STUDIES ON THE SALT-PRODUCTION FROM CONCENTRATED SEAWATER AFTER DESALINATION

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Abstract: Seawater desalination is a new solution to the water scarcity. However, if the concentrated seawater is discharged into the ocean directly after desalination, it will do harm to the eco-environment of the inshore area and sea water. The experiment about salt-production from concentrated seawater was performed by Tianjin Changlu Haijing Group Co., Ltd based on the R-O (Reverse Osmosis) seawater desalination research platform with the production capacity of one thousand ton purified water per day which was sponsored by Tianjin Municipal Science & Technology Commission. It shows a new way to combine the seawater desalination technology and salt-producing technology.

Keyword: seawater desalination; concentrated seawater; salt-production technology; biology governing

INTRODUCTION

China is a country that suffers from freshwater shortage, especially in the northern coastal area. Tianjin City is a resource-based water shortage city and is one of the serious water-deficit cities in China; the shortage of fresh water is becoming a bottleneck of the sustainable development of society and economy in Tianjin. To solve this problem efficiently, Tianjin makes great effort in the field of seawater desalination. The R-O (Reverse Osmosis) seawater desalination project with a production capacity of 1,000 ton purified water per day was sponsored by Tianjin Municipal Science & Technology Commission.

Seawater desalination also produces highly concentrated seawater as byproducts with the concentration of 6° Bé in addition to fresh water. If this concentrated seawater is discharged into the sea, it will harm ecosystems of the inshore area and the environment of ocean. On the contrary, if concentrated seawater is used for sea-salt production and the comprehensive utilization of sea chemical resources, the traditional low-concentration brine can be replaced. In this way, not only the release of concentrated seawater is solved, but also the land resource is rational employed and the production of sea salt is increased. Therefore, the experiment about salt-production from concentrated seawater was performed and the results are analyzed and researched.

GOAL OF THE EXPERIMENT

The creature in the normal sea salt production process is a balance system, which can ensure the production and the quality of salt. The inorganic nutrients, such as Nitrogen and Phosphorus, are imbibed by the salt ponds algae in the lower brine concentrating area. The salt pond algae are the food of Artemia. Artemia is decomposed in the area with higher concentrated brine.

There are several differences between seawater and the concentrated seawater after desalination. Firstly, seawater desalination includes a pretreatment on seawater to kill the aquatic organism. If the concentrated seawater is used as raw brine in solar salt plants, the area with lower brine-concentration may have eutrophication problems (rich nutrient) due to the scarcity of salt pond algae. The eutrophication problem of brine may cause Aphanathece slagnina to bloom and decrease the salt production. Secondly the pH of the concentrated seawater and the chemicals used in seawater desalination may also effect the solar salt production.

Facing Bohai Sea, an inland sea in China, the concentrated seawater after desalination becomes a severe problem. Using it as the raw materials of solar salt production is the most promising solution to this problem by now. The difference between seawater and the concentrated seawater may vary the production and the quality of salt. In this paper their differences in solar salt production will be studied.

EXPERIMENT

The experiment includes four parts. Two parts, focusing on the salt production, were conducted by a research team of Tianjin Changlu Haijing Group Co., Ltd. The other two parts, focusing on the biological management, were conducted by a research team of Tianjin University of Science & Technology.

Salt production simulation

The concentration and salt crystallization process of brine from salt ponds and the concentrated seawater after desalination was compared in the experiment. These two kinds of brine evaporate under the same conditions and from the equal concentration. The changes during the concentration were observed until the majority of salt crystallized. Compare the salt production of using different raw brine.

The concentrated seawater after desalination and brine from salt works of Haijing Group were measured in the equal volume at the same concentration. These two kinds of brine evaporate by solar and wind energy in troughs. The changes during the concentration were carefully observed until the concentration was 30°Bé. The salt was collected and analyzed.

