

A NEW UTILIZATION APPROACH OF NATURAL SODA ASH: TO MANUFACTURE SODIUM PERCARBONATE

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Abstract— Until now, natural soda ash ore is only used for manufacturing sodium carbonate and other common chemicals. As a fine chemical, the traditional method of sodium percarbonate takes sodium carbonate and hydrogen peroxide as raw materials. The primary goal of the present research is to explore a holistic route to manufacture sodium percarbonate from natural soda ash. The integrated approach avoids the operations of deep evaporation and calcination in the traditional manufacture process of sodium carbonate from natural soda ash. It also avoids the dissolution of merchandise sodium carbonate and any addition of salting-out agents in the production of sodium percarbonate. Taking Chagannuoer natural soda ash as raw material, the operating conditions were optimized by means of an orthogonal design $L_{32}(4^9)$. The results indicate that the availability ratios of H_2O_2 and Na_2CO_3 are higher than 75% and 81% respectively under optimal conditions. The IR and XRD characterizations denote that the major component of the prepared product is $Na_2CO_3 \cdot 1.5H_2O_2$. The research provides a case study for processes integration, and possibly contributes to the investigation of utilizing other natural resources.

Keywords— natural soda ash; sodium percarbonate; process integration; multi-index orthogonal design; natural resource

I. INTRODUCTION

Natural soda ash ore, is an mineral consisting mainly of soda ash (sodium carbonate, Na_2CO_3). Sodium bicarbonate ($NaHCO_3$), sodium sulphate (Na_2SO_4), and sodium chloride ($NaCl$) usually occur with Na_2CO_3 in natural soda ash. Vast natural soda ash deposits are widely distributed in nature, such as the Green River Basin of America, Inner Mongolia plateau and Henan province of China, the rift valley system of East Africa, and other areas around the world. Natural soda ash has been widely used to produce Na_2CO_3 , $NaHCO_3$, $NaOH$, Na_2SO_4 , and other common chemical products in the past several years. However, the high value-added fine chemical prepared from natural soda ash has not been reported.

The production processes of sodium carbonate from natural soda ash are usually classified as “monohydrate process”, “carbonation process”, and “sodium sesquicarbonate process”(China Soda Industry Association, 1990). These processes comprise a deep evaporation followed by a calcination step to convert monohydrate sodium carbonate ($Na_2CO_3 \cdot H_2O$), sodium bicar-

bonates, or sodium sesquicarbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) into anhydrous sodium carbonate, thus require the use of large quantities of coal fuel, gas or mixtures thereof. A typical monohydrate process is shown in Fig. 1.

Sodium percarbonate (SPC) is a non-toxic, water-soluble, crystalline peroxygen compound with the molecular formula $Na_2CO_3 \cdot 1.5H_2O_2$. It has a theoretical active oxygen concentration (AO) of 15.28% by weight. Sodium carbonate and hydrogen peroxide (H_2O_2) are released when SPC is dissolved in water. Owing to this characteristic, SPC finds widespread applications as bleaching agent, oxidizing agent, oxygen producing agent, disinfectant and so on (Chen and Chen, 2009).

The preparation methods of SPC, normally employing a reaction between hydrogen peroxide and sodium carbonate, are often classified as “dry process” and “wet process” and the latter is more widely used (Chen and Chen, 2009; Zhang and Zeng, 2005). To restrain the catalytic effects of transition metal ions in merchandise sodium carbonate on the decomposition of peroxide, stabilizing agents are usually introduced into the reaction system. The steps of wet process can be listed as: 1) mixing aqueous solutions of sodium carbonate and hydrogen peroxide under controlled reaction conditions, which include the concentrations, temperature, reaction time, and stabilizer; 2) after that SPC will crystallize out from the reaction system and then be separated by filtration or centrifugation. According to several published researches (Zhang and Zeng, 2005; Zhao *et al.*, 2006a,b), sodium sulphate and sodium chloride are usually used as salting-out agents in the production of SPC.

Process integration pays attention to the interactions between different unit operations and emphasizes a holistic approach to process design and allows industrial productions to be more economic, efficient and environmental friendly (El-Halwagi Mahmoud, 2006). In order to avoid the steps of deep evaporation and calcination in the manufacturing processes of sodium carbonate from natural soda ash, and the salting-out agents addition in the production of SPC, this investigation tries to obtain SPC from natural soda ash and hydrogen peroxide without adding extra salting-agents.

