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Research Article

Continuously Dynamic Mixing (CDM) Method and Greenhouse Salt Tunnel (GST) Technology for Sea Salt Production throughout the Year

Metode Continuously Dynamic Mixing (CDM) dan Teknologi Greenhouse Salt Tunnel (GST) Untuk Produksi Garam Sepanjang Tahun

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Abstract

One of the biggest challenges in sea salt production is unpredictable and unsuitable weather. Sea salt production process is very depended on the evaporation rate of sea salt production and it will be stopped in the rainy season. One of the alternative strategies to solve this problem is the application of greenhouse salt crystallization in sea salt production. This study aims to develop the technology to produce sea salt in the rainy season by applying Continuously Dynamic Mixing Method (CDM) in the Greenhouse Sea Salt Tunnel (GST). The application of CDM in the GST is an original innovation developed by the researchers of this study. Environmental parameters analyzed in the present study were daily temperatures, wind speed, evaporation rate, humidity, and Baumé scale value. The quality of the produced sea salt was evaluated from the water and NaCl content. The results of this study indicate that the application of the CDM method in GST makes the sea salt production from the raw water materials (± 2° Be) can be conducted in the rainy season. The optimum water and NaCl content of the produced sea salt is 98.05 % and 7 %, respectively. The production of sea salt for one cycle (15 days) in this study is 300 kg/GST-Crystallization (44 m^2). According to the results, the CDM method in the GST technology may improve the production of the sea salt in the rainy season and allow it to produce sea salt throughout the year.

Abstrak

Salah satu tantangan terbesar dalam produksi garam adalah kondisi cuaca yang tidak menentu ataupun tidak mendukung proses pengkristalan garam. Proses pembuatan garam yang sangat tergantung pada laju evaporasi membuat produksi garam akan berhenti pada musim hujan. Strategi pengoptimalan laju evaporasi dengan menggunakan rumah kristalisasi garam berkembang menjadi salah satu alternatif metode untuk mengatasi permasalahan tersebut. Studi ini bertujuan untuk mengembangkan teknologi produksi garam di musim hujan dengan menerapkan metode *Continuously Dynamic Mixing* (CDM) pada rumah kristalisasi berbentuk *Greenhouse Salt Tunnel* (GST). Penerapan metode CDM dalam teknologi GST merupakan inovasi teknologi yang dikembangkan khusus oleh peneliti dalam studi ini. Parameter lingkungan yang diteliti terdiri dari suhu harian (air dan udara), kecepatan angin, laju penguapan, kelembaban udara dan nilai skala Baumé dari air bahan baku garam. Kualitas produksi garam dievaluasi berdasarkan kandungan air dan kandungan NaCl. Hasil penelitian ini mengindikasikan kalau penerapan metode CDM pada GST membuat produksi garam yang dimulai dari air muda (± 2° Be) dapat dilakukan pada musim hujan. Garam yang dihasilkan berwarna putih dengan kandungan NaCl dan kadar air, secara berturut-turut, adalah 98.05 % dan 7 %. Hasil produksi garam per siklus produksi dalam musim hujan (15 hari) sebesar 300 kg/GST-Kristalisasi (luasan 44 m^2). Berdasarkan hasil penelitian, metode CDM pada teknologi GST membuat produksi garam pada musim hujan sehingga produksi garam dapat dilakukan sepanjang tahun.

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1. Introduction

Exploration and sustainable coastal and marine resources utilization became Indonesia's foundation to be the world's maritime axis (Bueger, 2015; Chapsos and Malcolm, 2017; Tu *et al*., 2018). The abundance of coastal and marine resources should have been used optimally for the development is the seawater. One of the main use of seawater was as the raw material in making sea salt (Adachi and Buseck, 2015; Fenner and Wright, 2014; Mdaners *et al*., 2010). Sea salt is an important commodity that was used to fulfill human needs, from consumption, industrial to pharmaceutical needs (Fenner and Wright 2014; Inguglia *et al*., 2018).

Sea salt production in Indonesia still could not meet the national sea salt needs (Guntur *et al*., 2018; Jaziri *et al*., 2018). Data released by the Ministry of Maritime Affairs and Fisheries (2018) said that national sea salt production in 2018 was less than 2.35 million tons of the total production target of 4.1 million tons. One of the main problems encountered in national sea salt production was unsupportive weather (Normala, 2018; Worstall, 2017). The decrease in sea salt production due to the unsupportive rainy season caused national sea salt supply shortage which would disrupt industrial activities with sea salt as their raw or supportive material in the production process (Worstall, 2017). To fulfill the sea salt needs, mainly industrial sea salt, therefore Indonesia had to import sea salt (Normala, 2018).

