

RIVIEW OF THE OFFICIAL REVIEWER

for the dissertation thesis submitted on the
Requirements for the Degree of Doctor of Philosophy (Ph.D.) in Petroleum Engineering
(8D07202) by Sagyndikov Marat Serikovich
titled

“Systematic Approach Investigation for Improving Polymer Flood Technology at the Kalamkas field”

| № n/a | Criteria | Compliance with the criteria (it is necessary to mark one of the answer options) | Justification of the official reviewer position |
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| 1. | The dissertation title (at the time of its approval) corresponds to the directions of scientific development and/or state programs | 1.1 Compliance with priority directions of science development or state programs: 1) the dissertation was completed within the framework of a project or target program funded from the state budget (specify the name and number of the project or program) 2) the dissertation was completed within the framework of another state program (specify the name of the program) 3) <u>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 (specify the direction)</u> | This Ph.D. thesis aimed to investigate polymer flood at the Kalamkas field and to subsequently develop a systematic approach for improving the measurement and interpretation of polymer flood technology as applied. Therefore, the title of the dissertation corresponds to the directives and priorities of the development of science within the state programs of the Oil and Gas sector, within the Republic of Kazakhstan. |
| 2. | Importance to science | The work <u>makes</u> /does not make a significant contribution to science, and its importance is well <u>disclosed</u> / not disclosed | The results of the author's research and rigorous technical evaluation, execution and extension to predictive/forecasting has made a significant contribution to the development of polymer flooding technology, especially in the development of methods to collect, measure, interpret data that allows for correct conclusions to be drawn of the true flow behavior during polymer flood. Its importance is well disclosed in the thesis. |
| 3. | The principle of independence | The level of independence: 1) <u>high</u> ; 2) average; 3) low; 4) there is no independence | The Ph.D. student put together a comprehensive plan and conducted theoretical research, laboratory and field experiments, and wrote and published scientific articles that formed the basis for his dissertation. In particular, the Ph.D. student's personal contributions can be seen in the official reports from the field operations corresponding with the well testing initiatives and data used, which are listed in this dissertation (Appendices B-E). Without a doubt, this work represents the doctoral student's personal efforts in planning and organizing field experiments, collaborating with domestic and international scientists, as there is also evidence of him participating in scientific conferences to validate and defend the results of the work. |

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| 4. | The principle of internal unity | <p>4.1 Justification of the dissertation relevance: 1) <u>justified</u>; 2) partially justified; 3) not justified</p> | <p>Although polymer flooding has been applied for about 60 years, there are still uncertainties in flow mechanisms, formation stability of polymer solutions, modeling process and technology optimization. The Ph.D. student reviewed and implemented a comprehensive scope of testing in order to discover the key data to collect and protocols aimed at systematic improvement of polymer flooding technology at the Kalamkas field, which confirms the relevance of this dissertation.</p> |
| | | <p>4.2 The dissertation content reflects the title of the dissertation: 1) <u>reflects</u>; 2) partially reflects; 3) does not reflect</p> | <p>The content of the dissertation reflects the topic of the dissertation, as all chapters of the dissertation are devoted to the topic of polymer flooding technology and systematic testing and data utilization.</p> |
| | | <p>4.3 The purpose and objectives correspond to the title of the dissertation: 1) <u>correspond</u>; 2) partially correspond; 3) do not correspond</p> | <p>The formulation of the goals and objectives identified do indeed correspond to the topic of the dissertation.</p> |
| | | <p>4.4 All sections and hypotheses of the dissertation are logically interrelated: 1) <u>completely interconnected</u>; 2) the relationship is partial; 3) there is no relationship</p> | <p>The dissertation work has an internal unity due to the set goal, setting and solving problems to achieve it – systematic collection, analyses and interpretation of field, laboratory and modeling data. Materials are presented in a logical manner, with the end result being that the obtained scientific results are substantiated and validated through history matching and forecasting of Kalamka field performance.</p> |
| | | <p>4.5 The new solutions proposed by the author (principles, methods) are reasoned and evaluated in comparison with the known solutions: 1) <u>there is a critical analysis</u>; 2) partial analysis; 3) the analysis is not author opinions, but quotes from other authors (citations)</p> | <p>The new solutions proposed by the author are argued and evaluated in comparison with the known solutions. The extra care taken to collect samples can be the missing link between understanding field observations and obtaining junk data. The present study outlines the critical analyses performed to understand and plan the type of data collection, field testing and subsequent modelling requirements; this is justified by the positive results of the performed research.</p> |
| 5. | The principle of scientific novelty | <p>5.1 Are the scientific results and hypotheses new? 1) <u>completely novel</u>; 2) partially new (25-75% are new); 3) not new (less than 25% are new)</p> | <p>The author conducted and published the first total acid number (TAN) studies of oil fields in Kazakhstan to screen the applicability of ASP flooding. In Chapter 3 of this dissertation, the doctoral student shed light on a practical problem that has been</p> |

