A New Technique of Plastic Film Covering of Solar Salt Production in the Rainy Region

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ABSTRACT

This paper describes the key of the process reformation—a new technique of plastic film covering used to reduce rainfall effect, which has been developed and solved according to the meteorological characteristics in the rainy region in China through scientific research and production practice. The former short-period crystallization process with frequent salt harvesting has been converted into the year-round crystallization of salt production.

Using the year-round process we are able to utilize nature for high and stable salt production, to improve salt quality and raise mechanization level of salt production. From the preliminary economic benefit obtained, it can be seen that the production cost of solar salt is reduced by more than 20 percent, meeting the demands of the development of salt production. In the paper, the method of spreading and collecting of plastic film and parameters concerned are also introduced. And the new technique is considered to be applicable to solar salt production in a rainy region.

INTRODUCTION

It is not difficult to give a full play to the advantages of solar salt production to utilize nature and save energy in the region with favourable meteorological conditions. How to produce more and better solar salt and to gain better technical and economic benefits in a rainy region, are problems to be studied and solved expeditiously. In the majority of the solar salt producing regions in China, the short-period crystallization process with frequent salt-harvesting has been utilized for many years. Because of inferior quality of salt and low yield per unit area and other problems, it seems that this technique cannot suit the requirements of industry and market. Therefore, we are faced with the need to research into a new technique and reform the former process.

THE PROBLEM PUT FORWARD AND ANALYSIS

Meteorological Conditions in Solar Salt Regions

The solar salt producing regions in China are distributed along the coast from Liaoning Province in the north to Guangxi Province in the South, with a vast and flat land. Of the total salt production in the country, 75% is solar salt. The meteorological conditions of the majority of the region are characterized by raininess in summer. This region of south China has a climate with high temperatures, higher relative humidity and raininess. According to the rainfall amount and the duration of rainy season, the rainy region may be divided into three types of regions. The annual evaporation and rainfall of various regions are tabulated in Table 1. The mean values of the monthly evaporation and rainfall of the three regions are plotted in Figures 1, 2 and 3. The figures show that in Region I, the rainy season is in July and August, in Region II from June to September, and in Region III from June to October. It can be seen clearly from the meteorological characteristics in the solar salt producing region in China that evaporation is still high in the rainy season.

Short-Period Crystallization Process and its Disadvantages

In Region I, the rainy season is comparatively short and rainfall is concentrated. Because the salt production was interrupted by the rainy season, in addition, with low temperature and shortage of brine in winter, a certain proportion of the crystallizing ponds would not operate. The traditional short-period crystallization process was carried out in spring and autumn. They were called "Spring Solar Salt Production" and "Autumn Solar Salt Production," respectively. The salt production from March to June accounted for 80% of the annual salt production.

TABLE 1

Annual Evaporation and Rainfall in the Three Regions

Region	Item	Annual Evaporation (mm)	Annual Rainfall (mm)
I	Mean value in 20 years	1715.9	548.5
	The year of minimum rainfall in 20 years	1898.6	340.5
	The year of maximum rainfall in 20 years	1418.2	886.8
II	Mean value in 20 years	1847.7	947.8
	The year of minimum rainfall in 20 years	2105.8	611.5
	The year of maximum rainfall in 20 years	1867.2	1452.3
III	Mean value in 16 years	1919.4	1108.1
	The year of minimum rainfall in 16 years	2291.0	571.8
	The year of maximum rainfall in 16 years	1790.1	1832.9

Figure 1. The mean value of the monthly evaporation and rainfall of Region I.