Innovation technology to optimize salt folk production in Indonesia is very important to be developed. One of the technologies that is needed in salt folk production in Indonesia is the technology that allows sea salt production to be carried out both in the rainy season and dry season. Related researches about sea salt production in the rainy season in Indonesia are still rarely carried out. This research is aimed to analyze and develop methods and sea salt production technology by using greenhouse technology in the rainy season. The results of this research will become important fundament in developing concepts and technology to develop the strategy of sea salt production throughout the year.

Technology developed through this research was *Continuously Dynamic Mixing* (CDM) method and *Greenhouse Salt Tunnel* (GST) technology in salt folk production. The developed CDM method and GST technology were applied to the salt pond with an area of 1 Ha where 10% of the area was used to build GST construction. This research was the first research developing CDM method and GST technology to produce sea salt in the rainy season. The research result would be able to inform the application of the CDM method and GST technology which allowed sea salt production to be carried out in the rainy season so that sea salt production was possible to do throughout the year.

2. Materials and Methods

2.1 Area Study and Implementation Time

This research was carried out in the salt pond in Leranwetan Village, Tuban District, East Java. This salt pond was the Experimental Land for Salt Folk Production, Coastal and Marine Research Center Brawijaya University (PSPK UB). This experimental land was the research location of PSPK UB together with PT. Kencana Tiara Gemilang (KTG), Fisheries and Animal Husbandry Office of Tuban (Diskanak), and Bojogkan Sea Salt Farmer Group. The research started in mid-December 2018 until January 2019. The rainfall rated between 230-282 mm/month. The rain fell almost every day. The duration of exposure during the research was 126-129 hours/month (BMKG Tuban, 2019).

2.2 Environmental Parameter Measurement

Measured environmental parameters were daily temperature (the air around GST, the air in the GST, and the water in the GST), wind velocity, evaporation rate, air humidity, and Baumé scale value of water. Environmental Parameter measurement was carried out three times a day, at 07:00, 12:00, and 17:00 Western Indonesia Standard Time. Room temperature was measured using Digital Thermometer (HTC-2). Wind velocity was measured using Digital Anemometer (GM8902, Benetech). Evaporation rate was estimated from the decrease in water level due to the evaporation in every meter square of GST. Humidity was measured using Digital Hygrometer (HTC-2). The water Baumé scale was measured using Boumehydrometer (Alla France 0-30).

2.3 Sea Salt Quality Measurement

Sea salt quality was measured using Saltdeck (Saltdec, M102). Measured sea salt quality parameters were water content and NaCl of the produced sea salt. Sea salt quality measurement was carried out after 4 days of storage in the warehouse (Sea Salt Warehouse, Cempokorejo Village, Palang Sub-district, Tuban District, East Java).

2.4 *Greenhouse Salt Tunnel Specification*

Sea salt farm used to produce sea salt had a total area of 1 Ha. GST was built ± 1000 m^2 on 10% of the total area of the sea salt farm. The construction design of GST used in this research is shown in Figure 1. GST had a size of 12x5 meters (4 units) and 11x4 meter (10 units).

GST constructions contained three main parts, namely UV plastic, tunnel structure, and tunnel geo-membrane base. UV plastic used transparent plastic (with a thickness of 200 µm) while tunnel geo-membrane base used black HDPE membrane (with a thickness of 300 µm). Plastic and geo-membrane were provided by PT. KTG, Singosari Indonesia. GST building structure used dried bamboo.

Figure 1. Technology Design *Greenhouse Salt Tunnel*

3. Result and Discussion

This sea salt production research was carried out using Continuously Dynamic Mixing (CDM) method in Greenhouse Salt Tunnel (GST) technology to keep producing sea salt in the rainy season. This technology application allowed sea salt production to be carried out throughout the year. By increasing the period of sea salt production because of the production in the rainy season, salt folk production in Indonesia was expected to be increased in the future. This research also analyzed the quality of sea salt (water content and NaCl content) that was produced through the CDM method application in the GST.

3.1 Environmental Parameters

Environmental parameters observed in this research were daily temperature (the air around GST, the air in the GST, and the water in the GST), wind velocity, evaporation rate, air humidity, and Baumé scale value of water in the GST. Results to environmental parameter measurement during this research are explained as follows.

