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METEOROLOGICAL AND PHYSICAL CONDITIONS OF SALT PAN AREAS WITH FILTERING-THREADED TECHNOLOGY (TUF) IN CIREBON REGENCY, INDONESIA

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ABSTRACT

Salt pans in Indonesia are commonly set in batch operation and highly depend on the meteorological condition. Moreover, the common salt pans are considerably limited in the area (averagely 0.5-1 Ha) as it is not organized by industries or governments; local farmers instead. However, with such confinement, there are some salt pans particularly with filtering-threaded technology system (TUF system) that successfully produce salt with high production (>100 tons/Ha/season) and grade-1 quality. The present study is aimed to get insight on the meteorological condition at the salt pans using TUF system and the physical condition of the sea brine obtained from the TUF in the local salt pans in Cirebon Regency. Measurements on temperatures (air, brine and soil), humidity, wind direction and speed, brine conductivity, brine density and salinity were conducted at the pre-crystallizer pond, brine storage pond, channels, the condenser, and the reservoir. The meteorological parameters were recorded hourly using Automatic Weather Station and the data were taken during 49 hours, from August 26-28, 2014 started at 04.00 pm. Meanwhile, the physical parameters of the brine were measured every three hours using water quality meter. The results showed that the meteorological condition, brine physical condition, and the process occurred during salt production were still in agreement and met the theoretical condition or modeling. Even though the relative humidity and some wind speed in the present study area were out of the standard criteria recommended (<50% for relative humidity and >5m/s for wind speed), the study showed that salt still can be produced in condition of relative humidity (52-88%), wind speed (0.2-5.7 m/s), and ambient temperature (23.2-32.4 ^{o}C). Interestingly, it is found that brine thickness and volume could be adjusted to get an optimum temperature of brine (reached 36.2 ^{o}C), in order to enhance the evaporation process. The highest soil temperature (34.7 ^{o}C) was found at 15.00 in the pre-crystallizer ponds. Meanwhile, the lowest temperature (26.7^{o}C) was found early morning at 04.00 in the reservoir pond. Brine in the pre-crystallizer had highest thermal storage capacity during daytime (06.00-16.00), whereas soil in the pre-crystallizer tended to store heat during the nighttime (18.00-22.00). Brine and soil temperature fluctuation indicate that solar irradiation and convection process transferring heat energy from soil to brine occurs and also took an important part in the evaporation process. It therefore can be concluded that by understanding the condition of meteorology at the salt pan areas and the brine characteristic obtained, the appropriate technology resulting high-quality and quantity salt production could be devised.

Keywords: meteorological condition, physical condition, salt pan, filtering-threaded technology (TUF), Cirebon

INTRODUCTION

Brine characteristics are changing accordingly with the evaporation process occurred in the salt ponds upon salt production. A marked change is thermo-physic aspect depended on the meteorological/ atmospheric condition such as solar radiation, wind speed, relative humidity, and temperature. Coleman (2000) stated that evaporation process would be better understood by understanding the concept of the vapor pressure of the liquid. The vapor pressure at equilibrium depends on the kinetic energy and the property of the liquid. Evaporation requires dry and warm/hot condition. At this condition, relative humidity will be low, so that a lot of moistures will be deposited in the air column. When saturated, the vapor will move to the drier column so that the column in the evaporated area could store more vapor. The Wind contributes only in transferring the saturated air to the less dense nor saturated air column and releasing heat energy (Kore, 2006).

Salt pans in Indonesia are typically in a batch operation. Batch salt pans are generally located in marginal monsoon tropics, marginal Mediterranean zones, and drier wet tropics. Salt pans are managed during the salt-making season to produce salt. While in the offseason, the pans are emptied from brine and

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then functioned as fish ponds. The salt pans consist of some small ponds with shallow depth. In a batch operation, salt is harvested manually. The salt pans with the batch operation are different from the other types of salt pans, like continuous and seasonal salt pans in which bigger and relatively deep ponds are found. Continuous salt pans are located in dry tropics zone, whereas the seasonal ones are in monsoon tropics and Mediterranean zones. Machine harvests are used in these salt pans (Collman, 2015).

Due to highly dependent on atmospheric/ meteorological condition, batch salt pans are interesting to be studied. One of the reasons is the high salt production resulted from this batch operation, although it is constrained by some factors. As an example, batch salt pans located in Cirebon Regency which is applied with filtering-threaded technology (Teknik Ulir Filter, TUF) could produce > 100 tons/Ha/season salts with high quality (grade-1) and acceptable to certain industrial purposes (Kurniawan & Erlina, 2012).

The production cycle operated in small-scale salt pans is shorter. It requires a continuous brine supply, which sometimes is highly influenced by meteorological condition and the physical property of the brine. Therefore, it is necessary to well understand the meteorological condition and the brine physical properties derived from TUF system salt pans. It is suggested that by understanding these conditions, salt production in the batch salt pans in Indonesia could be optimized.