II. EXPERIMENTAL SECTION

A. Investigation System

Chagannuoer natural soda ash ore is located in Inner Mongolia of China contains more than 40 billion metric tons of fine ore, with the average composition shown in Table 1. Containing many kinds of typical associated

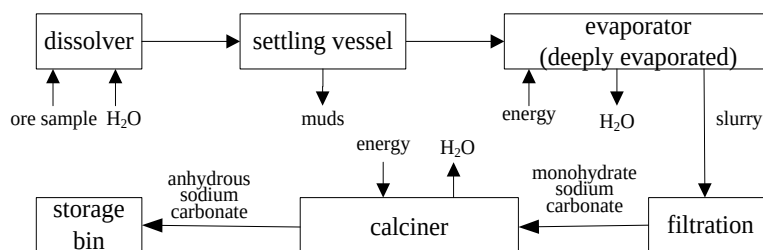


Fig. 1. Typical preparation process of sodium carbonate from natural soda ash

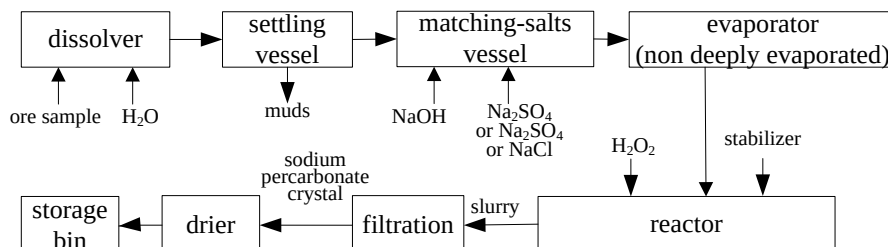
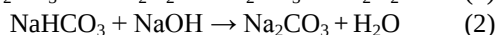
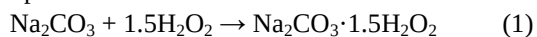


Fig. 2. The preparation route of SPC from natural soda ash

salts, the ore is a representative raw material. The total content of Na_2SO_4 and NaCl is relatively high, helpful to salt-out the SPC product.

B. Overall Idea

Our overall idea to produce SPC from natural soda ash is shown in Fig. 2, and the equation for main reaction is listed as Eq.1. The sample collected from Chagannuoer natural soda ash ore is crushed and then dissolved in water. To obtain clean natural soda ash solution, the cloudy suspension is flocculently flocculated. To fully utilize NaHCO_3 , stoichiometric sodium hydroxide (NaOH) is added into the clear solution to convert NaHCO_3 into Na_2CO_3 , and the reaction equation is shown in Eq.2. To improve the consistency, the weight ratio of $\text{Na}_2\text{CO}_3 : \text{Na}_2\text{SO}_4 : \text{NaCl}$ component ratio in the solution will be adjusted to the same as that of the neutralized average composition of the ore, which is given in Table 1. We call the operation as “matching-salts”. Then the liquid reacts with H_2O_2 , and the SPC crystal will be obtained after filtrating and drying operations. It should be noted that the process is designed only for experimental investigation. In large-scale production, if the concentrations of solutes could be high enough to satisfy the demand of the subsequent reaction, the evaporation operation can be elided.



C. Reagents and instruments

Sodium carbonate, sodium sulphate, sodium chloride, sodium silicate, Ethylenediaminetetraacetic acid disodium salt and hydrogen peroxide are of analytical grade. The SPC product was analyzed by X-Ray diffraction analyzer (D/MAX-III A, Kigaku, Japan) and FT-IR (FT-IR1730, Perkin-Elmer, America).

D. Investigation method

Preparation of natural soda ash solution or suspension

The chemistry analysis of the ore sample is reported in Table 1. The ore sample crushed by a wooden hammer was dissolved in water within a stainless barrel at $80 \pm 1^\circ\text{C}$. After 3 hours' agitation, the suspension was settled under the presence of anion flocculant (CW-0704) for more than 12 hours at $68 \pm 1^\circ\text{C}$, and then the clear solution was carefully transferred into another stainless barrel. According to Table 2, matching-salts was performed to adjust the weight ratio of $\text{Na}_2\text{CO}_3 : \text{Na}_2\text{SO}_4 : \text{NaCl}$ to 22.5:8.74:1. To investigate the effect of the concentration of Na_2CO_3 , the clear solution was concentrated by evaporation.