Crystallization could continue under the normal climatic conditions. However, due to the wide fluctuation of the frequency and amount of rainfall, salt was harvested frequently. After harvesting, a small amount of salt was left to ensure continuous crystallization. Before the beginning of the rainy season, salt was harvested as completely as possible. Because the crystallization period was short, the amount of salt harvested per hectare each time was only about 100 tons. At the same time, it was necessary to harvest salt with brine still in crystallizing ponds. Due to the clay floor of the ponds, silt must be removed from the salt after harvesting. Crystallizing ponds were fed in parallel and the brine depth was shallow, so it was called "Shallow Pond Crystallization." During crystallization, if there was a light or even moderate rain, in order to protect salt layers, the resulting diluted brine had to be decanted or drained out of crystallizing ponds. In Region II and Region III, the processes were basically similar, but the crystallization period was shorter with more frequent harvesting, and less salt was harvested each time. Here salt was harvested as completely as possible. This kind of process had many disadvantages, such as the wide range in output between bumper harvest and shortfall, low output, inferior quality, low labour efficiency, high cost, high intensity of labour and over-elaborate operations. Another defect was that it was difficult to realize the mechanization of salt production, because salt layers were thin and the amount of salt thus produced was not sufficient to be harvested and transported by mechanical equipment. Furthermore, in the rainy season, the solar salt production was stopped, and after harvesting it was necessary to repair the pond floor. Moreover, a part of the evaporation of the other production season was used to compensate for the loss due to rainfall. So the effective utilization factor of evaporation for this process was very low.

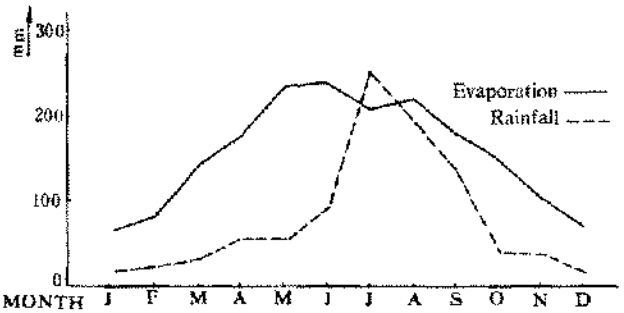

Figure 2. The mean value of the monthly evaporation and rainfall of Region II.

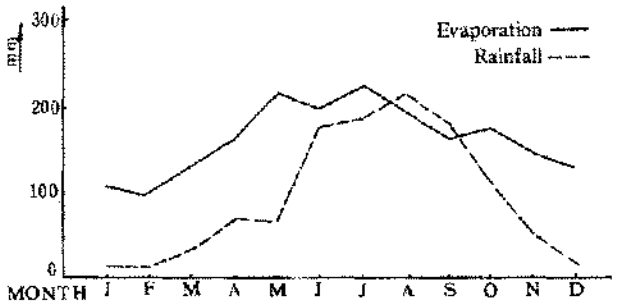

Figure 3. The mean value of the monthly evaporation and rainfall of Region III.

Calculation of Production Capacity and Assumptions

The authors consider that depending on how the problem of rainfall is coped with, there are about three methods that seem to be used as a solar salt production process. One of them is used in the region with favourable meteorological conditions. This is an in-situ evaporation method without decanting the diluted brine from ponds. Another method is used in the rainy region; any diluted brine is decanted or drained out of crystallizing ponds, i.e., the Chinese traditional short-period crystallization process.

The third, assumed, method is that of reducing the rainfall effect. Now we may calculate the salt production capacities based on the above-mentioned methods according to the meteorological conditions of Region I. For simplicity, the following empiric formula is used:

$$G = 3.4418\left[E_d F_g - \tfrac{1}{2}R\left(1 + \frac{1}{F_b}\right)\right]F_b$$

where

- G = salt production (tons) per hectare, based on crystallizing area
- E_d = evaporation (mm) from weather bureau evaporimeter
- F_g = ratio of the evaporation of weather bureau evaporimeter to that of pond area
- F_b = ratio (average value) of evaporation of brine during crystallization to that of pure water
- R = rainfall (mm).

The result of the calculation is shown in Table 2.

