



DEVELOPMENT PROSPECTS OF NEW TECHNOLOGIES OF LITHIUM-CONTAINING PRODUCTS

A. Anarbayev¹, M. Ylbekova¹, S. Tleuova¹, M. Yeskendirova¹, Zh. Khusanov², B. Kabyzbekova³ and N. Anarbayev²

¹Department of Chemical Technology of Inorganic Substances, The Higher School of Chemical Engineering and Biotechnology, M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan

²Regional Engineering Laboratory Structural and Biochemical Materials, M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan

³Department of Metallurgy, The Higher School of Chemical Engineering and Biotechnology, M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan

E-Mail: anarbayev.a.a@mail.ru

ABSTRACT

The research purpose is experimental studying of technological regimes of lithium-containing compounds manufacture using water of Kazakhstan salty Priaral'ye lakes. First of all, the brine's chemical composition and impurity content were preliminary determined. Change of the precipitation yield depending on the extraction time, volume of the extracted raw material was studied and the optimum parameters of obtaining a lithium concentrate from the brine was determined. The purification process of the lithium concentrates from Ca^{2+} , Mg^{2+} and other metals ions was investigated. Effective methods of the brine's purification and sedimentation of lithium as lithium carbonate are suggested. The experimental results show, that the purification degree of lithium chloride concentrate by a lime-soda method makes 99,9 %. The four-component mixture formed at the lithium chloride cleaning and consisting of magnesium hydroxide, calcium borate, barium sulphate and calcium carbonate acts as a precipitator of heavy metals - lead, arsenic, zinc, copper and cadmium. It was established, that the optimum ratio of brine: butanol: SAS is 1:3:0,015-0,020; in this case the precipitate mass is 0,47-0,48 g. The lithium transition degree into the extract makes 96,7-98,9 %. The extraction technique of lithium chloride recovery from the brine and processing of lithium-containing concentrates proves the efficiency of the methods of lithium carbonate obtaining and its purification from Ca^{2+} and Mg^{2+} ions and other metals.

Keywords: hydro mineral raw material, brine, lithium chloride, lithium carbonate.

INTRODUCTION

The interest in lithium manufacture has increased as a result of scientific and technical achievements and demand for it for nuclear synthesis and making electronic instrumentation. For commercial purposes, lithium is extracted from salty water of mineral springs, sea water or the deposits which are precipitated from brines. Lithium is applied in defence industry for making ceramic parts of different devices and extra strong glass. It is also used in radio and optical devices, metal-halogen lamps, in nuclear power engineering, electronics, and different space and aviation technologies for strengthening the armour in planes.

Lithium is found in nature either in solid ores or in liquid brines. The limited reserves of lithium ores and high costs of its extraction specify that manufacture of lithium from salts will soon become a tendency.

The largest lithium resources are granite pegmatites of a sodium-lithium type as lithium in nature is closely connected with sodium, especially in deposits of residual crystallization. However, last years the great importance is attached to sedimentary-type deposits, underground mineralized water and salty lake water (Compelo Staff Writer, 2018; World lithium reserves by country, 2017).

The major part of lithium (up to 80 %) is concentrated in natural water. For this reason, scientists of a number of countries - the USA, Chile, Argentina, Brazil, Japan, etc. - constantly carry out researches on extraction

of lithium from natural water. It is known, that 70 % of the lithium suitable for industrial mining are situated in Chile, Bolivia and Argentina in saline lands of Atacama, Uyuni and Hombre Muerto Deserts (Kay 2018; Brito 2016). Australia, Chile, Argentina, China were the world leaders in the mining of lithium ores in 2016-2017 (A battle for supremacy in the lithium triangle, 2017; Rosatom accumulates Chilean lithium, 2017).

Extraction of rare-earth elements (REE), including extraction of lithium from brine and also from solid deposits has been carried out by many researchers (Xu, Chen, Wan, Gasem, Wang, He, Adidharma and Fan, 2016; Kan, Murtazin, Issabekov and others., 2016). So, Albemarle Corp (ALB) has counted on sea water, a number of California companies have focused on geothermal sea water, Lithium Americas within the scope of Lithium Nevada project develops a new technology to extract lithium from hectorite clay (Sociedad Quimica y Minera de Chile SA., Beth McKenna, 2018). Company Simbol has developed the technology and constructed the pilot plant which can filter 20 gallons per a minute (Lithium Mining in US. Borate Hills, Nevada, US).

