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Mathematical Analysis of CaO Content Variation in Acidic Wastewater and Mineralized Mass Mixture from Central Kyzylkum Phosphorite Based on Exponential Decay Model

Yuldasheva A.P., *Shamuratov S.Kh., Kurambayev Sh.R., Radjabov M.F.

Urgench State University named after Abu Rayhon Beruni, Urgench, Uzbekistan

**Corresponding author email: sanjar.sh@urdu.uz*

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ABSTRACT
This article investigates the reduction behavior of calcium oxide (CaO) content in mixtures of mineralized mass (MM) from Central Kyzylkum phosphorite and acidic wastewater (AWW) from the oil and fat industry, using experimental data and a mathematical approach. The study was conducted at 60°C, with the AWW: MM ratio varying from 100:10 to 100:40. The CaO content in each mixture was determined and analysed in terms of its mass ratio. Results demonstrated a systematic decrease in CaO content with an increasing proportion of MM. The initial rate of decline was rapid and then gradually slowed. An exponential decay model was employed and characterized by parameters. A first-order differential equation was applied and refined using experimental data. The initial value and decay constant were found to be C_0 = 67.39 and k = 0.0401, respectively. The resulting exponential equation showed a high degree of correlation with experimental points ($R^2 \approx 0.98$). This study offers a structured evaluation of CaO behavior in complex systems through mathematical modeling, which can be used to control processes in real technological conditions. The modeling outcomes may serve as a methodological basis for developing kinetic models involving other ions and components in future research.

Keywords: CaO, exponential decay, mineralized mass, wastewater, mathematical modeling, predictive model.

Information about authors:

Yuldasheva Asal Pulat kizi
Student, faculty of Chemical Technology, Urgench State University named after Abu Rayhon Beruni, Urgench, H. Olimjon Street 14, 220100, Uzbekistan. Email: shamuratovsx@gmail.com

Shamuratov Sanjarbek Khusinbay ugli
Doctor of Philosophy in Technical Sciences, Associate Professor at the Faculty of Chemical Technology, Urgench State University named after Abu Rayhon Beruni, Urgench, H. Olimjon Street 14, 220100, Uzbekistan. Email: sanjar.sh@urdu.uz; ORCID ID: https://orcid.org/0000-0002-1040-1807

Kurambayev Sherzod Raimbergenovich
Doctor of Technical Sciences, Dean of the Faculty of Chemical Technology, Urgench State University named after Abu Rayhon Beruni, Urgench, H. Olimjon Street 14, 220100, Uzbekistan. Email: sherzod.sh@urdu.uz; ORCID ID: https://orcid.org/0009-0003-3986-5079

Radjabov Mansur Farkhadovich
Candidate of Technical Sciences, Head of the Department of Food Technology, Urgench State University named after Abu Rayhon Beruni, Urgench, H. Olimjon Street 14, 220100, Uzbekistan. Email: mansur.ra@urdu.uz; ORCID ID: https://orcid.org/0000-0003-2068-0595

Introduction

Acidic wastewater generated during processing operations in the oil and fat industry represents one of the most pressing environmental issues today. In particular, wastewater produced during the separation and refining of soapstock contains high concentrations of ions such as H^+, SO_4^{2-}, Cl^-, Na^+, and Mg^{2+}. These chemically aggressive components significantly disrupt the pH balance in aquatic environments [[1], [2], [3], [4], [5]].

This leads to severe damage to natural ecological systems. It negatively impacts the quality of groundwater. It disrupts the microbiology of soils. It reduces biodiversity [[6], [7]]. It also destabilizes the food chain and natural biocycles. Such wastewaters degrade very slowly in nature. In most cases, they are discharged directly into surface water bodies. This dramatically increases environmental risk. Industrial facilities often release these wastes without treatment [[8], [9], [10], [11]].

Such practices contradict global environmental protection standards. Especially when the wastewater has a pH below 4, the high acid load makes neutralization absolutely essential. Neutralization is the chemical conversion of harmful acidic components into stable, environmentally safe forms. It is a crucial step in ensuring ecological safety in industrial processes. When selecting neutralizing agents, several criteria must be considered. Economic viability, environmental safety, technological compatibility, and local availability are key among them [[12], [13], [14], [15], [16]].

