**Theoretical Studies on Obtaining Hexamethylenetetramine Based on Filter Liquid in the Production of Soda Ash**

Elyor Atasheva), Dilnoza Jumaniyazova, Rasulbek Jabbiyev, Guli Komilova, Maxsud Jumaniyazov

*Urgench State University named after Abu Rayhan Beruni, Urgench, Uzbekistan*

*a)Corresponding author: elyor.a@urdu.uz*

**Abstract:** In this scientific research the filter liquid of the Kungirot soda plant was chosen as the object of implementation of one of the main requirements of the present day, the principle "Production – Waste – Production". It is known that in the process of distillation of soda production in the traditional Solve method, the filter liquid is processed with a suspension of Ca(OH)2 and ammonia and CO2 are returned to the cycle. However, in this process, at the expense of each ton of calcined soda, a large volume of distilled liquid consisting of about 9.3-9.5 m3 of CaCl2 suspension is released and sent to permanent storage. In the presented scientific work, it is possible to recycle the filter liquid and obtain hexamethylenetetramine and HCl from it, leaving CaO as a commodity product without consumption, thereby eliminating the ecological problem of waste, also known as "white seas". The chemical basis of the proposed technological process relies on the interaction reaction of formaldehyde and ammonium chloride. Given the negative nature of this reaction, the thermodynamic characteristics of equilibrium reactions were initially studied in order to determine optimal conditions and parameters to achieve high yield of the target substance.

**Keywords:** filter fluid, formaldehyde, condensation, hexamethylenetetramine, enthalpy, entropy,

**INTRODUCTION**

Despite the fact that the development of scientific and technological development depends on the efficient and complete use of natural resources, the generation of industrial waste continues due to the use of outdated technologies in raw material processing. One of these includes the technology for the production of soda calcined using the Solve method.

The production of soda by the ammonia method, which uses a very common raw material, such as table salt and limestone, is highly organized, has continuity, integrated automation and high cost-effectiveness. However, in soda technology, the efficiency of using raw materials is low, heat energy losses are high, about 1.5 tons of sodium chloride and the same amount of calcium carbonate raw materials are consumed to obtain one ton of soda. At the same time, the so-called "distiller liquid" generates about 9.3-9.5 m³ of waste, the temperature of which is around 96-100°C, with the loss of up to 30% of raw materials and thermal energy with industrial waste.

The article published by Zong, Y. et al. analyzes the state of existing knowledge on ammonia-soda sludge (soda residue), describes the sources of formation, physicochemical properties (high alkalinity, high reactivity, enhanced viscosity), environmental risks and areas of application, from which it is possible to develop wastewater treatment, adsorbents, phosphate-fixators, building materials [1].

In another work by the above authors, a novel route for the processing of distillation waste (consisting of the main component - CaCl₂ and NaCl) into CaCO₃ and HCl is proposed. In this, a reactant-extraction-crystallized scheme (trioctyl amine/isoamyl alcohol-based extraction system is used). It has been shown that it is possible to selectively convert calcium to carbonate and at the same time form hydrochloric acid (HCl) [2].

Czaplicka, N., & Konopacka-Łyśkawa, D. studied the environmental problems of soda (soda ash) production according to the "Solvey" process, high energy consumption, CO₂ emissions, the formation of a large amount of CaCl₂ saline solution, and modifications in recent years. Particular focus is placed on the integration of membrane technologies, ammonia recovery, saline disposal and circular economy principles, e.g. process intensification with a view to reducing waste and EF principles such as brine processing, NH₃ reuse and EF [3].

At a current density of 0.1167 A/cm², the removal of NH₄⁺ by 71.6% and Cl⁻ by 26.9% was achieved. Removal increased with an increase in current and temperature, but decreased with an increase in the initial concentratsia of ions. The second-order model showed the optimum: 0.2 A/cm², 36.8 °C, [Cl⁻]\_0 = 7.4×10³ mg/L. The method provides a path to the reduction of HF₃ and a decrease in the Cl⁻ content [4].

