1. Correlation of evaporation time to (a) humidity and salinity, and (b) wind speed and evaporation rate in the flow rate of 0.6 L/s.

Fig. 1 showed that the humidity and the wind speed have a less significant effect on salinity and evaporation rate. It can be explained that the weather conditions are relatively stable during the experimental period. At low seawater flow rates, external factors may be more influential because the contact between the sprayed water and the surrounding air is longer. In general, evaporation ponds for salt crystallization are located on the coast with strong winds and very supportive sunlight. Therefore, the use of spray evaporation can accelerate the evaporation rate and the evaporation time becomes faster. The increased in evaporation rate as the increase in salinity was more influenced by the flow rate of sea water. In addition to affecting salinity, it also affects the evaporation time to reach a degree of salinity of 24 Be (Fig2). Each spray evaporation cycle would show an increase in salinity. High salinity will overcome the effect of increasing temperature so that evaporation eventually decreases over time [15].

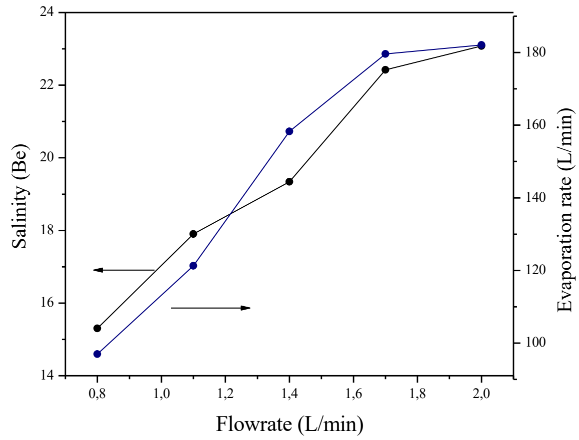

Fig. 2. Effect of flow rate to salinity and to evaporation rate at 90h evaporation time.

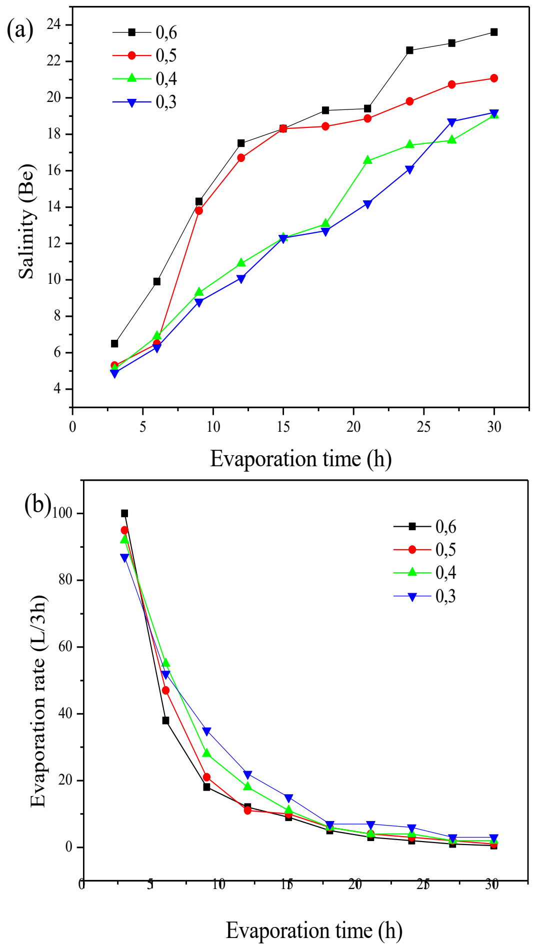

Fig. 3 Correlation of evaporation time to (a) salinity and (b) evaporation rate in the flow rate range of 0.3-0.6 L/s.