The first method is very simple. But in the case of Region I, the salt output will be reduced. In Region II and Region III, salt will not be produced. Therefore, it is very obvious that this method is not feasible. As mentioned above, except that the yield of the second method is low, it has many disadvantages. When the third method is used, it is quite clear that there will be a potential increase in capacity.

How can the influence of rainfall be reduced? In order to make good use of nature, plastic film is used in agriculture. It is also used in solar salt production to prevent brine from leaking through pond floors. If we use plastic film to isolate rainwater from brine and drain it out of ponds, it seems that continuous production is not impossible.

In a word, it is necessary to conduct research into the reform of the traditional process and reduction of rainfall effect according to the meteorological characteristics of the region, so that nature can be fully utilized and the needs of production mechanization may be well satisfied.

THE NEW TECHNIQUE OF PLASTIC FILM COVERING

A waterproof plastic film is selected to cover the brine surface of the crystallizing pond. During rainfall, brine is isolated from rainwater by the plastic film. Therefore, salt layers and brine are protected from the rainfall effect. After rain, rainwater on the plastic film will be drained out of the crystallizing ponds. When the rainwater has been removed, the plastic film is collected and salt production is resumed.

Spreading and Collecting of the Plastic Film

Because of the large area which the plastic film covers, rapid speed is required for spreading and collecting, and the operation frequently encounters strong winds. Hence, spreading and collecting of the plastic film is a very difficult technical problem. It has been solved through research. Spreading and collecting equipment has been successfully test-manufactured. The performances of the equipment are as follows. Each set of equipment can simultaneously spread or collect the plastic films of two crystallizing ponds (the area of each pond is 16,000 m^2). Spreading and collecting of the plastic film can be completed in 20 minutes, respectively. The power consumption of the equipment is low. Its rated power is 7 kw. Only two operators are needed for each pond.

The mechanical equipment for plastic film spreading and collecting is shown in Figure 4. It consists mainly of a drum, a spreading and collecting device, a trailing system and tracks. The drum, with a length of 66 to 88 meters, is the principal component that spreads or collects plastic film. In order to ensure its concentricity and mechanical strength, we must make a special design of it, thereby meeting the requirements.

The spreading and collecting device is used to rotate the drum, which draws the trailing system that is made up of plastic ropes and plank. The trailing system draws plastic film automatically to the tracks, which are fixed to levees of the crystallizing pond and keep the plastic film from being shifted by wind.

After the equipment is installed, first of all, the plastic film may be wound around the drum. When it is necessary to cover the crystallizing pond with plastic film, the spreading and collecting device is started to rotate the drum and spread plastic film. Under the action of the trailing system, plastic film automatically comes into the tracks and covers the brine surface in an orderly fashion.

TABLE 2

Calculation Result of Production Capacity of Crystallizing Pond

Type	I	II	III
Method	The in-situ evaporation method without decanting the diluted brine from ponds	The traditional method—the diluted brine decanted out of pond	The assumed method of reducing rainfall effect (Assume R = 0)
Salt production capacity of crystallizing pond (ton/hectare)	374	900	1824