In the stat Rahimpour, H. et al. a critical review of modern environmental problems and innovative solutions in the production of soda is presented (Solvay et al.). It includes a discussion of the generation of liquid and solid waste (including post-distillation liquids), their chemical nature, environmental risks and promising strategies for waste reduction / recycling (membrane methods, electrolysis, carbonate, resource conservation). Recommendations for the modernization of technological schemes to reduce the negative impact are presented [5].

In Wu*, C.* A vacuum membrane distillate was used for the separation and recovery of ammonia from wastewater with high ammonia concentratsia (feed-wastewater of the soda industry). Hydrophobic PVDF membranes were used; the effect of the initial concentratsia of ammonia and pH on the efficiency of recovery, the speed of transfer and the characteristics of the resulting ammonia product was investigated.

The authors of the article Szapliska, N., & Konopaska-Łjśkawa, D. presented a new combined scheme for the removal and recovery of НҲ₃ and CO₄²⁻ from the wastewater of the Solvay solution. The method is based on electrocoagulation with the addition of CaO as a buffer reagent. Under optimal conditions (3.5 g CaO/100 ml, 19.95 mA/cm², 35 °C, mixing 0.76 R/s), the following removals were achieved: ammonia ~99.50%, sulfate ~96.03%. The method is applicable to various industrial and municipal effluents [7].

The paper presents a single-stage "green" photocatalytic method for the production of HMTA from methanol and ammonia with simultaneous separation of T, with the use of Pt/TiO₂ (Pt/P25). It is shown that the presence of ammonia inhibits the formation of by-products (ethylene glycol), provides high selectivity (>99%) and stability of the catalyst; the influence of the Pt state and treatment conditions on the activity is discussed [8].

In the articles of Oba, J. et al., it is reported that HMTA was found in several carbonaceous meteorites. The authors analyze the possible mechanisms of the formation of HMTA (the reaction of ammonia with formaldehyde in the interstellar medium and during thermal processing), discuss its stability during planetary accretion and assume role as a precursor of organic molecules important for prebiological chemistry [9].

In the work of Kuvshinov, D. G. hexamethylenetetramine is used as a fuel/gearbox in the method of solution-combustion synthesis of nickel-containing catalysts. It is shown that the obtained catalytic materials are effective for the catalytic decomposition of methane with the co-production of hydrogen and nanocarbon fibers; the composition, morphology, and activity in decomposite Sh₄ are discussed [10].

Scientists from Uzbekistan M. Zh. Zhumaniyazov and others have already proved that ammonium waste from soda production plants can be used as a corrosion inhibitor. For the purpose of scientific substantiation of this (CH2)₆N –NH₄H2PO₄– H2O over a wide temperature range, the polytherm of the triple system has been studied. Concentration and temperature ranges of crystallization for the primary components and the novel compound NH4H2PO₄·2(CH2)₆N ·8 H2O have been determined. The properties and structure of the resulting substance were investigated by X-ray space, thermal, and IQ spectroscopy methods [11].

The same authors studied the polytherm of the hexamethylenetetramine-nitrate ammonium-vode system in order to scientifically substantiate the effective use of ammonium-containing waste. In the polythermic diagram (CH2)6N4, 2NH4NO3, ice and the temperature limits of crystallization of the formed new compound (CH2)6N4• 2NH4N03•3H20 are delineated. The properties and properties of a new compound were defined by modern physicochemical methods. [12].

The article by Sharofat Masharipova and others presents innovative technology for the production of hydrophobic calcite. Particular attention is paid to the evaluation of the properties of hydrophobic calcite by standardized methods (GOST 30136-9). The resulting material has been found to have a better dispersibility capability in polymer matrices, which defines its possibility for its application as an effective complement for paint and varnish products, building mixtures and polymer composites. The research confirms that it is possible to purposefully form the desired properties of calcite by changing the conditions of synthesis and serves to the development of environmentally friendly and resource-saving technologies, allowing for efficient disposal of industrial waste, as well as creating functional materials with high added value for various industrial sectors [13].