Considering these factors, this study selected the mineralized mass derived from the Central Kyzylkum Phosphorite Complex as the neutralizing material. This material is an industrial byproduct from phosphorite processing. It contains chemically active oxides such as CaO, MgO, Al_2O_3, and SiO_2. These oxides can react with acidic ions. The material is natural, locally sourced, cost-effective, and environmentally safe. It exists in large quantities as a byproduct and is typically unused [[13], [14], [15], [16], [17]].

Utilizing it for neutralization offers dual benefits. First, it helps detoxify acidic industrial wastewater. Second, it enables the reuse of industrial mineral waste. This approach aligns with the concept of waste-from-waste technology. Additionally, the Central Kyzylkum mineralized mass demonstrates stable neutralizing behavior against a variety of ionic contaminants [18]. It performs consistently under mechanical mixing and elevated temperature conditions. It does not generate toxic byproducts, forming inert residues instead. Previous studies have not sufficiently evaluated this material's potential. Its kinetic behavior and consumption rate in neutralization processes have not been thoroughly analyzed [[19], [20], [21]].

Most earlier studies rely on laboratory observations without theoretical modeling. This limits their applicability in real industrial scenarios. Therefore, the present research focuses on assessing this material's efficiency in neutralizing real acidic wastewater. Samples of acidic wastewater were treated with varying doses of mineralized mass [[13], [14]]. The decrease in CaO concentration during treatment was analyzed. Neutralization efficiency and reagent consumption were evaluated [[22], [23]]. From a practical perspective, this approach aids in optimizing reagent dosage. It also allows for analysis of how waste composition affects neutralization. The results guide industrial applications. The findings help establish a technological basis for achieving regulatory compliance in wastewater treatment. In essence, this study offers an effective, sustainable, and economically feasible solution for neutralizing acidic industrial effluents. It contributes directly to environmental protection, resource conservation, and waste valorization [13].

Experimental part

The AWW sample was collected from an oil and fat processing plant in Uzbekistan. Preliminary chemical analysis revealed a pH ≈ 2.8 and high concentrations of SO_4^{2-} (1190 mg/L), Cl^- (2120 mg/L), Na^+, Mg^{2+}, and H^+ ions [[13], [14], [15], [16]]. The chemical composition of acidic wastewater produced during the process of extracting fatty acids from soapstock is presented in Table 1.

MM was obtained from Central Kyzylkum's limestone-rich deposits and contained CaO (43,17%), CO_2 (14,01%), P_2O_5 (15,09%), and SO_3 (2,17%). Samples were mixed at 60 ± 1°C in the following mass ratios: 100:10, 100:15, 100:20, 100:25, 100:30, 100:35, and 100:40.

Each sample consisted of 100 g AWW and the corresponding MM amount. They were stirred for 30 minutes at 400 rpm. CaO content was determined from the dry residue using gravimetric methods. Each experiment was repeated three times, and average values were recorded. Based on the data, a mathematical model was constructed to describe CaO decrease with increasing MM.

Modeling was conducted in Origin 2021 Pro using scatter plots and exponential regression:

$$C_{(x)} = C_0 \cdot e^{-kx}$$

Table 1 - Chemical composition of acidic wastewater (AWW) produced during the process of extracting fatty acids from soapstock

Cations	mg/l	meq / l	% -eq / l	Anions	mg/l	meq / l	% -eq / l
H^+	100	100	81	Cl^-	38114	1073	50
Na^+	431560	1876.41	11	SO_4^{2-}	48165	1003.13	46
K^+	-	-	-	NO_2^-	20.11	-	-
NH_4^+	99	5.44	-	NO_3^-	842	13.65	-
Ca^{2+}	299	11	1	CO_3^-	-	-	-
Mg^{2+}	1831	151	7	HCO_3^-	3447	55.18	4
Fe^{3+}	0.4	0.03	-	**Total**		**2148.08**	**100**
Fe^{2+}	32	1.08	-				
Total		**2144.96**	**100**				

Modeling was performed using the "Nonlinear Curve Fit" function based on the sample function “ExpDec1”.

The initial values of the parameters C_0 and k were automatically determined, and their optimal values, along with confidence intervals, were provided.