Russia has a number of mica deposits, which are characterized by the highest lithium content (mica is an accompanying element of rare-earth metals). A half of these deposits is situated in Murmansk Oblast (Lithium potential of Russia, 2016). In addition, the first in the world experimental installation on extraction of lithium compounds from poor ores started to work in Russia; this



installation allows one to extract lithium in two times cheaper in comparison with extraction of lithium from rich ores using old methods (Shartogasheva 2017). The installation has been developed by specialists of Moscow Institute of Steel and Alloys and satisfies the requirements of Russian enterprises for this raw material.

The Aral Sea region contains considerable resources of chloride and sulphate salts and hydro mineral raw materials in brine lakes. Water of these lakes contains lithium. Extraction of lithium from the hydro mineral raw materials is a perspective direction for Kazakhstan as deposits of lithium-containing ores are limited. Usually, lithium is found as an accompanying element of such metals as tantalum, niobium, tungsten and tin. The considerable part of lithium is in lake water and silt, underground water, sea water (1,5-10,5 mass %). Recovery of lithium from complex mineral compounds is often inexpedient because of a low lithium extraction degree.

The brine of Southern and Northern basins of Zhaksykylysh Lake in Priaral'ye contains 40-60 mg/l of lithium (Mg^{2+} - no more than 0,2 %, Ca^{2+} - no more than 0,4 %, SO_4^{2-} - no more than 1,2 %). Lithium content in the lake silt is considerably higher and makes 60-120 mg/kg (Petrov A., Botayev K., 2019, History and culture of salt.). Therefore it is necessary to concentrate the brine to the needed quality of lithium concentrate. The available reserves of hydro mineral raw materials (lake brine, silt, salt sediments) in the Aral region can provide the annual industrial demand for lithium in the country.

METHODS

The experiments were implemented using a laboratory setup composed of a glass flask in volume of 100 ml equipped with a backflow condenser and an agitator. The flask was fixed in a temperature-controlled water bath of a ULABUT-4302E type with a blade agitator. For each the experiment 10-50 ml of the brine and the calculated quantity of butyl alcohol are loaded into the flask. The hashing duration was changed from 10 to 30 minutes for determination of the optimum time of lithium chloride extraction.

The brine samples were preliminary blended. The sampled aliquots were put in the flask placed in the thermostat with a rpm governor, and then 30 ml of butyl alcohol was added. The water-alcohol mixture was mixed during the fixed time. In the case of application of water-free butanol, in the course of hashing the white sodium chloride sediment is precipitated on the water-alcohol interphase boundary.

On the expiry of the specified time the sample was transferred in a separating funnel for separation of the water and butanol, and after the separation the bottom

water layer containing sodium chloride is poured out. The alcohol layer is evaporated to dry; the residue is additionally dried for removal of the butanol traces in a drying cabinet at the temperature of 130⁰C. The formed lithium concentrate is purified from the lime-soda solution impurity. The formed deposit is analyzed for determination of lithium content using devices ICP-820M, Cary-50 and Dron-4.

RESULTS AND DISCUSSIONS

At the development of effective lithium carbonate production technology the initial raw material was the natural brine containing lithium and sodium chlorides and calcium, magnesium, boron impurities. A mixture of three components -lithium-containing brine:butanol:SAS (a surface-active substance) in the ratio of 1:3:0,015-0,020 is extracted at the temperature of 25⁰C within 10-30 minutes. The sodium chloride deposit is separated from the solution. The butanol is distilled off from the solution, and lithium chloride remains in a solid state.

