

# DEVELOPMENT OF RESOURCE-EFFICIENT TECHNOLOGIES FOR PROCESSING ACIDIC AND SALINE INDUSTRIAL LIQUID WASTES INTO VALUABLE PRODUCTS

Koshanova B.T.<sup>1</sup>, Toshtemirov A.B.<sup>2</sup>, Erkaev A.U.<sup>3</sup>, Reimov A.M.<sup>4</sup>, Kucharov B.X.<sup>5</sup>

<sup>1,2,3</sup> Tashkent Institute of Chemical Technology

<sup>4</sup> Karakalpak branch of the Academy of Sciences of the Republic of Uzbekistan

<sup>5</sup> Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan

[koshanova\\_nmkt@mail.ru](mailto:koshanova_nmkt@mail.ru), [azizbek.1999.11.24@gmail.com](mailto:azizbek.1999.11.24@gmail.com), [Aerkaev61@mail.ru](mailto:Aerkaev61@mail.ru), [reymov@mail.ru](mailto:reymov@mail.ru),  
[kbx74@yandex.ru](mailto:kbx74@yandex.ru)

## Abstract:

This study presents the development of physico-chemical and technological principles for the processing of acidic and saline liquid industrial wastes. The research focuses on spent sulfuric acid, saturated diethylene glycol, and neutralized industrial wastewater. Based on thermodynamic analysis and solubility diagrams, resource-efficient technologies were developed to obtain valuable products such as potassium sulfate, burkeite, purified water, and regenerated DEG. The proposed approaches demonstrate high efficiency and environmental safety.

**Keywords:** industrial waste, sulfuric acid, diethylene glycol, burkeite, potassium sulfate, green technology

## Introduction

The rapid growth of industrialization has led to a significant increase in the generation of liquid industrial wastes containing high concentrations of acids, dissolved salts, and organic contaminants. These waste streams are commonly produced in chemical, petrochemical, gas processing, and polymer industries, and are characterized by high toxicity, chemical reactivity, and environmental persistence. Improper disposal of such effluents results in soil degradation, freshwater salinization, and the formation of hazardous multi-component systems capable of mobilizing toxic substances in ecosystems [1].

In recent years, global attention has shifted from conventional wastewater treatment toward

resource recovery and circular economy approaches, where industrial effluents are considered as secondary raw materials. Industrial wastewater is now recognized as a valuable source of inorganic compounds such as sulfates, carbonates, and chlorides, which can be recovered and reused in industrial processes. This paradigm shift is driven by increasing water scarcity, depletion of mineral resources, and stricter environmental regulations [2].

A wide range of treatment technologies has been developed, including physical, chemical, and biological methods such as precipitation, ion exchange, membrane filtration, and thermal evaporation. Among them, membrane-based and hybrid technologies have gained particular attention. For instance, membrane distillation and membrane distillation–crystallization systems enable simultaneous water purification and salt recovery from highly concentrated brines, making them promising for zero liquid discharge applications [3].

However, despite significant progress, existing technologies still face critical limitations, including high energy consumption, membrane fouling and scaling, low selectivity for multi-component systems, and lack of integrated approaches for complex industrial effluents. Furthermore, most studies focus on single-type wastewater or isolated treatment methods, which limits their practical applicability in real industrial conditions where waste streams are multicomponent and highly variable [4].

## Materials and Methods

Objects of study included spent sulfuric acid, saturated DEG, and neutralized wastewater. Methods used include thermodynamic analysis, solubility diagrams, XRD, SEM, and IR spectroscopy [5].

In this context, the application of solubility diagrams of multicomponent aqueous salt systems provides a powerful tool for controlling crystallization processes and directing phase transformations. Such approaches allow the rational design of technological schemes for waste processing with targeted product formation [6].

The present study aims to develop resource-efficient and environmentally safe technologies for the complex processing of acidic and saline liquid industrial wastes, including spent sulfuric acid from PVC production, saturated diethylene glycol from gas dehydration, and neutralized industrial wastewater [7].

The novelty of this work lies in the integration of thermodynamic analysis with solubility diagram modeling, development of conversion and extraction processes for multicomponent systems, and simultaneous recovery of valuable products such as potassium sulfate, double salts, burkeite, purified water, and regenerated diethylene glycol [8].