Solar evaporation of brine in salt ponds

A modified slat ponds was designed to using the concentrated seawater to produce salt under natural conditions. A comparison was made between the slat production and quality of natural salt production and salt producing by the concentrated seawater. The results were essential for the large scale application of producing salt by the concentrated seawater after desalination. The bioremediation technology was applied to ensure the whole experiment carried out under natural conditions.

Bioremediation technology study

Table 1 Nutrient (N&P) contents of brine in experiment

	Nitrogen (umol/L)	Phosphorus (umol/L)	Others (g/L)	
1#	1000	40		
2#	500	20		
3#	200	8	$FeCl_3.6H_2O$	1.36
4#	100	4	$MnCl_2.4H_2O$	0.4
5#	50	2	H_3BO_3	33.6
6#	25	1	EDTA－2Na	45.0
7#	0	0	0	

Bioremediation

Since Carpelan , L.H. announced the theory of salt pond ecosystem and the relationship between salt pond ecosystem and salt production in 1950s, the effect of salt pond ecosystem has been considered an important factor to obtain higher salt production and better salt quality during the salt production process.

The salt pond ecosystem contained different halophile species in salt pond. The halophile species were interdependent and their connection formed the food chains of the salt pond ecosystem. A balanced salt pond ecosystem was able to increase the salt production and salt quality.

The method of the following bioremediation to the concentrated seawater after desalination was investigated in this experiment in order to rebuild the salt pond ecosystem and bio-manage system.

1) Introduce Dunaliella viridis to the brine (6°Bé) ;

2) Introduce Artemia franciscana to the brine (8°Bé~18°Bé).

Dunaliella viridis was introduced to the modified salt ponds for this experiment in July 4th, 2005. The total solution volume of Dunaliella viridis culture was $10m^3$ and the density was 120×10^4cells/ml, conducted in two steps.

According to the papers posted by Davis and Sorgeloos, Artemia franciscana was suitable to resolve the eutrophication problem of Chinese salt pond. Artemia culture was added into the modified salt pond by the ratio of 15 Artemia franciscana to one liter brine.

RESULTS AND ANALYSIS

Salt production simulation

The chemicals of the brine were analyzed in salt production simulation. The result was showed in table 2&3. The total salt content in the CSD and SW brine was respectively 65.22g/l、66.06g/l in 6.02°Bé;320.47g/l 、 322.76g/l in 26.02°Bé; 363.60g/l、363.26g/l in 30.12°Bé. The results in table4~6 showed that the chemicals of the concentrated seawater after desalination are the same as those of brine from seawater. So salt-production by the concentrated seawater after desalination was the same as salt-production by seawater in chemical point.

Table 2 Chemical composition of concentrated seawater after desalination

	C(°Be′)	T(°C)	Chemical composition (g/l)						
			$CaSO_4$	$MgSO_4$	$MgCl_2$	NaCl	KCl	Na/Mg	pH
CSD	6.26	15	2.59	4.15	6.45	50.65	1.38	8.02	7.40
CSD	9.33	15	3.73	6.16	10.20	76.58	2.09	7.83	7.47
CSD	11.73	15	4.96	7.28	12.70	97.18	2.60	8.11	7.69
CSD	14.73	15	3.81	9.84	16.33	124.20	2.70	7.93	7.45
CSD	15.73	15	3.65	9.98	18.36	137.26	3.07	8.05	7.44
CSD	18.03	15	3.00	11.85	21.93	162.60	4.61	8.00	7.37
CSD	19.83	15	2.48	15.40	24.07	186.51	5.28	7.93	7.29
CSD	21.93	15	2.11	17.08	27.17	210.57	5.95	7.97	7.54
CSD	24.02	15	1.75	14.05	35.08	228.79	6.70	7.63	7.61
CSD	25.82	15	1.75	14.95	37.93	253.52	7.24	7.85	7.43
CSD	26.22	15	1.31	16.50	40.18	254.68	7.80	7.37	7.64
CSD	26.63	15	1.17	27.45	45.69	247.19	9.82	5.65	7.31
CSD	27.08	15	0.82	34.71	55.54	229.92	12.73	4.27	7.34
CSD	27.78	15	0.64	44.92	69.90	210.46	15.81	3.07	7.28
CSD	28.28	15	1.22	52.66	83.97	190.03	18.97	2.33	7.16
CSD	29.18	15	0.58	66.37	102.70	168.63	23.34	1.67	7.05
CSD	30.12	15	0.29	74.23	116.46	147.24	25.38	1.29	7.15
CSD	30.82	15	0.29	80.10	126.10	134.91	28.61	1.1	7.02

Note: CSD—Concentrated Seawater after Desalination.