3.1.1 Daily Temperature

The daily temperature that was measured was room temperature in the GST, water temperature in the GST, and free air temperature around GST (Figure 2a, 2b, and 2c). Temperature measurement was done three times a day (at 07:00, 12:00, and 17:00 Western Indonesia Standard Time). The results of the temperature measurement showed that the temperature in the GST was 27-45°C, water temperature in the GST was 27-43°C, and the temperature outside the GST was 27-38°C. These results indicated that daily temperature in the research site varied. From the daily temperature measurement, the temperatures at 12:00 were higher than the temperatures at 07:00 and 17:00. While the temperatures in the morning (at 07:00) and in the afternoon (at 17:00) were relatively not much significantly different.

Temperature measurement results indicated that GST construction could maintain higher water temperature and air temperature than the temperature around the GST. It indicated that there was heat trapped through GST construction. The trapped heat became the energy to make the evaporation process occurred in GST. With this preserved condition, water aging process and salt crystallization could be carried out even in the rainy seasons (Jaziri *et al*., 2018).

3.1.2 Wind Velocity

Wind velocity was measured in this research because the existence of wind could bring water vapor out of GST to the free air. This process would determine the sea salt production rate in the GST (Santosa, 2014). Wind velocity in the GST measured three times a day

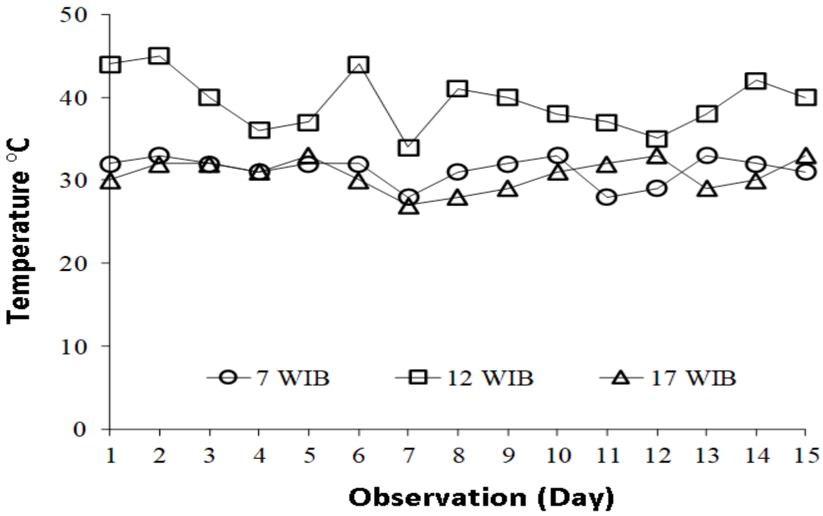

Figure 2a. Room Temperature in the Greenhouse Salt Tunnel

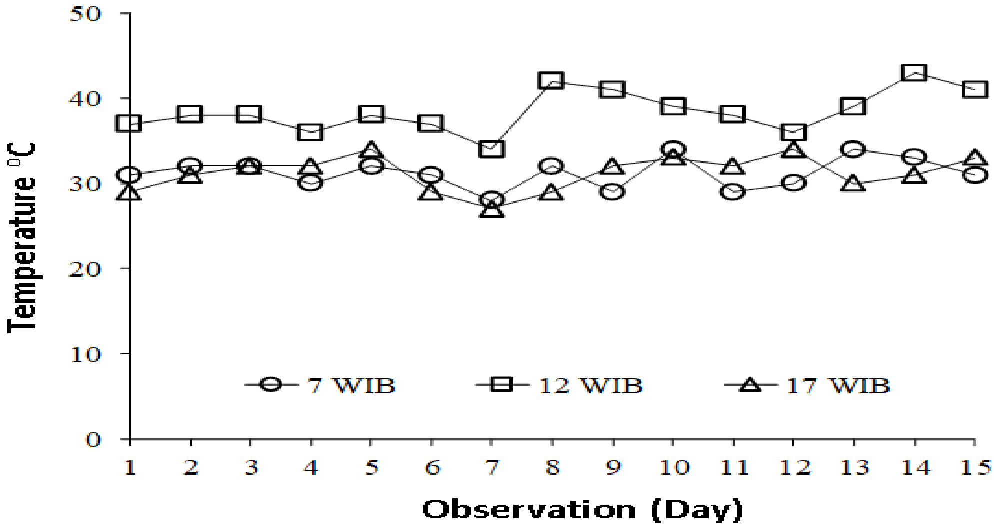

Figure 2b. Water Temperature in the Greenhouse Salt Tunnel