Preparation of SPC

Natural soda ash solution or suspension containing 50 g sodium carbonate was allowed to react with H_2O_2 added at a certain feed rate. The wet SPC product was obtained from the reaction slurry by vacuum filtration and then was dried in a vacuum oven at 50°C under the pressure of 160 mmHg. The yield (mass, g) and AO value of SPC are used to evaluate the experimental performance. The $L_{32}(4^9)$ orthogonal table (Ma *et al.*, 1989) is employed to investigate the following eight factors: (A) reaction temperature, (B) reaction time, (C) molar ratio of $\text{H}_2\text{O}_2 : \text{Na}_2\text{CO}_3$, (D) feeding time of H_2O_2 , (E) concentration of Na_2CO_3 , (F) concentration of H_2O_2 , (G) dosage of sodium silicate (stabilizer), and (H) dosage of Ethylenediaminetetraacetic acid disodium salt (stabilizer). The factor and level settings are shown in Table 2. The experiment conditions and results are listed in Table 3. The significance tests of different factors on yield and AO are evaluated by means of the F-test, and the final optimized conditions are determined by the multi-index comprehensive evaluation method (Li and Hu, 2009).

Chemical analysis methods

Analysis for ore sample and natural soda ash solution

The total alkalinity (involving sodium bicarbonate and sodium carbonate) was titrated using methyl orange solution as indicator (with a mass fraction uncertainty of

1.2%). Sodium bicarbonate was determined using phenolphthalein solution as the indicator (with a mass fraction uncertainty of 1.5%). Sodium carbonate was determined by the quantity difference between total alkaline and sodium bicarbonate. Sodium sulphate was determined by gravimetric method. Sodium chloride was determined by Mohr's method.

Analysis for SPC

The AO of SPC was titrated using potassium permanganate standard solution (with a mass fraction uncertainty of 0.2%). The carbonate was determined by sulfuric acid solution using phenolphthalein solution as the indicator as before (with a mass fraction uncertainty of 1.2%).

III. RESULTS AND DISCUSSION

A. Preparation of clean natural soda ash liquid

According to the mass compositions of the ore sample and clean liquid listed in Table 1, the content of Na_2CO_3 is slightly higher but those of other constituents are slightly lower than the mean ore composition (shown in Table 1). After introducing stoichiometric NaOH to turn NaHCO_3 into Na_2CO_3 , a given quantity of Na_2SO_4 and NaCl are added to make the mass ratio of Na_2CO_3 : Na_2SO_4 : NaCl equal to 22.5:8.74:1.

B. Preparation of SPC

The orthogonal design scheme, experimental results and the consequences of statistical analysis for yield and AO indexes are presented in Table 2-4, respectively.

The yield of obtained SPC appears to vary markedly from 19.15 to 68.95 g. K_1 , K_2 , K_3 , and K_4 represent the total yield of Level 1, Level 2, Level 3 and Level 4 of a certain factor, respectively. If F value of a factor is higher than the F-critical at the significance level of 0.01, 0.05, or 0.10, the factor is significant at the confidence level of 0.99, 0.95, or 0.90 and is given the significance symbol of ***, **, or *, respectively. In Table 4, the variance analysis shows that at the 99% confidence level, the effects of the reaction temperature (A), concentration of Na_2CO_3 (E), and concentration of H_2O_2 (F) are confirmed. At the 95% confidence level, the effects of the reaction time (B) and molar ratio (C) are acknowledged. According to K_1 , K_2 , K_3 and K_4 , considering the production cost, the optimal conditions merely for yield index can be taken as $A_1B_1C_3D_4E_3F_2G_3H_4$, which are: reaction temperature, 20°C; reaction time, 60 min; mole ratio of H_2O_2 : Na_2CO_3 , 1.45; feeding time of H_2O_2 , 20 min; concentration of Na_2CO_3 , 33%; concentration of H_2O_2 , 50%; dosage of sodium silicate, 0.001 mol; dosage of Ethylenediaminetetraacetic acid disodium salt, 0.001 mol.

The AO of obtained SPC is relatively high and appears to vary from 11.62 to 14.73. K_1 , K_2 , K_3 , and K_4

represent AO sum of Level 1, Level 2, Level 3 and Level 4 of a certain factor, respectively. Table 4 indicates the summary of the variance analysis. From the table, it is clear that the effects of reaction temperature (A) and concentration of Na_2CO_3 (E) are confirmed at the 99% confidence level. At the 95% confidence level, the effects of the feed time of H_2O_2 (D) and dosage of sodium silicate (G) are acknowledged. The molar ratio (C) is also of consequence, which is statistically significant at the 90% confidence level. According to K_1 , K_2 , K_3 and K_4 , with consideration of the production costs, the optimal conditions only for AO index can be taken as $A_3B_4C_2D_1E_1F_4G_1H_4$, which are: reaction temperature, 30 °C; reaction time, 30 min; mole ratio of H_2O_2 : Na_2CO_3 , 1.5; feeding time of H_2O_2 , 40 min; concentration of Na_2CO_3 , 20%; concentration of H_2O_2 , 20%; dosage of sodium silicate, 0.004 mol; dosage of Ethylenediaminetetraacetic acid disodium salt, 0.001 mol.