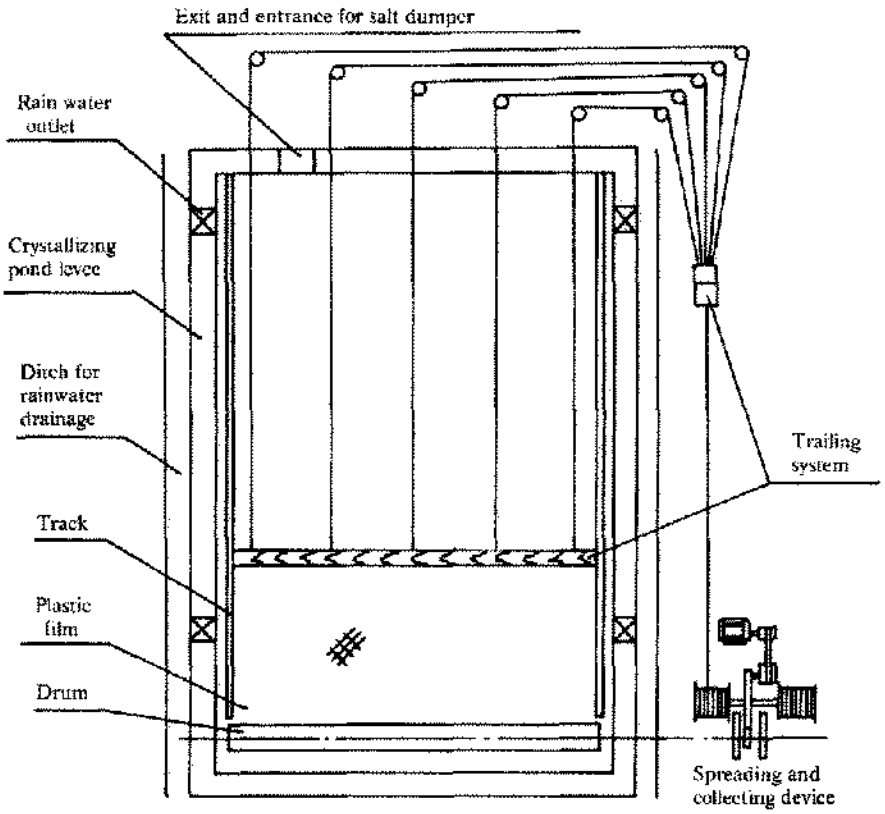

Figure 4. The diagram of plastic film spreading and collecting equipment.

When the ponds are covered completely, the spreading and collecting device is stopped. When it is necessary to collect plastic film, the drum is reversed, so that plastic film automatically and progressively departs from the tracks and it is wound around the drum in good order. As soon as the plastic film is collected completely, the device is stopped.

Selection of Plastic Film

The plastic film used for salt production is a waterproof aging-resistant film with a long service life and low cost. Its thickness varies from 0.1 to 0.15 mm. It is soft in a temperature range from 0° to 50°C and will not react chemically in brine.

The service life of the plastic film is the primary factor that determines the cost. If the service life is short, the plastic film will be replaced frequently. This is not only very wasteful of manpower but also increases the cost. Therefore, it is necessary to develop an aging-resistant plastic film to prolong its service life. Through the indoor experiment of accelerated aging under the circumstances of artificial climate and the outdoor experiment of continuous exposure, the very formulation to prepare the plastic film with the optimum aging-resistant performance was chosen from a lot of formulations. The plastic film prepared according to this formulation has been used for five years and can be further used.

Windproof Problem of Plastic Film

The solution of the windproof problem is a prerequisite to the safe use of plastic film. Before and after rain there is always a strong accompanying wind. Especially problematic is that there are about six typhoons which make landfall on the coast of south China annually. After the typhoons there is torrential rain in general. Therefore, the problem of windproofing must be studied for the application of plastic film covering. Through experiments, the configuration of the crystallizing pond covered with plastic film is modified and the sealing device is used to prevent wind from blowing into the pond through the edges of the plastic film. As a result, this problem has been solved effectively. In salt production, the plastic film used to cover the crystallizing pond can withstand a violent storm (wind speed is 28.5 to 32.6 m/s) so that safety in production may be ensured.

Drainage of Rainwater on Plastic Film

During rain, the rainwater on the plastic film must be drained out of the crystallizing pond simultaneously in order to collect the plastic film after the rain and resume

salt production. Rainwater can flow together by the action of wind, and then through a specially designed outlet device, it is drained rapidly out of the crystallizing ponds. Although the area of crystallizing pond covered with plastic film is large and rainwater on the plastic film is shallow, the surface of the plastic film is flat and sleek and rainwater is apt to flow. Under the action of wind, it flows to the leeward side of the pond. When the wind speed is more than 1.6 to 3.3 m/s, rainwater will be drained out of ponds effectively.

