Vol. 10, No. 3, 2016 Chemical Technology

Oleg Yurchenko[1], Olga Kalinenko[1], Olexandr Baklanov[1] and Larisa Baklanova[2]

THE USE OF ULTRASOUND FOR OBTAINING PHARMACEUTICAL GRADE SODIUM CHLORIDE

[1]V. N. Karazin Kharkiv National University
4 Svobody Sq., 61022 Kharkiv, Ukraine; yurchenko@karazin.ua
[2]Ukrainian Engineering and Pedagogical Academy
16 Universitetskaya St. 16, 61003, Kharkiv, Ukraine

Received: April 04, 2015 / Revised: June 10, 2015 / Accepted: December 22, 2015

Abstract. The use of ultrasound (US) in the preparation of pharmaceutical grade (PG) sodium chloride by the sampling of final product from a vacuum evaporator during the process of obtaining the "Extra" class table salt at the crystallization stage of the sodium chloride has been investigated. The US had been used: 1) for the content control of the base matter – sodium chloride in the stock – natural brine (sonoluminescent spectroscopy method). It is necessary to create the appropriate crystallization conditions by the control of the vacuum evaporator parameters – temperature and pressure; 2) at the crystallization stage of the sodium chloride to reduce the co-crystallization between the sodium chloride and the sulfate ions. It has been shown that the use of US allows reducing the sulfate ions content in the final product and getting sodium chloride PG satisfying the requirements of pharmacopoeia standard (PS) 42-2572-88.

Keywords: sodium chloride PG, ultrasound, table salt, sonoluminescent spectroscopy method.

1. Introduction

Usually table salt "Extra" or sodium chloride chemically pure (CP) is purified to the PG by barium chloride treatment to remove sulfate ions [1].

Tyumen chemical plant and a number of other companies work by the same technology. They supply sodium chloride PG used to make saline to Ukraine [1]. Thus, barium salts can get into the final product. The technique used to identify barium salts based on adding 0.5 ml of 10 % sodium sulfate solution to 10 ml of 5 % sodium chloride solution at pharmacopoeia standard (PS) 42-2572-88 does not ensure the presence of barium microquantities [1].

It is known that first potassium chloride and then sodium chloride is precipitated at brine heating in vacuum evaporators. Consequently the sampling of NaCl PG satisfying PS 42-2572-88 during crystallization from vacuum evaporator at table salt production was suggested [2]. However, research-industrial production in Slovyansk salt plant showed that 10–17 % of the product did not satisfy the requirements of FS 42-2572-88 sulfate ions content which should not exceed 0.005 % [3]. It is necessary to control the vacuum evaporator thermal regime to reduce the co-crystallization between the sodium chloride and the sulfate ions by temperature and pressure changes [3]. It was found that the production of sodium chloride PG by the vacuum evaporators requires to immediate respond to changes of the brine composition supplied from the well and to change the settings of the vacuum evaporator, respectively. The task was complicated by the aperiodic cyclical nature of changes in the brine composition in each well. Furthermore, after sampling brine from the depth of 300–400 m changed its primary structure due to pressure decrease. At the same time the brine entered in the vacuum evaporators almost at the same pressure as in natural conditions [3]. Consequently, there is a difference in the brine composition in the sample and in the bulk brine during continuous sampling for analysis by gravimetry, titration, flame atomic absorption spectrometry, and fixed option sonoluminescent spectroscopy methods. Due to this fact, the efficiency of the vacuum evaporators is decreasing. The crystallization conditions of the sodium chloride are violated resulting in occurring of co-crystallization processes and worsening of sodium chloride quality. The crystallization conditions of the sodium chloride are unoptimal resulting in co-crystallization and worse NaCl quality [3, 4].

We have previously proposed to use the new "sonoluminescent spectroscopy" method for automatic

brine analysis of the main substance content and the most significant impurities. This method is used to optimize the vacuum evaporators thermal regime in order to increase the safety of its work [5, 6].