According to Table 4 and the above analysis, dosage of Ethylenediaminetetraacetic acid disodium salt (H) isn't statistically significant for any index and thus can be picked as H_4 . Since feed time of H_2O_2 (D) and dosage of sodium silicate (G) only have significant effect on AO index, they can be taken as D_1 and G_1 respectively. Reaction time (B) and molar ratio (C) can be selected as B_1 and C_3 , respectively, as they are more significant for yield index than for AO index. There are larger gaps between the F values of Factor A or E and critical value used in F test for index yield than for AO index at the same confidence level, that means the two factors have more significance for yield index than for AO index, thus factor A and E can be chosen as A_1 and E_3 , respectively. Based on these analyses, without involving the concentration of H_2O_2 , the optimized condition can be determined as $A_1B_1C_3D_1E_3G_1H_4$.

Although concentration of H_2O_2 is significant only for yield index, with a view to the cost of various concentrations of H_2O_2 , the determination of Factor F needs further investigation and economic evaluation. The supplementary experimental results investigating the effect of the concentrations of H_2O_2 under the above optimized condition ($A_1B_1C_3D_1E_3G_1H_4$) are shown in Table 5. It can be seen that the utilization rates of H_2O_2 and Na_2CO_3 grow with the increase of the H_2O_2 concentrations but there is only slightly increase when the concentration rises from 35% to 50%. However, the AO decreases evidently with the increase of H_2O_2 concentration. Taking into consideration of the cost, the concentration of H_2O_2 can be chosen as from 27.5% to 35%.

Table 1. Mass composition of Chagannuoer natural soda ash ore, sample and clean liquid

Item	Na_2CO_3 /%	NaHCO_3 /%	Na_2SO_4 /%	NaCl/%	H_2O /%	Insolubles/%
average composition*	24.83	2.79	11.01	1.26	56.29	3.28
Ore sample	27.62	1.49	10.05	1.11	56.31	3.13
Clean liquid before matching salts	9.80	0.42	3.58	0.36	85.84	—
Clean liquid after matching salts	10.26	—	3.99	0.45	85.30	—

*According to reference (China Soda Industry Association, 1990)

Table 2. Experimental factors and levels

levels	Factors							
	A /°C	B /min	C	D /min	E /%	F /%	G /mol	H /mol
1	20	60	1.30	40	20	35.0	0.004	0.006
2	25	180	1.50	50	30	50.0	0.002	0.002
3	30	120	1.45	30	33	27.5	0.001	0.004
4	35	30	1.40	20	25	20.0	0.006	0.001

According to the above analysis, the final optimized conditions are as follows: temperature 20°C, reaction time 60 min, mole ratio of $\text{H}_2\text{O}_2:\text{Na}_2\text{CO}_3$ 1.45, concentration of Na_2CO_3 33%, dosage of sodium silicate 0.004 mol, dosage of Ethylenediaminetetraacetic acid disodium salt 0.001 mol, feed time of H_2O_2 40 min, and concentration of H_2O_2 27.5-35%.

As shown in Table 5, under the optimized conditions, the availability ratios of H_2O_2 and Na_2CO_3 are higher than 75% and 81% respectively. The product prepared with 27.5% H_2O_2 was used for IR and XRD identification.

C. Identification of SPC product

IR spectra of the obtained sample was investigated in KBr pellets and recorded in the range of 450-4000 cm^{-1} . The comparison in Table 6 shows that the observed bands of the sample are in agreement with the values of $\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}$ published by Jones and Griffith

(1980). It should be noted that the splitting of the torsion of O-H is not observed, which may be related with the crystal quality or measure conditions. The IR data of $\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}$ at 25°C reported by Carrondo *et al.* (1977) also does not involve the splitting of the torsion of O-H.