Based on the modeling results, the coefficient of determination (R^2) was found to be higher than 0.98, indicating a strong fit of the exponential model.

All graphs were plotted using the Origin 2021 Pro software environment.

Model-predicted CaO (%) values were calculated using the exponential equation above.

Absolute deviation (Δ) was calculated as the difference between modeled and experimental CaO values [[24], [25]]:

$$\Delta = C_{model} - C_{experimental}$$

Relative error (%) was determined using the formula:

$$\text{Relative error} = \left|\frac{\Delta}{C_{experimental}}\right|$$

Results and Discussion

The CaO content in the resulting products was determined experimentally by preparing mixtures of acidic wastewater and mineralized mass in different mass ratios.

The experiments were conducted at a temperature of 60 °C, with each trial repeated three times, and average values were calculated. The mass ratios of AWW: MM (Acidic Wastewater: Mineralized Mass) were gradually increased from 100:10 to 100:40.

The results indicate that as the proportion of MM increases, the percentage of CaO in the mixture decreases sharply.

This can be explained by the reaction of CaO present in the MM with H^+ ions and other acidic ions found in the AWW, leading to its gradual reduction.

Table 2 and Figure 1 below show the AWW: MM ratio and the corresponding observed CaO content (%).

Table 2 - CaO content in mixtures at increasing AWW:MM ratios

№	AWW:MM Ratio	CaO (%)
1	100:10	46.52
2	100:15	36.49
3	100:20	28.98
4	100:25	23.39
5	100:30	18.94
6	100:35	17.65
7	100:40	16.17

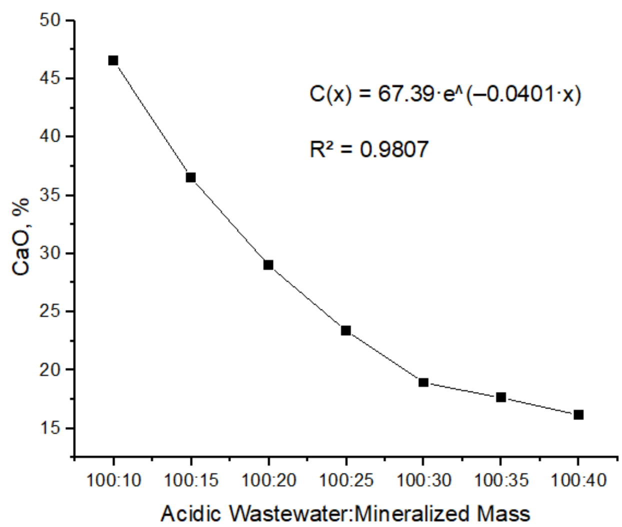

Figure 1 - Exponential decrease in CaO content in the mixture depending on the increase in the AWW:MM ratio

In the sample with a mass ratio of 100:10, the CaO content was 46,52%, whereas at the 100:40 ratio, it dropped to 16,17%. A sharp decline in CaO content was observed during the initial three stages -from 100:10 to 100:25-indicating that reactive CaO actively participated in neutralization reactions with the acidic components of the AWW. This range represents the zone of highest neutralization efficiency for CaO, where the most significant changes occurred. From 100:25 to 100:40, the decrease became more gradual, suggesting that the remaining CaO content declined slowly due to residual reactions.

The exponential decay behavior observed in the graph was confirmed by the model, and the high R^2 value (0,9807) indicates excellent agreement between the model and the experimental data.

The trajectory of CaO reduction was accurately described by the following model:

$$C_{(x)} = 67{,}39 \cdot e^{-0.0401\mathrm{x}}$$

In this case, $C_{(x)}$ -represents the percentage of CaO depending on the amount xxx of mineralized mass (MM); 67,39 is the initial maximum reactive capacity (i.e., the CaO value when the MM amount is close to zero); 0,0401 is the decay coefficient.

According to the graph analysis, the functional decrease of CaO corresponds to the characteristics of a classical kinetic model. This behavior reflects similar reactivity trends observed during the neutralization of real industrial wastewater. The values given in the table are very close to the results of the mathematical model, with an average relative error of approximately 3–4%. Such closeness demonstrates the reliability of the model and enables the identification of optimal technological regimes for various AWW: MM (Acidic Wastewater : Mineralized Mass) mass ratios.