Table 3 Chemical composition of seawater in concentrating process

	C(°Be′)	T(°C)	Chemical composition (g/l)						
			$CaSO_4$	$MgSO_4$	$MgCl_2$	NaCl	KCl	Na/Mg	pH
SW	6.26	15	2.31	4.63	6.32	51.46	1.34	7.94	8.15
SW	9.63	15	3.62	6.51	10.47	79.45	2.16	7.84	7.28
SW	11.73	15	4.72	8.52	12.84	96.38	2.51	7.58	7.44
SW	14.73	15	3.81	10.36	16.83	128.51	2.70	7.91	7.75
SW	15.63	15	4.04	10.99	17.97	137.06	2.88	7.92	7.65
SW	18.33	15	2.99	11.79	23.25	166.91	3.62	7.89	7.66
SW	19.93	15	2.77	15.85	23.97	188.47	5.16	7.95	7.59
SW	22.23	15	2.04	16.88	27.54	209.53	5.75	7.89	7.70
SW	23.82	15	1.75	14.05	34.67	228.32	6.82	7.68	7.44
SW	26.02	15	1.75	15.85	39.06	258.57	7.53	7.72	7.58
SW	26.42	15	1.75	15.21	39.67	259.01	7.86	7.72	7.46
SW	26.63	15	1.11	29.44	47.58	247.64	9.98	5.38	7.42
SW	27.08	15	0.87	38.54	57.62	228.82	12.73	4.00	7.44
SW	27.78	15	0.87	46.91	72.91	206.00	16.04	2.88	7.36
SW	28.18	15	0.87	55.68	84.34	189.54	18.39	2.27	7.30
SW	29.28	15	0.64	66.45	104.57	166.69	22.88	1.63	7.17
SW	30.12	15	0.29	72.94	115.44	148.59	26.00	1.32	7.02
SW	31.12	15	0.30	82.58	128.89	131.60	28.10	1.04	7.14

Note: SW—Sea Water.

Table 4 Salt production in simulation experiment /kg/m^3

	Sample	Sampling date	Production (wet basis)	Production (dry basis)	Remarks
SW	SW 1#	Sep. 23,2004	15.5	14.5	
	SW 2#	Sep. 23,2004	15.5	14.49	Salt produced by CSD is 14.73 kg/m^3, by SW is 14.50 kg/m^3. Change value 1.59%
	average		15.5	14.5	
CSD	CSD 1#	Sep. 23,2004	15.75	14.53	
	CSD 2#	Sep. 23,2004	15.9	14.93	
	average		15.83	14.73	

Note: CSD—Concentrated Seawater after Desalination;
SW—Sea Water.

Table 5 Salt quality in simulation experiment

Name	Sample	Moisture	H_2O	insoluble sub.	$CaSO_4$	$MgSO_4$	$MgCl_2$	NaCl
Industrial salt	SW1#	6.42	0.58	0.01	0.64	0.35	1.27	90.73
	SW2#	6.52	0.49	0.01	0.7	0.4	1	90.88
	Average(wet basis)	6.47	0.54	0.01	0.67	0.38	1.14	90.81
	Average(dry basis)			0.01	0.72	0.4	1.22	97.65
Industrial salt	CSD1#	7.76	0.64	0.01	0.69	0.59	1.31	89
	CSD2#	6.07	0.47	0.01	0.73	0.4	0.95	91.37
	Average(wet basis)	6.92	0.56	0.01	0.71	0.5	1.13	90.19
	Average(dry basis)			0.01	0.77	0.53	1.22	97.47