Extraction of lithium chloride with butanol was carried out in the presence of sulfanole (SAS); in this case the lithium chloride transition degree into the extractant is maximal at the expense of increase in the brine-butanol contact surface. At the SAS dissolution there is the substitution of molecules on the solvent surface and increase in the intermolecular distances owing to the fast and reversible molecular exchange. The crystalline sodium chloride deposit is separated from the extractant and the basic solution. The alcohol is removed from the lithium chloride concentrate by distillation. The formed lithium chloride concentrate, which contains calcium, magnesium, boron and sulphate-ion impurities, is fed to the soda-lime treatment.

To determine optimum parameters of the lithium chloride extraction the initial brine of Priaral'ye brine lakes was used. The brine chemical composition: LiCl - 162,05 mg/kg, $CaCl_2$ - 4293,54 mg/kg, $MgCl_2$ —57862,12 mg/kg, $Na_2B_4O_7$ - 472,54 mg/kg, Na_2SO_4 -13676,55 mg/kg, Fe_2O_3 - 443,92 mg/kg, SiO_2 -6220,36 mg/kg and heavy metals Pb - 104,98 mg/kg, Zn -24,59 mg/kg, Cd - 0,86 mg/kg, Cu - 43,98 mg/kg, As - 8,07 mg/kg, butyl alcohol (extractant) and sulfanole (SAS). Consumption of the initial materials: brine - 10-50 ml, butyl alcohol - 30 ml, sulfanole - 0,10-0,25 ml; in this case the brine - butanol - SAS ratio was 1:3:0,010-0,020. The experiments were carried out at the constant temperature (25⁰C), the process duration was changed from 10 to 30 minutes. After termination of the extraction the chemical composition of the precipitated sodium chloride was, mass %: NaCl - 98,9; Na_2SO_4 - 0,001; $MgCl_2$ - 0,001; $CaCl_2$ -0,002; H_2O - 1,09. The results of the experiments are represented in Table-1.

**Table-1.** Indices of the technological regime of obtaining lithium chloride (butanol volume is 30 ml).

Experiment No.	Brine volume, ml	SAS volume, ml	Extraction time, min	Weight of the extract, g	LiCl extraction degree, %
1	10	0,10	10	0,31	84,9
2	10	0,10	15	0,46	91,7
3	10	0,10	20	0,47	93,6
4	10	0,10	25	0,41	91,4
5	10	0,10	30	0,36	87,4
6	10	0,15	10	0,32	86,9
7	10	0,15	15	0,47	96,7
8	10	0,15	20	0,48	98,9
9	10	0,15	25	0,42	94,6
10	10	0,15	30	0,36	88,7
11	10	0,20	10	0,32	87,1
12	10	0,20	15	0,48	96,9
13	10	0,20	20	0,47	96,3
14	10	0,20	25	0,42	92,8
15	10	0,20	30	0,37	89,1
16	10	0,25	10	0,33	86,8
17	10	0,25	15	0,46	94,9
18	10	0,15	15	0,35	86,9
19	20	0,15	15	0,30	84,4
20	30	0,15	15	0,31	84,2
21	50	0,15	15	0,30	83,9

As follows from the data of Table-2, at the constant brine consumption (10 ml) and extractant volume (30 ml) and in the presence of sulfanole the lithium chloride extraction degree gradually increases at increase in the process duration from 10 to 30 minutes. So, if the extraction time is 10 minutes the lithium chloride extraction degree makes 86,95 %, at 15 minutes - 96,7 %, at 20 minutes - 98,9 %; at the time of 30 minutes the lithium chloride extraction degree decreases and makes 88,7 %. With increase in the brine volume at the constant butanol consumption and with growth of the process time from 10 to 25 minutes the lithium chloride extraction degree gradually increases, and change of the SAS consumption from 0,10 to 0,15 ml promotes increase in

the transition degree of lithium chloride in the extract. The subsequent increase in the butanol and SAS amount has not the influence on the lithium chloride transition degree in the extract. At the brine volume of 10 ml and SAS volume of 0,15 ml the highest lithium extraction degree makes 98,9 %; with increase in the brine volume to 50 ml the lithium extraction degree decreases to 83,9 %.

It was established, that the optimum *brine:butanol:SAS* ratio is 1:3:0,015-0,020; in this case the deposit mass makes 0,47-0,48 g. The transition degree of lithium in the extract is equal 96,7-98,9 %. The composition of the lithium chloride concentrate produced under the optimum conditions is represented in Table-2.

