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INVERSE PROBLEM OF THE GRAVIMETRY FOR OIL AND GAS FIELDS

ABSTRACT

of the dissertation in partial fulfillment of the requirements
for the degree of Doctor of Philosophy (PhD) in specialty
6D060300 – "Mechanics"

Relevance of the research. Among the main energy carriers in the modern world, oil occupies a special place, while remaining a strategically important product that has a significant impact on the global economy. The increase in oil production volumes directly depends on accurate data on the location of oil in the subsurface of the field.

In terms of energy and labor intensity, among the main stages in oil production, the stage of oil and gas field exploration can be distinguished. It is associated with a large expenditure of labor, time and money. The technical and economic indicators of exploration work are influenced by such factors as the accuracy of measuring instruments and instruments, the organization of their operating modes, the influence of the environment on the measurement of instrument readings, etc. At the same time, it is known from the practice of operating oil and gas fields, that oil in the extraction process can flow into neighboring spaces under the influence of pressure and other factors, which greatly complicates the process of oil production. This is due to complex physical processes and phenomena in the field's operation, caused by technical, technological and geological factors as a result of complex interaction. Larger spatial movements of oil, which, as a rule, are random in nature. What is the effect of atmospheric pressure forces and other complicating factors? All of them require a thorough study of the influence of these factors on the dynamics of oil movement c in order to predict further actions during the operation of an oil and gas field.

The current state of these problems is poorly understood. In general, exploration works are carried out during the initial exploration of the field and are not repeated due to high time and financial costs. Initial exploration data significantly cnarrow the range of problems under consideration and provide only a first approximation of them, on the basis of which accelerated exploration can be done. At the same time, the amount of gravimetric data is very limited, thus complicating the mathematical side of their solution. Available mathematical models, as a rule, do not allow for a comprehensive qualitative and quantitative analysis of inverse gravimetry problems. It is necessary to develop modern mathematical models for oil and gas field exploration from the perspective of the possibility of highly computational environments. Application of modern mathematical methods for their solution with the use of high-performance computing complexes and visualization packages for analyzing the dynamics of an oil field during oil production in order to ensure uninterrupted operations on subsurface extraction.

Thus, **the relevance of the research topic** is beyond doubt and is of scientific and practical interest.

Objective: to develop a mathematical model and solve the inverse problem of gravimetry for reconstructing the density of minerals based on gravity measurements (gravity exploration) for oil and gas fields.

In connection with this goal**, the following research objectives follow**:

– Mathematical modeling of the distribution of the gravitational field potential in an inhomogeneous medium;

– Development of an algorithm for numerical investigation of a mathematical model, its software implementation and analysis of the influence of process parameters;

– Statement of the problem of restoring the density of a gravitational anomaly based on the results of measuring the gravitational field on the external surface;

– Development of an algorithm for solving the inverse gravimetry problem for oil and gas fields and its software implementation;

– Numerical solution of the inverse gravimetry problem for oil and gas fields using gravity exploration data.

Object of research. The object of research is geological and lithological profiles of the field, gravimetric data,used in the oil and gas industry for geodynamic monitoring of oil and gas fields, which change under the influence of external forces and the environment.

Subject of the study. The subject of the study is the inverse problem of gravimetry of oil and gas fields, taking into account complicating factors in the process of oil production.

Research methods: methods of nonlinear mechanics of deformable media; methods of mathematical modeling of geophysics problems; variational methods; modern numerical methods of information technology; symbolic computing packages for numerical modeling and visualization of technological processes; theory of direct and inverse problems; theory of inverse problems of mathematical physics; optimal control theory.

The scientific novelty of the work consists in setting new direct and inverse problems of geophysics. Qualitative analysis of inverse geophysics problems to be solved. Development of algorithms for solving inverse geophysics problems and their software implementation.

Scientific provisions submitted for defense

– mathematical model of the gravitational field propagation in an oil and gas field, numerical solution of the problem and corresponding software, estimation of the influence of process parameters, determination of the gravitational field potential based on the real geological and lithological profile of the oil field;

– statement of the problem of restoring the density of a gravitational anomaly based on the results of measuring the gravitational field on the external surface, proof of the uniqueness of the problem solution, development and software implementation of an algorithm for solving inverse problems using the gradient method and the Monte-Carlo method, evaluation of the accuracy of solving the inverse problem depending on the location of the gravitational anomaly and its size;

– formulation of the inverse gravimetry problem with data on the inner surface in the presence of two gravitational anomalies, development and software implementation of an algorithm for solving the inverse problem using the Nelder-Mead method, evaluation of the accuracy of solving the inverse problem depending on the relative location of gravitational anomalies and their size;

The reliability and validity of scientific statements, conclusions and results of the dissertation work is confirmed by the use of basic fundamental laws and relations of deformable solid mechanics in the construction of mathematical models; comparison of calculation results with experimental data; comparison and satisfactory agreement of the obtained models and research results with the results of other authors' works; proven theorems confirming the correctness of the applied mathematical methods.

Theoretical and practical significance of the study.