Note: CSD—Concentrated Seawater after Desalination;

Table 6 Distribution of industrial salt's particle size in simulation experiment

Name		CSD1#	CSD2#	CSD Average	SW1#	SW2#	SW Average
Sample(g)		288.23	290.41	289.32	289.21	293.38	291.30
screens(g)	>4.0mm	18.76	24.27	21.52	21.27	31.08	26.18
	4~3.5mm	18.56	13.38	15.97	15.07	14.67	14.87
	3.5~2.8mm	63.72	54.43	59.08	67.33	54.22	60.78
	2.8~2.0mm	43.27	40.82	42.05	50.06	45.67	47.87
	2.0~1.0mm	94.54	100.95	97.75	112.57	101.62	107.10
	<1.0mm	49.38	56.56	52.97	22.91	46.12	34.52
ratio(%)	>4.0mm	6.51	8.36	7.43	7.35	10.59	8.97
	4~3.5mm	6.44	4.61	5.52	5.21	5.00	5.11
	3.5~2.8mm	22.11	18.74	20.42	23.28	18.48	20.88
	2.8~2.0mm	15.01	14.06	14.53	17.31	15.57	16.44
	2.0~1.0mm	32.80	34.76	33.78	38.92	34.64	36.78
	<1.0mm	17.13	19.48	18.30	7.92	15.72	11.82
average size(mm)			2.19			2.27	

Solar evaporation of brine in salt ponds

The experiment about solar evaporation of two kinds of brine in salt ponds (concentrated seawater after desalination and seawater) showed a slight increase of salt production by the former brine. The salt produced by the concentrated seawater after desalination was 0.51% higher than that produced by seawater at the same salt pond area. Water content of the salt produced by the concentrated seawater after desalination was almost the same as that of salt produced by seawater.

Table 7 Salt yield comparison produced by two kinds of brine

Product	Raw material	Duration of salt making process	Production Area (m^2)	Salt yeild (kg)	Salt yeild per unit Production area (kg/m^2)
Industrial salt	CSD	From 12th, June2005 to 12th, June 2006	900	151500	168.33
Industrial salt	SW	From 12th, June2005 to 12th, June 2006	51840	8682000	167.48

Note: CSD—Concentrated Seawater after Desalination;
SW—Sea Water.

Table 8 Salt quality comparison produced by two kinds of brine

Note: CSD—Concentrated Seawater after Desalination;

Name	Raw brine	Moisture	insoluble sub.	CaSO4	MgSO4	MgCl2	NaCl
Industrial salt	CSD	3.33	0.07	0.45	0.09	0.28	95.75
		1.6	0.04	0.49	0.15	0.3	97.15
		2.28	0.02	0.5	0.06	0.23	96.81
Average		2.5	0.04	0.48	0.1	0.27	96.57
Industrial salt	SW	2.62	0.03	0.3	0.18	0.52	96.64
		2.07	0.03	0.32	0.22	0.46	96.97
		2.3	0.03	0.42	0.14	0.31	96.6
Average		2.33	0.03	0.35	0.18	0.43	96.74

SW—Sea Water.

Bioremediation technology experiment

From table 5, we can conclude that the average nutrient (N&P) uptake rate of Dunaliella viridis was 96.6%. The results show an increase nutrient uptake rate by boost the initiative nutrient density, both to N and P. This may be induced by different proliferation of Dunaliella viridis in the brine.

The experiment about the Artemia's ingestion rate of Dunaliella viridis showed that the optimal Dunaliella viridis density is 100×104cells/ml brine for 500×104Artemia per liter brine in Artemia incubation.