It is known that the US-assisted treatment changes the conditions of the crystal formation and crystal growth, and allows to influence the co-crystallization processes [7, 8].

This paper is devoted to the use of US in the preparation of sodium chloride PG at the following stages: 1) for the content control of the base matter – sodium chloride in the stock – natural brine (sonoluminescent spectroscopy method). It is necessary to create the appropriate crystallization conditions by the control of the vacuum evaporator parameters – temperature and pressure; 2) at the crystallization stage of sodium chloride to reduce the co-crystallization between the sodium chloride and the sulfate ions.

2. Experimental

We proposed an automated system to obtain sodium chloride PG. This system consisted of sonoluminescent sensor immersed directly into the well and sonoluminescent spectrometer based on atomic absorption spectrometer AAS-3 (Germany) and vacuum evaporator. The last one was improved to automatically tune vacuum evaporator depending on brine composition [5, 6]. The analytical signal is transferred from the sensor to sonoluminescent spectrometer at the frequencies of 500–600 MHz and to control equipment of the vacuum evaporators of 650–800 MHz. Brine sample in the sensor cell is renewed and the following measurement is taken every 25 min, which corresponds to technological cycle of brine service in the vacuum evaporators. Moreover the analysis results were obtained prior to technological cycle, which allows to adjust the parameters of the vacuum evaporator automatically [5]. The system was sonicated by 0.03–0.15 W/cm^2 500 kHz–1.2 MHz US at the stage of sodium chloride crystallization. We carried out the determination of the main substance in the brine by sonoluminescent method [6, 7]. We used the modernized medical device SONOPULS(R) (Italy) for US-assisted treatment of sodium chloride brine in the vacuum evaporator at pulse mode. The Slovyansk source natural brine 250–300 g/l was used as the stock, the sodium chloride content was 180–210 g/l, potassium chloride content was 5–10 g/l, calcium chloride content was 20–40 g/l, and sulfate ions content was 10–40 g/l.

3. Results and Discussion

The US-assisted treatment influences the sulfate ions content in the final product during the sodium chloride crystallization (Tables 1 and 2). The optimum conditions were found to be frequency of 550 kHz–1 MHz (Table 1), at intensity of 0.05–0.10 W/cm^2 (Table 2). The sulfate ions content was 0.0152–0.0159 % without US and 0.0037–0.0042 % with US-assisted treatment in the optimum conditions. Therefore, in the crystallization moment the optimum US-assisted treatment allows to obtain sodium chloride PG satisfying the requirements of PS 42-2572-88 at sulfate ions content [1]. Determination of sulfate ions was carried out by turbidimetry method according to [1].

The co-crystallization processes and the amount of sulfate ions in resulting product were reduced at same US parameters (Tables 1 and 2) [8, 9]. Perhaps it is due to the increase in the crystallization rate and decrease in the co-crystallization rate [8]. The US-treatment can affect the crystal size. Crystal size can increase or decrease depending on US parameters [8-10]. The reduction of crystals can lead to the difficulties during final product separation from solution and washing.

The particle size of the sodium chloride without US: less than 0.1 mm – 1 %; 0.1–0.4 mm – 9 %; 0.4–0.5 mm – 70 %; 0.5–0.8 mm – 10 %; 0.8–1.2 mm – 10 %.

The particle size of the sodium chloride at optimal US: less than 0.1 mm – 1 %; 0.1–0.4 mm – 5 % ; 0.4–0.5 mm – 75 %; 0.5–0.8 mm – 15 %; 0.8–1.2 mm – 5 %.

A slight increase of the medium basic fractions of the final product was observed and the abrupt decrease of the crystals size was not observed at optimal conditions US. Consequently, the negative US effect on the extraction of the final product from solution and washing was not observed.