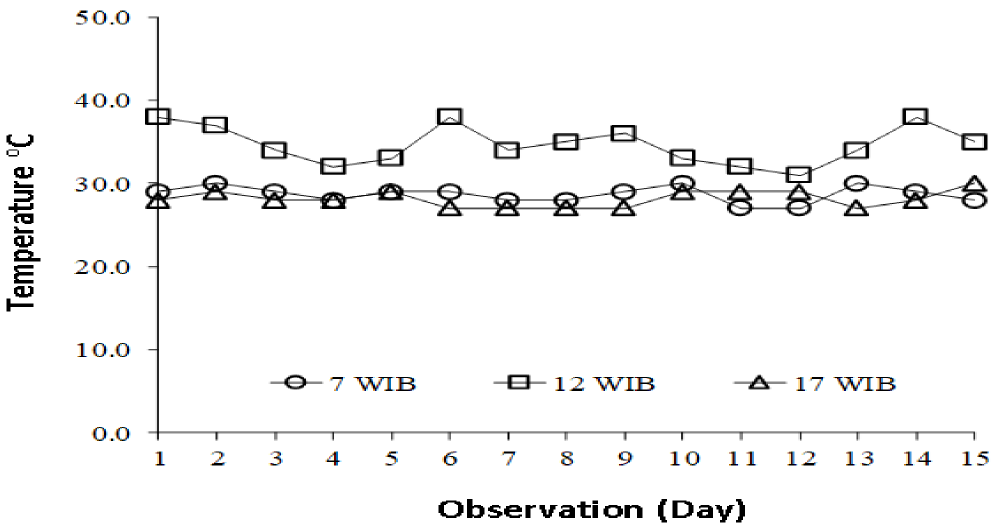

Figure 2c. Air Temperature outside the Greenhouse Salt Tunnel

(at 07:00, 12:00, and 17:00 Western Indonesia Standard Time) during 15 days of sea salt production (Figure 3). The highest wind velocity was at 12:00 with an average of 2.6 m/s. The wind velocity at 07:00 (with an average of 1.5 m/s) generally was a bit faster than the velocity at 17:00 (1.3 m/s). The wind would bring water vapor from the evaporation process in the GST out of the GST so that it would not fall in the water if condensation occurred. The water vapor that was transferred by the wind would make air pressure in the GST lower than the pressure in the water. Therefore, the evaporation process would keep on occurring (Santosa, 2014). The results of wind velocity measurement inside the GST indicated that GST construction was able to maintain the wind velocity so that it could support the sea salt production process.

3.1.3 Evaporation Rate

Sea salt production process occurred as the water molecule evaporates to the air, therefore salt crystallization occurred (Aboufoul *et al*., 2019; Giustini *et al*., 2019; Wang *et al*., 2019). Therefore, sea salt production using GST was also analyzed by measuring the evaporation rate during sea salt production in the GST. Figure 4 showed the water evaporation rate on average in the GST. The average water evaporation rate was taken from all GST except the GST which was functioned as a crystallization table. The evaporation rate at the GST of crystallization could not be taken because sea salt crystallization occurred on the crystallization table. The daily evaporation rate in the GST was in an average of 0.1-0.2 cm/m^2. The rain fell almost every day during the

