ABSTRACT

of the dissertation on the topic:

"Improving the technology of processing Kazakhstan's natural sodium and potassium salts", submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D07160 – "Chemical technology of inorganic substances"

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The relevance of the problem. Given Kazakhstan's high demand for sodium salts and the need to make effective use of domestic mineral resources in the current economic climate, the development of resource-saving and technologically efficient methods for producing chlorides, sulphates, phosphates, soda ash, caustic soda and other inorganic products from naturally available chloride salts.

Significant reserves of natural sodium-containing salts rich in sodium chloride and containing various impurities have been identified in the republic. These deposits include Inder and Satimola in the Atyrau region, Aschykol in the Zhambyl region, and deposits in the Suzak district of the Turkestan region. However, due to the lack of technologies for the deep processing of such complex salt resources in Kazakhstan, these deposits have not yet been put to industrial use.

In recent decades, various companies have studied the feasibility of commercial development of the Satymola deposit. Initial studies were aimed at assessing potassium reserves and developing technologies for its extraction and processing. In 2011, the State Reserve Committee of the Republic of Kazakhstan approved a report on the assessment of reserves. Currently, the potash deposit is considered a promising raw material base for the production of potash fertilisers for agriculture in Kazakhstan and foreign countries.

Sodium chloride is widely used in the chemical industry, which determines the need to increase its production volumes. The growth in demand for sodium chloride in the chemical sector is associated with its use as a basic raw material in the production of chlorine, soda and other products. In industry, NaCl is used both as a crystalline product and in the form of halite solutions.

In addition, the demand for sodium chloride is constantly increasing in the energy, oil and gas, light industry, livestock and other sectors of the economy. This leads to stricter requirements for the quality, chemical purity and particle size distribution of the product, which necessitates the improvement of table salt production technologies and the solution of a number of new scientific and technical problems.

Table salt is widely used in various sectors of the national economy. In the chemical industry, it serves as the main raw material for the production of sodium, chlorine and their most important inorganic compounds. In addition, sodium chloride is used in preservation technologies and in food preparation. The product available on the market is a substance with a crystalline structure of a specified particle size, consisting mainly of NaCl.

Kazakhstan's potash deposits have significant strategic potential. One of the most promising sites is the Satymol deposit in West Kazakhstan Region, where plans are in place to process ore to produce potassium chloride concentrate with a content of up to 95%. The Zhilyan deposit in the Aktobe region has several industrial horizons, which opens up opportunities for comprehensive processing. The Chelkar and Inder deposits are

also significant potassium-containing resources. Kazakhstan has announced plans to build a potash fertiliser plant with a capacity of up to 94,000 tonnes of KCl per year based in Satymol, which will reduce dependence on imports.

The relevance of potash ore processing in Kazakhstan is determined by both internal and external factors. Firstly, the development of agriculture requires a sustainable supply of mineral fertilisers to increase crop yields and food security. Secondly, modern processing technologies allow not only the production of potash fertilisers, but also the extraction of associated elements, which increases economic efficiency and reduces the environmental impact. Against the backdrop of growing global demand for potash salts, Kazakhstan has the potential to become a major producer and exporter of salt products.

Currently, improving the technologies for processing natural sodium and potassium salts in Kazakhstan, as well as developing processes for purifying salts from impurities to obtain high-quality sodium chloride, is one of the most pressing scientific and practical tasks.

The purpose of the work.

The purpose of the work is to improve the processing technologies for sodium and potassium salts in Kazakhstan in order to obtain high-quality products – sodium chloride and potassium chloride – as well as to develop an optimal technological scheme for purifying salts from the Satymol and Bakhyt-Tany deposits from impurities.