Sonochemical reactions do not occur by the US-assisted treatment in salt solutions and at dissolved gas presence due to the fact that gases enter the cavitation cavity and block the excited states or reasonably reduce the possibility of the electrical breakdown [9]. Gas concentration should be saturaterd to prevent sonochemical reaction [9, 11]. Earlier [11] we found a possibility to stop sonochemical reaction in the brine up to 250 g/l. The positive effect of the sonication was almost absent at CO_2 saturation (Table 1). Perhaps, US action is based on speeding up and intensifying of acoustics flows [8]. Correspondingly, the data in Tables 1, 2 show the possibility to obtain the sodium chloride PG satisfying the requirements of PS 42-2572-88 at sulfate ions content. Also it is shown that the table salt obtained after the sodium chloride sampling does not satisfy the requirements of standards by sulfate ions content (not more 0.020 %) but satisfies the requirements to the high class table salt [1]. It should be noted that optimum US-assisted treatment allows reasonably reducing the sulfate ions content in the in table salt at the crystallization moment (Tables 1, 2).

Table 1

Effect of US frequency on content of sulfate ions in sodium chloride PG and "Extra" table salt ($n = 6$; $P = 0.95$)

US frequency, kHz	Content of sulfate ions, %															
	Without US		500		540		550		600		900		1000		1010	
Samples	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr
Sodium chloride PG	0.0152± ±0.0012	0.075	0.0079± ±0.0006	0.068	0.0053± ±0.0004	0.067	0.0045± ±0.0003	0.063	0.0043± ±0.0003	0.063	0.0037± ±0.0002	0.064	0.0044± ±0.0003	0.063	0.0060± ±0.0004	0.066
Sodium chloride PG*	0.0159± ±0.0013	0.077	0.0076± ±0.0005	0.068	0.0055± ±0.0004	0.067	0.0047± ±0.0004	0.082	0.0044± ±0.0003	0.063	0.0040± ±0.0002	0.064	0.0048± ±0.0003	0.063	0.0067± ±0.0005	0.068
Table salt after NaCl sampling	0.7126± ±0.0695	0.093	0.5432± ±0.0473	0.083	0.5105± ±0.0439	0.082	0.4142± ±0.0356	0.082	0.4352± ±0.0374	0.082	0.4824± ±0.0420	0.083	0.4893± ±0.0426	0.083	0.5960± ±0.0413	0.066
Table salt after NaCl sampling*	0.7134± ±0.0696	0.093	0.5437± ±0.0474	0.083	0.5109± ±0.0445	0.083	0.4147± ±0.0357	0.082	0.4356± ±0.0375	0.082	0.4826± ±0.0420	0.083	0.4900± ±0.0427	0.083	0.5964± ±0.0519	0.083

Note: *experiments were carried out in CO_2 saturated environment to inhibit US reactions [9]

Table 2

Effect of US intensity on content of sulfate ions in sodium chloride PG and "Extra" table salt at 600 kHz ($n = 6$; $P = 0.95$)

US intensity, W/cm^2	Content of sulfate ions, %															
	Without US		0.03		0.04		0.05		0.06		0.09		0.10		0.12	
Samples	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr	$\bar{c} \pm \varepsilon$	Sr
Sodium chloride PG	0.0152± ±0.0012	0.075	0.0121± ±0.0009	0.073	0.0064± ±0.0004	0.065	0.0045± ±0.0003	0.063	0.0044± ±0.0003	0.063	0.0037± ±0.0002	0.064	0.0044± ±0.0003	0.063	0.0060± ±0.0004	0.065
Table salt after NaCl sampling	0.7126± ±0.0696	0.093	0.7022± ±0.0648	0.088	0.6321± ±0.0564	0.085	0.4142± ±0.0356	0.082	0.4125± ±0.0355	0.082	0.4121± ±0.0355	0.082	0.4076± ±0.0346	0.081	0.5305± ±0.0462	0.083

The disadvantages of the method of obtaining the sodium chloride PG are impossibility to obtain the "Extra" class table salt and increase of power consumption due to using the US generator. The possibility of using the pulse US was investigated to reduce power consumption.