METHODOLOGY

The study was conducted in August 26 – 28, 2014 which was the early season of salt production. It was carried out at the local salt pans at Subdistrict Ambulu, District Losari, Cirebon Regency ($6^{o}48.771$ – $6^{o}48.979$ S and $108^{o}48.748$ – $108^{o}48.904$ E) as shown in Figure 1.

The local salt pans selected for this study are batch operated salt pans with Threaded Filtering Technology System (also commonly known as TUF system). Bramawanto *et al.* (2015) mentioned that the structure and composition of TUF system salt pans consist of at least three main ponds, i.e. reservoir, condenser, and crystallizer ponds (Figure 2). In addition, these salt pans are also structured with channels, brine storage ponds, and pre-crystallization ponds. The reservoir is ponds at which organic materials contained in seawater/low-density (1 – 5oBe) brine are precipitated. Usually, the thickness of brine in this reservoir is 70 – 100 cm deep. Brine at 5^{o}Be is then fed to the condenser to a height of 5-7 cm. In the condenser, the solution is allowed to evaporate until the density reaches 15 or 20^{o}Be. The pre-crystallization pond is ponds where high-density brine (20 – 25^{o}Be) is collected and stored for crystallization process later at the crystallization ponds. Channels are narrow ponds with averagely 1-m deep that usually surround the salt pans. Channels are intermediate ponds that are used to accelerate brine at 10 fed from to reach 15^{o}Be to keep brine supply. This channel is typical in Indonesia salt pans.

Ambient Temperature, Relative Humidity, and Wind Measurement

In the study, parameters like ambient temperature, relative humidity, and the wind was recorded using automatic weather station (AWS) Davis Vantage Pro 2. The instrument was installed at open area and with no

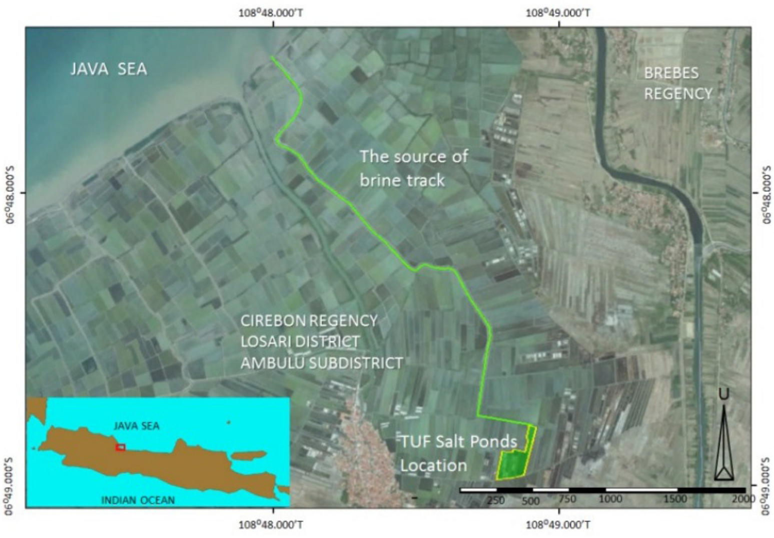


Figure 1. The study area of local salt pans.

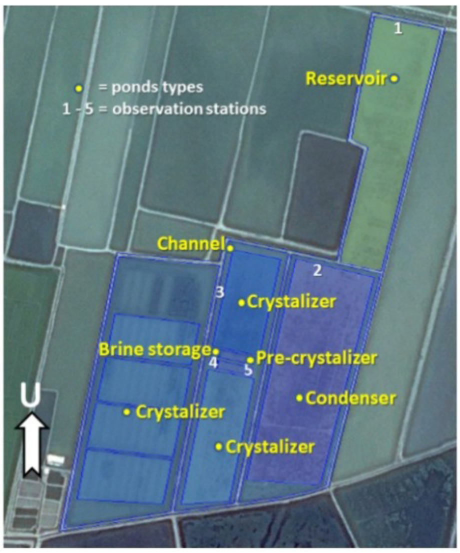


Figure 2. The structure of TUF system salt pans.

obstacle. Data were recorded hourly from August 26-28, 2014 started at 04.00pm.

Brine Temperature, Conductivity, Density, and Salinity Measurement

Brine temperature, conductivity, salinity and density were measured in the brine surface of the reservoir, condenser, channel, brine storage, and pre-crystallization ponds. The first three parameters were measured using hand-held water quality meter (WQC-24 DKK-TOA). Meanwhile, brine density was measured by Hydrometer (Baume meter). Data were recorded every 3 hours started from 09.00 am at August 27, 2014 to 04.00 pm at August 28, 2014.

Soil Temperature

Soil temperature was determined using hand-held thermometer Lutron LM-8000. Similarly, it was done at the reservoir, condenser, channel, brine storage, and pre-crystallization ponds. The measurement was carried out by penetrating the thermometer tip into the soil dike nearby the brine surface of the ponds. Data were collected every three hours started from 09.00 am at August 27th to 04.00 pm at August 28th, 2014.

