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# The Innovation Breakthrough in Digital and Disruptive Era

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# Experimental Investigation of a Convection - Improved Solar Salt Evaporation System

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**Abstract.** The need for salt in Indonesia has recently intensified, as evidenced by the increasing salt demand in various sectors, including consumption, industry, and pharmaceuticals. However, this need has not been fulfilled optimally because of the dependence of salt production on natural weather. Thus, the development of enhanced evaporation technologies to improve evaporation rates has gained much attention. This study aimed to use proposed technology to enhance salt production by evaporating seawater. This method was used to accelerate the evaporation rate of brine by increasing its specific gravity before it entered a crystallization pond. An experimental investigation was carried out to determine the evaporation rate of the system. The results showed that this system can improve the evaporation rate by 11 times compared to conventional methods. The highest accumulated evaporation rate that could be achieved was 34.85 L/m2/day, while the lowest accumulated evaporation rate was found to be 23.6 L/m2/day. Using the proposed system, the time required to enhance the brine specific gravity from 1,030 kg/m3 to 1,208 kg/m3 can be reduced from 30 days to 15 days. This study revealed that using a convection-improved solar salt evaporation system can enhance brine evaporation and reducing the current time consumption and land requirements of saltworks.

## 1 Introduction

Demand for salt in Indonesia has risen due to its need in various sectors, including consumption, industry, and pharmaceuticals [1]. In 2021, domestic salt production could not meet national demand, and the remaining need was imported [2]. Most salt production in Indonesia has been carried out using traditional methods, such as using a solar energy source to evaporate seawater [3]. Evaporation ponds are commonly used to enhance the salinity of seawater by evaporating it via solar energy [4]. However, this method requires large surface areas and depends on the weather [5]. When using traditional methods, the typical way to enhance the evaporation rate is by expanding the pond area [6]. Weather is the main obstacle in traditional salt production, which is related to the time it takes for seawater to evaporate and convert to crystallized salt. Cloudy weather decreases the rate of evaporation. As a result, salt production capacity also decreases. Other factors also influence evaporation, such as relative air humidity, ambient temperature, wind speed, and salinity [7].

Indonesia has a tropical climate with two seasons: rainy and dry. In the dry season, the availability of sunshine is relatively high, making it suitable for sea salt production. Recently, several methods for improving the evaporation rate of seawater have been developed, including geomembrane, tunnel, and thread filter technologies [8] – [10]. However, these methods still require a large number of evaporation areas. Furthermore, this evaporation method relies on solar energy and is available only during the day [11].

To enhance the evaporation rate, a convection-improved solar salt evaporation system was developed [12]. The system had the additional benefit of requiring less land to produce the same quantity of salt. Research conducted by [13] revealed that using evaporation enhancement technology for brine desalination significantly reduced the land area required for the process. The authors named the technology Wind-Aided Intensified eVaporation (WAIV). The evaporation process occurs on the surface of the WAIV media, which is installed vertically. Solar and wind energy combined increase the evaporation rate.

A study by [14] involved an evaporation simulation study using cross-flow wind and experimental data. The authors used inexpensive materials and suggested that the proposed evaporation technology was an economical option for enhancing the evaporation rate. Significant water evaporation rates were achieved using the favorable conditions of a high water inlet temperature and a low inlet air relative humidity. Finally, [7] researched how to accelerate the evaporation rate of water for cooling and salt production purposes. They concluded that wind-driven technology can enhance evaporation and estimated that the evaporation rate could be up to 83,000 L/m2/year and salt as a byproduct could be produced at a rate of 5.8 tons/m2/year. Notably, the evaporation area can be reduced by up to 58%.

An experimental pilot study using WAIV studied not only brine evaporation but also mineral product production [15]. The study found that WAIV units can improve the evaporation rate by ten times compared to traditional evaporator ponds using local on-site weather data. Mineral byproducts, such as magnesium and calcium salt, were also generated. Besides increasing the evaporation rate, WAIV technology can also be implemented in desalination plants. For example, [16] examined the feasibility of using WAIV in a desalination plant for the sustainable treatment of brine water. Compared to disposal techniques, WAIV was 3.25 times cheaper than evaporation ponds.
Based on the literature review, convection-improved technology not only increases the evaporation rate of brine but also reduces the land area needed and time-consuming for evaporation and generates additional mineral products. To the best of the author's knowledge, no experimental study has investigated the application of convection-improved technology to evaporate brine in a salt production system in Bangkalan Regency on Madura Island. This study used the proposed technology, an improved solar salt evaporation system, to accelerate the increase in the specific gravity of the brine. This system works by enhancing the evaporation rate of brine by maximizing the wind and sun's natural energy. The results showed that salt production capacity can be increased. This research contributes to the literature on the use of convection-improved solar salt evaporation system technology, which can effectively evaporate brine in small- and large-scale salt production systems in Indonesia.