Table-2. The chemical composition of the lithium concentrate.

Sample No.	Lithium concentrate's composition, g/kg							Note
	LiCl	CaCl ₂	MgCl ₂	Na ₂ B ₄ O ₇	Na ₂ SO ₄	Fe ₂ O ₃	SiO ₂	
1	11,06	7,08	336,99	70,71	31,08	0,48	4,46	Exp. 7
2	11,18	7,10	337,81	70,96	32,13	0,49	4,48	Exp. 8

The experimental results show the possibility of obtaining the lithium chloride concentrate with lithium

chloride content of 11,06-11,18 g/kg at extraction of the brine with butanol in the presence of SAS; as a result of



purification of the concentrate it is possible to produce high-purity lithium carbonate.

To remove impurities of calcium, magnesium and boron salts, sulphate ions, iron, silicon and heavy metals such as lead, zinc, cadmium, copper and arsenic we used the lithium chloride concentrate obtained at the

previous experiment. Judging by the results of the chemical analysis of the lithium chloride concentrate produced at the extraction of the brine (table 3) it contains the presence of impurities and heavy metals microimpurities. The lithium chloride concentrate's composition is represented in Table-3.

Table-3. Content of microimpurities in the lithium chloride concentrate (mcg/kg).

Sample No.	Lithium concentrate composition, mcg/kg					Note
	Pb	Zn	Cd	Cu	As	
1	13861,81	92713,20	873,58	39705,01	5687,54	Exp. 7
2	13986,79	93014,17	886,25	39912,56	5712,24	Exp. 8

Certain amounts of sodium and calcium hydroxides, soda and barium carbonate were added to the preliminary produced concentrate. The mixture was agitated within 4-20 min. The deposit formed was filtered from the of lithium chloride solution. The experiments were implemented at different concentrations of the lithium chloride solution, solution pH, deposit-solution contact time and ratios of $Mg(OH)_2:CaB_4O_7:BaSO_4:CaCO_3=1:0,33-0,34:0,24-0,25:0,03$ (this mixture was applied as a precipitator of heavy metals).

The lime-soda treatment of the lithium-containing concentrate was realized in two stages. At the first stage the concentrate was mixed with a sodium

hydroxidesolution and lime to remove magnesium and boron impurities. The process was carried out at the temperature of 25-30°C within 10-30 minutes at pH of 8-10. The pH value was maintained using sodium hydroxide and sodium carbonate. At this stage not only magnesium, boron, barium and calcium salts precipitate, but also Fe_2O_3 and SiO_2 . An advantage of this way is the high rate of settling of the deposit and heavy metals microimpurities at the expense of complex precipitators. The heavy metals are precipitated simultaneously with the basic deposit of $Mg(OH)_2$, CaB_4O_7 , $BaSO_4$, $CaCO_3$ and separated from the lithium chloride solution by means of filtration. The chemical composition of the purified lithium chloride is represented in Table-4.

Table-4. Residual content of impurities after purification, g/kg.

Sample No.	Composition of the purified lithium concentrate, g/kg							Note
	LiCl	Ca ²⁺	Mg ²⁺	B ²⁺	SO ₄ ²⁻	Fe ₂ O ₃	SiO ₂	
1	11,10	0,0052	0,0085	0,0071	0,021	0,0049	0,0004	Exp. 1
		99,60*	99,99*	99,99*	99,92*	98,99*	99,99*	
2	11,92	0,0097	0,0091	0,0069	0,020	0,0047	0,0004	Exp. 2
		99,62*	99,99*	99,99*	99,93*	98,99*	99,99*	
Average content	11,51	0,0074	0,0088	0,0070	0,021	0,0048	0,0004	

Note: * denominator - purification degree, %

To determine the salt content in the extract the mass was dried and investigated using device Dron-4. The lithium chloride diffraction pattern is shown in Figure-1.

