ANNOTATION

of the dissertation submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D07202 – "Petroleum Engineering"
by Saule Zhalgasbaikyzy Abileva on the topic:

"Improving of Chemical and Thermal Methods for Increasing Oil Production from Heterogeneous Formations"

Introduction

Under modern oil production conditions, a significant number of developed fields are characterized by high reservoir heterogeneity, complex filtration and storage properties, and the presence of hard-to-recover oil reserves. These factors significantly complicate field operation processes and require scientifically grounded solutions to enhance production efficiency.

Traditional methods of increasing oil recovery, such as water or gas injection and thermochemical treatment, often demonstrate low efficiency in reservoirs with high heterogeneity and complex oil compositions. Therefore, there is a need to develop new technologies that ensure flow redistribution, activation of stagnant zones, and an increase in the oil recovery factor. The application of polymer and gel-polymer compositions, combined thermochemical technologies, and methods that consider the rheological characteristics of hard-to-recover oils is of particular relevance.

This study examines a method for enhancing oil recovery and reducing water cut in wells through gel-polymer treatment. High-viscosity gel-polymer compositions were developed, and their thermal stability was studied over 45 days. Additionally, compositions for gel destruction were formulated. However, this method is less effective compared to polymer flooding, which covers larger reservoir volumes, whereas gel-polymer treatments have a localized effect on individual wells. Moreover, the use of polymer gels iэn production wells carries the risk of reducing oil permeability and decreasing well flow rates.

In this regard, the third chapter of the dissertation is dedicated to studying the filtration of polymer solutions and unique oils with an exceptionally high resin content in a porous medium. It also presents the results of numerical modeling of full-scale polymer flooding within a development element of one of Kazakhstan's oil fields.

The study indicates that the efficiency of polymer flooding is limited in layered reservoirs with impermeable barriers between oil-saturated layers. In such conditions, reducing the mobility ratio below 1 does not lead to additional reservoir sweep improvement. Therefore, the third chapter examines a model of a heterogeneous layered reservoir with an impermeable interlayer, for which a combined thermal treatment method with alkali injection has been developed.

Relevance of the Study

The modern stage of oil and gas industry development is characterized by an increasing share of hard-to-recover hydrocarbon reserves associated with heterogeneous reservoirs. The reserves of high-viscosity oil and bitumen are estimated at 790 billion to 1 trillion tons, which is 5–6 times greater than the remaining recoverable reserves of light oils (162 billion tons). The development of these resources requires new enhanced oil recovery (EOR) technologies.

The extraction of heavy oils is complicated not only by the low mobility of reserves but also by the high degree of reservoir heterogeneity and their complex filtration-capacity properties. These factors significantly hinder field operation processes and necessitate the improvement of existing chemical and thermal methods for oil recovery enhancement. Such methods include gel-polymer treatment, polymer flooding, and thermal methods. Special attention is given to in-situ combustion and other thermal recovery techniques.

All of mentioned methods are widely used today; however, they have limitations that restrict their effectiveness. In particular, in heterogeneous reservoirs, these methods fail to achieve a significant increase in reservoir sweep efficiency. It is evident that an urgent scientific and technical challenge is to improve chemical and thermal methods of oil recovery to enhance their effectiveness in heterogeneous reservoirs.

This dissertation is dedicated to solving this problem this and holds significant scientific, technical and economic importance for oil production in Kazakhstan, which determines the relevance of the research topic.

Justification of the Need for This Research. Many oil fields in Kazakhstan are characterized by complex geological and physical conditions, with a significant portion of produced oil coming from depleted reservoirs. The implementation of effective reservoir stimulation technologies is a key factor in ensuring sustainable oil production. Among the most promising methods are thermal and chemical treatments, as well as their combination.

Research Objective

The objective of this dissertation is to develop technological solutions for improving chemical and thermal methods of enhancing the recovery of hard-to-extract oils from heterogeneous reservoirs.

