REVIEW

of the official reviewer for dissertation work Rakhym Akmaral Bakhytzhankyzy on the theme «Sorbents based on aluminosilicate raw materials for heavy metal ions, bisphenol-A and propranolol extraction from aqueous solutions» presented for the degree of Doctor of Philosophy (PhD) in the specialty «6D060600 – Chemistry».

№	Criteria	Eligibility (one of the options must be checked)	Justification of the position of the official reviewer
1.	The topic of the thesis (as of the date of its approval) corresponds to the directions of development of science and/or state programs	1.1 Compliance with priority areas of science development or government programs:	
		1) The thesis was completed within the framework of a project or target program financed from the state budget (indicate the name and number of the project or program) 2) The thesis was completed within the framework of another state program (indicate the name of the program) 3) The dissertation corresponds to the priority direction of the development of science, approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (indicate the direction)	The dissertation was carried out within the framework of scientific projects funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan (project numbers **AP08957166** and **AP09260116**). The research topic directly aligns with priority areas of national scientific development related to water purification technologies, environmental safety, development of cost-effective sorbents, and rational use of natural mineral resources. The study contributes to solving tasks outlined in state programs on ecology and sustainable environmental management, as it is aimed at creating efficient adsorbent materials based on natural aluminosilicates for the extraction of toxic heavy metals and organic pollutants from aqueous media. The work also corresponds to the priority direction "Environmental protection, rational use of natural resources and development of clean technologies", approved by the Higher

			Scientific and Technical Commission. The objectives of the dissertation are consistent with Kazakhstan's strategic priorities in the field of water treatment, environmental chemistry, and green technologies, as the results can be applied to improve wastewater purification processes and reduce anthropogenic pollution.
2.	Importance for science	The work makes/does not make a significant contribution to science, and its importance is well disclosed/not disclosed	The dissertation makes a significant contribution to the development of modern adsorption science and environmental physical chemistry. The author has obtained new fundamental data on the physicochemical behavior of natural and modified aluminosilicate sorbents, determined the mechanisms of interaction between the sorbents and various classes of pollutants (heavy metal ions, phenolic endocrine-disrupting compounds, and pharmaceutical molecules), and identified the role of ion exchange, physisorption, chemisorption, and hydrophobic interactions in these processes. The work advances scientific understanding by proposing a new methodological approach ("Na–H method") for distinguishing the contributions of physical adsorption and ion-exchange processes to the overall adsorption mechanism. This approach represents a valuable scientific innovation in the field of adsorption

			mechanistic studies. The results obtained expand knowledge on the surface chemistry of zeolite–surfactant and clay–surfactant systems, including multilayer surfactant adsorption, surface recharging phenomena, changes in acidity and porosity, and structure–property relationships that govern sorption efficiency. The scientific importance is fully disclosed: the dissertation provides detailed kinetic, thermodynamic, structural, and mechanistic analysis supported by extensive experimental evidence, making the obtained results relevant for further fundamental studies in adsorption chemistry, material science, and environmental remediation technologies.
3.	The principle of independence	Self-reliance level: **1) High;** 2) Medium; 3) Low; 4) No independence	The dissertation demonstrates a high level of independence in the execution of experimental work, data interpretation, and formulation of scientific conclusions. The author personally carried out the synthesis of all series of sorbents (initial, Na-modified, acid-activated, and surfactant-modified), performed their physicochemical characterization (SEM, XRD, FTIR, Raman, BET, CEC, PZC), and conducted comprehensive adsorption studies involving heavy metal ions, bisphenol-A, and propranolol.

			The doctoral candidate independently processed and analyzed large experimental datasets, including adsorption isotherms, thermodynamic calculations, kinetic modeling, and error function analysis using nonlinear regression. The work also includes the author's own approach to mechanistic interpretation, supported by original experimental findings. The personal contribution is explicitly confirmed in the dissertation: the author conducted the experiments, processed the results, prepared visualizations, and wrote the draft versions of scientific publications. The volume and complexity of the tasks performed indicate that the candidate possesses strong experimental skills, deep understanding of adsorption chemistry, and the ability to independently plan and execute scientific research. Therefore, the dissertation fully satisfies the criterion of **high independence**.
4.	The principle of inner unity	4.1 Justification of the relevance of the thesis: **1) Justified;** 2) Partially justified; 3) Not justified.	The relevance of the dissertation is fully justified, as the work addresses the urgent problem of removing toxic heavy metals and organic pollutants from water using cost-effective natural aluminosilicate sorbents. The study corresponds to global and national priorities in environmental safety, wastewater treatment, and development of sustainable purification technologies. The growing contamination of water