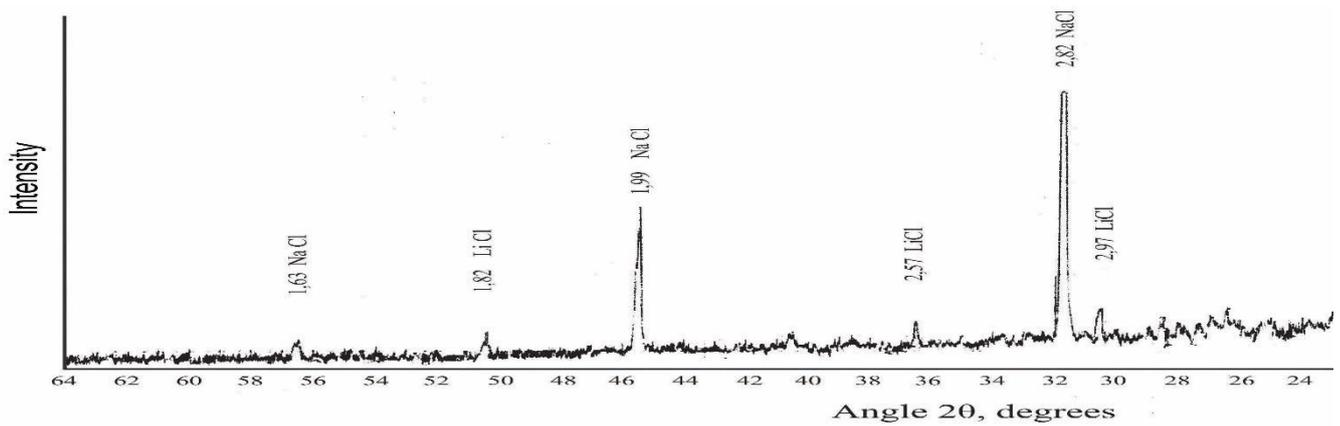


Figure-1. The lithium chloride diffraction pattern.

As follows from Figure-1, the peaks of 2,97; 2,57; 1,82Å in the diffraction pattern corresponds to LiCl, and the peaks of 2,82; 1,99; 1,63Å - NaCl.

At the beginning of the lithium chloride extraction process there was precipitation of sodium chloride crystals. The crystalline sodium chloride was separated from the water and organic phase. Sodium chloride after the

separation was dried and investigated using a scanning electron microscope. The results of determination of the elemental composition and structure of the product are represented in Figure-2. The microstructure of the sample is characterized by the fine-grained sodium chloride crystals with small impurity of vermiform magnesium sulphate crystals and lamellar magnesium chloride ones.

