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A REVIEW STUDY ON AN INTEGRATED METHOD FOR SOLVING PROBLEMS ASSOCIATED WITH THE RE-DEVELOPMENT OF WATERFLOODED FIELDS

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ABSTRACT: The purpose of this article is to develop a specific integrated method to solve the emerging problems of re-development of a flooded oil field. The following methods were used in the study: analysis, generalization, mathematical modeling and experiment. The result is a comprehensive method that can improve the efficiency and economics of post-development waterflooding. A feasibility study of the flow chart of measures to improve the efficiency of field re-development made it possible to create a comprehensive methodology for choosing stimulation methods and modern technologies that increase the efficiency of both production wells and oilfield equipment. The studies were carried out on the example of the Uzen deposit. This study showed that silica gel is the most effective technology for the development of low-permeability reservoirs in the studied field. In addition, the use of a composition of silicate microgel systems, polymers, and surfactants has been shown to improve the geological characteristics of the combined systems and the properties of the oil.

Keywords: Oil production, Productive horizon, Low-permeability reservoirs, Silicate micro-gel systems, Information bank

1. INTRODUCTION

One of the main methods used to stimulate oil reservoirs in the Republic of Kazakhstan is the artificial flooding method. Thus, the issue of rational re-development of waterlogged fields has become one of the most urgent and significant.

Western Kazakhstan is an oil and gas region where most of the major fields, particularly in the Atyrau region, have entered the third and fourth stages of field development. The water cut of oil production has increased significantly. Over the past decade, the average water cut in this region has increased by 80%, and the water-oil factor has reached 4 t/tonne. Considering this development trend and estimates, the well stock of these fields could become highly watered and exceed 85%, and the water-oil factor could reach 6 t/tonne [1].

Currently, oil production is increasing mainly offshore in the Caspian Sea as a result of the discovery and commissioning of new fields. The research on oil-bearing reservoirs has been the subject of many foreign researchers' works. Xiong et al. have determined through experiments and field practice that multiple waterfloods can improve reservoir properties, change rock wettability, reduce residual oil saturation, increase oil displacement efficiency, and the final oil displacement efficiency can reach 80%[2]. Duan et al. developed a four-dimensional model of a waterflooded reservoir to explore its characteristics more precisely [3]. The results guided a comprehensive assessment of the Nanpu oil field in China for the different phases. Based on an analysis of the waterflood curve characteristics and logging curve optimisation, an accelerated waterflood identification model was established [4]. The validity of this method was confirmed during the model verification process.

Ansori et al. conducted a numerical modeling analysis using HEC-RAS 5.0.7 to simulate flood inundation and dam break of Way Apu dam in Indonesia for the purpose of identifying flood mitigation risk zone and early warning system within the downstream area [5]. Sulong and Romali reviewed methods for creating multivariate flood damage models, which consider the impact parameters and resistance parameters to provide a comprehensive assessment of flood damages and can generate synthetic data to address data scarcity issues in developing countries [6].

Aljifri developed two sets of empirical correlations for predicting the oil recovery factor of waterflooded strata [7]. The first set includes parameters such as reservoir heterogeneity, viscosity, permeability anisotropy and injection rate. The second set consists of two models: one to predict the oil recovery factor during water breakthrough and the other at the end of this process. The developed model enabled a more precise determination of the oil recovery factor during waterflooding. Kazimov considered a method of enhanced oil recovery by displacing residual oil with chemicals in hard-to-recover fields [8].

The purpose of this research is to develop a specific integrated method, namely modelling the solution to the emerging problems of the re-development of a waterflooded oil field.

2. RESEARCH SIGNIFICANCE

The research presented in the article is relevant to the oil and gas industry as it proposes an integrated method to overcome the challenges of re-developing a waterflooded oil field. Waterflooding is a common secondary oil recovery method that involves the injection of water into an oil reservoir to displace residual oil and increase production rates. However, the process can be challenging due to the inhomogeneous nature of reservoirs, resulting in uneven displacement and reduced efficiency. The findings of this study are significant as they can help improve the efficiency and economics of waterflood post-development, which can have a significant impact on the oil and gas industry.

