REVIEW
of the official reviewer for dissertation work of
Makhmut Yerian on the theme «Development of hybrid high-performance algorithms for numerical simulation of oil displacement problems»
presented for the degree of Doctor of Philosophy (PhD) in the specialty «8D06105 - System Engineering»

№	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 corresponds to the priority direction of science development approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan: "Advanced Production, Digital and Space Technologies". The work is related to this direction through the development of high-performance CPU, GPU, and hybrid algorithms for numerical simulation of applied engineering problems.
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 contributes to the development and comparative analysis of high-performance algorithms for numerical simulation of polymer flooding problems. Its importance is sufficiently disclosed through the connection between numerical modelling, parallel computing, and practical reservoir simulation tasks.
3.	The principle of independence	Self-reliance level: 1) High; 2) Medium;	The dissertation demonstrates a high level of independent work, since the author develops a complete computational pipeline and

		3) Low; 4) No independence	implements several CPU, GPU, and hybrid parallel algorithms. The obtained results are supported by benchmarking and profiling experiments.
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 research is justified by the need to accelerate numerical simulations used in polymer flooding and enhanced oil recovery problems. The work addresses an important computational aspect of applied reservoir modelling.
		4.2 The content of the thesis reflects the topic of the thesis: 1) Reflects; 2) Partially reflects; 3) Does not reflect	The content reflects the declared topic. The dissertation consistently considers the mathematical model, sequential numerical algorithm, CPU and GPU parallel implementations, hybrid algorithms, benchmarking, and validation.
		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 correspond to the topic of the thesis. They are aimed at developing, implementing, and comparing high-performance algorithms for the selected polymer flooding computational model.
		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	The sections are logically interconnected and form a consistent structure. The thesis proceeds from the model and numerical scheme to parallel implementations and then to comparative performance analysis.
		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 proposed solutions are compared with known CPU, GPU, and hybrid approaches to reservoir simulation algorithms. The comparative analysis supports the author's positioning of the work as an HPC implementation and benchmarking contribution.

		4) the analysis is absent.	
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 mathematical model and basic numerical scheme are based on known approaches, while the organization of the full computational pipeline and its CPU/GPU/hybrid implementations contain new implementation level results. Therefore, the novelty is best assessed as partial but sufficient for the specialty.
		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 because they provide comparative performance conclusions for several parallel implementations applied to the same polymer flooding pipeline. The main value lies in benchmarking, profiling, and identifying hardware-related performance limitations.
		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 technical decisions are partially new and reasonable. The most important ones are the full-pipeline CUDA shared-memory tiling and the triple-hybrid MPI+OpenMP+CUDA implementation.
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)	The main conclusions are supported by numerical experiments, performance measurements, and profiling results. The evidence is sufficient for the stated aim of comparing high-performance implementations of the considered computational model.
7.	The main provisions for the defense	It is necessary to answer the following questions for each provision separately: 7.1 Is the provision proven? 1) proven; 2) rather proven; 3) rather not proven;	**Main provision for defense 1: full-pipeline CUDA shared-memory tiling** The provision is proven because the dissertation presents the corresponding CUDA implementation, benchmarking, and profiling results. The result is not trivial, since shared-

		4) not proven 5) in its current wording, it is impossible to verify whether the statement has been proven. 7.2 Is it trivial? 1) yes; 2) no 3) in its current wording, it is impossible to verify whether the statement is trivial. 7.3 Is it new? 1) yes; 2) no 3) in its current wording, it is impossible to verify the novelty of the statement. 7.4 Application level: 1) narrow; 2) medium; 3) wide 4) in its current wording, it is impossible to determine the scope of application of the statement. 7.5 Is it proven in the article? 1) yes; 2) no 3) in its current wording, it is impossible to verify whether the statement has been proven in the article.	memory tiling is extended to the pressure, saturation, and polymer-concentration parts of the computational pipeline. It is also reflected in the article "A CUDA performance study of global- and shared-memory kernels for the Buckley-Leverett polymer-flooding problem". **Main provision for defense 2: triple-hybrid MPI+OpenMP+CUDA algorithm** The provision is proven by the implementation and comparison with other CPU, GPU, and hybrid variants. The result has a medium application level, since it is demonstrated for the considered one-dimensional computational model and can guide further development of hybrid simulation codes. It is supported by the published works on MPI+OpenMP, MPI+CUDA, and CUDA-based implementations, while the integrated triple-hybrid result is presented in the dissertation as the final development of these approaches.
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 methodology is described in sufficient detail. The dissertation presents the model assumptions, discretization, time-stepping algorithm, implementation variants, and profiling methodology.
		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:	The results were obtained using modern computer technologies and research tools. The work applies OpenMP, MPI, CUDA, Intel

		1) yes; 2) no	VTune, mpiP, NVIDIA Nsight Compute, and NVIDIA Nsight Systems.
		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	The conclusions are confirmed by computational experiments and performance measurements. The numerical experiments support the comparison of the proposed implementations within the selected model and hardware environment.
		8.4 Important statements are confirmed / partially confirmed / not confirmed by references to current and reliable scientific literature	The important statements are supported by references to relevant literature on polymer flooding, numerical reservoir simulation, parallel computing, and GPU acceleration. The literature base is sufficient for the aims of the dissertation.
		8.5 Used literature sources are sufficient/not sufficient for a literature review	The literature sources are sufficient for the reviewed research area. They cover the main topics needed for the dissertation: polymer flooding, mathematical modeling, numerical methods, and high-performance computing.
9	Practical value principle	9.1 The thesis has theoretical value: 1) yes; 2) no	The thesis has theoretical value in the systematic formulation of the computational pipeline and in the analysis of its performance behaviour on different parallel architectures. This value is mainly connected with computational science and system engineering.
		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 thesis has practical importance for the implementation and optimization of numerical simulation codes on CPU, GPU, and hybrid architectures. The results may be useful for

			similar stencil-based and reservoir simulation computations.
		9.3 Are the practice suggestions new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The practical suggestions are partially new. They are useful for selecting appropriate parallelization strategies and understanding performance limitations for similar computational problems.
10.	The quality of writing and design	Academic writing quality: 1) high; 2) average; 3) below average; 4) low.	The dissertation is generally well structured and understandable. Minor formatting and presentation issues are present, but they do not prevent understanding of the main scientific and technical results.
11.	Notes on a thesis		The dissertation is a completed research work with clear relevance, a consistent structure, and sufficient experimental support. As recommendations for further development, it would be useful to extend the approach to multidimensional and more realistic reservoir models, to further clarify scalability on larger hardware systems, and to continue improving the presentation of benchmark data. These remarks are recommendatory in nature and do not reduce the overall positive assessment of the dissertation.
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 publications correspond to the dissertation topic and reflect the main results of the research. Their scientific level is sufficient for the specialty, since they cover numerical modelling, GPU computing, and hybrid parallel implementation.

	the doctoral student on the topic of research)		
13.	Decision of the official reviewer (pursuant to paragraph 28 of the present Model Regulations)		Taking into account the relevance of the topic, the developed computational algorithms, the benchmarking and profiling results, and the publications on the topic of the dissertation, **I recommend awarding the degree of Doctor of Philosophy (PhD) to Makhmut Yerlan in the specialty «8D06105 – System Engineering».**

Official Reviewer:

Ph.D., Associate Professor,
Professor at the Department of Mathematics,
Sarsen Amanzholov East Kazakhstan University

(signature)

Dossan Baigereyev