			bodies and the need for efficient sorbents clearly demonstrate the scientific and practical necessity of the research.
		4.2 The content of the thesis reflects the topic of the thesis: **1) Reflects;** 2) Partially reflects; 3) Does not reflect	The content of the dissertation fully reflects its stated topic. All sections—from the synthesis and modification of aluminosilicate sorbents to their physicochemical characterization and detailed adsorption studies—are directly aligned with the research aim of developing effective sorbents for the extraction of heavy metal ions, bisphenol-A, and propranolol from aqueous solutions. The experimental and discussion parts consistently correspond to the thematic focus of the work.
		4.3. The purpose and objectives correspond to the topic of the thesis: 1) correspond; 2) partially correspond; 3) do not correspond	The purpose and objectives of the dissertation fully correspond to its topic. The defined goals—obtaining modified aluminosilicate sorbents, studying their physicochemical properties, evaluating adsorption efficiency, and establishing adsorption mechanisms—directly derive from the central theme of developing effective sorbents for pollutant removal from water. All research tasks consistently support the achievement of the main objective.
		4.4 All sections and provisions of the thesis are logically interconnected: 1) completely interconnected; 2) the interconnection is partial; 3) there is no interconnection	All sections of the dissertation are logically connected, moving consistently from material synthesis to characterization and adsorption studies. Each chapter supports the overall research objective and builds upon the

			previous results.
		4.5 The new solutions (principles, methods) proposed by the author are reasoned and evaluated in comparison with the known solutions: 1) there is a critical analysis; 2) partial analysis; 3) the analysis does not represent one's own opinions, but quotes from other authors	The new methodological approach and mechanistic interpretations proposed by the author are well-reasoned and supported by experimental data. The dissertation includes critical comparison with known solutions and demonstrates the advantages of the developed methods.
5.	Scientific novelty principle	5.1 Are the scientific results and provisions new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The dissertation presents scientifically new results, including the first-time synthesis of aluminosilicate sorbents modified with SLES and DDAB and a newly proposed approach for evaluating adsorption mechanisms. The novelty is clearly demonstrated through structural, kinetic, and mechanistic findings not previously reported for these systems.
		5.2 Are the dissertation findings new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The dissertation findings are partially new, as the author obtained original results on adsorption capacities, mechanism differentiation, and surface chemistry changes after modification. These findings expand existing knowledge and introduce new interpretations supported by experimental evidence.
		5.3 Technical, technological, economic or management decisions are new and reasonable: 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The proposed technical approaches for sorbent modification and pollutant removal are partially new and scientifically justified. The results demonstrate improved adsorption efficiency and offer practical applicability in water purification technologies.

6.	The validity of the main findings	All main conclusions are/are not based on scientifically significant evidence or well-grounded (for qualitative research and areas of training in the arts and humanities)	All main conclusions are well-grounded and supported by experimental data, including structural analysis, adsorption isotherms, kinetic and thermodynamic modeling. The evidence presented is sufficient to confirm the reliability of the findings.
7.	The main provisions for the defense	It is necessary to answer the following questions for each provision separately: 7.1 Is the provition proven? **1) proven;** 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; **2) no** 7.3 Is it new? **1) yes;** 2) no 7.4 Application level: 1) narrow; **2) medium;** 3) wide 7.5 Is it proven in the article? **1) yes;** 2) no	**Provision 1.** The first provision is sufficiently proven by the results of structural characterization and adsorption experiments. The author clearly demonstrates how modification of aluminosilicates enhances their sorption properties toward heavy metals and organic pollutants. The obtained data fully confirm the validity and scientific relevance of this provision.
		1) proven; 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; **2) no**	**Provision 2.** The second provision is supported by detailed kinetic, isothermal, and thermodynamic analyses. The interpretation of adsorption mechanisms is based on consistent experimental evidence and is not trivial, as it offers new insights into the role of ion