Table 9 Conversion rate of nutrient and phosphorus of Dunaliella viridis

	Starting nitrogen density (mg/L)	Ending nitrogen density (mg/L)	nitrogen uptake rate (%)	Starting phosphorus density (mg/L)	Ending phosphorus density (mg/L)	phosphorus uptake rate (%)
1#	14.383	0.107	99.3	1.321	0.065	95.1
2#	7.383	0.052	99.3	0.701	0.015	97.9
3#	3.183	0.039	98.8	0.329	0.017	94.8
4#	1.783	0.041	97.7	0.205	0.013	93.6
5#	1.083	0.037	96.6	0.143	0.015	89.8
6#	0.733	0.030	95.9	0.112	0.012	89.4
7#	0.383	0.044	88.5	0.081	0.012	85.3

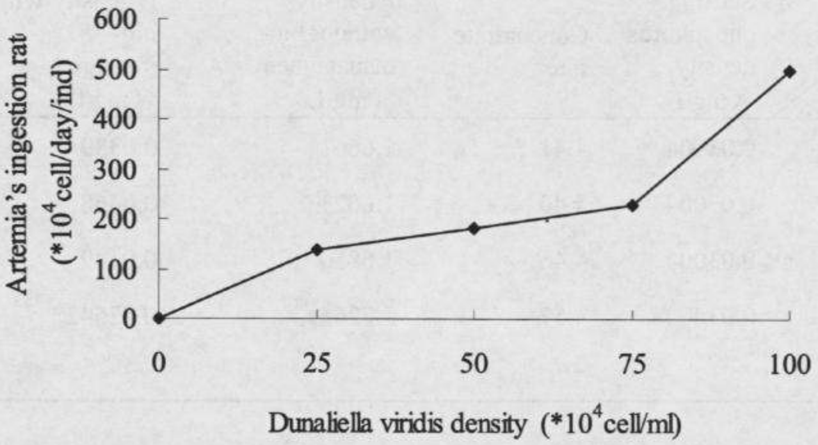

Fig. 1 Experiment about the Artemia's ingestion rate of Dunaliella viridis

Biological control

The large scale experiment in salt pond lasedt for one year and the results showed that the restore period of salt pond bio-system for salt production by the concentrated seawater after desalination need approximately three month to achieve bio-management capacity like that of natural salt pond.

Table 10 Experiment about inorganic nutrient (Nitrogen) reducing rate

	Starting nitrogen density (mg/L)	Concentrate rate	N density without bio-management (mg/L)	N density with bio-management (mg/L)	nitrogen uptake rate (%)
2005.7	0.3778	4.41	1.6661	0.422	74.7
2005.9	0.3778	4.40	1.6623	0.144	91.3
2005.11	0.3778	4.46	1.6850	0.424	74.8
2006.6	0.3778	4.57	1.7265	0.7116	58.8
Average	—	—	—	—	74.9

Table 11 Experiment about inorganic phosphorus reducing rate

	Starting phosphorus density (mg/L)	Concentrate rate	P density without bio-management (mg/L)	P density with bio-manage (mg/L)	phosphorus uptake rate (%)
2005.7	0.03004	4.41	1.6661	0.0339	74.4
2005.9	0.03004	4.40	1.6623	0.0468	64.6
2005.11	0.03004	4.46	1.6850	0.0149	88.9
2006.6	0.03004	4.57	1.7265	0.02542	81.5
Average	—	—	—	—	77.4

Table 12 The investigation results about halophilic bacteria density in salt pond using two kinds of brine

(Uint/ml brine)

	CSD1	CSD2	CSD3	SW1	SW2	SW3
2005.9	650	150	20	1200	330	80
2005.11	1150	350	80	1300	300	100
2006.6	850	200	60	720	230	40

CONCLUSIONS

The experiment in lab shows that the concentrated seawater after desalination can be used for salt production and the large scale experiment with bioremediation verify it. So the seawater, a kind of raw materials in salt making method, can be replaced by the concentrated seawater after desalination. Making salt by the concentrated seawater after desalination can raise salt production as well as avoid pollution to the inshore area, especially for Bohai Sea. Still, there are some difficulties to be settled, such as the pollution evaluation of the chemicals used in seawater desalination procedure and the management and recovery of salt pond ecosystem using the concentrated seawater after desalination as raw material. Further research and investigation should be carried on.

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