3. MATERIALS AND METHODS

To conduct this study, methods of analysis, generalisation, mathematical modelling and experimentation were used, resulting in the development of an integrated method for the re-development of waterflooded fields. An experiment was performed to determine changes in viscosity and interfacial tension as a function of polymer concentration and water density between 1000 and 1180 kg/m^3, and a geological model of the lithology cube was established. The research was conducted at the Uzen field, Republic of Kazakhstan.

Detailed development of modelling approach to the solution of the problem of additional development of waterflooded oil fields has allowed presenting the sequence of implementing a complex method of additional development of waterflooded oil fields using the step-by-step performance of specific operations in the most effective way. During the experiment, the polymeric compositions used to explore changes in viscosity and interfacial tension as a function of polymer concentration and water density were carboxymethyl cellulose (CMC) brand “Kamcel”, polyacrylamide (PAA) brand “DP9-8177” and hydroxyethyl cellulose (HEC) brand “Natrosol 250 HHR-P”. Water thickening was performed using PAA. In implementing the integrated method, several interrelated elements (stages) were intended to be performed sequentially, which, to date, have not been used in the practice of pre-field development (Fig. 1).

The initial element included a targeted integrated analysis and synthesis of reservoir and process performance, wells and other technical facilities, and environmental conditions. For this purpose, a digital filtration model was established using 3D geological modelling software according to the regulations on establishing models of permanent geological and technological oil and gas condensate reservoirs. Compared to existing models, its main advantage is that it is based on three independent determinations of current oil saturation: by simulating reservoir development using a three-dimensional multiphase mathematical model, by interpreting a set of hydrodynamic studies, and by using approximate hydrodynamic calculations of production well parameters [9].

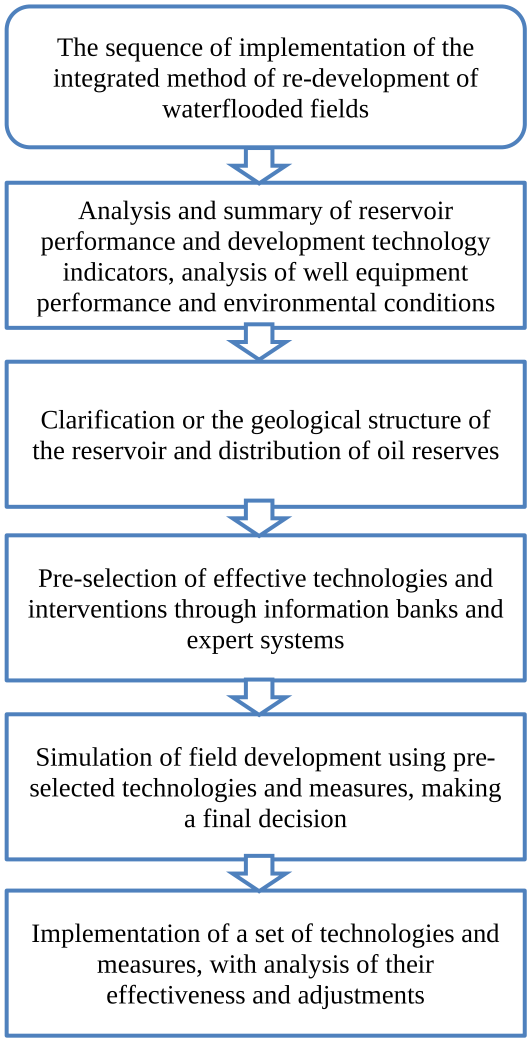

Fig.1 The sequence of interconnected phases of waterflood completion

One example of the application of the integrated method is the construction of lithology, sandstone and parameter cubes in the Uzen field. The lithology cube is the main parameter cube in the 3D geological model, as it is its values that determine the presence or absence of a reservoir in the 3D space. The parameters in each cube cell are discrete and have a value corresponding to a collector code or non-collector code. For each of the modelled horizons, lithology cubes were constructed based on the results of geographical information system data processing, defining the type of lithology of the interlayers identified in the section.