		7.3 Is it new? **1) yes;** 2) no 7.4 Application level: 1) narrow; **2) medium;** 3) wide 7.5 Is it proven in the article? **1) yes;** 2) no	exchange, hydrophobic interactions, and multilayer surfactant adsorption. The provision is reflected in the author's publications, confirming its reliability.
		1) proven; 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; **2) no** 7.3 Is it new? **1) yes;** 2) no 7.4 Application level: 1) narrow; **2) medium;** 3) wide 7.5 Is it proven in the article? **1) yes;** 2) no	**Provision 3.** The third provision is proven through comparative evaluation of different modification methods and their impact on sorbent performance. The author shows that the developed approach leads to improved removal efficiency and can be applied in water purification technologies. The novelty and practical importance of this provision are clearly demonstrated by the presented results.
8.	The principle of reliability Reliability of sources and information provided	8.1 Choice of methodology - is justified or the methodology is described in sufficient detail **1) yes;** 2) no	The choice of methodology is fully justified, as the dissertation employs appropriate physicochemical methods (SEM, XRD, FTIR, BET, CEC, PZC) for characterizing aluminosilicate sorbents and modern approaches for adsorption analysis. The methodology is

			described in sufficient detail to ensure reproducibility of the results.
		8.2 The results of the thesis were obtained using modern methods of scientific research and methods of processing and interpreting data using computer technologies: **1) yes;** 2) no	The results were obtained using modern scientific methods, including advanced surface characterization techniques and comprehensive adsorption modeling. Data processing and interpretation were performed using contemporary computational tools, ensuring accuracy and reliability.
		8.3 Theoretical conclusions, models, identified relationships and patterns have been proven and confirmed by experimental research (for areas of training in pedagogical sciences, the results have been proven on the basis of a pedagogical experiment): **1) yes;** 2) no	Theoretical conclusions and identified relationships are fully supported by experimental data, including structural analysis and adsorption studies. The consistency between theoretical assumptions and measured results confirms the reliability of the proposed mechanisms.
		8.4 Important statements are confirmed / partially confirmed / not confirmed by references to current and reliable scientific literature	Important statements in the dissertation are confirmed by references to current and reliable scientific literature. The author uses recent sources to support methodological choices, theoretical interpretations, and comparisons with existing adsorption studies.
		8.5 Used literature sources are sufficient/not sufficient for a literature review	The literature sources used in the dissertation are sufficient for a comprehensive review of the topic. The author includes relevant and up-to-date studies covering adsorption mechanisms, sorbent modification methods, and environmental

			applications.
9	Practical value principle	9.1 The thesis has theoretical value: **1) yes;** 2) no	The dissertation has clear theoretical value, as it expands scientific understanding of adsorption mechanisms on modified aluminosilicate surfaces. The findings contribute to the development of surface chemistry and adsorption theory.
		9.2 The thesis is of practical importance and there is a high probability of applying the results obtained in practice: **1) yes;** 2) no	The dissertation has significant practical importance, as the developed modified aluminosilicate sorbents demonstrate high efficiency in removing heavy metal ions, bisphenol-A, and contaminants from water. The obtained results show that the proposed materials can be applied in real water purification systems due to their affordability, environmental safety, and regeneration potential. The study provides clear recommendations for improving sorbent modification procedures to enhance adsorption capacity. The findings are relevant for industrial and municipal wastewater treatment technologies, where low-cost and effective sorbents are in high demand. The high probability of practical application is supported by the reproducibility and stability of the developed sorbents under various experimental conditions.
		9.3 Are the practice suggestions new? 1) completely new; **2) partially new (25-75% are new);**	The practical suggestions presented in the dissertation are partially new, as they introduce improved modification