The sulfate ions content decreased in sodium chloride PG final product at the pulse US-treatment (Table 3). The optimal US parameters such as duty cycle, pulse period, intervals between pulses and pulse repetition were found experimentally (Table 3). The waves microshock intensity increases at pulse US mode. In this case the crystallization centers appear and the crystallization rate increases. As a result, crystal porosity and the sulfate ions co-crystallization decreases as well (Table 3) [8-10]. Additionally, the use of pulse US leads to 2.5–3.5 time power consumption decrease. Thus, power consumption at brine treatment in vacuum evaporator is 0.020–0.025 kW/1·kg of sodium chloride at usual US-treatment and 0.007–0.010 kW/1·kg of sodium chloride at pulsed US-treatment.

Table 3

Effect of pulsed US parameters with a frequency of 1 MHz on the content of sulfate ions

Ratio ("duty cycle"), ms	Pulse period, ms	Intervals between pulses, ms	Pulse repetition, ms	Content of sulfate ions, %
1:5 (20 %)	2	8	10	0.0023
1:10 (10 %)	1	9	10	0.0031
1:20 (5 %)	0.5	9.5	10	0.0035
Iternal US (1 MHz)	–	–	–	0.0048

Table 4

Analytical results for the major component and the sulfate ions as determined in the brine and the sodium chloride PG, respectively (n = 6; P = 0.95)

	Content of NaCl in the brine, g/l				Content of SO_4^{2-} in $NaCI_{PG.}$, %			
	Automatic sonoluminescent spectroscopy		Usual sonoluminescent spectroscopy		Automatic sonoluminescent spectroscopy		Usual sonoluminescent spectroscopy	
	$\hat{c} \pm \varepsilon$	Sr	$\hat{c} \pm \varepsilon$	Sr	$\hat{c} \pm \varepsilon$	Sr	$\hat{c} \pm \varepsilon$	Sr
Brine 1 h later	210±0.13	0.06	195±0.06	0.03	0.0048±0.00001	0.02	0.0056±0.00001	0.02
Brine 1 h later*	210±0.13	0.06	195 ± 0.06	0.03	0.0152±0.00002	0.01	0.0159±0.00002	0.01
Brine 2 h later	215±0.14	0.06	195 ± 0.06	0.03	0.0043±0.00001	0.02	0.0054±0.00001	0.02

Note: * not US-assisted at the moment of sodium chloride crystallization

Table 5

Analytical results for sodium chloride PG* (n = 6; P = 0.95)

Sodium chloride parameters according to the requirements of PS 42-2572-88	Sodium chloride PG prepared by traditional technology	Sodium chloride PG of research-experimental UkrNDIsol plant
Sodium chloride: *not less than 99.5 %*	99.8	99.7
Sulfate ions: *0.005%*	0.0014	0.0023
Calcium: *0.006%*	0.0043	0.0046
Ammonium: *0.004%*	0.0022	0.0029
Iron: *0.003%*	0.0012	0.0010
Heavy metals: *0.0005%*	*less than* 0.0005	*less than* 0.0005
Arsenic: *0.00005 %*	*less than* 0.00005	*less than* 0.00005
Absence of barium, potassium, magnesium	Absence	Absence
Absence of barium, %	0.0000052	*less than* $1.0 \cdot 10^{-7}$
Loss on drying: 0.5%	0.2	0.2

Note: * determination of sulfate ions were carried out by turbidimetry. Determination of iron, calcium and barium were carried out by atomic absorption method [1] and other parameters were determinated at PS 42-2572-88.

Measurement results of major component obtained by both automatic and usual sonoluminescent spectroscopy method were different. This process is influenced by cyclic aperiodic changes of the brine composition and the pressure change of the brine during sampling (Table 4) [3, 5]. The data in Table 4 demonstrated that sulfate ions content at using the automatic determination of the basic component and automatic setup of vacuum evaporator is much lower that at manual setup. This is caused by the influence of the basic brine component concentration on its crystallization conditions [3, 5]. It should also be noted that the impact by US with the frequency of 550 kHz–1 MHz and intensity of 0.05–0.10 W/cm^2 at crystallization time allows reducing the sulfate ions content both at manual and automatic setup of vacuum evaporator (Table 4). However, lesser concentration of sulfate ions meeting the requirements of PS 42-2572-88 was reached only by automatic sonoluminescent spectroscopy and US impact at sodium chloride crystallization moment (Tables 4 and 5).