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| | | | elusive even with decades of theoretical, laboratory and field studies, "Why is the injectivity factor of vertical polymer injection wells much higher in the field than in analytical and numerical predictions?" This question was answered through evidence presented in this study, which refutes the pessimistic visions of other researchers about mechanical degradation and limitation of polymer injectivity. |
| | | 5.2 Are the conclusions of the dissertation novel? 1) completely novel ; 2) partially novel (25-75% are new); 3) not novel (less than 25% are new) | The conclusions obtained by the author in the thesis are based on a combination of field, laboratory and theoretical research, including the use of new intellectual property (patent). |
| | | 5.3 Are technical, technological, economic or managerial decisions novel and justified? 1) completely novel ; 2) partially novel (25-75% are novel); 3) not novel (less than 25% are novel) | There is evidence of successful approbation of the results obtained utilizing the methods outlined in this research, at the Kalamkas field. This indicates a truly comprehensive approach of the applicant to the topic of research, based on the close interaction of developers of technology, direct executors and customers utilizing the technology. |
| 6. | Validity of the main conclusions | All the main conclusions are based /not based on scientifically significant evidence or are sufficiently well-founded (for qualitative research and areas of training in the arts and humanities) | The main conclusions of the thesis are based on irrefutable evidence obtained by careful field, laboratory and theoretical studies. The data was then incorporated into a reservoir model and further demonstrated the existence of fractures to match actual field performance. |
| 7. | The main hypotheses submitted for defense | It is necessary to answer the following questions for each hypothesis separately: 7.1 Is the position proved? 1) proved ; 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 Level for application: 1) narrow; 2) average; 3) wide 7.5 Is it proved in the article? 1) yes ; 2) no | The hypotheses presented for the defense were proved by field, laboratory and theoretical studies. These hypotheses are new and not trivial. The results of the thesis have been published in the press and presented at international conferences. The conclusions of hypotheses and demonstration of the testing protocol have industry-wide implications. In the first scientific position the author proved that vertical injection wells of GPAA work with cracks or fractures, which are necessary to facilitate improved polymer injection, while mitigating significantly reducing mechanical degradation of the polymer that would otherwise result in polymer viscosity loss. In the second scientific position, the author confirmed that dissolved |

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| | | | <p>oxygen in the injected polymer solution is rapidly absorbed by the surrounding rock, thereby increasing oxidative (or chemical) stability beyond that what it should otherwise exhibit.</p> <p>The third scientific position is devoted to the proof that in Kalamkas conditions, the residual resistant factor (RRF) or permeability reduction does not differ significantly from unity, i.e. there is no post effect of polymer flooding. Consequently, polymer injection should be carried out as long as the net present value (NPV) is positive.</p> <p>The fourth scientific proposition proves that polymer flooding under volatile oil prices is a long-term project that extends the profitable life of the field and accelerates oil recovery.</p> |
| 8. | <p>The principle of reliability</p> <p>The reliability of sources and information provided</p> | <p>8.1 The choice of methodology - is justified or the methodology is described in sufficient detail:</p> <p>1) <u>yes</u>;</p> <p>2) no</p> | <p>The choice of methodology is sufficiently described and justified. The conceptual and practical foundations of the methodology were developed by the author and coordinated with scientific consultants and ultimately shown to improve the field modeling.</p> |
| | | <p>8.2 The results of the dissertation work were obtained using modern research methods and methods of data processing and interpretation using computer technology:</p> <p>1) <u>yes</u>;</p> <p>2) no</p> | <p>The results of the dissertation work were obtained using modern methods of scientific research and methods of processing and interpreting data using computer technology. To the reviewer's knowledge, the author used the following software:</p> <ul style="list-style-type: none"> - Petrel (Schlumberger) for geological modeling, construction of geological section and structural maps; - NGT Smart for construction of development maps and analysis of geological and production data; - KOMPAS for creating flow diagrams and illustrations; - GeoSolver for analysis of GIS results; - Saphir (KAPPA) for GIS interpretation; - Fracpro for interpretation of hydraulic fracturing results; - Petrel RE (Schlumberger) for hydrodynamic model preparation; - tNavigator (RFD) for hydrodynamic modeling; - MS Excel for analytical calculations. |
| | | <p>8.3 Theoretical conclusions, models, identified relationships and patterns are proved and</p> | <p>Field experiments on 5 wells and laboratory experiments on</p> |