In establishing a detailed three-dimensional geological model, the vertical dimensions of the cells were chosen based on the requirements of maximum detail in the model. As a rule, these are values comparable to the resolution of a geographical information system complex. However, when designing mesh models for hydrodynamic modelling, the final model size, i.e., the number of active cells involved in the modelling, is of particular significance. Precisely this determines the calculation time of the model and, the possibilities for model customisation.

4. RESULTS

The success of a re-development of waterflooded oil fields is a complex task that depends on the accuracy of development and application of rational technological solutions to impact the reservoir system, oil production methods and technologies, and well construction in complex geological and ecological conditions. The irregularity of oil displacement with injected water is important as phenomena such as waterflooding tongues and increased water volume can occur during oil production, particularly when developing reservoirs in stratified reservoirs (Fig. 2).

Complications with the drilling of new wells are associated with higher reservoir pressures. Current well workovers and the necessity of "priming" the reservoir require that the bottom-hole zone remains clean after these activities have been performed. The difficulties of oil field development are caused by environmental problems caused by forced extraction and injection of large volumes of associated water, obsolete stock of production and injection wells, the degree of wear of oilfield pipelines, and the identification of sources of oil product spills that are becoming more frequent.

The example of the Uzen field demonstrates the changing properties of the reservoir fluid. Intense drainage of the reservoir system at the start of operations, without reservoir pressure maintenance, resulted in the development of a dissolved gas regime due to reservoir pressure decrease below saturation pressure, accompanied by degassing of the oil in the reservoir, up to and including gas release.

Analysis of downhole oil samples demonstrated that, compared to the initial characteristics, the saturation pressure and gas content parameters had decreased while density and viscosity had increased. As of January 1, 2019, the watercut of the horizons is as follows: 13 horizon – 75.2%, 14 horizon – 83.1%, 15 horizon – 81.6%, 16 horizon – 84.6%, 17 horizon – 84.6%, 18 horizon – 77.4% [1].

Residual oil reserves in waterflooded reservoirs are concentrated in developed regions in the fields that have been drilled and exploited for a long time. Notably, residual oil production after the waterflooding process is concentrated in both large low-permeability (Zhanazhol) and high-permeability oil fields (Uzen, Zhetybai), where initial oil flow rates from new wells in these production facilities often exceed those of newly commissioned low-permeability reservoirs of newly discovered (Rozhkovo) fields [10].