Based on these observations, it was determined that applying CaO in a calculated dose allows effective adjustment of the mixture to meet regulatory pH levels. The decreasing trend of CaO percentage in AWW: MM mixtures was described using an exponential regression model based on experimental data. In this model, the independent variable is the amount of MM (g), while the dependent variable is the CaO percentage (%). As a result of exponential regression performed in Origin 2021 Pro, the following mathematical model equation was obtained.

The model's goodness-of-fit is represented by the value:

$$R^2 = 0{,}9807$$

which indicates a strong correlation between the experimental results and the model.

The linearized graph generated from the model nearly fully encompasses the experimental data points, visually confirming the high degree of conformity.

The high rate of decrease in the initial stages suggests that CaO acts more actively as a neutralizing agent during the early increases in MM quantity.

Using the model equation, one can calculate in advance either the required amount of MM for neutralizing AWW or the residual CaO percentage. This enables the optimization of reagent consumption, technological process control, and effective adjustment of waste to meet pH standards in practical applications. The exponential nature of the model reflects the progressively slowing behavior of the process, which may be attributed to the gradual depletion of reactive components.

The mathematical analysis also provides theoretical justification for the dynamic decrease of CaO content depending on the AWW:MM ratio. This mathematical approach enables digital control, optimization, and forecasting of reagent requirements in the neutralization process.

Table 3 presents the experimentally determined CaO percentages for various AWW:MM mass ratios, as well as the values calculated based on the exponential model.

As shown in Table 3, the relative error in most cases does not exceed 5–7%, indicating high model accuracy. In particular, for MM amounts between 10-30 g, the model closely matches the experimental data. Although deviations slightly increase at 35–40 g, the overall trend remains consistent. These results confirm the reliability of the model and its practical predictive value.

Table 3 - Experimental vs. modeled CaO content and relative errors

AWW:MM	Exp. CaO (%)	Model CaO (%)	Δ (%)	Rel. Error (%)
100:10	46.52	45.13	+1.39	2.99
100:15	36.49	36.93	–0.44	1.20
100:20	28.98	30.22	–1.24	4.28
100:25	23.39	24.73	–1.34	5.73
100:30	18.94	20.24	–1.30	6.85
100:35	17.65	16.56	+1.09	6.17
100:40	16.17	13.56	+2.61	16.14

As observed from the table, the CaO percentages calculated using the model closely match the experimental values. For each data point, both the absolute difference in CaO content and the relative error are indicated separately. In most cases, the relative error remains below 5%, demonstrating the high accuracy of the model. Only at the MM ratio of 40 g does the relative error reach approximately 16%, which may be attributed to possible experimental uncertainties or secondary influencing factors in the reaction process. Overall, the modeled CaO reduction closely follows the trajectory of the experimental values, indicating high reliability of the developed exponential model. This table was provided to verify the agreement between the results of mathematical modeling and empirical data, assess the level of accuracy, and justify the applicability of the model in industrial practice. Furthermore, the table facilitates forecasting of CaO consumption and supports technological planning through analytical interpretation of experimental results.

The column labeled "Difference (Δ)" in the table represents the direction of deviation between the model and actual measurements (+/–), helping identify whether the model underestimates or overestimates the values. Such a table enhances the scientific credibility of the analysis results and plays an important role in documenting the modeling process.