Meteorological and Physical Conditions Analysis

Several studies had been done to investigate the relationship and the influence of physical process and meteorological phenomena on brine evaporation (Zhang *et.al.,* 1993; Coleman, 2000; Kokya & Kokya, 2006; Kore, 2006; Akridge, 2008; Horri *et al.,* 2014; Davarzani *et al.,* 2014). Some studies mostly used a mathematical modeling approach, as done by Zhang *et al.* (1993); Kore, S., 2006; Akridge (2008); Horri *et al.* (2014). Their studies suggested that evaporation was influenced by specific variables such as ambient temperature, wind speed, relative humidity, atmospheric pressure, water surface temperature, heat exchange rate, absorbance-reflection of solar radiation, thermal current, and pond depth. Furthermore, Mickley (2006) specifically concluded that a complex interaction between salinity and evaporation was observed. The present study was interested to analyze the interaction among meteorological and physical conditions at Salt Pan Areas with Filtering-Threaded Technology System (TUF system).

RESULTS AND DISCUSSION

Brine Conductivity, Density, and Salinity

The brine properties, in terms of conductivity, density and salinity are shown in Table 1. It can be seen that the brine highest conductivity was observed in the pre-crystallizer. Lower conductivities are found respectively in brine storage, channel, condenser, and reservoir. The difference between the lowest and the highest conductivity within the ponds ranged from 0.37-0.81 mS/cm. The highest difference was found in the channel, followed by the condenser. This could be attributed to the reason that brine is highly evaporated in these two ponds, contributing to the significant changes in the conductivity. It was observed that the evaporation in the reservoir was lower than expected. It could be ascribed to the fact that reservoir was continuously received brine from irrigation channels to keep the brine supply. This practice contributed to a lower conductivity change of the brine.

A similar trend to the conductivity was also observed in the brine density and salinity. It is observed that the difference between the highest and the lowest density in the pre-crystallizer is 5oBe. This is attributed to the decrease in brine thickness and volume. As the brine is more concentrated upon evaporation, the activities of the salt ions become stronger. The salinity of the several ponds in the salt pans (channels, brine storage, and pre-crystallizer) could not be determined due to beyond detection limit of the instrument. Water quality meter used in the study has salinity detection range of 0-40 PSU (Anonym, 2010). Only salinity in reservoir and condenser was detected.

Meteorological Characteristics

The meteorological characters in the salt pans during the study are presented in Figure 3. It is generally observed that the pattern of the wind speed was in direct proportion to the pattern of the ambient temperature, but inverse to the pattern of the relative

Table 1. Brine conductivity, density, and salinity

Ponds types	Conductivity (mS/cm)		Density (^{O}Be)		Salinity (PSU)	
	lowest	higest	lowest	higest	lowest	higest
Reservoir	4.55	4.92	2	2	29.9	32.6
Condenser	5.27	6.03	3	4	35.6	39.8
Channel 8.99	9.80	7	8	> 40	> 40	
Brine Storage	12.19	12.73	10	12	> 40	> 40
Pre-crystallizer	17.99	18.83	20	25	> 40	> 40