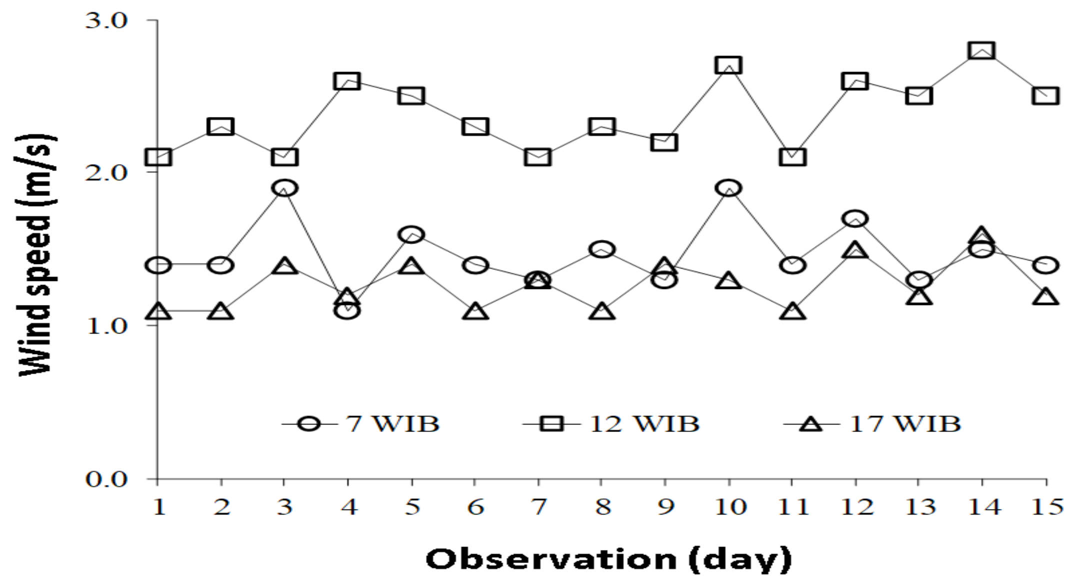

Figure 3. Win Velocity inside the Greenhouse Salt Tunnel

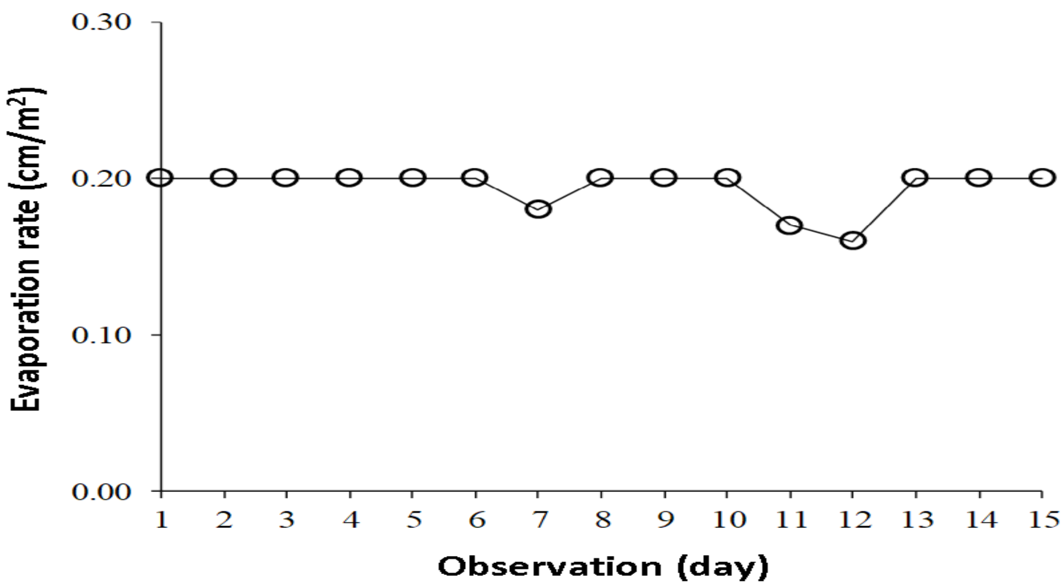

Figure 4. Average Daily Evaporation Rate in the Greenhouse Salt Tunnel

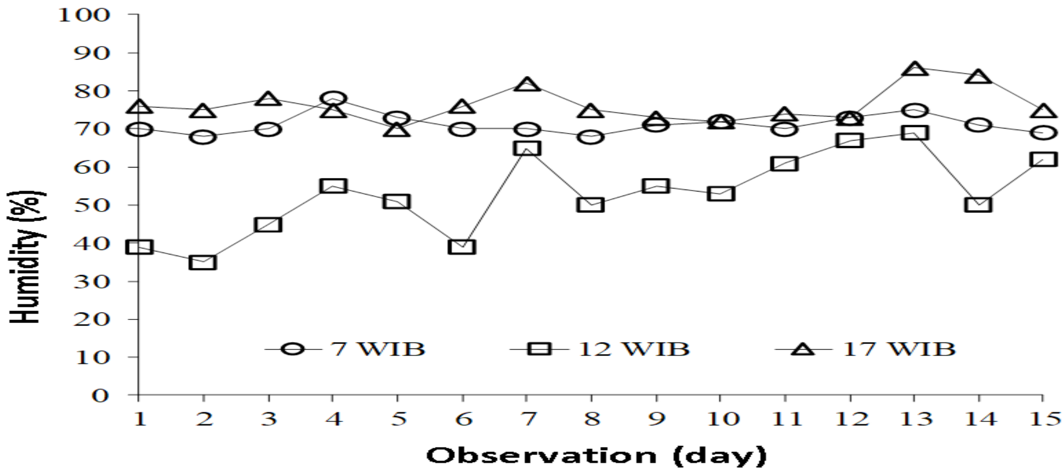

Figure 5. Humidity in the Greenhouse Salt Tunnel

sea salt production process. The water evaporation rate measured in this research indicated that the evaporation process towards sea salt crystallization could be carried out in the rainy season by using GST technology. Evaporation rate decreased on the 7th, 11th, and 12th days of observation due to the hard rain.

3.1.4 Humidity

Humidity was the number of water vapor in the air (Lakitan, 1994). Figure 5 showed the humidity measured in this research. High humidity in the GST indicated that the water evaporation process towards sea salt crystallization could be carried out during the rainy season. Measurement results indicated that the highest humidity occurred at 07:00 (78%) and 17:00 (86%). During sea salt production with GST technology, the lowest humidity occurred at 12:00. Low humidity occurred at the highest point of temperature (Figure 1) and wind velocity (Figure 2). It indicated that the water evaporation process towards sea salt crystallization could be optimized by using GST. This result indicated that GST technology could be applied to produce sea salt even in the rainy season.

3.2 Continuously Dynamic Mixing

In principle, the water aging process in the sea salt production process was Baumé scale value improvement of the water used as a raw material in sea salt making. Baumé scale value adjustment was the core of all sea salt production process (Korovessis and Lekkas, 1999). Generally, the water saturation level of all the GST in this research has increased. Adjustment to the water mixing and transference to increase Baumé scale value of water was the strategy built in this research as a method in utilizing GST technology to produce sea salt in the rainy seasons.

The GST technology developed in this research could maintain and make a supporting environment for the water evaporation process. The GST technology also ran very well to protect aged water and sea salt crystal from the mixing with rainwater. To optimize GST technology in sea salt production in the rainy season, a series of a method for managing Baume scale value of water.

This research composed a series of water management methods in sea salt production called *Continuously Dynamic Mix*ing (CDM) method. The basic principle of CDM was to carry out water mixing and transference process continuously and dynamically to make sure that the water aging proses kept going on and the water volume was enough to be raised on the crystallization table. Volume adjustment was carried out to make sure that sea salt production in the rainy season would be effective and efficient.

In the CDM method, sea salt production was divided into 4 stages, namely; 1) water collection and evaporation stage, 2) dynamic mixing stage, 3) storing stage, and 4) crystallization. The explanations of these stages are explained as follows

3.2.1 Water Collection Stage

At this stage, the water used as the raw material of sea salt production was collected in the GST Bosem with a Baumé water scale value of 2-6°Be. GST Bunker for young water was prepared to hold young water from the GST Bosem with a Baumé water scale value of 5-6°Be. Once the water with a Baumé water scale value of 6°Be was enough, the water was then transferred to the GST *Peminihan* I until it reached Baumé water scale value of 7-8°Be.