4. Conclusions

It was experimentally determined that it is possible to obtain the sodium chloride PG by sampling during manufacturing of the table salt using US at sodium chloride crystallization and using automatic method “sonoluminescent spectroscopy” for determination of the major component content. This technology allows to obtain sodium chloride PG satisfying the requirements of PS 42-2572-88 and the high class table salt.

The advantages of the proposed technology are: 1) the opportunity to obtain the product without using the Barium salt, which reduces the costs and excludes the presence of barium impurities in the sodium chloride PG; 2) the opportunity to using the equipment after some technology correction for production of the table salt "Extra" class and as a result to increase the quantity of the sodium chloride PG without significant cost.

References

[1] Baklanov O., Avdeenko A., Chmilenko F. *et al.*: Analitichna Khimiya Kukhonnoï Soli i Rozsoliv. DDMA, Kramatorsk 2011.
[2] Bidusenko A., Dubovichenko A., Karpenskii I. *et al.*: Pat. SSSR 779305, Publ. Nov. 15, 1980.
[3] Furman A., Bel'dy M. and Sokolov I.: Povarennaya Sol. Proizvodstvo i Primenenie v Khimicheskoi Promyshlennosti. Khimiya, Moskva 1989.
[4] Chmilenko F., Baklanov A., Sidorova L. *et al.*: Izv. Vuzov, Khimiya i Khim. Tekhnol., 1997, **40**, 65.
[5] Yurchenko O., Baklanov A., Baklanova L. *et al.*: Visnyk Kharkiv. Nats. Univ., 2013, **22**, 220.
[6] Baklanov O., Chmilenko F., Evgrafova N. *et al.*: Nauk. Visnyk Volin. Nats. Univ., 2008, **13**, 66.
[7] Hayashi Y. and Choi P.-K.: Ultrason. Sonochem., 2015, **23**, 333.
[8] Golyamin I.: Ultrazvuk. Malenkaya Entsiklopediya. Sov. Entsikl., Moskva 1979.
[9] Margulis M.: Zvukokhimicheskie Reaktsii i Sonolyuminestsentsiya. Khimiya, Moskva 1986.
[10] Krasulya O., Shestakov S., Bogush S. *et al.*: Ultrason. Sonochem., 2014, **6**, 2112.

ВИКОРИСТАННЯ УЛЬТРАЗВУКУ ПРИ ОТРИМАННІ ХЛОРИДУ НАТРІЮ ФАРМАКОПЕЙНОЇ ЧИСТОТИ

Анотація. *Досліджено використання ультразвуку (УЗ) при одержанні хлориду натрію фармакопейної чистоти внаслідок відбору частини готового продукту з вакуум-випарного апарату в процесі одержання кухонної солі сорту «Екстра» на стадії кристалізації хлориду натрію. УЗ використовувався: 1) для контролю вмісту основної речовини – хлориду натрію в сировині – природному розсолі (метод сонолюмінісцентної спектроскопії), що необхідно для створення відповідних умов кристалізації – внаслідок регулювання параметрів вакуум-випарного апарату – температури та тиску; 2) на стадії кристалізації хлориду натрію для зменшення процесів сокристалізації хлориду натрію з сульфат-йонами. Показано, що використання УЗ дозволяє зменшити вміст сульфат-йонів в кінцевому продукті та отримати хлорид натрію фармакопейної чистоти, який задовольняє вимогам фармакопейного стандарту (ФС) 42-2572-88.*

Ключові слова: *хлорид натрію фармакопейної чистоти, ультразвук, кухонна сіль, метод сонолюмінісцентної спектроскопії.*