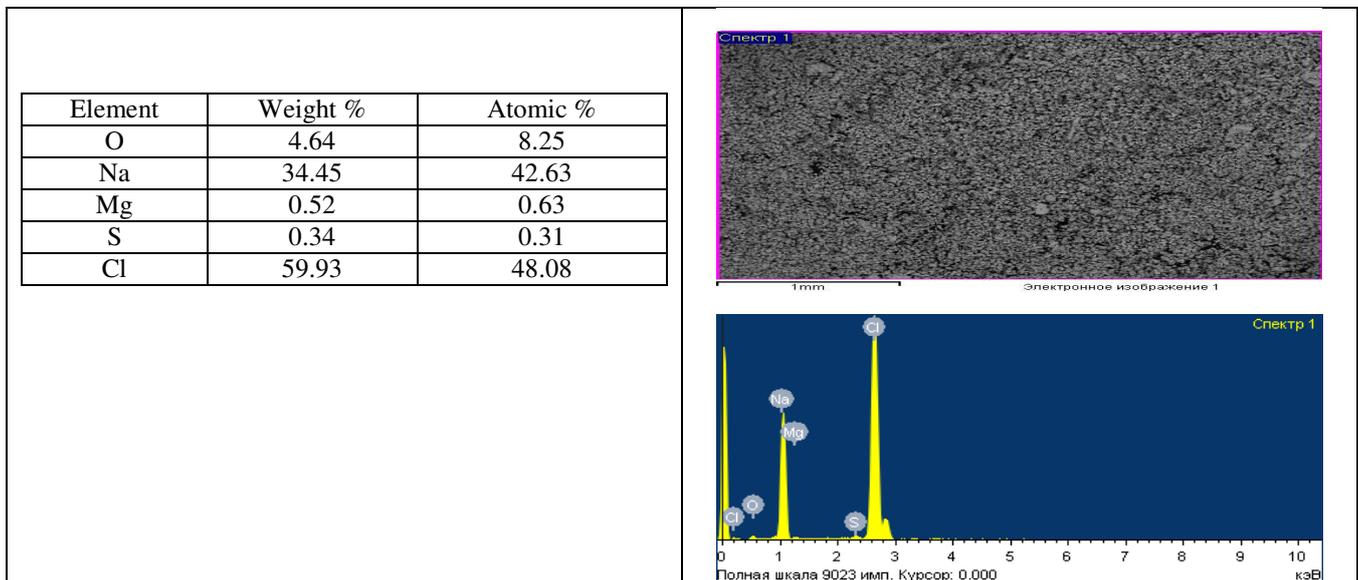


Figure-2. The elemental analysis of the concentrate produced from the Priaral'ye lake brine.

The produced sodium chloride as a technical product is used at thermal power stations, and after its purification it can be applied for production of sodium chloride superior-quality. The infrared spectra of the

sample, obtained on the IR-Fourier spectrometer Shimadzu IR Prestige-21, show the presence Li-Cl bonds, which intensity corresponds 861,91, 1414,04, 1621,92 cm^{-1} (Figure-3).

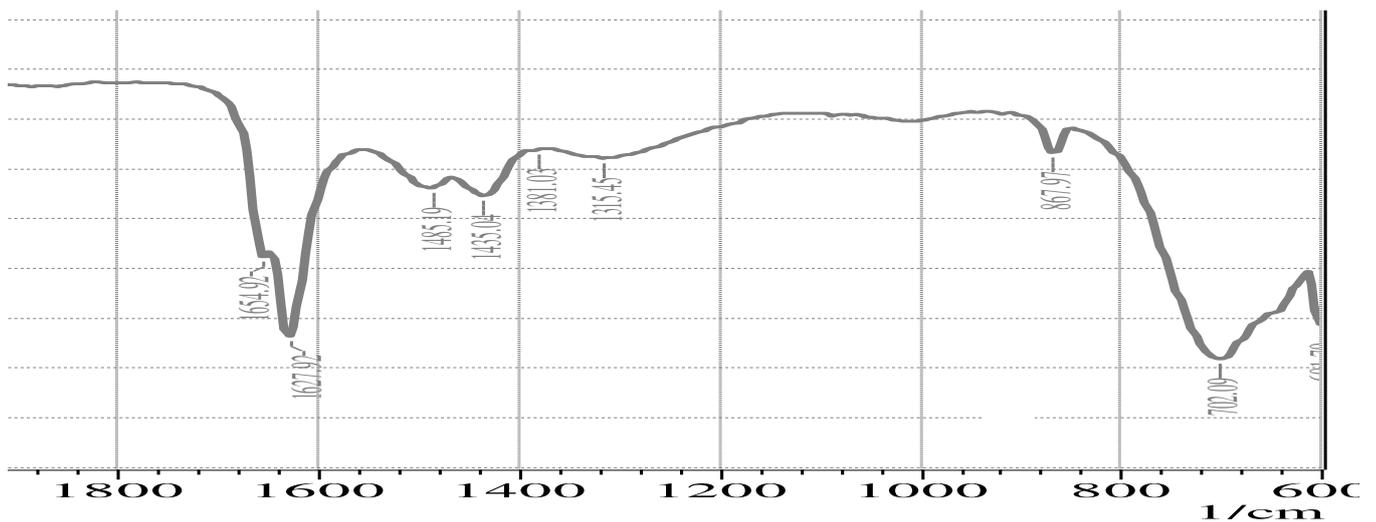


Figure-3. The infrared spectra of the lithium chloride produced.

The absorption spectra of the product are characterized by the feebly marked absorptions in the area of $612\text{-}730\text{ cm}^{-1}$ specific to lithium chloride, and also the intense waves in the area of $1414\text{-}1621\text{ cm}^{-1}$ characteristic for sodium and magnesium compounds.