ADVANTAGES AND APPLICATION OF PLASTIC FILM COVERING TECHNIQUE

The success of the development of the plastic film covering technique has solved the key problem in the reformation of the traditional process, bridging the gap between spring and autumn salt production seasons that were interrupted by a rainy season. The year-round crystallization process now can be realized in a rainy region. It not only reduces the rainfall effect and raises the utilization factor of evaporation but also paves the way for adoption of certain technical devices to improve salt quality. Thus a high and stable yield can be obtained. And what is most important is the formation of a thick salt layer so that the amount of salt is large enough to be harvested and transported by mechanical equipment. All the operational procedures, including crystallization, harvesting, transportation, washing and heaping of salt, are integrated properly, thus constituting a complete and perfect process of mechanized production of solar salt. So the mechanization level in solar salt production in the rainy region is raised. The new technique and process have been applied in the rainy region in China and initially changed the state of solar salt production.

Further Utilization of Nature

Solar salt production is carried out under the natural conditions. Hence, it is very important to make good use of favourable factors and avoid unfavourable ones. After the adoption of the plastic film covering technique, compared with the traditional short-period process, nature can be further utilized in the following aspects.

1. *Utilization of evaporation.* Except for the small amount of evaporation that is not utilized during the period when salt is harvested once a year and during rainfall when the crystallizing pond is covered by plastic film, all the rest of evaporation time can be fully used on the basis of improving the accuracy of weather forecasting and technical management. Many problems are solved, such as the problem of evaporation which cannot be utilized during the rainy season in the former short-period crystallization process, the problem of the evaporation consumed by reevaporation of the brine in the crystallizing pond diluted by rainwater, the problem of the evaporation lost due to dissolution of the salt remaining in the crystallizing pond after harvesting, and the problem of the evaporation wasted during the period when the pond floor is under repair and rearrangement. According to the results of the pilot salt plant, the utilization factor of the annual evaporation can reach 80–85% and more than 85% of the annual rainfall loss can be eliminated.

2. *Saturated brine utilization.* The consumption of saturated brine per ton of salt is notably reduced. Through determination, about 5.6 m^3 of saturated brine, including the brine lost due to leakage, will be sufficient to produce one ton of salt. As to the brine used in the short-period process, it would be far more than this figure. The main reason is that the brine in the crystallizing pond was lost due to frequent rainfall and reevaporation was needed for restoration, and the brine loss due to the second leakage would occur. Under the circumstances of heavy rain or swift rain, when the density of diluted brine becomes lower than that of the seawater brought to the salt field, it must be drained out of the salt field. In addition, there were various operations such as the irrigation of the pond, the drainage of the pond, and so forth, that would cause brine loss. Therefore, all this was the reason why the consumption of saturated brine per ton of salt was so high and the utilization factor was low. After the adoption of the plastic film covering technique, the brine in the crystallizing pond was deeper; the crystallizing pond itself plays a role of protection of brine, thus reducing rainfall effect and raising the utilization factor of brine.

Compared with the former short-period crystallization process, because natural processes are further utilized, the salt yields per unit production area in Region I and Region II are increased by 27% and 36%, respectively. The salt yields per crystallizing area are increased by 49% and 71%, respectively.

With the appearance of the plastic film covering technique, it becomes favourable to provide a chemical factory with bittern of a higher density and reduce the coal consumption. It is another aspect to further utilize nature.

Besides, the application of the plastic film covering technique lessens the range between bumper harvest and shortfall in output which is caused by the effect of meteorological factors. It has been proved over the last few years that this range is reduced from ±45% to ±15%.

Improvement of Salt Quality

As far as salt quality is concerned, the main problem is that the salt contains more insoluble impurities. With the appearance of the plastic film covering technique, the conditions to protect the salt floor of the pond in the rainy season are provided. With the year-round crystallization process, salt can be harvested by mechanical equipment

on the salt floor, thus the contradiction between the mechanical harvester and the compressive strength of the pond floor is solved. At the same time, mud impurities from the clay pond floor and dust in rainwater are all avoided. The operation of silt removal in the short-period crystallization process is also omitted. These play an important role in reduction of impurities in salt and improvement of salt quality.