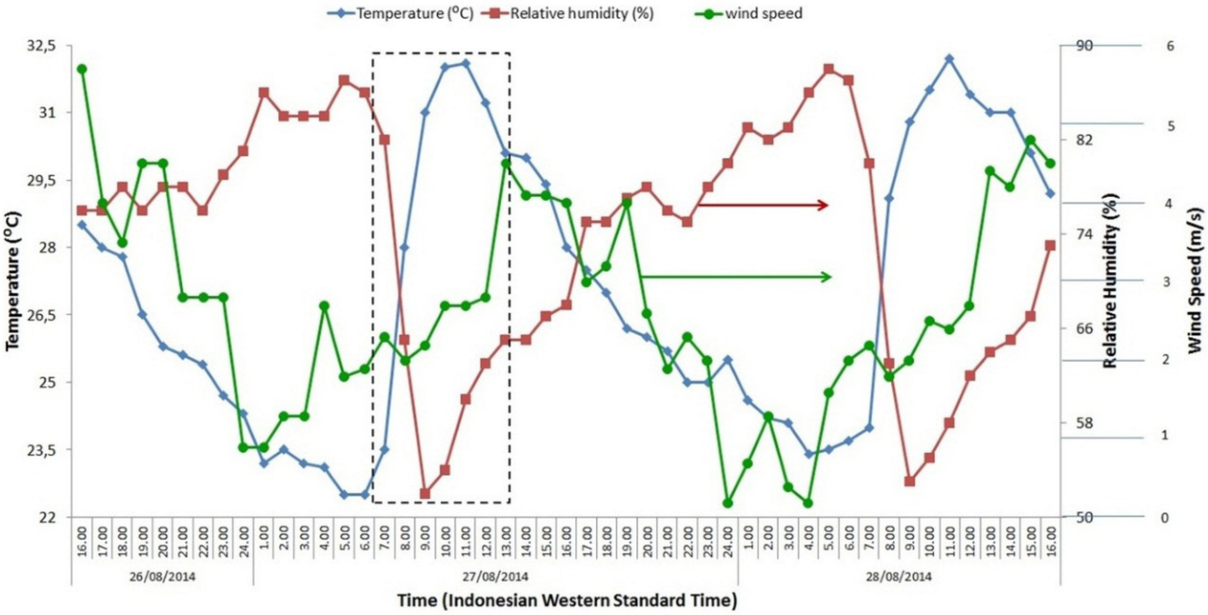


Figure 3. Measurement results of ambient air temperature, relative humidity, and wind speed.

humidity. Interestingly, an anomaly was observed in the patterns in which the humidity was significantly increased after 2-hours of a remarkable temperature increase occurring at 07.00. This was also followed by the increase of the wind speed. It can be explained that the increase of temperature accumulates the water vapor resulted from seawater/brine evaporation. Accordingly, it also generates the saturated vapor movement to the less dense and drier air column, contributing to the strong sea breeze formation during the day. Simulation results by Davarzani *et al.* (2014) showed that wind speed contributed to the drying process in the non-isothermal system. High wind speed would increase the heat and mass transfer through convection at the free flow areas.

Relative humidity in the study area ranged from 52-88% (Figure 3). The present condition is less favorable for brine evaporation process. Some previous studies suggested the favorable relative humidity for salt production is < 50% (Pranowo *et al.,* 2013; Upe *et al.,* 2002; Purbani, 2001). Regardless the high humidity, this area could produce salt with good quality. Moreover, Nadjib (2007) found that in general the salt quality resulted from salt pans at Astanajapura District, an area close to the present study area, was higher than those resulted from salt pans at Kaliori Sub-district – Rembang and Pademawu Sub-district – Pamekasan.

It is also seen from Figure 3 that in the evening, the relative humidity in salt pan area kept increasing when both the ambient air temperature and wind speed gradually decreased. It is suggested that the evaporation process was still lasting as the results of saturated vapor accumulated above the salt pan surface, thus increasing the vapor pressure. The saturated condition and high pressure could be easily recognized by dew fall in the next early morning, making the air temperature cold and dike surfaces wet. However, when the air temperature deliberately increased in the morning, relative humidity would immediately decrease and reach the lowest point at around 09.00 local times. This suggested the fluctuation of air temperature significantly determined the change in relative humidity and wind speed.

Wind speed during observation ranged from 0.2 to 5.7 m/s with an average of 2.65 m/s . According to Beaufort scale, it is in calm to moderate breeze scale (Anonym, 2015). This average value was below the standard value recommended for salt production, i.e. >5m/s (Pranowo *et al.,* 2013; Upe *et al.,* 2002; Purbani, 2001). On the other hand, Davarzani *et al.* (2014) found that in his simulation, the drying process in the non-isothermal system could occur at the speed of 0.002 – 6.0 m/s. In his study, he found that the optimum wind speed was 2 - 6 m/s. Another previous study by Mannar, 1982 also suggested that the wind speed was recommended at around 0.833 – 4,167 m/s, so that the wind would not blow the silt, sand dust, and other fine particles into the salt pans which could interfere the salt quality produced. The range meets the wind speed in the present study. Meanwhile, the highest frequency distribution of the wind class in the study area was 36%, found at 2.1-3.6 m/s wind class (Figure 4). No frequency distribution was detected at wind class of 8.8-11.1 m/s and ≥ 11.1 m/s.

Figure 4 shows that wind blew dominantly from the northeast during the day and south during the night. The coastal area and the salt pans are located in north and south, respectively. The wind profile in the study was strongly influenced by the land and sea breeze. Wind blowing from the northeast was stronger than that from the south. This is in agreement with previous results by Anzhar & Yarianto (2000) that at Ujung Lemahabang, located in northern Java coasts, the wind blew dominantly from the north at the day and from the south at night during the dry season.

Temperature Dynamics: Air, Brine and Soil

In salt pans, the temperature is fluctuated dynamically caused by solar irradiation (Figure 5).The graphic showed that the profile of ambient temperature