## 2 Material and Method

### 2.1 Experimental Setup

A schematic diagram of the convection–improved solar salt evaporation system model is presented in Fig. 1. This device consists of several components: a nonwoven geotextile membrane, a brine reservoir pond, piping, a steel frame, and a brine pump. This design is referred to in [13], with several novel modifications for field application. The frame structure is made of inexpensive steel with additional corrosion protection coatings. In addition, for field application, the frame can be made from natural bamboo or wood, which is widely available on Madura Island. This will improve its durability and reduce cost. This study uses steel to stabilize the holding loads during an experimental investigation. The frame has dimensions of 3 m, 2 m, and 3 in height, width and length, respectively, with an additional brine reservoir of 0.3 m high on the bottom side. A brine reservoir pond made of high-density polyethene membrane ensures no leakage of brine from the reservoir into the ground. A 300-watt submersible brine pump circulates brine from the reservoir pond to the top of the convection–improved solar salt evaporation system. The brine flows through a 0.5-inch polyvinyl chloride vertical pipe, and the horizontal pipe is perforated on top with holes of a diameter of 2 mm, which are uniformly distributed throughout the nonwoven geotextile membrane. The nonwoven geotextile membrane is used as a convection medium and arranged in a zig-zag manner with a distance of 20 cm between the membrane, thus it can maximize the convection phenomena accelerated by sun and wind energy.

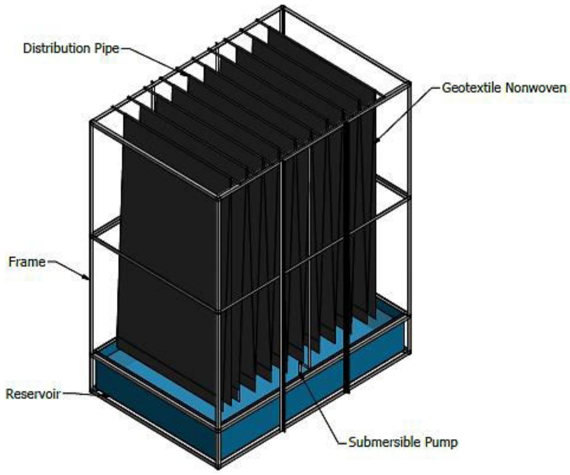


**Fig. 1**. Convection-improved solar salt evaporation system

Therefore, the evaporation rate of brine is increased.

### 2.2 Experimental Methodology

The reservoir pond stores brine with an initial volume of 1,800 litres and a specific gravity of 1,030 kg/m3. The experimental setup was in an open area of the mini salt plant of Universitas Trunojoyo Madura, Bangkalan, East Java, Indonesia, with exposure to direct, natural sunlight and wind. This mini salt plant is a pilot project for developing a salt production plant in the future. The brine circulation from the pump ran for 24 hours to allow the influence of the parameters of the natural weather conditions. The study was carried out to estimate the evaporation rate and salinity enhancement in the brine. The evaporation rate was calculated by measuring the decrease in the brine volume in the reservoir pond, while the relative density of liquids reflects the salinity of brine. Furthermore, a hydrometer was used to measure the relative density of liquids during the experiment. The influence of ambient temperature, relative humidity, and wind speed on cumulative evaporation was also studied.

**Table 1**. Range and accuracy measuring instrument

| No | Name | Range | Accuracy |
|---|---|---|---|
| 1 | Digital Anemometer | 0-30 m/s | ± 0.1 m/s |
| 2 | Humidity meter | 0-100 RH | 0.1% RH |

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|---|---|---|---|
| 3 | Digital Thermometer | -10 to 60°C | ± 1.0°C |
| 4 | Hydrometer | 0.950 - 1.000 g/ml | ± 0.0002 |
| 5 | Scientific ruler | 0-30 cm | 1 mm |

The ambient temperature, relative humidity, wind velocity, and volume reduction were measured using a digital thermometer, humidity meter, digital anemometer, and scientific ruler, respectively, as presented in Table 1. The temperature, relative humidity, and wind speed values are essential because they affect the convection and brine evaporation rate. Relative humidity values are represented as percentages, while the temperature values are in degrees Celsius. During the experiment, the wind speed was not constant—wind speed is affected by evapotranspiration, ambient relative humidity, and temperatures—and is valued in meters per second [17]–[20]. The annual solar daily radiation and wind speed in Bangkalan are presented in Fig. 2 [21]. These measurements were carried out periodically every hour during the 24-hour experiment.