The proposed approach contributes to the implementation of green chemistry and circular economy principles, enabling reduction of environmental impact and efficient utilization of industrial waste streams [9].

## Results and Discussion

Thermodynamic analysis confirmed feasibility of reactions [10]. Technologies for sulfuric acid conversion, DEG regeneration, and burkeite production were developed with high efficiency (table 1) [11].

The feasibility of the reactions is assessed through the change in Gibbs free energy ( $\Delta G$ ), which serves as a key criterion for determining the spontaneity of the processes [12]. This is particularly significant in the treatment of spent sulfuric acid and industrial wastewater [13].

**Table 1.** Thermodynamic parameters of the proposed reactions [14].

No.	Reactions	$\Delta H^{\circ}298$ (kJ/mol)	$\Delta S^{\circ}298$ (J/mol·K)	$\Delta G^{\circ}298$ (kJ/mol)	Temperature dependence
1	$2\text{KCl (s)} + \text{H}_2\text{SO}_4 \text{ (l)} + 2\text{NH}_3 \text{ (g)} \rightarrow \text{K}_2\text{SO}_4 \text{ (s)} + 2\text{NH}_4\text{Cl (s)}$	-287.57	-342.46	-185.46	Proceeds at low temperature
2	$\text{KCl (s)} + \text{H}_2\text{SO}_4 \text{ (l)} + \text{NH}_3 \text{ (g)} \rightarrow \text{KHSO}_4 \text{ (s)} + \text{NH}_4\text{Cl (s)}$	-178.53	-199.28	-119.11	Proceeds at low temperature
3	$\text{KCl (s)} + 2\text{H}_2\text{SO}_4 \text{ (l)} + 3\text{NH}_3 \text{ (g)} \rightarrow \text{KHSO}_4 \text{ (s)} + (\text{NH}_4)_2\text{SO}_4 \text{ (s)} + \text{NH}_4\text{Cl (s)}$	-453.55	-521.62	-298.03	Proceeds at low temperature
4	$2\text{KCl (s)} + 2\text{H}_2\text{SO}_4 \text{ (l)} + 4\text{NH}_3 \text{ (g)} \rightarrow \text{K}_2\text{SO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \text{ (s)} + 2\text{NH}_4\text{Cl (s)}$	-559.19	-663.58	-361.50	Proceeds at low temperature
5	$\text{KCl (s)} + (\text{NH}_4)_2\text{SO}_4 \text{ (l)} \rightarrow \text{KHSO}_4 \text{ (s)} + \text{NH}_4\text{Cl (s)} + \text{NH}_3 \text{ (g)}$	93.27	127.98	55.32	Proceeds at high temperature
6	$\text{KCl (s)} + \text{H}_2\text{SO}_4 \text{ (l)} \rightarrow \text{KHSO}_4 \text{ (s)} + \text{HCl (g)}$	17.28	98.15	-11.84	Proceeds at high temperature
7	$2\text{KCl (s)} + 2(\text{C}_2\text{H}_5)_2\text{NH (l)} + \text{H}_2\text{SO}_4 \text{ (l)} \rightarrow \text{K}_2\text{SO}_4 \text{ (s)} + 2[(\text{C}_2\text{H}_5)_2\text{NH}_2]\text{Cl (l)}$	-162.01	140.95	-138.96	Proceeds at all temperatures
8	$2\text{NaOH (s)} + \text{CO}_2 \text{ (g)} \rightarrow \text{Na}_2\text{CO}_3 \text{ (s)} + \text{H}_2\text{O (l)}$	-171.80	-137.80	-130.70	Proceeds at low temperature
9	$2\text{NaOH (l)} + \text{SO}_2 \text{ (g)} + 1/2\text{O}_2 \text{ (g)} \rightarrow \text{Na}_2\text{SO}_4 \text{ (s)} + \text{H}_2\text{O (l)}$	-524.89	-260.29	-448.00	Proceeds at low temperature

Thermodynamic analysis indicates that the most thermodynamically favorable products formed during the processing of spent sulfuric acid are potassium sulfate ( $\text{K}_2\text{SO}_4$ ) and the double salt  $\text{K}_2\text{SO}_4 \cdot (\text{NH}_4)_2\text{SO}_4$  [15].