Thus, the data obtained show that the brine of Priaral'ye lakes can be applied for production of valuable products - lithium chloride and table salt.

The purified lithium chloride preferably reacts with sodium hydroxide forming lithium hydroxide. Lithium hydroxide is in the solution as its solubility at $20\text{-}40^{\circ}\text{C}$ makes $12\text{-}13\text{ g}$ in 100 g of water. The solution after purification contains: $\text{LiOH}\text{-}99,21\%$, $\text{Ca}^{2+}\text{-}0,11\%$, $\text{Mg}^{2+}\text{-}0,13\%$, $\text{B}^{2+}\text{-}0,10\%$, $\text{SO}_4^{2-}\text{-}0,33\%$, $\text{Fe}_2\text{O}_3\text{-}0,07\%$, $\text{SiO}_2\text{-}0,006\%$. The residual content of the microimpurities is represented in Table-5.

Table-5. Composition of the purified lithium concentrate.

Sample No.	Composition of lithium concentrate, mcg/kg						Note
	LiOH	Pb	Zn	Cd	Cu	As	
1	6,241	1,02	1,20	0,36	18,62	0,42	Exp. 7
		99,99*	99,98*	99,92*	99,95*	99,98*	
2	6,317	1,14	12,18	0,39	20,01	0,34	Exp. 8
		99,98*	99,97*	99,93*	99,94*	99,99*	
Average content	6,279	1,08	11,69	0,37	19,31	0,38	

The results show that the deep purification of the lithium-containing solution from Pb, Zn, As microimpurities to purity of $99,98\text{-}99,99\%$ and from Cu, Cd to purity of $99,92\text{-}99,95\%$ can be reached within 30 minutes. The lithium hydroxide solution, obtained under the optimum conditions, is subjected to carbonization with carbonic gas at temperature of $25\text{-}40^{\circ}\text{C}$.

After the filtration the wet lithium carbonate deposit was dried at the temperature of $100\text{-}120^{\circ}\text{C}$. The dry deposit contains (mass %): $\text{Li}_2\text{CO}_3\text{-}99,9$; Na - $0,0001$; K - $0,00012$; B - $0,0001$; Mg - $0,00004$; $\text{SO}_4^{2-}\text{-}0,002$. The analyses results show that the product corresponds to high-purity lithium carbonate.

The research has shown, that the extraction method with use of sulfanole and butanol in comparison with the known sorption technique (sorbents are H_2TiO_3 , Ni_6MnO_8 , NUMS-K-1, NUMS-K-2) (Chen, Wu, Ju, Zhang, Xue and Xing 2018, Chaban, Dzyazko and Bystryk, 2019; Gu, Sun, Han, Cui and Wang 2018) allows

us to lower costs for the preparation of sorbents, to increase the lithium chloride extraction degree to $98,9\%$ and also to produce the more concentrated lithium-containing concentrate. The SAS application promotes the increase in the lithium chloride transition in the concentrate and production of high-purity Li_2CO_3 .

CONCLUSIONS

The experimental results show, that at increase in the brine volume at the constant butanol consumption and with growth of the process time to 25 minutes the lithium chloride extraction degree increases, and change of the SAS consumption from $0,10$ to $0,15\text{ ml}$ promotes the growth of the transition degree of lithium chloride in the extract. The subsequent increase in the butanol and SAS amount do not influence on the lithium chloride transition degree in the extract. The maximum lithium extraction degree at the brine volume of 10 ml and SAS volume of $0,15\text{ ml}$ makes $98,9\%$.