The article published by Dilnoza Jumaniyazova and others focuses on the creation of innovative anti-corrosion composite materials to protect iron-based metals from corrosion. For the purpose of activation of functional groups of raw materials, thermooxidation was performed in atmospheric air for 60–70 min at a temperature of 210–220°C. This processing process enables to synthesize novel anticorrosive coatings by increasing the reactivity of phenol hydroxide, aldehyde and carboxyl groups. To further enhance the anticorrosive properties of the content, hexamethylenetetramine (CH2)₆N at a concentration of 0.1–0.2% was introduced into it. The prepared composite coatings were applied to St3 branded steel and tested at different temperatures at different concentrations H₂SO₄, HNO₃ and HCl environments. The results of the research were confirmed by chemical and physical-chemical analyses, laboratory experiments and industrial tests [14].

This paper, published by Maxsud Jumaniyazov and others, presents a kinetic study of rapid phosphating compositions designed to protect metals from corrosion under industrial conditions. Extraction phosphoric acid, furfuryl alcohol, hexamethylenetetramine, and industrial waste from lignin-hydrolysis were used in the composition. Quantitative parameters of composition (mass fraction relative to absolute dry residue, %): S – 17.34, N – 6.43, O – 43.50, phenolic groups (–OH) – 5.06, methoxy (–OCH₃) – 3.06, carboxyl (–COOH) – 1.18, total acidity groups – 6.24, ash residue – 4.12–2.74. Also used a natural mineral - vermiculite. The kinetic parameters obtained reveal the mechanisms governing the process of rapid phosphating. The results of the study have significant relevance in the development of more environmentally friendly and sustainable protective coatings that serve to extend the service life of metal structures and reduce resource consumption [15].

A study by scientists such as Patra, D., Mishra, P., & Sahoo, S., examined nanoparticles synthesized with the presence of GMTA (hexamethylenetetramine) as a stabilizer/formation agent, their optical and structural properties, as well as antimicrobial activity against a range of microorganisms. The positive effects of GMTA on particle morphology and their bactericidal efficacy have been established [16].

**METHODS**

The main objects in conducting theoretical and applied research in this work served filtrating fluid - a waste from the production of soda. In addition, Formaldehyde CH2O 37%, hydrocarbonate ammonium (NH4HCO3), carbonate ammonium ((NH4)2CO3) and chloride ammonium (NH4Cl) salts ch.d.a. stamps were used. Solubility and interaction diagrams were performed by the visual-polythermic method in physicochemical researches. The following generally recognized methods of analytical chemistry were used in quantitative chemical analysis: calcium content was determined by the volumetric method of complexometry, and element composition in terms of carbon, nitrogen and hydrogen was analyzed. Kinematic viscosity was measured using a VPJ-type viscometer with a capillary diameter of 1.47mm. The accuracy of the results was ±0.0001·10⁻¹ m²/s.

The specific mass of the solutions under study was determined on a capillary pycnometer with a volume of 5 cm³. To determine volume, pycnometer was filled with bidistilled water, thermostated at 25°C and measured on scales. Based on the dry pycnometer mass, the density of water at 25°C, and the mass of the pycnometer filled with water, its actual size was calculated. Measurement accuracy ±0.00005 mg. The rN-meter of the solution was measured using 121-V.

Based on Hess's law, the thermodynamic indices of each reaction such as enthalpy (ΔN), entropy (ΔS), isobarno-isothermic potential (*ΔG*), and equilibrium constants (Kr) were calculated.