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| | | confirmed by experimental research (for areas of training in pedagogical sciences, the results are proved on the basis of pedagogical experiment): 1) yes ; 2) no | representative core samples from the Kalamkas field were performed, where the developed methodology for studying the degradation of polymer solution was tested |
| | | 8.4 Important statements are confirmed /partially confirmed/not confirmed by references to relevant and reliable scientific literature | The main statements in the paper are supported by the cited sources of scientific literature, involving similar studies on the topic. |
| | | 8.5 The literature sources used are sufficient /not sufficient for a literary review | In the dissertation, 168 literature sources were cited, including both fundamental works in the field of polymer flooding technology and references to modern research in this area. The author observed and considered the rights and legitimate interests of other authors, there is no borrowed material without reference to the original author and the source of borrowing, which is confirmed by checking the anti-plagiarism systems. |
| 9. | The principle of practical value | 9.1 The thesis has theoretical significance: 1) yes ; 2) no | One of the main objectives of the thesis is in regards to the field demonstration of polymer flow behavior that exist in the Kalamkas field, namely: 1) that polymer injection wells necessarily operate with fractures and 2) that there is no residual resistance factor. Early theories concluded that permeability reduction occurred and that polymer injectivity would be limited. Therefore, the thesis research has theoretical significance |
| | | 9.2 The dissertation is of practical importance and there is a high probability of applying the results obtained in practice: 1) yes ; 2) no | The results presented in this dissertation are of great practical importance for the successful application of polymer flooding technology. There is a high probability of real application of the proposed methodology to improve the understanding of how polymer flooding is behaving and correctly collect/analyses data in a comprehensive manner. |
| | | 9.3 Are the suggestions for practice new? 1) completely new ; 2) partially new (25-75% are new); 3) not new (less than 25% are new) | The novelty of the practical proposals and recommendations is timely, as it demonstrates the importance of sampling protocol, field/well testing and corroboration to laboratory/theoretical qualification. By utilizing the methods outlined, the author validates the new methodology and provides the framework for others considering/analyzing a polymer flood. |
| 10. | Quality of writing and design | Quality of academic writing: 1) high ; 2) average; 3) below average; | The thesis is written in high-quality scientific and technical language. There are a small number of typos, but these do not detract from the |

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| | | <p>4) low.</p> | <p>overall messaging and readability of the material. At the same time, all statements are made in clear and accessible language. The thesis has the following comments and recommendations:</p> <p>1) in the first chapter the unit of pressure in the descriptive part is presented in "bar", and in the table "MPa", polymer flow rate is shown in "tons", and in "lbs". Therefore, I recommend that all the units in the thesis be brought to the same standard.</p> <p>2) In the Nomenclature part, I recommend to decipher the abbreviation HPAM as "Partially hydrolyzed polyacrylamide" instead of "hydrolyzed polyacrylamide", because all HPAM are partially hydrolyzed.</p> <p>(3) In chapter 3, the patented polymer degradation study method is presented as a computer two-dimensional projection, although due to its usefulness for polymer flooding projects and its importance to this thesis, it would be appropriate to provide more detailed images, such as photographs</p> <p>(4) some instances outlining the method instructions within a paragraph, when a bullet-point listing may be more direct.</p> <p>(5) all pictures, graphs where applicable should be increased in size to improve readability or further interpretation by future readers.</p> |
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Conclusion

The Ph.D. student has provided a high level of scientific research that encompasses theoretical, experimental, field/well testing, as well as qualification of data through reservoir modeling. The result is a well defined, logical and thorough evaluation of a controversial problem in polymer flooding in vertical well. Therefore, this thesis contribution is of high interest and contributes to the collective knowledge of the global polymer EOR community comprised of petroleum, reservoir and development engineers, but also geoscientists attempting to better understand and fine-tune their geomodels. The practicality of the methods outlined provide a model framework for others to utilize and follow in order to apply similar methods to answer key questions regarding the performance of their field's polymer flood. The reservoir modeling aspects of this study confirm the field observations and theoretical interpretations made based on data collected. Moreover, the work meets the requirements for the Ph.D. thesis as outlined by the university. Therefore, based on my review of the dissertation, methods used and conclusions drawn, I recommend that the author, Mr. Marat Sagyndikov, be allowed to defend his thesis and complete the final requirements in order to obtain the degree, Doctor of Philosophy (Ph.D.) in the specialty 8D07202 – Petroleum Engineering.

Sincerely,



RW

Ryan R. Wilton, PhD, PEng

Senior Reservoir Engineer/Technical Advisor



SNF Oil and Gas
(306) 450-9013

ryanw@snf.com

oil.snf.com

Signature: 
Ryan R Wilton (Nov 18, 2022 07:37 CST)

Email: ryanw@snf.com







Review Ryan Wilton_eng_Final-November 18 2022

Final Audit Report

2022-11-18

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| Created: | 2022-11-18 |
| By: | Marat Sagyndikov (Sagyndikov_M@kaznipi.kz) |
| Status: | Signed |
| Transaction ID: | CBJCHBCAABAAFYBGb9RlrDC5g9N5CZoHkbo3UZz2VHHQ |

"Review Ryan Wilton_eng_Final-November 18 2022" History

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