Conclusion

The research findings confirmed that the decrease in CaO content within AWW and MM mixtures exhibits an exponential trend. As the AWW:MM mass ratio increased, a consistent reduction in CaO percentage was observed, which is explained by the complete reaction of the reagent with the acidic environment. The coefficient of determination (R^2) of the model was found to be 0,9807, indicating a high degree of agreement between experimental results and theoretical predictions. The difference between modeled and experimental values ranged between 3–6 %, with the relative error remaining minimal. The analytical table visually and quantitatively confirms the discrepancy between the model and actual measurements. Based on this model, it is possible to pre-calculate the required amount of MM or CaO for neutralizing industrial wastewater, optimize reagent consumption, and bring the pH of the effluent to regulatory levels. The high initial reactivity of CaO and the subsequent slowdown observed in the later stages of the neutralization process are well reflected in the model, further demonstrating that exponential regression accurately represents real chemical-technological behavior. The model's simple structure allows for its practical application in rapid calculations in industrial settings. This scientific approach helps fill the existing gap in mathematical modeling for acidic wastewater neutralization. The study enables a deeper understanding of the interaction mechanism between industrial effluents and neutralizing reagents, with validation and prediction supported by empirical data. Moreover, the findings lay a scientific foundation for the development of cost-effective and efficient neutralization methods utilizing MM-containing technogenic waste materials.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Орталық Қызылқұм фосфоритінен алынған қышқыл ағынды сулар мен минералданған масса қоспасындағы СаО құрамының өзгерісін экспоненциалды ыдырау моделінің негізінде математикалық талдау

Юлдашева А.П., *Шамуратов С.Х., Курамбаев Ш.Р., Раджабов М.Ф.

Әбу Райхан Бируни атындағы Үргеніш мемлекеттік университеті, Үргеніш, Өзбекстан

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АННОТАЦИЯ

Бұл мақалада Орталық Қызылқұм фосфоритінің минералданған массасы (ММ) мен май өнеркәсібінің қышқыл ағынды суларының (ҚАС) қоспаларындағы кальций оксиді (CaO) мөлшерінің төмендеу үрдісі эксперименттік деректер мен математикалық әдісті қолдана отырып зерттеледі. Зерттеу 60°C температурада жүргізілді, ҚАС:ММ ара қатынасы 100:10-нан 100:40-қа дейін өзгертілді. Әр қоспадағы CaO мөлшері оның массалық қатынасына байланысты анықталып, талданды. Нәтижелер ММ үлесі артқан сайын CaO мөлшерінің жүйелі түрде азаятынын көрсетті. Бастапқыда төмендеу жылдамдығы жоғары болып, кейіннен біртіндеп баяулады. Экспоненциалды ыдырау моделі қолданылып, тиісті параметрлермен сипатталды. Бірінші ретті дифференциалдық теңдеу эксперименттік деректер негізінде қолданылып, жетілдірілді. Анықталған бастапқы мән мен ыдырау тұрақтысы сәйкесінше C_0 = 67,39 және k = 0,0401 болды. Алынған экспоненциалды теңдеу эксперименттік нүктелермен жоғары дәрежелі корреляцияны көрсетті (R^2 ≈ 0,98). Бұл зерттеу математикалық модельдеу арқылы күрделі жүйелердегі CaO әрекетін құрылымдық тұрғыдан бағалауды ұсынады, оны нақты технологиялық жағдайларда процестерді басқару үшін қолдануға болады. Модельдеу нәтижелері болашақ зерттеулерде басқа иондар мен компоненттерді қамтитын кинетикалық модельдерді әзірлеуге методологиялық негіз бола алады.

Түйін сөздер: CaO, экспоненциалды ыдырау, минералданған масса, ағынды су, математикалық модельдеу, болжамдық үлгі.

Авторлар туралы ақпарат:

Юлдашева Асал Пулат қызы — *Студент, Әбу Райхан Беруни атындағы Үргеніш мемлекеттік университетінің химиялық технология факультеті, Үргеніш қаласы, Х. Олимжан көшесі, 14, 220100, Өзбекстан. Email: shamuratovsx@gmail.com*

Шамұратов Санжарбек Хұсынбайұлы — *Техника ғылымдары бойынша философия докторы, Әбу Райхан Беруни атындағы Үргеніш мемлекеттік университетінің химиялық технология факультетінің қауымдастырылған профессоры, Үргеніш қаласы, Х. Олимжан көшесі, 14, 220100, Өзбекстан. Email: sanjar.sh@urdu.uz; ORCID ID: https://orcid.org/0000-0002-1040-1807*

Құрамбаев Шерзод Райымбергенович — *Техника ғылымдарының докторы, Әбу Райхан Беруни атындағы Үргеніш мемлекеттік университетінің химия-технология факультетінің деканы, Үргеніш қаласы, Х.Олимжон көшесі 14, 220100, Өзбекстан. Email: sherzod.sh@urdu.uz; ORCID ID: https://orcid.org/0009-0003-3986-5079*