**RESULTS AND DISCUSSION**

In order to thermodynamically evaluate the probability of condensation reactions with formaldehyde of salts such as NH4Cl, NH4HCO3 and (NH4)2CO3 in the filter fluid and their general properties, we calculated the equilibrium constants lgKp, Gibbs free energy variation ΔG, reaction thermal effect and entropy values of these processes. Calculations were carried out on the basis of the initial and final reactions of ammonium salts and formaldehyde.

In accordance with Hess's law, the total heat effect of the reaction was determined as follows: From the sum of the formation heats of the products, the sum of the formation heats of the substances entering the reaction was subtracted.

or

Where: *∆H298*- heat effect of the reaction, Σ∆Hkon- the sum of the heat effects of the formation of the substances formed as a result of the reaction, *∆Hisx* is the sum of the heat of the formation of the substances entering the reaction. The entropy variations of the reactions were found by equation below.

Isobar-isothermic potentials (Gibbs free energy) were calculated by equation. The following equation is used to determine the equilibrium constants of the feedback reactions:

*∆G= -RT in Kp = -4,576 ig 576 kp.*

From this equation follows the following attitude:

ΔG here is Gibbs free energy. The negative value of Gibbs energy will be equal to:- *∆G = ∆H+T∆S.*

Where: ΔH – reaction heat effect.

The equilibrium constant of the reaction *was determined by ∆G= -RT InKp or* IgKr = ΔG/-2.303RT.

In order to evaluate the thermodynamic feasibility of the formation of hexamethylenetetramine (GMTA) by condensation of ammonium salts with formaldehyde, the main thermodynamic parameters for the following reverse reactions were calculated:

4 NH4Cl + 6CH2O ⮀ (CH2)6N4 + 4HCl + 6H2O

2 (NH4)2CO3 + 6CH2O ⮀ (CH2)6N4 + 2SO2 + 8H2O

4 (NH4)2HCO3 + 6CH2O ⮀ (CH2)6N4 + 4SO2 + 10H2O

The required thermodynamic data are obtained from the sources, the values of which are given in Table 1

**TABLE 1.** Thermodynamic characteristics of substances

|  |  |  |  |
| --- | --- | --- | --- |
| № | Naming Skills | ΔN, kDj/mol | ΔS, Dj/mol. K |
| 1  2  3  4  5  6  7 | Formaldehyde CH2O  Nexamethylenetetramine (CH2)6N4  Water H2O  Ammonium hydrogen carbonate NH4HCO3  Ammonium carbonate (NH4)2CO3  Ammonium chloride NH4Cl  Hydrochloric acid HCl | *-* 111,1  - 99,2  -285,8  -619,5  -  **508,6**  -314,2  -92,3 | 186,9  218, 66  69,91  216,0  184,08  134,3  186,9 |

Calculated thermodynamic values ​​for the condensation reaction of filter fluid.

I. Thermal effects for each reaction were found using the equations below:

= -259,8

= -701,8

= (99,2)(2858)-( 2478)(666,6) = 187,4

II. Calculations were made of the entropy change for each relaxation. The change in relaxation entropy is expressed by the equation:

III. Modification of the isobaric-isothermal potential of the calculated by the formula

For reaction: 4 NH4Cl + 6CH2O ⮀ (CH2)6N4 + 4HCl + 6H2O

*ΔG=* -341118,24 Dj/mol.

For reaction: 2(NH4)2CO3 +6CH2O ⮀ (CH2)6N4 +2CO2+8H2O

*ΔG= -701800- 298x711,62= -913862,76* Dj/mol.

For reaction: 4 (NH4)2HCO3 + 6CH2O ⮀ (CH2)6N4 + 4CO2 + 10H2O

*ΔG= -*187400- 298x1067,64= -505556,72 Dj/mol.