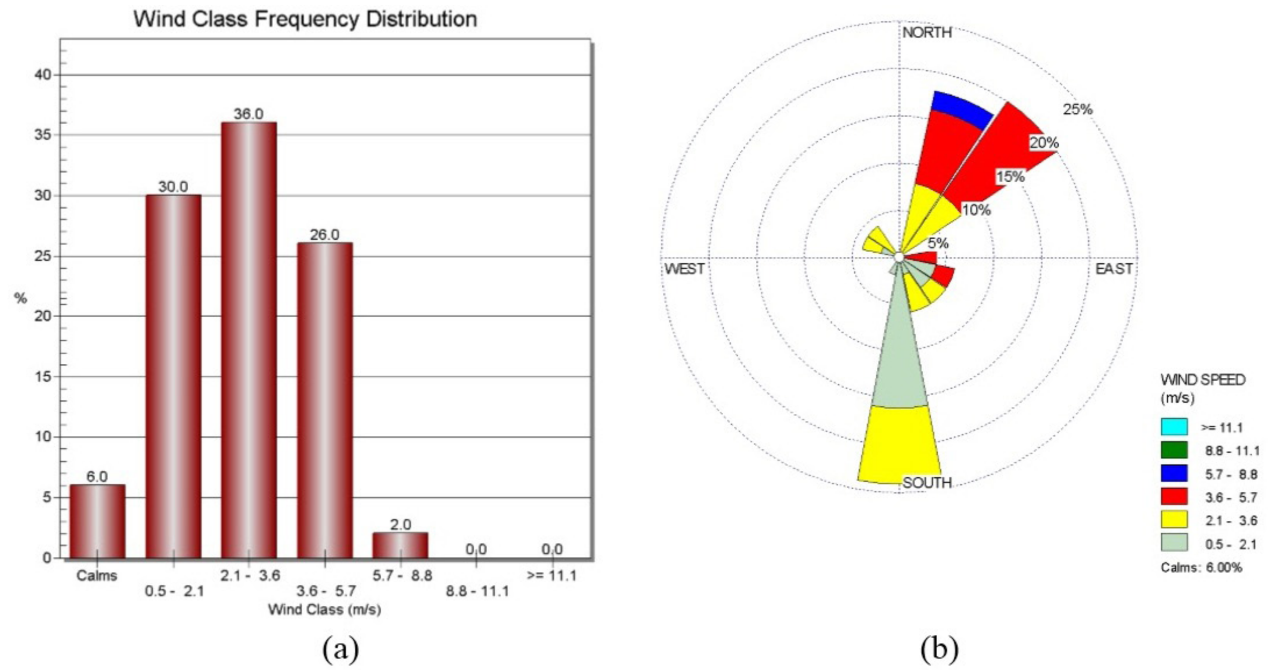
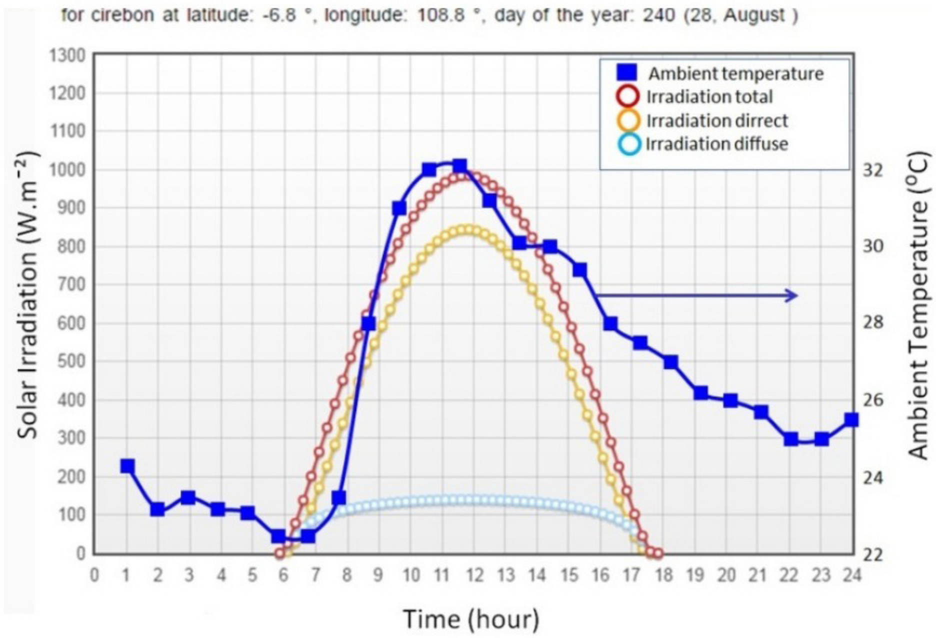


Figure 4. Wind profile: (a). wind class frequency distribution, (b). wind direction.



Note:
- Solar Irradiation calculated using solar calculator from http://www.meteoexploration.com/products/SolarCalculator.html
- Ambient temperature was measured in this study

Figure 5. The solar irradiation and ambient temperature at TUF system salt pans.

is almost similar to that of the solar irradiation profile. The ambient temperature would be reached the highest point when the sunshine is most intensive during daytime hours.