The feeding of ponds in series is better than ponds in parallel, but in the rainy region, it is not suitable to adopt the former. Because rainfall affects normal operation of the method of feeding in series, after rainfall the diluted brine of various steps of the crystallizing ponds due to rainwater must be decanted out of ponds, and before rain the brine must be drained out. In this case, the brines with different densities will mix on a large scale, thus reducing the brine quality and affecting salt quality. With the adoption of the plastic film covering technique, after rain the operation can be carried out continuously by the method of feeding in series. It is favourable to improve salt quality and increase salt production.

Due to rainfall effect, solar salt production could not be carried out with the ideal depth of brine; therefore, the traditional short-period process could only adopt the method of shallow pond crystallization. With the appearance of the plastic film covering technique, crystallization with deep brine can be realized. The depth of brine in a crystallizing pond can be controlled according to different seasons and climate changes. Salt may crystallize out at a comparatively low degree of brine supersaturation, so as to obtain compact and perfect crystals of sodium chloride. With deep brine, slow concentration, low speed of crystallization and a narrow range of change of brine density, temperature and supersaturation and so forth in a day and night, it offers a more stable condition for crystallization. In cooperation with other crystallization circumstances, it is very effective to improve salt quality.

Because of the practice of the new technique and the new process, salt quality has been raised. The data about the salt quality in Region I and Region II are tabulated in Table 3.

Mechanization of Salt Production

After the year-round crystallization process was practised and the mechanization of salt production was realized, we have changed the earlier method by which frequent rush-harvesting was carried out. On the basis of the new process, a new method is used routinely, by which salt is harvested once a year, anytime when necessary. The utilization factor of mechanical equipment is raised. Since the plastic film covering technique is adopted on a large scale in the rainy region in China, various types of mechanized continuous production lines have appeared. In the first type, salt in the crystallizing pond is harvested and transported by harvester and dumper, hydraulic pipes are used for transportation and washing, vibrating screen for dewatering and belt conveyer for stockpiling. In the second type, salt is harvested by pulling rakes, transported by small-size hydraulic pipes, dewatered in the stockpile, and then transported by boat to the store and transportation yard. The advantages of these production lines are very notable. Manpower and production costs are reduced, labour efficiency is raised, labour intensity is lightened and over-elaborate operations avoided. Compared with the short-period crystallization process, the worker's labour productivity in kind is raised. In Region I, Region II and Region III, it is raised by 190%, 100% and 230%, respectively. What is mentioned above indicates the improvement of the mechanization level and preliminary change in the state of solar salt production.

Application in Solar Salt Production

The plastic film covering technique has been popularized in the salt producing regions along the coast of China from Liaoning Province to Guangxi Province. The salt production of the regions where the plastic film covering technique is applied accounts for more than 30% of the total salt production of the country. Preliminary economic benefits are gained. The production cost of salt can be reduced by more than 20%.

CONCLUSIONS

The scientific research and production practice have proved that the application of the plastic film covering

TABLE 3

Data about the Salt Quality in Region I and Region II

Item			Soluble Impurity Ion (%)					
Region	NaCl (%)	H_2O (%)	In Total	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Insoluble Impurities (%)
I	96.10	3.39	0.283	0.17	0.035	0.078		0.06
II	95.13	3.47	0.66	0.41	0.12	0.11	0.02	0.07

technique can efficiently reduce rainfall effect and utilize nature, thereby ensuring stable production, high yield, high quality and mechanization of production of salt. It has promoted the development of salt production and better technical and economic benefits are gained. The authors hold that this technique may be applicable to the regions where the evaporation is still high during the rainy season although the rainfall is large.

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