Based on the above formulas, basic thermodynamic parameters such as entropy change, thermal effect and Gibbs free energy were calculated during condensation reactions of ammonium salts in filter liquids with formaldehyde. The presence of negative isobar-isothermic potential values in the studied reactions, the high equilibrium constant confirmed the high probability of obtaining hexamethylenetetramine, hydrochloric acid and carbonate anhydride on the basis of filter liquids in the production of soda by the ammonia method. The final results are presented in the table below:

**TABLE 2.** Thermodynamic parameters and equilibrium constants of synthesis of hexamethylenetetramine from ammonium salts in filter liquid circulation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| № | Condensation reaxium | ΔN,  kDj/mol | ΔS,  Dj/mol. K | *ΔG*  Dj/mol | Kp |
| 1  2  3 | 4NH4Cl + 6CH2O ⮀ (CH2)6N4 + 4HCl + 6H2O  2(NH4)2CO3+6CH2O⮀ (CH2)6N4 +2CO2 +8H2O  4NH4HCO3+6CH2O⮀ (CH2)6N4+4CO2+10H2O | -259,8  *-*701,8  187,4 | -272,88  -711,62  -1067,64 | -341118,24  -913862,76  -505556,72 | **6,04•1059**  **1,43•10160**  **3,97•1088** |

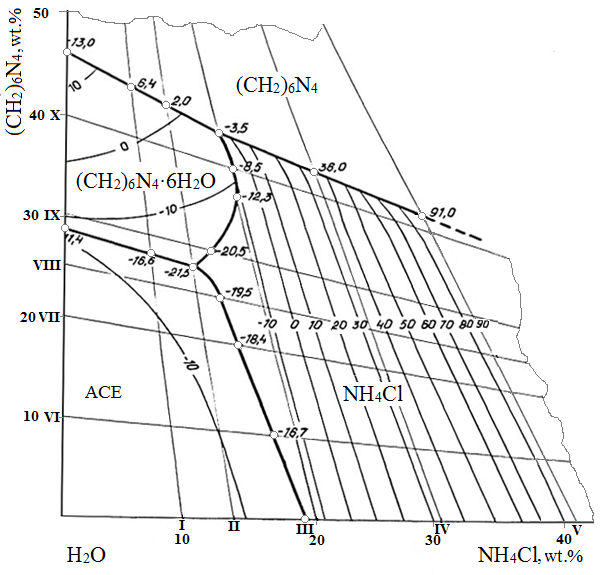
From the results of thermodynamic calculations can be seen that ammonium salts are fully condensed with formaldehyde. The high of the calculated equilibrium constants is indicative of the magnitude of the probability that the above reactions will take place. The order of location of salts depends on the degree of their dissociation and the attenuation of this dissociation in the presence of suitable acids, and is thus consistent. Considering that the degree of dissociation of salts is directly related to the level or constant of dissociation of the corresponding acids, it can be concluded that the degree of conversion of ammonium salts to HMTA depends on the degree of dissociation of the acids that form exactly those salts.

In this study, the co-soluble equilibrium state of the (CH2)6N₄–NH₄Cl–H₂O system was investigated in order to scientifically substantiate the synthesis of hexamethylenetetramine from a filter liquid formed during the calcined soda production process.

The mutual solubility of the (CH2)₆N – H2O and NH₄Cl– H2O systems has been previously studied. The results of our re-examination of these systems confirmed the previous data obtained and we were confident that the eutectic point in the NH4Cl–H H2O system would be at a temperature of −15.4 °C and a content of 19.7% NH4Cl. When the amount of hexamethylenetetramine in the Kylic system of (CH2)₆N – H2O was increased, crystals were formed first to the cereal phase, then (CH2)₆N •6 H2O and pure state (CH2)₆N. At the eutectic point of the system, crystal fall of 28.8% (CH2)₆N4 was observed at a temperature of −14.4 °C. Crystallization of (CH2)₆N •6 H2O with ice was completed at a point of 46.5% (CH2)₆N₄ and 13°C. It was found that when temperature was increased, only anhydrous hexamethylenetetramine was present in the solid phase.

(CH2)₆N –NH4Cl– H2O polythermic system in the range from -21.7 to 90°C has been investigated. At higher temperatures, it increased the decay of NH4Cl involved in the system into NH3 and HCl.