Scientific Novelty

-For the gel-polymer composition [partially hydrolyzed polyacrylamide (PHPA) with a molecular weight of 6–7 million Da and a hydrolysis degree of 5% / chromium acetate], dependencies of the dynamic viscosity of solutions and polymer gels at 39°C were obtained as a function of chemical concentrations and shear rates. It was demonstrated that increasing the polymer concentration from 0.5% to 2.5% leads to an increase in dynamic viscosity from 5,486 cP to 267,505 cP at a shear rate of 0.6 s^{-1}—that is, a fivefold increase in polymer concentration results in a 48-fold increase in viscosity.

-For the first time, filtration rate dependencies on pressure gradients over a wide temperature range were obtained for a unique non-Newtonian oil with an extremely high resin content (73%), as well as a high sulfur (9%), asphaltene (5%),

and paraffin (4.5%) content. This allowed the determination of critical shear pressure gradients, enabling the identification of stagnant zones in the reservoir where oil filtration does not occur due to insufficiently high pressure gradients.
-For high-resin (22%) and paraffinic (5.2%) oil from Field X, dependencies of the oil displacement efficiency (ODE) on polymer concentration and the volume of the polymer solution slug were obtained for the first time. The results showed that the optimal polymer concentration and slug volume are 0.4% and 70% of the oil pore volume, respectively.
-A combined stimulation technology for layered heterogeneous reservoirs was developed and experimentally validated. This technology includes the injection of hot water, air, an alkali slug with a concentration of 3–5%, and a water-air mixture. The results demonstrated flow redistribution due to the formation of a high-viscosity emulsion after alkali injection into the high-permeability layer. The oil displacement efficiency from the low-permeability layer increased from 54% to 64%.

Research Object. The object of the study is heterogeneous reservoirs with hard-to-recover oil reserves.

Research Subject. The subject of the study is the oil displacement process from heterogeneous layered reservoirs using chemical and thermal agents.

To achieve the stated objective, the following tasks were set and solved in this work:
-Laboratory testing of gel-polymer compositions;
-Displacement of high-viscosity oil using polymer solutions in packed models;
-Numerical modeling of polymer flooding;
-Development of a combined stimulation method based on in-situ steam generation and alkali solution injection for oil displacement from heterogeneous layered reservoirs.

Methods for Solving the Set Tasks
The tasks were addressed through experimental and hydrodynamic modeling, as well as pilot field studies.

Key Findings Submitted for Defense:
-Regularities of gel formation, thermal stability, and degradation of gel-polymer compositions were established. It was found that the formation of strong gels (viscosity >200,000 cP) requires a polymer concentration of ≥2.5%, leading to high solution viscosity (>400 cP) and the risk of uncontrolled hydraulic fracturing. This justifies the need to develop alternative oil recovery methods and water cut reduction techniques without crosslinking agents to improve oil displacement efficiency.
-Experimental studies on determining the critical shear pressure gradient in a porous medium for unique non-Newtonian oil with an extremely high resin content

(73%) allowed for the identification of stagnant zones in the reservoir. Filtration tests with polymer solutions showed that the optimal polymer solution slug volume is 70% of the oil pore volume in the reservoir. Numerical modeling demonstrated that full-scale polymer flooding increases oil production by 15% and reduces water production by 26%, whereas localized polymer flooding at two wells proved ineffective.

-The combined thermal stimulation technology with alkaline slug injection (30% of the pore volume) increases the reservoir sweep efficiency by the thermal agent and enhances the average oil recovery factor from 65% to 76%. The introduction of the alkaline solution leads to a 5.7-fold increase in the pressure drop in the high-permeability layer, which activates oil displacement from low-permeability zones, where the temperature reaches 360°C, while in the high-permeability layer, it remains at 210°C.