Раджабов Мансур Фархадович — *Техника ғылымдарының кандидаты, Әбу Райхан Беруни атындағы Үргеніш мемлекеттік университетінің Тағам технологиясы кафедрасының меңгерушісі, Үргеніш қаласы, Х. Олимжан көшесі, 14, 220100, Өзбекстан. Email: 6ansur.ra@urdu.uz; ORCID ID: https://orcid.org/0000-0003-2068-0595*

Математический анализ изменения содержания CaO в кислых сточных водах и смеси минерализованной массы из фосфоритов Центральных Кызылкумов на основе модели экспоненциального распада

Юлдашева А.П., *Шамуратов С.Х., Курамбаев Ш.Р., Раджабов М.Ф.

Ургенчский государственный университет имени Абу Райхона Беруни, Ургенч, Узбекистан

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АННОТАЦИЯ

В данной статье исследуется поведение снижения содержания оксида кальция (CaO) в смесях минерализованной массы (ММ) из фосфоритов Центральных Кызылкумов и кислых сточных вод (КСВ) масложировой промышленности, используя экспериментальные данные и математический подход. Исследование проводилось при температуре 60°C, при этом соотношение КСВ:ММ варьировалось от 100:10 до 100:40. Содержание CaO в каждой смеси определялось и анализировалось в зависимости от ее массового соотношения. Результаты показали систематическое снижение содержания CaO при увеличении доли ММ. Первоначальная скорость снижения была высокой, а затем постепенно замедлялась. Для характеристики процесса использовалась модель экспоненциального распада с соответствующими параметрами. Дифференциальное уравнение первого порядка было применено и уточнено с использованием экспериментальных данных. Начальное значение и константа распада были определены как C_0 = 67,39 и k = 0,0401 соответственно. Полученное экспоненциальное уравнение продемонстрировало высокую степень корреляции с экспериментальными точками (R^2 ≈ 0,98). Данное исследование предлагает структурированную оценку поведения CaO в сложных системах посредством математического моделирования, которое может быть использовано для управления процессами в реальных технологических условиях. Результаты моделирования могут служить методологической основой для разработки кинетических моделей с участием других ионов и компонентов в будущих исследованиях.

Ключевые слова: CaO, экспоненциальный распад, минерализованная масса, сточные воды, математическое моделирование, прогнозная модель.

Информация об авторах:

Юлдашева Асал Пулат кизи
Студент, факультет химической технологии Ургенчского государственного университета имени Абу Райхона Беруни, Ургенч, улица Х. Олимжона, 14, 220100, Узбекистан. Email: shamuratovsx@gmail.com

Шамуратов Санжарбек Хусинбай угли
Доктор философии в области технических наук, доцент факультета химической технологии Ургенчского государственного университета имени Абу Райхона Беруни, Ургенч, улица Х. Олимжона, 14, 220100, Узбекистан. Email: sanjar.sh@urdu.uz; ORCID ID: https://orcid.org/0000-0002-1040-1807

Курамбаев Шерзод Раимбергенович
Доктор технических наук, декан химико-технологического факультета Ургенчского государственного университета имени Абу Райхана Беруни, Ургенч, улица Х. Олимжона, 14, 220100, Узбекистан. Email: sherzod.sh@urdu.uz; ORCID ID: https://orcid.org/0009-0003-3986-5079

Раджабов Мансур Фархадович
Кандидат технических наук, заведующий кафедрой технологии пищевых продуктов Ургенчского государственного университета имени Абу Райхана Беруни, Ургенч, улица Х. Олимжона, 14, 220100, Узбекистан. Email: mansur.ra@urdu.uz; ORCID ID: https://orcid.org/0000-0003-2068-0595

References

[1] Dumont M-J, & Narine SS. Soapstock and deodorizer distillates from North American vegetable oils: Review on their characterization, extraction and utilization. Food Research International. Elsevier BV. 2007; 40(8):957-974. https://doi.org/10.1016/j.foodres.2007.06.006

[2] Haas Michael J. Improving the Economics of Biodiesel Production through the Use of Low Value Lipids as Feedstocks: Vegetable Oil Soapstock. Fuel Processing Technology. Elsevier BV. 2005; 86(10):1087-1096. https://doi.org/10.1016/j.fuproc.2004.11.004