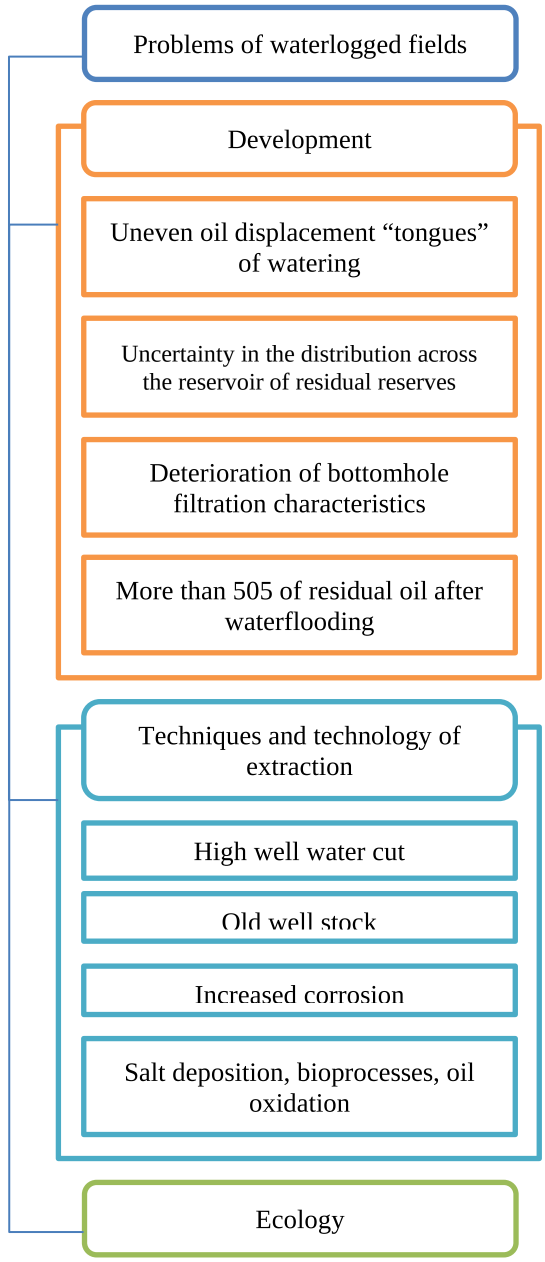

Fig.2 A set of problems related to the development of waterflooded fields

Since 2000, there has been a big jump in oil production in the Uzhen field. This growth is due to the commissioning of new production wells and the measures taken to increase oil recovery [10]. In the Uzen field, two options were considered for injecting a cross-linked polymer system (CPS) into the injection wells.

Table 1 Substantiation of oil production rates by wells

Year	Options	Increase in oil production rates after hydraulic fracturing			
		0.1-5	5-10	10-30	30-44
2017	Number of wells	17	14	80	7
	Average increase in flow rate	3.3	7.8	18.1	36.8
	Share of wells	14.4	11.9	67.8	5.9
2018	Number of wells	27	51	58	1
	Average increase in flow rate	2.5	7.1	14.3	35.9
	Share of wells	19.7	37.2	42.3	0.7
2019	Number of wells	28	43	49	-
	Average increase in flow rate	2.81	7.8	14.2	-
	Share of wells	23.3	35.8	40.8	-
2020	Number of wells	8	16	24	-
	Average increase in flow rate	2.7	7.8	14.7	-
	Share of wells	16.7	33.3	50.0	-
2021	Number of wells	18	32	40	16
	Average increase in flow rate	3	7	14	5
	Share of wells	17.3	30.7	38.4	15.3

Source: compiled by the authors based on [10].

The first option is stationary pumping mode. The second is periodic individual treatment of injection wells. Table 1 demonstrates the substantiation of oil production rates by wells for Uzen over the period of 2017-2021. The following actions are considered when expanding the RPM system: injection of water into the pressurised system, treatment with surfactants (SAS) of wells with increased injectivity, and injection of thickened water using CPS.

The effective condition of oil reservoir system treatments and the selection of ways to enhance their effect on oil production depends on information about their filtration-volume properties. An assessment of the Uzen field operation has demonstrated that the current methods of RPM systems used to improve oil recovery are insufficient; the most acceptable technology at the late stage of development in the least permeable parts of the reservoir is the silica gel technology. The simultaneous use of a SAS and silicate micro-gel system (SGMS) as components of the oil-displacing fluid interfacial tension is slightly reduced compared to SAS solutions, as can be observed from the data in Table 2.

Experimental tests have demonstrated the ability to modify the porous rock filtration parameters of the SMGS test system, which increase the residual resistance coefficient; thus, the silicate micro-gel structure can block the permeability of the porous layer (Fig. 4). The residual resistance factor is increased by a factor of 4.5 by increasing the mass concentration of the silicate micro-gel elements in the structural form by an average of 15%.

During field tests with FP-307, POLY-T-101 and DP9-8177, there was a marked reduction in well water cut (Fig. 5). Injection of a polymer compound based on polymer DP9-8177 into the reaction wells resulted in a 1-3% reduction in water cut. By pumping in a polymer compound based on the POLY-T-101 polymer, the water content is reduced by 2-4%. When using FP-307, the water content was reduced by 4%. As can be observed from the technological indicators presented, 6 out of 14 reactive production wells responded to the injection of the polymer-based polymer composition DP9-8177. On average, oil production per well increased by 1.79 tonnes per day [11].