Observations in the study show that the solubility of (CH2)₆N and NH4Cl decreases as the temperature rises. Based on the data from the study of the intersolubilities of the re-studied (CH2)₆N₄– H2O and NH4Cl– H2O binary systems and the (CH2)₆N –NH4Cl– H2O tertiary polythermal system, a polythermal diagram was drawn and presented in Figure 1.

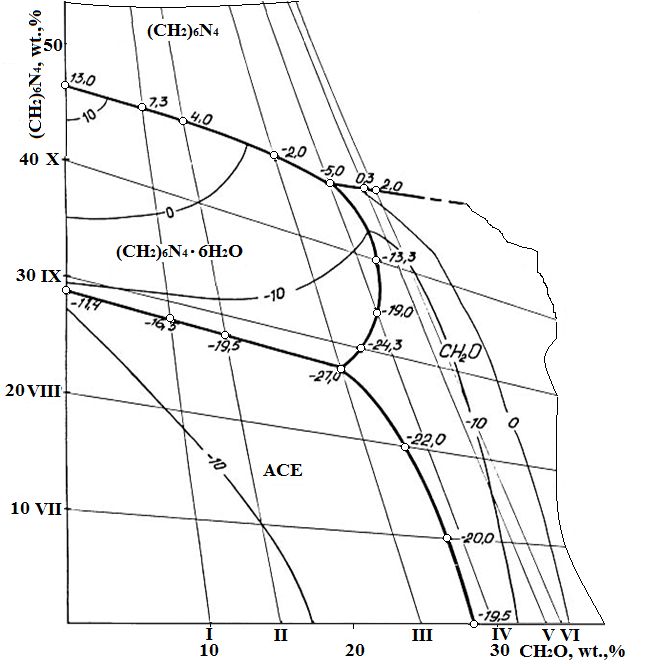


**FIGURE 1.** Solubility polytherm of the system (CH2)₆N₄–NH4Cl–H2O

According to the information presented in the figure, the diagram shows 4 crystallization boundaries, consisting of ice, hexamethylenetetramine hexahydrate, hexamethylenetetramine, and ammonium chloride. It was determined that the temperature at the intersection of their boundaries was −21.7 °C, the eutectic content was 10.5% NH₄Cl, 25.3% (CH2)₆N and 64.2% H₂O. The temperature at the intersection point of (CH2)₆N, (CH2)₆N₄•6 H2O and NH4Cl was –3.5 °C and (CH2)₆N 38.0%. As can be seen in the figure, a large part of the diagram is covered by the crystallization boundary of (CH2)₆N. This is explained by the limited solubility of (CH2)₆N₄ and a further decrease in the presence of ammonium chloride. In the diagram (CH2)₆N • H2O occupied the smallest crystallization area.

(CH2)₆N –NH4Cl–H₂O polythermic system was not observed to form new chemicals as a result of the study of their mutual solubility within the boundaries of established temperatures and concentrations .

In our subsequent study, the intersolubilities of the (CH2)₆N –CH2O– H2O tertiary polythermic system were investigated and the concentration and temperature limits regarding the melting of its constituent components were determined in order to further substantiate the possibilities of obtaining hexamethylenetetramine by exposure to formaldehyde to NH₄C. The results obtained are presented in Figure 2.