Research objectives:

– Determination of the chemical and mineralogical composition of natural sodium and potassium salts in the Republic of Kazakhstan;

– Study the solubility of sylvinite mineral at a temperature of 100 °C in the KCl–NaCl–H_2O system and the processes of potassium chloride and sodium chloride separation from solutions;

– Determination of effective technological parameters for the purification of waste (NaCl) after processing natural sodium chloride and sylvinite ore from impurities;

– Development of an effective technology for the purification of waste (NaCl) after processing natural sodium chloride and sylvinite ore from impurities.

Research objects. The objects of research are natural sodium salts from the Bakhyt-Tany deposit and potassium-containing salts from the Satimola deposit.

Research Methods

Chemical and instrumental analysis methods were used to accomplish the main research objectives. Studies were conducted on the extraction of sodium salt from potash ore by dissolving it in a mother liquor. The potassium and sodium content in the studied systems was determined using a Kvant-2 atomic absorption spectrometer and a PFA-378 flame photometric analyser. The analysis of raw materials and products was carried out using spectral-microscopic, X-ray, differential thermal and IR spectroscopic methods. Semi-quantitative X-ray analysis of solid phases was performed on a Bruker D8 Advance device, and the processing of the obtained diffractograms and calculation of interplanar distances were performed using computer software. Sedimentation analysis of the insoluble residue was performed using an ФСК-6 photosedimentometer. Mathematical modelling of the experimental data was performed in Excel, and the significance of the regression coefficients was determined by calculating the Fisher criterion.

The main provisions submitted for defense

– chemical and mineralogical compositions of sylvinite and halite ores from the Satimola and Bakhyt-Tańy deposits;

– mathematical processing of experimental data on the purification of sodium chloride from calcium and magnesium with determination of significant coefficients of regression equations;

– determination of the parameters of the dissolution process of sylvinite salt from the Satimola deposit;

– calculation of the Gibbs free energy of reactions involving calcium and magnesium salts, sodium and barium carbonates, as well as the interaction of sodium phosphate with halite salt from the Bakhyt-Tańy deposit;

– development of an improved technology for the purification of halite salt from the Bakhyt-Tańy deposit and the processing of sylvinite ore from the Satimola deposit;

– development of an improved technology for processing sylvinite ore from the Satimola deposit.

The main results of the study.

– chemical and mineralogical compositions of sylvinite and halite mineral salts from the Bakhyt-Tańy and Satimola deposits;

– mathematical processing of experimental data on the purification of sodium chloride from calcium and magnesium with determination of the significant coefficients of regression equations;

– determination of the parameters of the dissolution process of sylvinite salt from the Satimola deposit in the ternary KCl–NaCl–H_2O system;

– calculation of the Gibbs free energy of reactions involving calcium and magnesium salts, sodium and barium carbonates, as well as the interaction of sodium phosphate with halite salt from the Bakhyt-Tańy deposit;

– development of an improved technology for the purification of halite salt from the Bakhyt-Tańy deposit and the processing of sylvinite ore from the Satimola deposit.

Justification of the novelty and significance of the obtained results

Studies of the physicochemical fundamentals of sodium chloride processing obtained from sodium and potassium salts were carried out with the aim of producing high-quality and environmentally safe chemical products.

– The chemical and mineralogical compositions of the natural salt deposits Bakhyt-tany and Satimola were determined. Halite predominates in the Bakhyt-tany salt with the presence of gypsum and magnesium chloride, while the Satimola salt contains sylvite and halite with minor amounts of anhydrite, kieserite, polyhalite, and insoluble residues.

– The kinetic regularities of the purification process of the halite mineral from impurity components were established. Based on an analysis of the temperature dependence of the process rate using the Arrhenius equation, it was shown that within the studied temperature range the process proceeds in the diffusion-controlled regime, indicating that the rate is limited by the mass-transfer stage.

– On the basis of calculated Gibbs energy values for the impurity removal process, it was demonstrated that under the given temperature conditions the reactions are thermodynamically feasible and are accompanied by the formation of complex compounds $CaSO_4$, $CaCO_3$, $Ca_3(PO_4)_2$, $Mg_3(PO_4)_2$ and $BaSO_4$ which ensure selective

removal of impurity components from the halite structure, as well as by a shift of reaction equilibrium toward the reactants.