Polymer solutions and silicate micro-gel systems were prepared using fresh water. From the experimental data, when the mass concentration of polymers in the SMGS composition is increased from 0.1 to 0.5%, the viscosity of the composition increases by a factor of 1.5-3, although a significant increase is observed in the system with the addition of hydroxyethyl cellulose. A dependence on the establishment of an adsorption layer on the surface of the silica gel elements is observed, and the viscosity of the dispersion system is increased. The simultaneous application of a composition of silicate micro-gel systems, polymers and SAS has improved the geological features of the combined systems and the oil-washing properties (Fig. 6, 7).

5. DISCUSSION

Chudinova et al. [12] analysed research on the choice of geological and technical measures and systematised geological and technical operations for each type of residual oil. Residual oil reserves are hard to recover and are mostly found in areas that are not subject to vertical and lateral waterflooding. The results of this work helped the authors to implement the integrated method when drilling additional wells.

Table 2 Interfacial tension values of SMGS and SAS composites

Geological areas of zonal ore reserves	On the Geofizicheskoe chrome deposit				On the Lisakovsk iron ore deposit			
	Geoind. qualimetric attributes, %	Variance, D/σ	RMS error, M	Error reduction rate, unit fraction/%	Geoind. qualimetric attributes, %	Varianc, D/σ	RMS error, M	Error reduction rate, unit fraction/%
Area of the zonal reserve of ordinary low-grade ores ($n_1 = 40$)	C_i<46	2.61/1.62	0.26	1.6/36.0	C_i<36.6 (n=90)	11.8/3.4	1.6/36.0	1.3/21%
Area of the zonal reserve of moderately concentrated ores ($n_2 = 83$)	46<C_{moi}<52	1.72/1.31	0.14	2.9/70.0	36.6<C_{moi}<46 (n=117)	3.3/1.8	2.9/70.0	2.6/60%
The site of the zonal reserve of rich high-grade ores ($n_3 = 35$)	C_i>52	2.06/1.45	0.24	1.7/41.0	-	-	-	-
By base geological reserve (N=158 samples)	46÷52	26.8/5.2	0.41	1.6÷2.5	22÷46 (N=207 samples)	45.4/67	0.44	1.3÷2.5

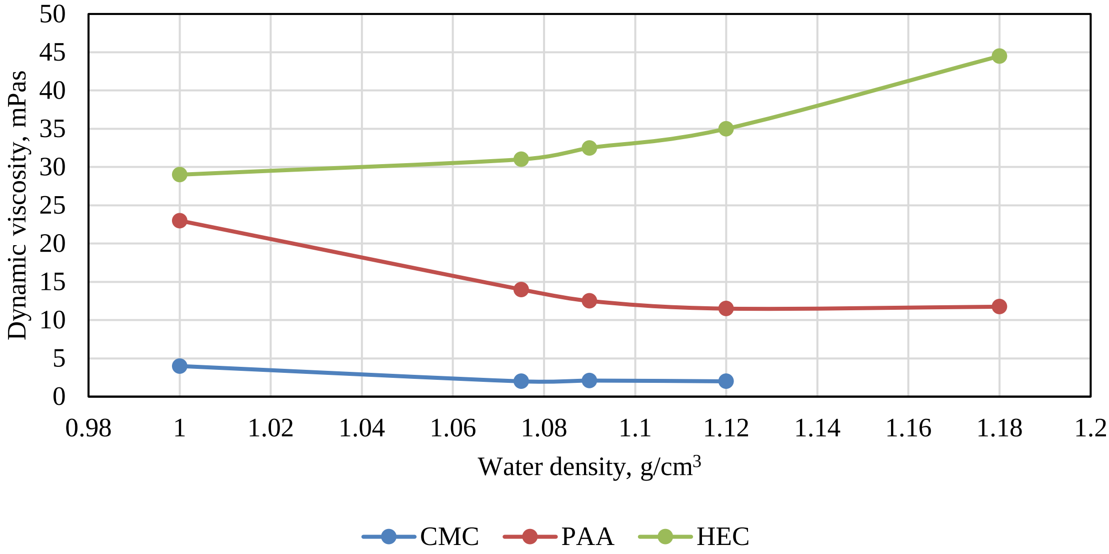

Fig.4 Variation of the dynamic viscosity of 0.3% polymer compositions as a function of water density