The most intense peaks should be pay attention to when manipulating X-ray diffraction data (Warren, 1990). The d values of eight most intense peaks and maximum d value at scattering angles (2 θ) of 34.95°, 37.09°, 32.64°, 32.85°, 45.72°, 26.51°, 23.58°, 24.57°, and 11.22°, are 2.57, 2.42, 2.75, 2.73, 1.98, 3.37, 3.78, 3.63, and 7.92, respectively, which are in relative agreement with the data reported by PDF card (no 11-656) corresponding to $\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}$.

According to the above discussion, the major component of the sample is $\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}$.

IV. CONCLUSIONS

An efficient route to manufacture sodium percarbonate from natural soda ash instead of sodium carbonate is explored. The process conditions were optimized by means of multi-factor orthogonal test method. Taking Chagannuoer natural soda ash as raw material, the optimal conditions are easy control and described as follows: reaction temperature, 20°C; reaction time, 60 min; mole ratio of $\text{H}_2\text{O}_2:\text{Na}_2\text{CO}_3$, 1.45; concentration of

Table 3. Results of $L_{32}(4^9)$ orthogonal experiments

no	factors									Yield /g	AO /%
	A(1)	B(2)	C(3)	D(4)	E(5)	F(6)	G(7)	H(8)	Blank(9)		
1	1	1	1	1	1	1	1	1	1	43.80	14.58
2	1	2	2	2	2	2	2	2	2	57.45	12.54
3	1	3	3	3	3	3	3	3	3	59.70	12.01
4	1	4	4	4	4	4	4	4	4	50.20	12.83
5	2	1	1	2	2	3	3	4	4	51.60	12.62
6	2	2	2	1	1	4	4	3	3	33.30	14.73
7	2	3	3	4	4	1	1	2	2	53.35	12.46
8	2	4	4	3	3	2	2	1	1	65.40	11.85
9	3	1	2	3	4	1	2	3	4	52.85	14.28
10	3	2	1	4	3	2	1	4	3	55.35	12.75
11	3	3	4	1	2	3	4	1	2	53.60	13.50
12	3	4	3	2	1	4	3	2	1	33.85	14.25
13	4	1	2	4	3	3	4	2	1	56.80	12.31
14	4	2	1	3	4	4	3	1	2	20.90	12.81
15	4	3	4	2	1	1	2	4	3	27.50	13.00
16	4	4	3	1	2	2	1	3	4	52.75	13.02
17	1	1	4	1	4	2	3	2	3	55.90	11.62
18	1	2	3	2	3	1	4	1	4	68.95	11.69
19	1	3	2	3	2	4	1	4	1	53.30	12.20
20	1	4	1	4	1	3	2	3	2	41.50	12.34
21	2	1	4	2	3	4	1	3	2	50.85	12.94
22	2	2	3	1	4	3	2	4	1	45.50	13.27
23	2	3	2	4	1	2	3	1	4	45.90	13.22
24	2	4	1	3	2	1	4	2	3	57.90	12.49
25	3	1	3	3	1	2	4	4	2	44.50	14.58
26	3	2	4	4	2	1	3	3	1	52.60	12.46
27	3	3	1	1	3	4	2	2	4	42.50	12.85
28	3	4	2	2	4	3	1	1	3	48.55	13.94
29	4	1	3	4	2	4	2	1	3	49.00	13.01
30	4	2	4	3	1	3	1	2	4	19.15	14.46
31	4	3	1	2	4	2	4	3	1	38.30	13.97
32	4	4	2	1	3	1	3	4	2	53.35	13.27

Table 4. Statistical analysis for the orthogonal experimental results

index		A(1)	B(2)	C(3)	D(4)	E(5)	F(6)	G(7)	H(8)	Blank(9)
Yield	K ₁	430.80	405.30	351.85	380.70	289.50	410.3	377.10	396.10	389.55
	K ₂	403.80	353.20	401.50	377.05	428.20	415.55	381.70	376.90	375.50
	K ₃	383.80	374.15	407.60	373.70	452.90	376.40	373.80	393.65	387.20
	K ₄	317.75	403.50	375.20	404.70	365.55	333.90	403.55	369.50	383.90
	Sum of square	871.42	234.95	246.78	74.22	1996.4	531.86	67.39	62.52	14.162
	Degree of freedom	3	3	3	3	3	3	3	3	3
	F	61.532	16.59	17.426	5.24	140.97	37.56	4.76	4.42	
AO	Significance test	***	**	**		***	***			
	K ₁	99.81	105.94	104.41	106.84	116.16	104.23	106.35	104.60	104.89
	K ₂	103.58	104.71	106.49	104.95	101.84	103.55	103.14	102.98	104.44
	K ₃	108.61	103.21	104.29	104.68	99.67	104.45	102.26	105.61	103.55
	K ₄	105.85	103.99	102.66	101.38	105.18	105.62	106.10	104.66	104.97
	Sum of square	5.19	0.50	0.92	1.93	9.40	0.28	1.61	0.45	0.16
	Degree of freedom	3	3	3	3	3	3	3	3	3
	F	32.63	3.17	5.80	12.12	59.06	1.75	10.09	2.80	
	Significance test	***		*	**	***		**		