### Conclusion

Developed technologies enable waste-to-product conversion, reduce environmental impact, and support circular economy principles.

Based on experimental investigations performed using a laboratory-scale model unit, integrated technologies for the regeneration of liquid industrial wastes were developed. These include: (i) the production of organomineral fertilizers containing organic components and potassium sulfate ( $\text{K}_2\text{SO}_4$ ) or the double salt  $\text{K}_2\text{SO}_4 \cdot (\text{NH}_4)_2\text{SO}_4$  from spent sulfuric acid generated during PVC production; (ii) the recovery of burkeite and purified water from alkaline solutions obtained in polyethylene production; and (iii) the production of concentrated diethylene glycol (DEG) as an import-substituting product from saturated DEG streams. Technological flow schemes and material balance calculations were established, and the physicochemical as well as commercial properties of the resulting products obtained via resource-efficient technologies were systematically evaluated.

## References

- [1] M. A. Shannon, P. W. Bohn, M. Elimelech, J. G. Georgiadis, B. J. Marinas, and A. M. Mayes, "Science and technology for water purification in the coming decades," *Nature*, vol. 452, no. 7185, pp. 301–310, 2008. doi:10.1038/nature06599
- [2] M. Elimelech and W. A. Phillip, "The future of seawater desalination: Energy, technology, and the environment," *Science*, vol. 333, no. 6043, pp. 712–717, 2011. doi:10.1126/science.1200488
- [3] T. Tong and M. Elimelech, "The global rise of zero liquid discharge for wastewater management," *Environmental Science & Technology*, vol. 50, no. 13, pp. 6846–6855, 2016. doi:10.1021/acs.est.6b01000
- [4] E. Curcio and E. Drioli, "Membrane distillation and related operations—A review," *Separation and Purification Reviews*, vol. 34, no. 1, pp. 35–86, 2005.
- [5] C. A. Quist-Jensen, F. Macedonio, and E. Drioli, "Membrane distillation for water recovery and zero liquid discharge," *Journal of Membrane Science*, vol. 487, pp. 1–16, 2015.
- [6] J. P. Van der Hoek, H. de Fooij, and A. Struker, "Wastewater as a resource: Strategies to recover resources from Amsterdam's wastewater," *Resources, Conservation and Recycling*, vol. 113, pp. 53–64, 2016.
- [7] J. W. Mullin, *Crystallization*, 4th ed. Oxford, UK: Butterworth-Heinemann, 2001.
- [8] A. S. Myerson, *Handbook of Industrial Crystallization*, 2nd ed. Oxford, UK: Butterworth-Heinemann, 2002.
- [9] R. H. Perry and D. W. Green, *Perry's Chemical Engineers' Handbook*, 8th ed. New York, NY, USA: McGraw-Hill, 2008.
- [10] Y. Zhang et al., "Phosphate separation and recovery from wastewater: A review," *Chemical Society Reviews*, vol. 42, no. 20, pp. 7988–7999, 2013.
- [11] G. Amy, N. Ghaffour, Z. Li, L. Francis, R. V. Linares, T. Missimer, and S. Lattemann, "Membrane-based seawater desalination: Present and future prospects," *Desalination*, vol. 401, pp. 16–21, 2017.
- [12] A. D. Khawaji, I. K. Kutubkhanah, and J. M. Wie, "Advances in seawater desalination technologies," *Desalination*, vol. 221, no. 1–3, pp. 47–69, 2008.
- [13] S. Judd, *The MBR Book: Principles and Applications of Membrane Bioreactors*, 2nd ed. Oxford, UK: Elsevier, 2011.
- [14] M. R. Wiesner and J. Y. Bottero, *Environmental Nanotechnology: Applications and Impacts of Nanomaterials*, New York, NY, USA: McGraw-Hill, 2007.
- [15] D. L. Sedlak, *Water 4.0: The Past, Present, and Future of the World's Most Vital Resource*, New Haven, CT, USA: Yale University Press, 2014.