		3) not new (less than 25% are new)	methods and optimized adsorption conditions for enhanced pollutant removal. These recommendations expand existing practices and offer more efficient approaches for wastewater treatment applications.
10.	The quality of writing and design	Academic writing quality: 1) high; **2) average;** 3) below average; 4) low.	The academic writing quality is at an average level: the structure is clear, and the material is presented logically. The dissertation meets formal requirements, though some sections could benefit from more concise formulation and stylistic refinement.
11.	Notes on a thesis	1. Lack of justification for the choice of error functions in the "Error function analysis" section In the "Error function analysis" section Table 6 lists the error functions used — RMSE, SEE, ARE, MSE, χ^2, and others. However, the author does not explain by what criteria these parameters were selected and what their advantages are in relation to the adsorption models presented in the dissertation. There is also no discussion of the sensitivity of models to various error functions and how the use of alternative metrics could affect the interpretation of the results. Detailing the methodological grounds for choosing statistical tools would enhance the analytical rigor of the work. 2. Lack of justification for the choice of hydrochloric acid (HCl) for the activation of sorbents The dissertation lacks a methodological justification for the choice of hydrochloric acid (HCl) as an acid activation agent for zeolite and clay. The dissertation presents the results of the treatment of sorbents with HCl solutions, but it does not specify why this reagent was preferred over other acids (H_2SO_4, HNO_3, H_3PO_4 etc.) and what criteria were used to select the optimal acidic agent. In addition, the effect of various anions on the sorbent structure, leaching	

		mechanisms, and material stability is not discussed. Adding a justification for the acid choice would increase the methodological transparency and reproducibility of the study. 3. The issue of regeneration and reuse of sorbents is not sufficiently disclosed Despite the fact that adsorption materials are positioned as practical and low—cost, the dissertation lacks an analysis of their stability during repeated use - data on desorption, structural changes after recycling, and loss of activity are not presented. This reduces the practical completeness of the study. 4. The thermal stability of sorbents has not been studied experimentally, despite the use of highly concentrated solutions of acids and surfactants The structural destruction of zeolite after acid treatment is discussed, however, the author does not perform TGA/DTG or other methods to assess the thermal stability and stability of the samples. This is important because modifications change the sorbent structure.	
12.	Scientific level of the doctoral student's articles on the topic of research (in case of defense of the dissertation in the form of a series of articles, the official reviewers comment on the scientific level of each article of the doctoral student on the topic of research)	The main results of the dissertation are presented in **14 publications**, demonstrating a solid scientific level of the doctoral student's research output: • Two articles in international peer-reviewed journals with non-zero impact factor, one of which is published in a Q1 journal (IF = 5.876) according to the Web of Science database, confirming the high relevance and novelty of the results. • Four articles in journals recommended by the Committee for Quality Assurance in the Field of Education and Science of the Ministry of Higher Education of the Republic of Kazakhstan, reflecting the national scientific recognition of the obtained results. • Two articles in international conference proceedings indexed in Scopus and Web of Science, confirming international visibility of the research. • Six abstracts at international conferences where the author	

		presented results on sorbent modification, adsorption kinetics, and mechanism identification. The publication set demonstrates a consistently high scientific level, covering all major directions of the dissertation: physicochemical characterization, heavy metal adsorption, BPA and PRO sorption mechanisms, surfactant modification effects, and optimization of sorption conditions.	
13.	Decision of the official reviewer (pursuant to paragraph 28 of the present Model Regulations)	The dissertation demonstrates scientific novelty, methodological rigor, and practical significance in the development and characterization of modified aluminosilicate sorbents for the removal of heavy metals and organic pollutants from water. The main results are well-substantiated by extensive experimental data, supported by publications in high-ranking international journals, and presented in a logically structured manner. The comments and noted minor shortcomings do not affect the overall scientific quality or the validity of the conclusions. The author Rakhym Akmaral Bakhytzhankyzy deserves to award the degree of Doctor of Philosophy (PhD).	

In reviews, official reviewers indicate one of the following solutions:

1) to award the degree of Doctor of Philosophy (PhD);

Official Reviewer:

PhD, candidate of chemical sciences, senior researcher of the engineering profile Laboratory of Korkyt Ata Kyzylorda university, acting associate professor of the educational program “engineering technologies”
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/ Turmanov Rakhymzhan /

қолды РАСТАЙМЫН
ЗАВЕРЯЮ подпись

Қорқыт ата атындағы Қызылорда мемлекеттік университеті» коммерциялық емес акционерлік қоғамы
Адами ресурстарды басқару басқармасы
Управление человеческими ресурсами