**FIGURE 2.** Solubility polytherm of the system (CH2)6N4–CH2O–H2O

The diagram shows 10 inner sections, of which 6 are directed by H2O–CH2O- (CH2)₆N₄ and 4 by H2O -(CH2)₆N₄ to the CH2O side. The euphorbial point of the H2O –(CH2)₆N₄ system at a temperature of -11.4 corresponds to 29% (CH2)₆N4 and 71% H2O. At the eutective point in the H₂O– CH2O binary system, it has been proven to be a composition consisting of 28.8% CH2O and 71.2% H2O at a temperature of –19.5 °C. In the polythermal diagram, the boundary areas of ice, (CH2)₆N • H2O, (CH2)₆N and CH₂O were distinguished. It was found that the content at the co-crystallization eutectic point of ₆N₄, CH₂O and ice was 22% (CH₂)₆N₄, 19.5% CH2O, and 58.5% H2O. The bulk of the diagram was occupied by the hexamethylenetetramine crystallization area, with a relatively small area being CH2O. The formation of new chemical compounds was not observed at the temperature range studied and in the concentration range of (CH₂)₆N₄ and CH2O.

**CONCLUSION**

Thermodynamic analysis of the condensation reactions of ammonium salts such as NH4Cl, NH4HCO3, and (NH4)2CO3 with formaldehyde, which are consistent with the backbone components of the filter liquids that form in the production of soda, fully confirmed that hexamethylenetetramine can be obtained from the filter liquid. Based on the results of the study of solubility diagrams of triple polythermal systems (CH2)6N4–NH4Cl–H2O and (CH2)6N4–CH2O–H2O, the laws of formation of new solid phases, their influence on the solubility of components and the optimal conditions for the formation of new compounds made it possible.

The theoretical knowledge obtained as a result of the above investigations will allow creating a technology for the development of a technology for the transformation of filter liquid of soda production into hexamethylenetetramine.