Fig. 3 showed the correlation of evaporation time at various flow rates (0.3-0.6 L/s) to salinity. The observed salinity for up to 30h showed an increase of up to 22.6 Be at a flow rate of 0.6 L/s (Fig.3a.). Meanwhile, for the lower flow rates (0.8-2 L/min) the salinity reaches 23.6 Be for a 90h evaporation cycle (Fig. 4a). The evaporation rate decreased with increasing evaporation time (Fig. 3b and Fig. 4b). This is related to the higher salt concentration (salinity). An increase in salinity indicates a higher dissolved salt ion, as a result the free energy of water molecules decreases so that the saturated vapor pressure on the surface of the salt water also decreases at a certain temperature which causes the evaporation rate to decrease. The amount of evaporated water is not only due to the large flow rate but also to the number of spray nozzles and the area of the evaporation pond. Other factors to consider are humidity, weather, and wind speed. The area of the evaporation pond to accommodate bulk water from the spray nozzle is quite wide in the 2nd experiment, therefore the total water evaporation higher than the total water evaporation in the 1st experiment.

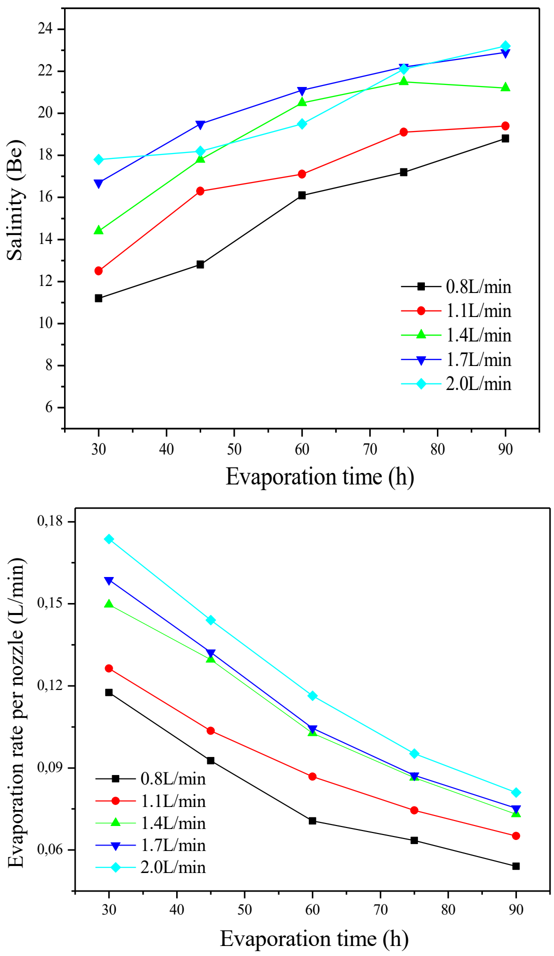

Fig. 4 Correlation of evaporation time to (a) salinity and (b) evaporation rate in the flow rate range of 0.8-2 L/min.

4 Conclusion

As previously described in the conventional salt production process, evaporation takes about 3-4 weeks to reach 23-24 B of salinity. The use of a spray pipe can reduce the evaporation time in 3-4 days to achieve the same salinity and in sunny weather. It is necessary to consider the energy used for pumps, but solar energy or wind energy in the coastal salt pond area can be an alternative energy source.

Acknowledgment

This research was supported by the Decentralization Research Project of the University of Pembangunan Nasional Veteran East Java, funded by the Ministry of Research and Technology

References

[1]. El-Agouz S.A., G.B. Abd El-Aziz, A.M.: Awad, Solar desalination system using spray evaporation, Energy 76 276-283 (2014)
[2]. Pambudi, N.A., Yusafiadi, J., Biddinika, M.K., Estriyanto, Y., Sarifudin, A.:An experimental investigation of salt production improvement by spraying and heating. Case Study on Thermal Engineering 30, 101739 (2022)
[3]. Akridge D. G.: Methods for calculating brine evaporation rates during salt production, J. of Arch. Sci. 35, 1453-1462 (2008)
[4]. Liu H, Huang Z, Liu K, Hu X, Zhou J. Interfacial solar-to-heat conversion for desalination. Adv Energy Mater.9(21): 1900310 (2019).
[5]. Tao P, Ni G, Song C, et al. Solar-driven interfacial evaporation. Nat Energy. 3(12) 1031-1041 (2018)
[6]. Chen, Q., Xu, G., Xia, P.: The performance of a solar-driven spray flash evaporation desalination system enhanced by microencapsulated phase change material, Case Studies in Thermal Engineering 27, 101267 (2021).)