[3] Dowd Michael K. Compositional Characterization of Cottonseed Soapstocks. Journal of the American Oil Chemists' Society. Wiley. 1996. https://doi.org/10.1007/bf02525458

[4] Barbusiński, Krzysztof, Sławomir Fajkis, and Bartosz Szeląg. Optimization of Soapstock Splitting Process to Reduce the Concentration of Impurities in Wastewater. Journal of Cleaner Production. Elsevier BV. January 2021; 280(2):124459. https://doi.org/10.1016/j.jclepro.2020.124459

[5] Ahmad, Talha, Tarun Belwal, Li Li, Sudipta Ramola, Rana Muhammad Aadil, Abdullah, Yanxun Xu, and Luo Zisheng. Utilization of Wastewater from Edible Oil Industry, Turning Waste into Valuable Products: A Review. Trends in Food Science & Technology. Elsevier BV. 2020; 99:21-33. https://doi.org/10.1016/j.tifs.2020.02.017

[6] Qasim, Wael, and Mane AV. Characterization and Treatment of Selected Food Industrial Effluents by Coagulation and Adsorption Techniques. Water Resources and Industry. Elsevier BV. 2013; 4:1-12. https://doi.org/10.1016/j.wri.2013.09.005

[7] Geetha Devi M, Shinoon Al-Hashmi ZS, and Chandra Sekhar G. Treatment of Vegetable Oil Mill Effluent Using Crab Shell Chitosan as Adsorbent. International Journal of Environmental Science and Technology. Springer Science and Business Media LLC. 2012; 9:713-718. https://doi.org/10.1007/s13762-012-0100-4

[8] Pintor Ariana MA, Andreia G Martins, Renata S Souza, Vítor JP Vilar, Cidália MS Botelho, and Rui AR Boaventura. Treatment of Vegetable Oil Refinery Wastewater by Sorption of Oil and Grease onto Regranulated Cork – A Study in Batch and Continuous Mode. Chemical Engineering Journal. Elsevier BV. 2015; 268:92-101. https://doi.org/10.1016/j.cej.2015.01.025

[9] Ahmad Ashfaq, Azizul Buang, and Bhat AH. Renewable and Sustainable Bioenergy Production from Microalgal Co-Cultivation with Palm Oil Mill Effluent (POME): A Review. Renewable and Sustainable Energy Reviews. Elsevier BV. 2016; 65:214-234. https://doi.org/10.1016/j.rser.2016.06.084

[10] Hmidi K, Ksentini I, and Mansour LB. Treatment of Olive-Pomace Oil Refinery Wastewater Using Combined Coagulation-Electroflotation Process. Journal of Water Chemistry and Technology. Allerton Press. 2017; 39:275-280. https://doi.org/10.3103/s1063455x17050046

[11] Mirshafiee Amir, Abbas Rezaee, and Rasol Sarraf Mamoory. A Clean Production Process for Edible Oil Removal from Wastewater Using an Electroflotation with Horizontal Arrangement of Mesh Electrodes. Journal of Cleaner Production. Elsevier BV. 2018; 198:71-79. https://doi.org/10.1016/j.jclepro.2018.06.201

[12] Ahmad Talha, Rana Muhammad Aadil, Haassan Ahmed, Ubaid ur Rahman, Bruna CV Soares, Simone LQ Souza, Tatiana C Pimentel, et al. Treatment and Utilization of Dairy Industrial Waste: A Review. Trends in Food Science & Technology. Elsevier BV. 2019; 88:361-372. https://doi.org/10.1016/j.tifs.2019.04.003

[13] Shamuratov Sanzharbek, Umid Baltaev, Umarbek Alimov, Namazov Shafoat, Sherzod Kurambaev, and Bazar Ibadullaev. Utilization Process Research of the Soap Industry Acid Waste Water with High Carbonate Phosphorite of Central Kyzylkum. E3S Web of Conferences. EDP Sciences. 2021. https://doi.org/10.1051/e3sconf/202126404079