**REFERENCES**

1. Zong, Y., Li, H., Zhang, Y., Chen, W., & Zhou, S. (2023). Research status of soda residue in the field of environmental pollution control. RSC Advances, 13(55), 35319–35333. <https://doi.org/10.1039/D3RA04863B>
2. Li, Y., Zhang, Y., Zhang, X., Wang, L., & Jiang, J. (2015). Preparation of calcium carbonate and hydrogen chloride from distiller waste based on reactive extraction–crystallization process. Chemical Engineering Journal, 268, 255–263. <https://doi.org/10.1016/j.cej.2014.12.058>
3. Czaplicka, N., & Konopacka-Łyśkawa, D. (2019). Studies on the utilization of post-distillation liquid from the Solvay process to carbon dioxide capture and CaCO₃ precipitation. SN Applied Sciences, 1(4), 1-10. <https://doi.org/10.1007/s42452-019-0455-y>
4. Haris, S., Mourad, A. A.-H., Al-Marzouqi, A. H., El-Naas, M. H., Van der Bruggen, B., & Al-Marzouqi, M. H. (2023). Evaluation of a combined approach for sulfate and ammonia recovery from treated brine using a simultaneous chemical precipitation and electrocoagulation processes. Sustainability, 15(23), 16534. <https://doi.org/10.3390/su152316534>
5. Rahimpour, H., Esmaeili, H., & Shariati, M. (2024). Toward sustainable soda ash production: A critical review on eco-impacts, modifications and innovative approaches. Results in Engineering, 22*, 102399.* <https://doi.org/10.1016/j.rineng.2024.102399>
6. Wu, C., Li, X., Xu, T., & Li, Y. (2016). Ammonia recovery from high concentration wastewater of soda ash industry with membrane distillation process. Desalination and Water Treatment, 57(10), 4633–4642. <https://doi.org/10.1080/19443994.2015.1010233>
7. Czaplicka, N., & Konopacka-Łyśkawa, D. (2020). Utilization of gaseous carbon dioxide and industrial Ca-rich waste for calcium carbonate precipitation: A review. Energies, 13(23), 6239. <https://doi.org/10.3390/en13236239>
8. Chen, W., Li, X., Zhang, Y., Li, J., & Liu, J. (2022). One-pot synthesis of hexamethylenetetramine coupled with H₂ evolution from methanol and ammonia by a Pt/TiO₂ nanophotocatalyst. ACS Omega, 7(23), 20078–20086. <https://doi.org/10.1021/acsomega.2c01323>
9. Oba, Y., Takano, Y., Naraoka, H., Watanabe, N., & Kobayashi, K. (2020). Extraterrestrial hexamethylenetetramine in meteorites: A precursor of prebiotic chemistry in the inner solar system. Nature Communications, 11(1), 6243. <https://doi.org/10.1038/s41467-020-20038-x>
10. Otaboev, K. A., Sherkuziev, D. S., Badalova, O. A., Radjabov, R., Namazov, S. S., & Seytnazarov, A. R. (2022). Mineralogical Composition of Kyzylkum Washed Dry Concentrate and Its Processing into Simple Superphosphate. Russian Journal of General Chemistry, 92(3), 505–517. <https://doi.org/10.1134/s1070363222030203>
11. Jakhonkulovna, S. M., Kamolovna, G. B., Zokirov, M., Tajimuratovna, B. U., Yumashev, A., Shichiyakh, R., Safarova, N. I., Nusratovna, A. N., Esanmuradova, N., Karimbaevna, T. M., Lazizakhon, A., & Ishankulov, A. (2025). Electrochemical biosensors for early detection of Alzheimer’s disease. Clinica Chimica Acta, 572, 120278. <https://doi.org/10.1016/j.cca.2025.120278>
12. Mamutov, B., Butkov, E., Hamzayev, A., Sherkuziev, D., Aripov, K., Ergasheva, F., & Ismoilova, K. (2021). Application of mineral fertilizers to increasing soil moisture and growth of forest seedlings for creation forest crops in Western Tien-Shan. E3S Web of Conferences, 304, 03007. https://doi.org/10.1051/e3sconf/202130403007
13. Kuvshinov, D. G., Shuvaeva, O. A., & Serpionova, E. A. (2019). Synthesis of Ni-based catalysts by hexamethylenetetramine–nitrates solution combustion method for co-production of hydrogen and nanofibrous carbon from methane. International Journal of Hydrogen Energy, 44(37), 20923–20933. <https://doi.org/10.1016/j.ijhydene.2019.04.179>
14. Zhumaniyazov, M. Z., Beglov, B. M., Khodzhaev, O. F., & Yuldashev, N. K. (2004). Solubility Polytherm of the Ternary system Hexamethylenetetramine-Ammonium dihydrogen Phosphate-Water. Russian Journal of General Chemistry, 74(7), 1001–1004. <https://doi.org/10.1023/b:rugc.0000045855.52134.25>
15. Jumaniyazov, M., Kurambayev, S., Atashev, E., Jumaniyozov, A., & Buranova, M. (2025). Determination of the composition of the Zinelbulak talc-magnesite deposit rock using modern physicochemical methods. E3S Web of Conferences, 633, 06002. https://doi.org/10.1051/e3sconf/202563306002
16. Masharipova, S., Jumaniyazov, M., Turkmenbaeva, M., & Kabulova, L. (2025). Study of physicochemical properties of hydrophobic calcite based on sugar factory defecates. E3S Web of Conferences, 633, 01003. <https://doi.org/10.1051/e3sconf/202563301003>
17. Jumaniyazov, M., Masharipova, S., Bekchanov, B., Masharipova, Z., & Kudiyarova, K. (2025). Obtaining the composition of ceramic bricks based on the color characteristics of the original sample. AIP Conference Proceedings, 3304, 040046. <https://doi.org/10.1063/5.0269042>
18. Jumaniyazov, M., Kurambayev, S., Atashev, E., Aitova, S., & Pirnapasova, H. (2025). The extraction of talc from Zinelbulak talc-magnesite raw materials. AIP Conference Proceedings, 3304, 040043. <https://doi.org/10.1063/5.0269064>
19. D., Mishra, P., & Sahoo, S. (2017). Optical and structural properties and antibacterial activities of HMT-assisted nanoparticle systems. Materials Science Forum, 901, 123–130. <https://doi.org/10.2991/icseee-16.2016.65>