F-critical (Li and Hu, 2009): $F_{0.01}(3,3)=29.46$, $F_{0.05}(3,3)=9.28$, $F_{0.10}(3,3)=5.39$ **Table 5.** The effects of concentration of H₂O₂

Concentration of H ₂ O ₂ / %	Yield / g	AO / %	Utilization rate / %	
			H ₂ O ₂	Na ₂ CO ₃
27.5	61.0	13.55	75.5	81.0
35.0	66.8	12.81	78.1	85.4
50.0	70.3	12.44	79.9	87.5

Table 6. Comparison of IR analysis of SPC sample and literature

absorbed bands of sample	absorbed bands of CO ₃ ²⁻ in Na ₂ CO ₃ ·1.5H ₂ O ₂ **
857	855
1446	1435
697,715	693,715
absorbed bands of sample	absorbed bands of H ₂ O ₂ in Na ₂ CO ₃ ·1.5H ₂ O ₂ **
3050,2900	3030,2900
1558	1570,1550
880,871	873,868
990,958	985,960
2505,2340	2490,2350

**According to reference (Jones and Griffith,1980)

Na₂CO₃, 33%; dosage of sodium silicate, 0.004 mol; dosage of Ethylenediaminetetraacetic acid disodium salt, 0.001 mol; feeding time of H₂O₂, 40 min; concentration of H₂O₂, 27.5-35%. The availability ratios of H₂O₂ and Na₂CO₃ are higher than 75% and 81% respectively. IR and XRD identification denote that the major component of the prepared product is Na₂CO₃·1.5 H₂O₂. The research provides a new approach to produce fine chemical from natural soda ash.

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REFERENCES

- Carrondo, C.T., W.P. Griffith, D.P. Jones and A.C. Skapski, "X-Ray Crystal Structure of the Industrial Bleaching Agent 'Sodium Percarbonate'[Sodium Carbonate-hydrogen Peroxide (2/3)]," *J. Chem. Soc. Dalton Trans.*, **23**, 2323-2327 (1977).
- Chen, X. and D. Chen, "Synthesis and Stabilization of Low-bulk-density Sodium Percarbonate," *Chemical Industry and Engineering Progress* (In Chinese), **28**, 292-296 (2009).
- China Soda Industry Association, *Soda Engineering Science*, Chemical Industry Press, Beijing (In Chinese) (1990).
- El-Halwagi Mahmoud, M., *Process Integration*, Elsevier Academic Press, London (2006).
- Jones, D.P. and W.P. Griffith, "Alkali-metal Peroxocarbonates, M₂[CO₃]·nH₂O₂, M₂[C₂O₆], M[HCO₄]·nH₂O, and Li₂[CO₄]·H₂O," *J. Chem. Soc. Dalton Trans.*, **12**, 2526-2532 (1980).
- Li, Y. and C. Hu, *Experiment Design and Data Processing*, Chemical Industry Press, Beijing (In Chinese) (2009).
- Ma, F., L. He, M. Yu and J. Fan, *Applied Probability and Statistics*, Higher Education Press, Beijing (In Chinese) (1989).
- Warren, B. E., *X-ray diffraction*, Dover Publications, New York (1990).
- Zhang, K. and F. Zeng, "The Production and Research Progress of Sodium Percarbonate," *Inorganic Chemicals Industry*, **37**, 18-20 (In Chinese) (2005).
- Zhao, H., C. Tang, D. Zhang, W. Xu and Y. Wang, "Solid-Liquid Equilibrium for the Quaternary System of Sodium Carbonate + Sodium Chloride + Hydrogen Peroxide + Water at 293.15 K," *J. Chem. Eng. Data*, **51**, 676-679 (2006a).
- Zhao, H., C. Tang, D. Zhang, W. Xu, Y. Wang and P. Jian, "Solubility and Phase Diagram for the Quaternary System Na₂CO₃ + Na₂SO₄ + H₂O₂ + H₂O at 293 K," *J. Chem. Eng. Data*, **51**, 1567-1570 (2006b).

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