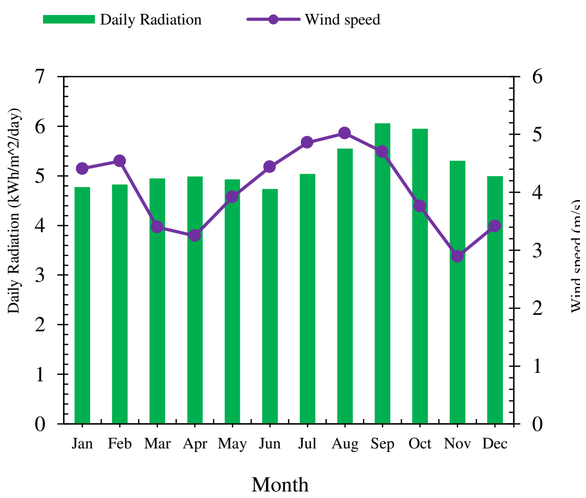


**Fig. 2** The annual solar radiation and wind speed profile in Bangkalan

## 3 Result and Discussion

### 3.1 WAIV Performance

Experimental data obtained from the convection-improved solar salt evaporation system was tested for its evaporation pattern over a period of operation. Figure 3 represents the proposed system's continuous process over the determined duration at a natural condition of ambient temperature, relative humidity, and wind speed. Natural conditions, such as slight rain and morning dew, also affected the system. This effect will increase the volume of brine water in the reservoir pond and decrease the cumulative evaporation.

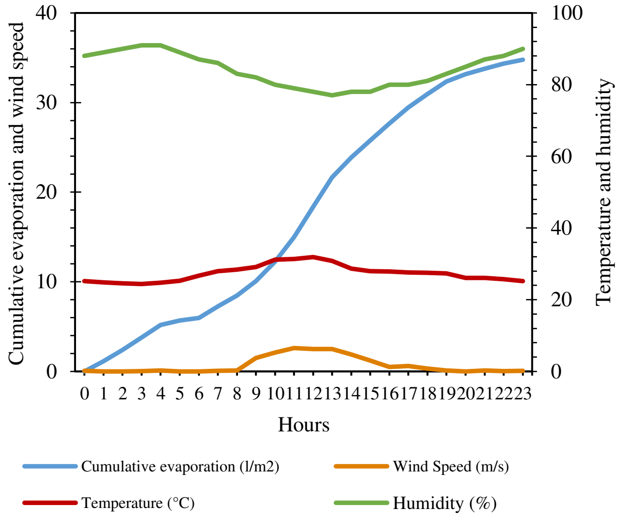


**Fig. 3.** Convection-improved solar salt evaporation system perfomance during the 24-hour operation

Figure 3 shows that by increasing the operation time by 24 hours, the cumulative evaporation increased from 0 to 34.85 L/m2. The cumulative evaporation experiences a significant increase during the day when the ambient temperature and wind speed are at a higher value. Subsequently, the cumulative evaporation increased slightly during the night. The cumulative evaporation value was 5.96 L/m2 at night and 19.80 L/m2 during the day in the presence of sunshine. Figure 3 revealed that the cumulative evaporation is higher when the weather conditions include a high wind speed and ambient temperature but lower in ambient relative humidity. These study results correspond to those in [14], confirming that the conditions for high water evaporation rates happen during midday when the ambient temperature and wind speed are high and ambient relative humidity is low. These results indicate that weather conditions play a vital role in the performance of the convection-improved solar salt evaporation system.

During the experiment, the system comparison was also investigated. The brine reservoir, without a nonwoven geotextile membrane as an evaporation media, was also observed. This experiment relies on natural weather to evaporate the brine water. During 24 hours of operation, the cumulative evaporation was 3.25 L/m2, equal to 3–3.5 mm/day. A similar report was also presented in [22], which investigated the evaporation rate in Indonesia, including Bangkalan. The study reported that the evaporation rate in Bangkalan was 3–4 mm/day. From the comparison data, it can be concluded that the convection-improved solar salt evaporation system can increase the evaporation rate of brine water 11 times. This result was 9.4 times higher than reported in [23]. The improvement in cumulative evaporation may be due to the quality of the nonwoven geotextile membrane and

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the structural design proposed system, which can improve the evaporation rate.