The present study showed that the highest temperature of brine was observed at noon (12:00 local time), i.e. 36.2°C in the pre-crystallizer. The lowest brine temperature was 23.6°C observed in the condenser at 04:00 am, local time (Figure 6). It was observed that brine temperature of pre-crystallizer was higher than that of the other pans. This is attributed to the heat capacity decrease resulting from reduced brine thickness and volume occurred in the pre-crystallizer compared to those in the other pans. To prevent high-temperature fluctuation, it is important to adjust the brine thickness in the pre-crystallizer since brine with high density hardly to evaporate. Zhang *et al.* (1993) mentioned that the evaporation rate profile of brine with a thickness of 0.02 m was nearly similar to the pattern of solar insolation. Meanwhile, salt pans with thicker brine layer (0.4 m) had a different profile from the solar insolation pattern. In deep salt ponds, the brine temperature increased slowly in the daytime

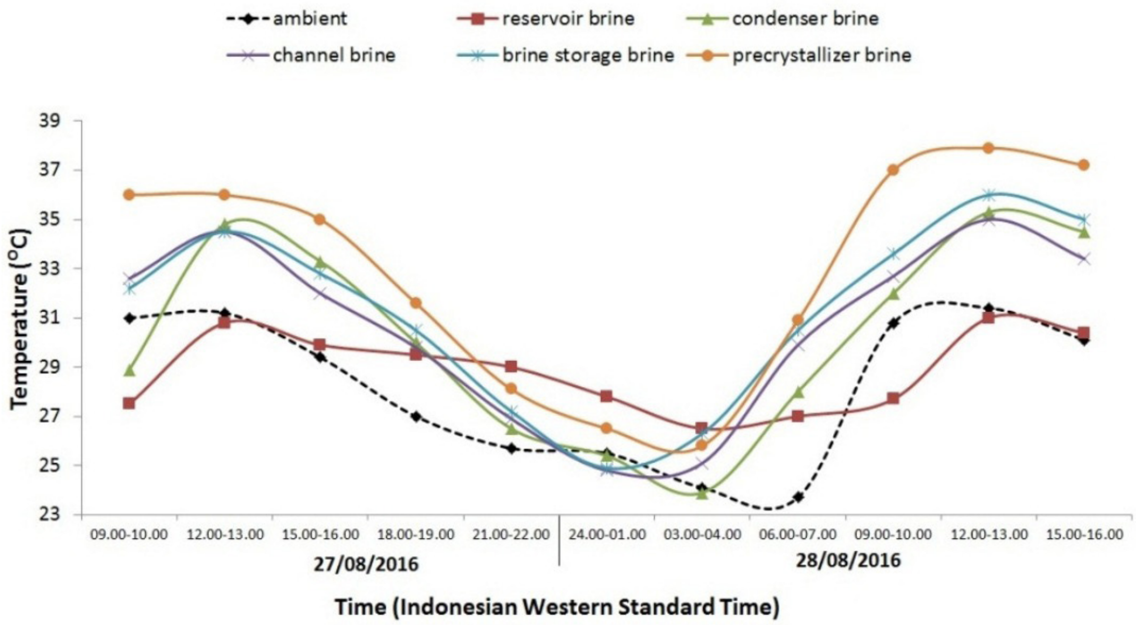


Figure 6. The brine temperature in TUF system salt ponds.