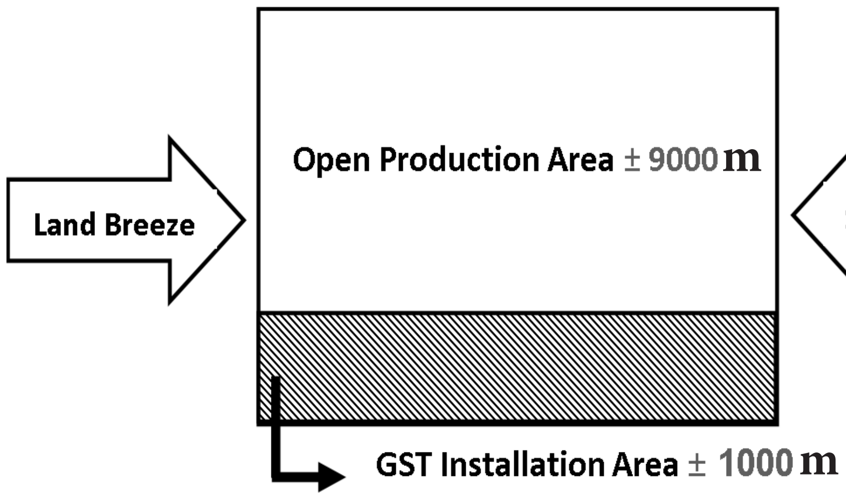

Figure 6. Production Site Management Map with Greenhouse Salt Tunnel technology

3.2.2 Dynamic Mixing Stage

The dynamic mixing stage is the stage of increasing water saturation level from 8°Be to 25°Be. This dynamic mixing stage functioned 6 GST *Peminihan* (*Peminihan* II-VII). The water in the GST *Peminihan* I – VII was continuously and dynamically mixed. Mixing was carried out by transferring the water with lower Baumé scale value to the higher Baumé scale value or vice versa. The primary basis of the transferring process was the Baumé scale value control to get the water with a higher scale value in the volume that was sufficient to be crystallized. Generally, Baumé scale value with CDM method ranged from 8-13°Be, 14-17°Be, 18-21°Be, and 22-25°Be.

3.2.3 Crystallization Stage

The crystallization stage was the final stage in sea salt production using the CDM method in the GST. The water would be flown to the GST Crystallization Table once the volume of aged water was sufficient to fulfill all provided GST crystallization tables (4 GST crystallization). The crystallization stage used aged water with a Baumé scale value of 25°Be to optimize the achievement of NaCl level of the salt produced. The sea salt would be harvested from the existing GST crystallization. Sea salt yields, that has been drained at the production land for about ± 6 hours, were brought into the salt warehouse to be drained again for about ± 4 days. Sea salt produced in this research reached 98.05% of NaCl content with 7% water content. It indicated that the application of the CDM method in GST technology could produce sea salt quality class 1 (K-1).

3.3 The strategy of Sea Salt Production throughout the Year

This research built the CDM method and GST technology to be able to produce sea salt throughout the year. To optimize sea salt production by applying this method and technology, approaches to the sea salt production strategy were needed; therefore, sea salt production could be carried out throughout the year. The strategies are explained as follows:

3.3.1 Site Management and GST

The production concept built in this research was sea salt production on a 1 Ha of production land. 10% of the area was used as GST construction. While the rest of it was an open area that would be optimized during the production period in the dry season. Figure 6 shows the site management map as follows.

In the tunnel installation area, 14 GST buildings were built; they consisted of: a) three Tdanon GSTs with a size of 12 x 5 meter (Bosem, Young Water Bunker and Aged Water Bunker), b) seven GST *Peminihan* with a size of 11 x 4 meter (*Peminihan* I – VII), ad c) four crystallization GSTs with a size of 11 x 4 meter (GST Crystallization I – IV). During the rainy season, all sea salt production processes, started from raw water collection, evaporation, until the crystallization process, would be carried out in the GST building. While during the dry season, all of the GSTs became the crystallization table, and the open land was functioned as the water catchment area of raw water and evaporation.

3.3.2 Conventional Method for Sea Salt Production

To understand the principle of sea salt production using the CDM method in GST, a general description for sea salt production using the conventional method was important to understand. Generally, sea salt production using the conventional method is explained in Table 1. Sea salt production using conventional methods was generally started from the land preparation in May and June. This is because the sea salt production could be carried out in the dry season where most of the salt farms were used as milkfish ponds or left unused. After about two months of preparation and the initial process of water aging, sea salt production was then carried out in July until the end of the dry season (usually around October). Sea salt production would stop once the rainy season started (around November).

the water aging process at the end of the month of the dry season (around October). However, in the conventional methods, aged water produced in that month may not be continued to the crystallization process as it was mixed with the rainwater.

Sea salt production using the CDM method with the GST technology was started by using aged water from the end of the dry season (around October). Some of the existing aged water was collected in the GST Bosem to be continued to the sea salt production series in the rainy season, while some other was directly raised to the GST Crystallization to be made into sea salt. By applying this strategy, sea salt harvest could be carried out in November. After the first harvest in the rainy season, GST crystallization would be refilled with aged water produced

Table 1. Time of Sea Salt Production using Conventional Method

Month											
1	2	3	4	5	6	7	8	9	10	11	12
Not producing			Preparation		Sea salt production				Not producing		

Table 2. Sea Salt Production Time by Using CDM Method with GST Technology in the Rainy Season

Month											
10	11	12	1	2	3	4	5	6	7	8	9
AT*	Aged Water and Salt Production (Rainy Season)						Dry season				

**Aged water produced in the dry season*

Table 3. Sea Salt Production Time by Using CDM Method with GST Technology (in the Dry Season)