The treatment of the lithium chloride concentrate with lime and soda allowed us to purify it to 99,9 %. And the four-component mixture (magnesium hydroxide, calcium borate, barium sulphate and calcium carbonate) formed in the course of lithium chloride cleaning acts as a precipitator of heavy metals (lead, arsenic, zinc, copper and cadmium). Thus, the suggested methods of lithium chloride extraction from brines and processing of lithium-containing concentrates have confirmed the efficiency of lithium sedimentation as lithium carbonate and its purification from Ca^{2+} and Mg^{2+} ions. The extraction of lithium chloride in the presence of SAS and cleaning the produced lithium concentrates from impurity reduces the price of the process and simplifies the lithium carbonate production technology

REFERENCES

- “Rosatom” accumulates Chilean lithium. The State company intends to collaborate in new projects on mining and processing of the metal. Newspaper “Business”, May, 25th, 2017, No. 089 (2586). <https://www.rbc.ru/newspaper/2017/05/26/> (accessed 17.10.2019).
- A battle for supremacy in the lithium triangle. La Paz, San Salvador de Jujuy and Santiago. The Economist, 2017, June 15. <https://www.economist.com/the-americas/2017/06/15/a-battle-for-supremacy-in-the-lithium-triangle>(accessed 17.10.2019).
- Beth McKenna. U.S. Lithium Mining Could Get a Boost From President Trump's Executive Order. March 9, 2018. <https://www.fool.com/investing/2018/03/09/us-lithium-mining-could-get-a-boost-from-president.aspx>
- Brito G. 2016. Lithium – a new tasty morsel for an investor. Reuters <https://ru.ihodl.com/investment/2016-06-09/litii-novyi-lakomyi-kusochek-dlia-investora/>(accessed 17.10.2019).
- Chaban M.O., Dzyazko Y.S. and Bystryk O.V. 2019. Materials based on Titanium and Manganese oxides for selective recovery of lithium from water sources. Ukrainian chemical journal “Physical chemistry”, 85: 88-100.
- Compelo Staff Writer. Top lithium producing countries. September, 14th, 2018. <https://www.compelo.com/energy/news/top-lithium-producing-countries/>(accessed 17.10.2019).
- Gu, D., Sun, W., Han, G., Cui, Q. and Wang, H/ 2018. Lithium ion sieve synthesized via an improved solid state method and adsorption performance for West Taijinar Salt Lake brine. Chemical Engineering Journal, 350: 474-483.
- History and culture of salt. http://www.araltuz.kz/ru/339-istorija_i_kultura_soli.html(accessed 17.10.2019).
- Kan S.M., Murtazin Ye.Zh., Issabekov R.B. and others. 2016. Analysis of technologies of lithium extraction from natural brines. Proceedings of the National Academy of Sciences of the Republic of Kazakhstan, 416: 112-118.
- Kay A. 2018. Top Lithium Producers by Country Interest in lithium continues to grow due to the metal’s role in the lithium-ion batteries that power electric vehicles (EVs). August 14th, 2018.
- Lithium Mining in US. Borate Hills, Nevada, US. <http://www.lithiummine.com/lithium-mining-in-usa>(accessed 17.10.2019).
- Lithium potential of Russia. The mysteries of our planet. Journal Rare earths. June, 13th, 2016. <http://rareearth.ru/ru/pub/20160613/02898.html>(accessed 17.10.2019).
- Chen M., Wu R., Ju S., Zhang X., Xue F. and Xing W. 2018. Improved performance of Al-doped LiMn_2O_4 ion-sieves for Li^+ adsorption. Microporous and Mesoporous Materials. 261: 29-34.
- Petrov A., Botayev K. and Lake Zhaksy-Kylysh. 2019. Newspaper Kyzyl-Orda news. January, 2019. <http://silkadva.com/ru/node/355>(accessed 17.10.2019).
- Shartogasheva A. 2017. Russia will switch over to own lithium. Publ. April, 26th, 2017. <https://www.popmech.ru/technologies/news-359302-rossiya-pereydyet-na-svoy-litii/>(accessed 17.10.2019).
- Sociedad Quimica y Minera de Chile SA. <https://www.bloomberg.com/quote/SQMUS><https://www.linkedin.com/company/sqm>(accessed 17.10.2019).
- World lithium reserves by country 2017. Statistics and facts on chemicals and resources. Chemicals & Resources, <https://www.statista.com/markets/410/chemicals-resources/>(accessed 17.10.2019).
- Xu X., Chen Y., Wan P., Gasem K., Wang K., He T., Adidharma H. and Fan M. 2016. Extraction of lithium with functionalized lithium ion-sieves. Progress in Materials Science. 84: 276-313.