[14] Shamuratov Sanjarbek, Umid Baltaev, Sanobar Achilova, Umarbek Alimov, Shafoat Namazov, and Najimuddin Usanbaev. Enhancement of Availability of High Calcareous Phosphorite by Neutralization of Acid Effluent and Composting of Cattle Manure. E3S Web of Conferences. EDP Sciences. 2023. https://doi.org/10.1051/e3sconf/202337703004

[15] Shamuratov Sanjarbek, Umid Baltaev, Olga Myachina, Umarbek Alimov, Elyor Atashev, and Tokhir Kuramboev. Agrochemical Efficiency of Slow Release Phosphate Fertilizers Derived on the Base of Phosphorite Activation. E3S Web of Conferences. EDP Sciences. 2023. https://doi.org/10.1051/e3sconf/202343403014

[16] Sotimboev Ilgizarbek, Umidbek Baltaev, Sanjarbek Shamuratov, Ruzimov Shamsiddin, Umarbek Alimov, and Mirzabek Saporboyev. Technical and Economic Efficiency of Processing Acidic Wastewater from the Oil and Fat Industry into Necessary Agricultural Products. E3S Web of Conferences. EDP Sciences. 2024. https://doi.org/10.1051/e3sconf/202456303072

[17] Turatbekova Aidai, Malokhat Abdukadirova, Sanjarbek Shamuratov, Bakhodir Latipov, Mirzabek Saporboyev, Jafar Shamshiyev, and Yusuf Makhmudov. Investigation of the Effect of Fertilizers on the Biochemical and Physical Characteristics of Carrots (Daucus Carota L.). E3S Web of Conferences. EDP Sciences. 2024. https://doi.org/10.1051/e3sconf/202456303074

[18] Sultonov BE, Kholmatov DS, Rasulov AA, and Temirov USh. Treatment of Phosphate Waste Generated during Thermal Processing of Phosphorites of the Central Kyzylkum. Obogashchenie Rud. Ore and Metals Publishing House. 2024. https://doi.org/10.17580/or.2024.04.06

[19] Shaymardanova Mokhichekhra, Kholtura Mirzakulov, Gavkhar Melikulova, Sakhomiddin Khodjamkulov, Abror Nomozov, and Oybek Toshmamatov. Studying of The Process of Obtaining Monocalcium Phosphate Based on Extraction Phosphoric Acid from Phosphorites of Central Kyzylkum. Baghdad Science Journal. College of Science for Women, University of Baghdad. 2024. https://doi.org/10.21123/bsj.2024.9836

[20] Sultonov BE, Nozimov ES, and Kholmatov DS. Recycling of Local Phosphate Waste - Mineralized Mass into Activated Phosphorus Fertilizers. Chemical Science International Journal. Sciencedomain International. 2023; 32(6). https://doi.org/10.9734/csji/2023/v32i6875

[21] Temirov Uktam, Nodir Doniyarov, Bakhrom Jurakulov, Najimuddin Usanbaev, Ilkhom Tagayev, and Abdurasul Mamataliyev. Obtaining Complex Fertilizers Based on Low-Grade Phosphorites. E3S Web of Conferences. EDP Sciences. 2021. https://doi.org/10.1051/e3sconf/202126404009

[22] Sedghkerdar Mohammad Hashem, Ehsan Mostafavi, and Nader Mahinpey. Investigation of the Kinetics of Carbonation Reaction with Cao-Based Sorbents Using Experiments and Aspen Plus Simulation. Chemical Engineering Communications. Informa UK Limited. 2015. https://doi.org/10.1080/00986445.2013.871709

[23] Sun Ping, John R Grace, Jim Lim C, and Edward J Anthony. Determination of Intrinsic Rate Constants of the CaO–CO2 Reaction. Chemical Engineering Science. Elsevier BV. 2008; 63(1):47-56. https://doi.org/10.1016/j.ces.2007.08.055

[24] Fritz Matthew S. An Exponential Decay Model for Mediation. Prevention Science. Springer Science and Business Media LLC. 2013; 15:611-622. https://doi.org/10.1007/s11121-013-0390-x

[25] Atashev E. Decomposition of Magnesite-Sparing Waste in Sulfuric Acid with a High Concentration: Empirical Modeling and Determination of Optimal Conditions. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2025; 339(4):71-78. https://doi.org/10.31643/2026/6445.41