**Table 2.** Results of experimental investigation

| Date (MM/DD /YY) | Average wind speed (m/s) | Average ambient temperature (C) | Average relative humidity (%) | Cumulative evaporation (L/m²) |
|---|---|---|---|---|
| 11/11/22 | 1.4 | 27.3 | 84.0 | 32.4 |
| 11/12/22 | 1.3 | 27.4 | 83.9 | 23.6 |
| 11/13/22 | 1.3 | 27.4 | 83.9 | 25.8 |
| 11/14/22 | 1.2 | 27.8 | 83.3 | 30.60 |
| 11/15/22 | 1.4 | 27.7 | 84.0 | 33.19 |
| 11/16/22 | 1.32 | 27.70 | 83.00 | 34.85 |
| 11/17/22 | 1.4 | 27.4 | 84.2 | 34.76 |

**Table 3.** Salinity enhancement during experiments

| Date (MM/DD/YY) | Cumulative evaporation (L/m²) | Initial specific gravity (Kg/m³) | End specific gravity (Kg/m³) |
|---|---|---|---|
| 11/11/22 | 32.4 | 1,030.00 | 1,039.00 |
| 11/12/22 | 23.6 | 1,030.00 | 1,034.50 |
| 11/13/22 | 25.8 | 1,030.00 | 1,035.00 |
| 11/14/22 | 30.6 | 1,030.00 | 1,038.40 |
| 11/15/22 | 33.2 | 1,030.00 | 1,040.67 |
| 11/16/22 | 34.9 | 1,030.00 | 1,041.23 |
| 11/17/22 | 34.8 | 1,030.00 | 1,041.21 |

Table 2 lists seven days of experimental investigation involving the convection-improved solar salt evaporation system. The experiment was conducted from November 11–17, 2022, during the rainy season. On 12 and 13 November 2022, the cumulative evaporation was lower than during the remaining days, and this happened due to minor rain conditions at night. However, 16 and 17 November 2022 generated higher cumulative evaporation because there was no rain during the day, and sunshine was present.

Overall, the convection-improved solar salt evaporation system shows good performance and is suitable for application in the salt production system. In addition, cumulative evaporation was predicted to generate better performance in the summer when the ambient temperature and wind speed are higher.

### 3.2 Effect of evaporation on salinity enhancement

Experiments were carried out by evaporating brine with a specific gravity of 1,030 Kg/m3 using a volume of 1800 litres. Evaporation by means of a convection-improved solar salt evaporation system can increase the specific gravity of brine water from 1,030 Kg/m3 to 1,041.21 Kg/m3 per day, as presented in table 3. This value equals 4.2 obe to 5.42 obe (Baumé scale) or 4.22% to 5.40% NaCl wt. Commonly, the brine from the evaporator to the crystallization pond has a specific gravity of 1,208 Kg/m3 or equal to 25 obe. The brine is easier to convert to salt crystals at this stage. The convection-improved solar salt evaporation system requires 15 to 17 days to increase the brine water from 1,030 Kg/m3 to 1,208 Kg/m3. In contrast, when using normal evaporation, it requires 30 days to achieve specific gravity of 1,208 Kg/m3 from 1,030 Kg/m3. It can be explained that the evaporation process using a convection-improved solar salt evaporation system can occur faster because it has a wider evaporator surface area than conventional methods at the same pond area. Following [12], which states that the evaporation rate was enhanced when the projected surface area of the evaporation area increased, this study reveals that the convection technology-improved solar salt evaporation system can reduce the land requirement of the salt evaporator with the same salt production quantity.

## 4 Conclusion

This study provides an experimental investigation of a convection–improved solar salt evaporation system. During the study, the proposed system was also compared with the conventional method, and it was discovered that the evaporation rate of brine can be increased using a proposed system. This system increases the evaporation rate by expanding the evaporation area with a nonwoven geotextile membrane. The study also revealed that a convection–improved solar salt evaporation system presents a promising simple technology to significantly reduce both time consumption and land requirements while increasing the brine salinity in saltworks. Using the proposed system, the time required to enhance the brine specific gravity from 1,030 kg/m3 to 1,208 kg/m3 can be reduced from 30 days to 15 days. Therefore, the proposed system will become an attractive simple technology for enhancing brine evaporation and reducing the current time consumption and land requirements of saltworks.

However, future works were also required to do experimental investigation in the summer season and other locations such as Sampang, Pamekasan, and Sumenep regency. That location has a large salt production field and is one of the largest saltworks in Indonesia.

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