Practical and Scientific Significance

The practical and scientific significance of this study lies in the investigation of gel formation and filtration processes of anomalous oils, the identification of critical shear pressure gradients, as well as the development and experimental validation of new reservoir stimulation technologies. For the first time: Dependencies of the dynamic viscosity of gel-polymer solutions have been obtained; Optimal parameters for polymer flooding have been determined; A combined thermal stimulation method with alkaline solution injection has been developed.

The research findings hold high practical relevance for the oil and gas industry, as they enable the enhancement of field development efficiency in geologically complex reservoirs. The developed methods and technologies can be directly implemented in the operational activities of oil production companies to optimize oil recovery processes, reduce water cut, and increase the oil recovery factor.

Thus, the results of this study can be applied by oil and gas companies to improve chemical and thermal methods for enhancing oil recovery from heterogeneous reservoirs.

Thesis Validation

The results of the dissertation have been validated at several international scientific conferences, including Almaty (2020, 2021, 2022) and Tyumen (2022).

Publications

The main findings, results, and conclusions of the dissertation are comprehensively presented in 18 scientific publications, including:

- 2 articles in international peer-reviewed scientific journals indexed in Scopus;
- 6 publications in journals recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan;

- 4 articles in other foreign scientific journals and publications;
- 5 papers in proceedings of international scientific and practical conferences;
- 1 patent.

Structure and Volume of the Work

The dissertation consists of an introduction, four chapters, a conclusion, and a list of references, which includes 111 sources. The content is presented on 118 pages of typed text, including 51 figures and 17 tables.

Main Content of the Work

1. Development of Gel-Polymer Compositions for Field Applications

- Developed dependencies of dynamic viscosity of gel-polymer solutions, allowing for the prediction of their behavior under reservoir conditions.
- Established relationships between polymer gel viscosity and chemical concentration, enabling the forecasting of gel behavior in the reservoir.
- Developed destructor compositions to mitigate the negative effects of gel-polymer treatments in production wells.

2. Determination of Technical Parameters for EOR Using Polymer Flooding Technology

- Established dependencies of oil displacement efficiency (ODE) on polymer solution concentration and slug volume, enabling an optimal selection of technology parameters for specific geological conditions.
- Simulation results demonstrated that full-scale polymer flooding increases oil production by 15% and reduces water production by 26%, in contrast to localized applications in individual wells.
- Determined the optimal polymer solution slug volume (70% of the pore volume of oil) to reduce uncertainties in designing enhanced oil recovery (EOR) treatments.
- Identified critical shear pressure gradients for highly resinous oil (73% resins, 9% sulfur, 5% asphaltenes, 4.5% paraffin), helping locate zones where oil filtration is hindered due to insufficient pressure gradients.
- The developed methodologies can be used in oil recovery simulations to improve waterflooding system designs and reduce residual oil saturation.

3. Development of a Thermo-Chemical Method to Improve Reservoir Sweep Efficiency

- Developed a combined treatment technology, incorporating the injection of hot water, air, alkaline solutions, and water-air mixtures, which increases the oil recovery factor from 65% to 76%.
- Demonstrated that alkaline solution injection facilitates flow redistribution by forming high-viscosity emulsions, activating oil displacement from low-permeability zones and enhancing thermal EOR efficiency.

- Implementation of this method enables a temperature increase in low-permeability layers compared to high-permeability ones, ensuring more effective oil displacement from heterogeneous layered reservoirs with impermeable interlayers. Achieving such an effect is challenging using gel-polymer treatments and polymer flooding alone.

Thus, this dissertation presents technological solutions to challenges encountered during enhanced oil recovery (EOR) operations.

The research in this study was carried out within the framework of the Grant Funding Projects of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

- **IRN AR22683343** – "Improving Decision-Making Methods for Selecting Enhanced Oil Recovery Technologies in Fields with Complex Geological Structures."
- **AR19674847** – "Study of the Mechanism of Water Influx and the Influence of Geological and Technological Factors on the Performance of Isolation Works."