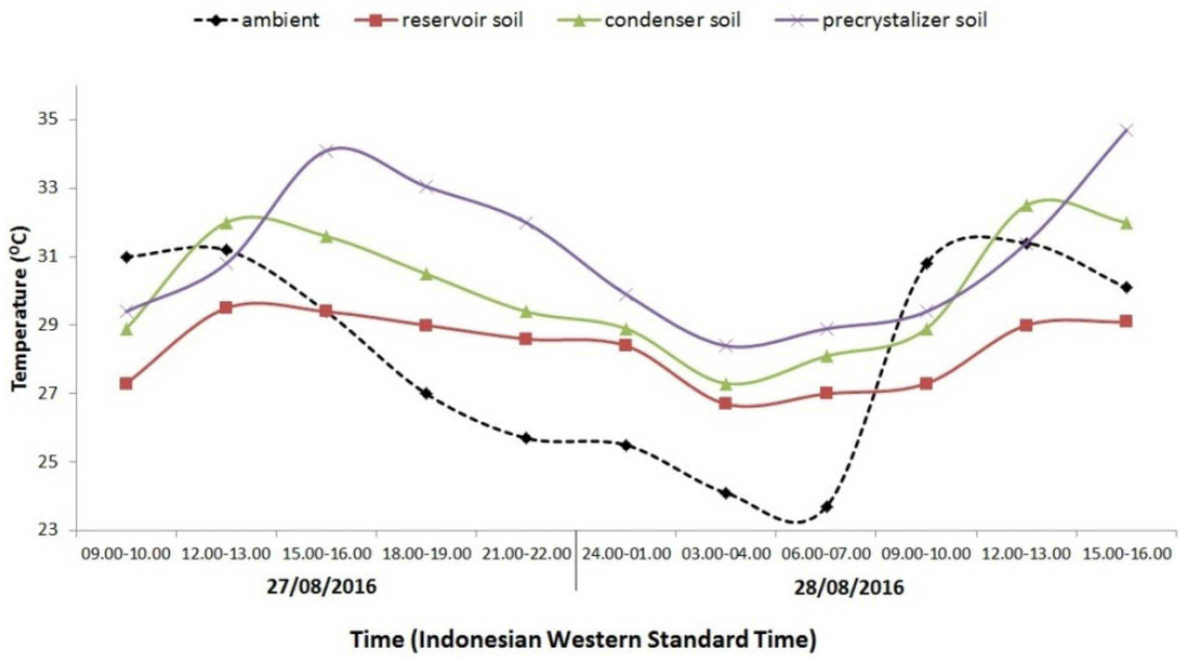
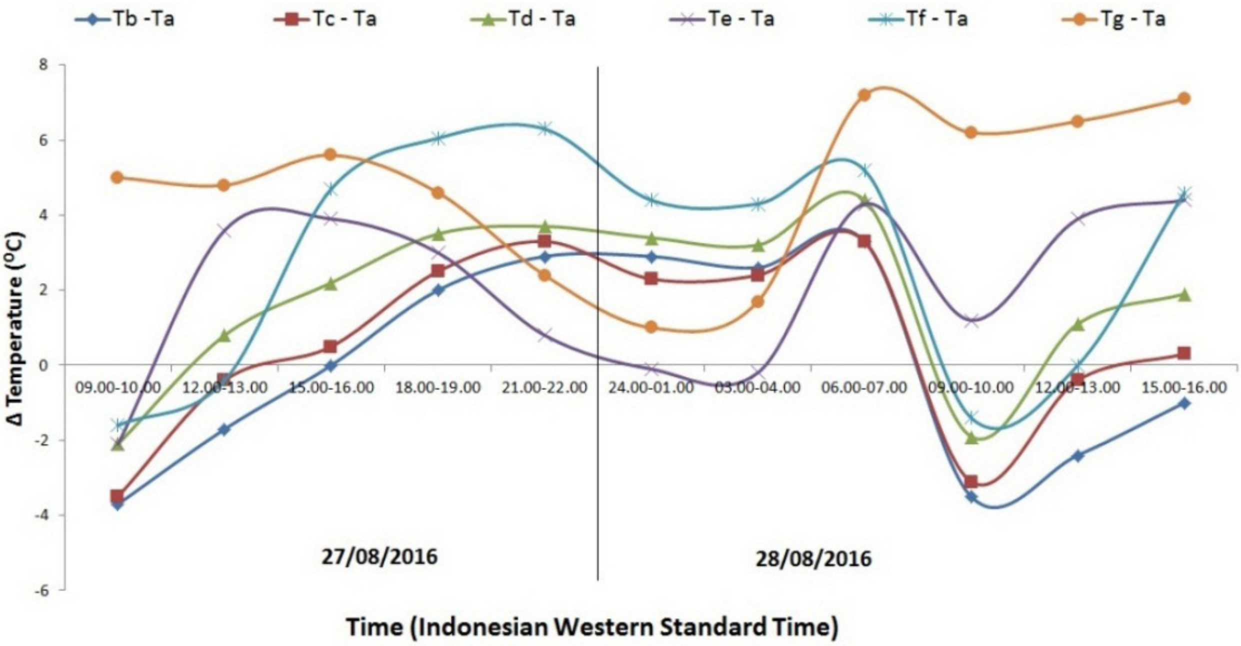


Figure 7. The soil temperature in TUF system salt pans.



Ta = ambient temp. T b = reservoir soil temp. T c = reservoir brine temp.
Td = codenser soil temp. T e = condenser brine temp. T f = precrystalizer soil temp.
Tg = precrystalizer brine temp.

Figure 6. The comparison of difference brine temperature and soil temperature to ambient temperature.

and decreased very slightly after sunset. It is therefore suggested that salt ponds with a thick brine layer could store energy and shift the evaporation process in the nighttime.

A similar pattern was also observed in the brine temperature pattern in the channel and brine storage. This is influenced by the increase in salinity. The Strong cohesive interaction between dissolved ions and water could inhibit the evaporative process, preventing water molecule from releasing to the air and reducing the spontaneous change of liquid to vapor phase (Miller, 1989; Kokya & Kokya, 2006). Leaney & Christen (2000) stated that evaporation rate would decrease exponentially with the increase of salinity.