– For the first time, optimal parameters for a sodium chloride purification technology were established. The improved technology differs from the conventional one in that mechanical impurities are removed at a liquid-to-solid ratio of 3:1, and sodium phosphate in an amount of 95% of the stoichiometric ratio required for complete precipitation of insoluble phosphates is added to the saturated sodium chloride solution; in addition, the evaporation and centrifugation stages are eliminated. It was found that the degree of purification of sodium salt from calcium and magnesium reaches 99.2% at a mixing temperature of 25 °C and a reagent interaction time of 30 minutes. A patent for the invention was obtained based on the developed method (No. 37341 dated 30.05.2025).

– For the process of sodium chloride purification from calcium and magnesium impurities, a model based on a fractional factorial experiment was proposed. The model makes it possible not only to describe but also to predict the degree of purification depending on the combination of technological parameters, thereby ensuring a justified selection of optimal process conditions. The regression equation coefficients were obtained through mathematical processing of the fractional factorial experiment data. The adequacy of the models was confirmed by fulfillment of the condition $F_{table} > F_{calculated}$ (5.1 > 4.5 for calcium and 5.1 > 4.1 for magnesium), indicating the statistical significance and predictive reliability of the developed regression equations.

– For the first time, the theoretical yield of crystalline KCl from the sylvinite of the Satimola deposit was calculated based on an analysis of the solubility diagram of the NaCl–KCl–H_2O system. This made it possible to substantiate the optimal temperature and time parameters of the dissolution and crystallization stages, including a dissolution temperature of 100 °C, a crystallization temperature of 25 °C, a solution-to-salt ratio of 1:1, and a process duration of 120 minutes.

– For the first time, with the aim of improving the technology for processing natural sodium and potassium salts, optimal parameters were determined for the purification of dump residues (sodium chloride) formed during the processing of sylvinite ore from the Satimola deposit, and new data were obtained on the interaction of sodium salts with sodium phosphate. The purification of dump residues from potassium chloride was calculated based on an analysis of the NaCl–KCl–H_2O solubility system, which made it possible to substantiate the conditions for potassium chloride separation. A technology was developed for the phosphate-based purification of dump residues and for potassium separation by dissolution in the NaCl–KCl–H_2O system, resulting in purification efficiencies of 99% for calcium and 98% for magnesium. The proposed method makes it possible to reduce the content of Ca^{2+} and Mg^{2+} impurities in sodium chloride to a level not exceeding 0.1% and ensures efficient transfer of potassium chloride into solution. The obtained results made it possible to improve the technological scheme for processing natural sodium and potassium salts.

Theoretical and practical significance of the research:

The theoretical significance of the dissertation lies in the development and deepening of physicochemical concepts concerning the purification of natural sodium and potassium salts from calcium and magnesium impurities. The study presents thermodynamic data on the interactions of Ca^{2+} and Mg^{2+} ions with sodium phosphate,

substantiates the direction and mechanism of reactions leading to the formation of sparingly soluble compounds and calcium and magnesium phosphates, and establishes the regularities of the influence of temperature and concentration factors on the efficiency of purification processes. The developed regression models and the results of phase equilibrium analysis in the NaCl–KCl–H_2O system expand the theoretical foundations for modeling, forecasting, and optimizing processes for the processing of saline mineral raw materials.

Practical significance of the study:

– Based on the results of the study, a technology for purifying halite salt from the Bakhyt-Tany deposits was developed. The developed technology is aimed at obtaining salt suitable for use in the food and pharmaceutical industries. The optimal mode for purifying sodium from sodium phosphate was determined, which ensures complete removal of impurities from sodium chloride. The process of washing sodium salt from mechanical impurities was also substantiated.