Month											
4	5	6	7	8	9	10	11	12	1	2	3
AT*	Aged water & salt production (Dry Season)						Rainy Season				

**Aged water produced in the rainy season*

3.2.3 Production in the Rainy Season Through CDM Method in the GST

The application of the CDM method and GST technology was to optimize the land condition so that it could be used to produce sea salt in the rainy season. The strategy started from the fact that not only the sea salt crystallization process could be carried out, but also through the application of the CDM method in the GST during the rainy season. This allowed sea salt harvest to be carried out during the rainy seasons. At the end of the rainy season (around April), sea salt production kept going on and the production process was focused on preparing the aged water. This aged water would be continued to be crystallized into sea salt in the dry season It should be noted that all of the GST switched function into crystallization tables during the dry season.

3.3.4 Production in the Dry Season Through CDM method in the GST

Different from the conventional method, sea salt production in the dry season with the CDM method approach in the GST would directly start the salt crystallization process at the beginning of the dry season (around May). Aged water that was raised to the crystallization table was the water produced in the end of the rainy season through the CDM method application in the GST.

Along with the sea salt crystallization process in the GST, sea salt farmers could prepare their salt ponds to optimize sea salt production in the dry season as the best season to produce sea salt. The sea salt production strategy in the dry season would be immediately continued to the production strategy in the rainy season as it was explained in advance. By combining these two production strategies, the CDM method application in the GST would allow sea salt production to be carried out throughout the year.

3.3.5 Sea Salt Production Estimation Result

This research carried out sea salt production during the rainy season to determine the best strategies to produce sea salt throughout the year. In this research, sea salt production in the rainy season through the land approach of 1 Ha with 14 units of GST produced a 300 kg/cycle/GST Crystallization of salt yields. 1 cycle of production needed 15 days. Therefore, sea salt yields would reach 1,200 kg/cycle/Ha by applying this production concept. Assuming that the rainy season would last for 6 months, sea salt production in the rainy season would reach 14.4 tons/Ha. This result was the additional yields that could be obtained by applying the CDM method in the GST technology.

In the dry season, the GST would be functioned as a crystallization table. The area used for the GST was ± 1000 m^2, while the remaining (± 9000 m^2) would be used to produce sea salt using the conventional method. This area was prioritized to become a reservoir area of the raw water and evaporation (*peminihan*). Assuming that sea salt production using conventional method would produce 25 tons/month/Ha of sea salt, then in 4 months of dry season (in the conventional method, the first 2 months were used for land preparation; therefore, there was no salt harvest) would produce 100 tons/Ha of sea salt.

Assumed that in the four effective months of production using the GST technology was equal to the conventional method, then the yields obtained in July-October would be 100 tons/Ha. Different from the conventional method, the GST technology application allowed sea salt harvest to be carried out at the beginning of the dry season (May and June). While using the conventional method, those months were used to prepare the land after the rainy season. This would cause an additional salt harvest for 2 months by utilizing GST technology (50 tons/Ha).

By utilizing GST technology and CDM method in sea salt production, then with production approach of I Ha of land area and 14 units of GST as they were used in the in this research, the total number of yields was 14.4 tons in the rainy season plus 150 tons in the dry season. The total estimation of sea salt yields obtained throughout the year was ± 164,4 tons/Ha/year.

In this research, the approach taken was sea salt production in the area of 1 Ha by using 14 units of GST in various sizes (GST Bunker, GST *Peminihan*, GST Crystallization) on the 10% of the land (± 1000 m^2). In its application, the GST size and the land area were very likely to be modified according to the land availability and funding. The result of this research indicated that the GST technology combined with the CDM method in sea salt production could be carried out throughout the year.

4. Conclusion

The result of this research indicated that *Continuously Dynamic Mixing* (CDM) method in sea salt production by using *Greenhouse Salt Tunnel* (GST) could optimized sea salt production in the rainy season. The approach to sea salt production strategy in the rainy season and the dry season synergistically based on the development of the CDM method in the GST technology allowed sea salt production to be carried out throughout the year. With the production approach of I Ha of land area and 14 units of GST, sea salt production obtained in the rainy season was ± 14,4 ton/Ha, and in the dry season was ± 150 ton/Ha. Sea salt yields estimation by applying GST technology and the CDM method with the production strategy approach developed in this research was ± 164.4 tons/Ha/year. The salt produced with the CDM method in the GST contained 98.05% of NaCl with the water content of 7%.

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Authors' Contributions

All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests

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