The theoretical significance of the work lies in the development of new mathematical models of the distribution of the gravitational field in an oil and gas reservoir, in the development of methods for identifying these models and algorithms for solving the corresponding direct and inverse problems of gravity exploration. The results of the dissertation can be used for monitoring existing oil and gas fields based on gravimetric measurements and designing new mineral deposits. The developed methods and their software implementation can also be used to solve various problems of computed tomography.

The practical significance of the dissertation research is that the application of modern methods of mathematical modeling and computer technologies brings the results obtained as close as possible to real processes, allows you to predict the value of the anomaly density of an oil and gas field with high accuracy, providing an effective and reliable underground picture of the oil and gas industry.

Connection of this work with other scientific research works. This work was carried out within the framework of projects of the grant financing program for basic research in the field of natural sciences
"Development of a geoinformation system for solving the problem of gravimetric monitoring of the state of the subsurface of oil and gas-bearing regions of Kazakhstan based on high-performance computing in conditions of a limited amount of experimental data" (2018-2020, AP05135158-OT-19).

Testing the work. The main results of the work were reported and discussed at the following events:

- scientific seminars U.A. Joldasbekov Institute of Mechanical Engineering (2017 – 2023, Almaty);
- International Conference "Inverse Problems in Finance, Economics and Life Sciences" (Al-Farabi Kazakh National University, Almaty, Kazakhstan, December 2017);
- V International Conference "Farabi Readings" (Al-Farabi Kazakh National University, Almaty, Kazakhstan, April 2018);
- International Scientific and Practical Conference "Actual problems of Informatics, Mechanics and Robotics. Digital technologies in mechanical engineering" (JIME, Almaty, Kazakhstan, October 2018);
- Tenth International Youth Scientific School-conference "Theory and numerical methods for solving inverse and ill-posed problems" (NSU, Novosibirsk, Russia, October 2018);
- XIII International Conference "Parallel Computing Technologies" (Kaliningrad, Russia, April 2019);
- The Eleventh International Youth Scientific School-conference "Theory and

numerical methods for solving inverse and ill-posed problems" (NSU, Novosibirsk, Russia, August 2019);

– Traditional April international mathematical conference in honor of the Day of Scientists of the Republic of Kazakhstan, dedicated to the 1150th anniversary of Abu Nasir al-Farabi and the 75th anniversary of the Institute of Mathematics and Mathematical Modeling. (Almaty, Kazakhstan, April 2020);

– scientific seminars of the Department of Mechanics of Al-Farabi Kazakh National University (2017–2020, Almaty).

Publications. On the topic of the dissertation, the author published 15 works, including 2 publications in scientificpublications included in the list recommended by the Committee for Control in the field of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for publishing the main results of scientific activity; 4 publicationsи in a scientific journal indexed by the Scopus database; 9 publications in scientific conferences, including 1 publication in the proceedings of foreign conferences, 4 publications in the proceedings of Russian scientific conferences, 4 publications in the proceedings of the national conference.

Personal contribution of the author. The main research results presented in the dissertation work were obtained by the author independently. In the joint article, the applicant completed the main part of the work, the co-authors participated in setting the task and discussing the results. The research supervisor Serovaisky S.Ya. was assigned a task, the applicant Kenzhebayeva M.O. belongs to the numerical implementation of the model, its qualitative and quantitative analysis and discussion of the results. In the works, the co-authors are responsible for setting the problem and implementing the Monte-Carlo method, while the applicant is responsible for numerical implementation of the model and analysis of the results. In the articles, the applicant contributed to the construction of the model and analysis of the results with co -author N. A. Toyganbayeva.

Structure and scope of the dissertation. The dissertation work consists of a title page, contents, designations and abbreviations, an introduction, four sections, a conclusion, and a list of 70 sources used. The total volume of the dissertation is 106 pages, including 13 illustrations and 21 tables.

Main content of the dissertation.

The introduction reflects the following points: the relevance of the topic of the dissertation research, the main purpose of the work, the object, subject and methods of research, scientific novelty, scientific and practical significance of the dissertation work, the degree of its development.

The first chapter describes the current state of the problem under study, and reviews existing works in the field of inverse gravimetric problems. A description of the process, a mathematical model of the direct gravimetry problem, a proof of the uniqueness of the solution of the optimization problem, the calculation of the gradient of the functional, and the solution of the direct problem on real data are also given.

The second chapter describes the solution of the inverse problem by the gradient method: generating artificial values of the potential and gradient of the gravitational field, solving the inverse optimization problem by the Monte-Carlo method, as well as analyzes the obtained calculations when changing the location and size of the anomaly and the influence of the epsilon value on the minimized functional.

The third chapter deals with the development of a refined mathematical model

of the propagation of the potential of the gravitational field of an anomaly, taking into account such complicating factors as: boundary conditions of the studied region, values of the gradient of the gravitational field on the inner region, etc. We formulate a refined inverse gravimetry problem, derive the gradient of the functional and the conjugate problem, prove the strict convexity of the functional, and analyze the results of the numerical solution of the problem.

In the fourth chapter, we consider the inverse problem of gravimetry with two anomalies. The problem statement, derivation of the functional gradient and conjugate problem, and analysis of the results of numerical calculations with two anomalies by the Nelder-Mead method are presented.

In conclusion, the main results and conclusions obtained in the dissertation work are presented.