– An improved technological scheme for the production of potassium and sodium salts with the determination of raw material consumption coefficients has been developed. A patent for the invention ‘Method for purifying sodium chloride’ (No. 37341, 30.05.2025) has been obtained for the developed technology.

The advantage of the developed technology is the possibility of eliminating concentrated hydrochloric acid, which causes corrosion of equipment and requires thorough washing of sodium chloride crystals with high-purity water, which significantly simplifies the overall technological process. In addition, the technology improves the degree of purification of sodium chloride from water-soluble impurities and simplifies the technological process by eliminating the evaporation and centrifugation stages. The developed and proposed technology could become the basis for the creation of domestic production of potassium and sodium salts, which is currently virtually non-existent in Kazakhstan.

Compliance with scientific development trends or government programs.

The work was carried out as part of the state budget research plan of the M. Auezov South Kazakhstan University, Department of Chemical Technology of Inorganic Substances, for 2016–2020 on topic B-16-02-03 ‘Research on the production of synthetic inorganic compounds from natural ore and mineral raw materials and man-made waste from various industries, as well as the development of alternative innovative technologies for raw material enrichment.’

In addition, work was carried out as part of a scientific project for 2021–2025 on topic B-21-03-02 ‘Development of new promising technologies for obtaining inorganic products, environmentally friendly fertilisers and plant growth regulators based on mineral raw materials and man-made waste, as well as improvement of traditional technologies.’

Certain stages of the dissertation research were carried out with financial support from the grant project “Zhas Galym” ЮКУ2024-005, implemented within the framework of the grant funding program for scientific research by young scientists at M. Auezov South Kazakhstan University.

The doctoral student's personal contribution to each publication.

The dissertation author independently carried out experimental and analytical studies, including physicochemical analysis, calculations, and generalization of the obtained results. The preparation and publication of materials on the research topic were performed by the author with consultative support from the scientific supervisors.

A total of nine scientific publications related to the dissertation topic have been published, including one article in an international scientific journal indexed in the Scopus database; three articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; four articles in the proceedings of international and national conferences; and one patent of the Republic of Kazakhstan. Based on the research results, an act on conducting experimental and laboratory tests aimed at improving the technology for processing natural sodium and potassium salts of Kazakhstan was obtained (dated 24.11.2025, No. 1). The research results were implemented in the educational process on 22.03.2025 (No. 3). The author's contribution to the preparation and publication of scientific materials is disclosed in the dissertation and confirmed by the relevant publications.

1. The article "The development of a technology for the purification of sodium chloride by removing impurities using the phosphate method," published in The Open Chemical Engineering Journal (29th percentile, Q3), presents data on the purification of sodium chloride using the phosphate method and the development of an improved technological flowsheet.
2. The article "Purification of Technical Sodium Chloride from the Tasty Tuz Deposit of the Republic of Kazakhstan," published in the Bulletin of the National Academy of Sciences of the Republic of Kazakhstan, provides data on the purification of sodium chloride ore using barium carbonate, as well as on the determination of optimal process parameters.
3. In the journal Kompleksnoe Ispolzovanie Mineralnogo Syra, the article "Methods for purifying table salt from the Bakhyt-Tany deposit" presents information on the preparation of a literature review, the results of physicochemical analysis of the halite mineral, and a comparison of the degrees of purification of sodium chloride from magnesium and calcium ions using lime, lime–soda, and phosphate methods.
4. In the journal Kompleksnoe Ispolzovanie Mineralnogo Syra, the article "Potash Ore Processing: Technology Research and Physicochemical Properties" presents the results of physicochemical analysis of sylvinite ore obtained from the Satimola deposit, as well as data on the process and results of halurgical processing of the ore.

Structure and volume of the dissertation. The dissertation work of 106 pages includes 33 tables and 45 figures. Structurally, the work consists of an introduction, five chapters, a conclusion, a list of used sources, including 122 titles, and 5 applications.