A significant difference of brine temperature profile was observed in the reservoir which had the lowest brine salinity ranging from 26.5-30.8°C. At 06:00-18:00 Western Indonesian Time, brine temperature in the reservoir was below those in the other ponds. Meanwhile, at 21:00-04:00 Western Indonesian Time, the brine temperature in the reservoir was higher than those in the other ponds. Brine temperature of the reservoir was relatively stable which was affected by the depth and volume of the reservoir. Bramawanto *et al.* (2014) stated that compare to those in other ponds, the higher volume of brine in reservoir slowed the temperature rise in the daylight. On the other hand, the higher brine volume could decelerate brine temperature decrease during the night and early morning, which was contributed to the absence of sunlight. This was observed in the reservoir. Different from that in the reservoir, the less amount of brine volume in other ponds contributed highly to temperature rise during the day and immediately decreased during the night. The present results were also in agreement with previous studies by Zhang *et al.* (1993); Jensen M.E. (2010); Xing *et al.* (2012); Chari *et al.* (2013). Their studies showed that according to both field observation and mathematical model, the dynamics of temperature in shallow water was affected significantly by the flux of surface radiation penetrating the water columns depending on its depths and volumes.

It was also found in the study that the temperature was higher in day-2 than that in day-1. This temperature rise contributed to the increase of density of the brine, which was significantly observed in pre-crystallizer ponds. This marked increase of brine density was observed when ponds were in the closed system. For the case in the reservoir, condenser and channel ponds, brine density was not remarkably increased due to the brine supply continuously flowing through the ponds. Brine supplied through the ponds was those with lower density to maintain the brine availability during the salt season.

The profile of soil temperature is given in Figure 7. The soil temperature in the figure represented that of the reservoir, condenser and pre-crystallizer ponds. Meanwhile, the soil temperatures of storage and channel ponds were not shown as they showed a similar trend to that of the condenser ponds. It is observed that the range of soil temperature fluctuation was narrow than ambient and brine temperature. The highest soil temperature (34.7°C) was found at 15.00 Western Indonesian Time in the pre-crystallizer ponds. Meanwhile, the lowest temperature (26.7°C) was found early morning at 04.00 Western Indonesian Time in the reservoir pond. The profile of soil temperature was likely in accordance with the profile of ambient temperature. However, different profiles of soil temperature in reservoir and condenser ponds in which the soil temperature was relatively homogeny.

Both water and soil are able to store heat. It can be seen from the narrow temperature range compared to the range of the ambient air. The difference in brine temperature to air temperature was calculated in the study. Similarly, the difference in soil temperature to air temperature was also measured in the study. The differences were performed to get insight on the capacity of either brine or soil in storing heat. It should be noted that the positive coefficient derived from the differences refers to the large thermal storage capacity of brine or soil. While the negative ones refer to the heat losses in the brine or soil. The result of this temperature difference is presented in Figure 8. From Fig. 8 we can see that pre-crystallizer ponds had the highest thermal storage. It seems that brine in the pre-crystallizer had highest thermal storage capacity during daytime (06.00-16.00), whereas soil in the pre-crystallizer tended to store heat during the nighttime (18.00-22.00). More interestingly, the ability of soil in storing heat in the pre-crystallizers at night apparently promoted the convection process from soil to the brine resulting to the warmer temperature of brine during the nighttime. A slightly similar trend was also observed in brine temperature of the condenser ponds at the nighttime. However, the thermal heat capacity of soil in condenser was not sufficient to warm the brine in the same way to that in the pre-crystallizer. According to Zhang *et al.* (2013) solar radiation at the soil surface is transformed sensible heat and latent heat in the soil. The only part of the solar radiation is absorbed by the water surface. Some other part penetrated into the pond bottom and warmed the bottom. It is therefore concluded that temperature dynamics plays an important role in the changes of the brine temperature and brine density, depending on the brine thickness and volume.

CONCLUSION

Meteorological and physical conditions at the salt pan areas with the threaded-filtering system still meet the theoretical approaches and modeling simulation based on several previous studies. Even though the relative humidity and some wind speed in the present study area were out of the common standard criteria recommended (<50% for relative humidity and >5m/s for wind speed), this study showed that production of salt still can be done in condition of relative humidity (52-88%), wind speed (0.2-5.7 m/s), and ambient temperature (23.2-32.4 °C). This study also found that brine thickness and volume are two important parameters to be adjusted to get an optimum temperature of brine (reached 36.2 °C in this study), in order to enhance the evaporation process. Soil temperature fluctuation was narrow than brine and ambient temperature. The highest soil temperature (34.7 °C) was found at 15.00 in the pre-crystallizer ponds. Meanwhile, the lowest temperature (26.7°C) was found early morning at 04.00 in the reservoir pond. Brine in the pre-crystallizer had highest thermal storage capacity during daytime (06.00-16.00), whereas soil in the pre-crystallizer tended to store heat during the nighttime (18.00-22.00). Brine and soil temperature fluctuation indicates that solar irradiation and convection process transferring heat energy from soil to brine occurs and also took an important part in the evaporation process.

However, further studies are recommended to specifically investigate the evaporation rate in each pond of salt pans in the representative period, for instance during one cycle of salt production. In addition, brine discharge is also necessary to determine so that brine volume/thickness could be controlled at the optimum temperature. A study in other salt pans using another technology is also necessary to conduct for comparison and baseline data.

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