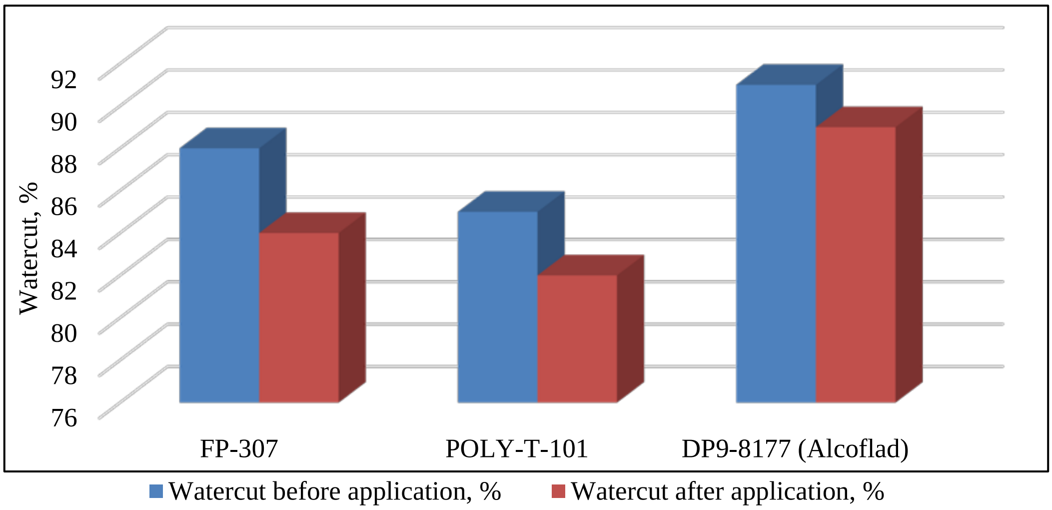

Fig.5 Results of FP-307, POLY-T-101 and DP9-8177 (Alcoflad) from experimental production tests [9]

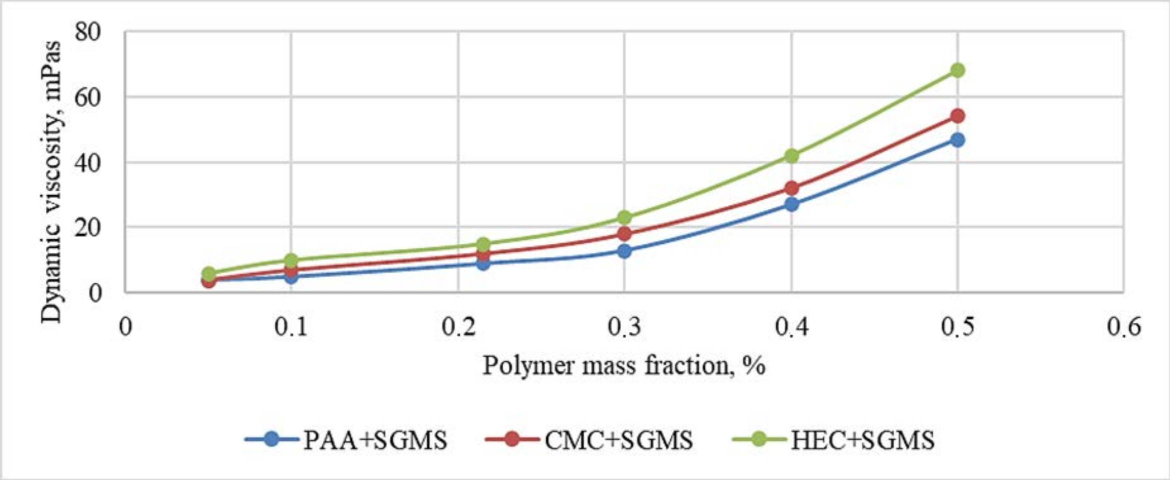

Fig.6 Change in dynamic viscosity of polymer composition and SMGS (10% of polymer mass fraction)

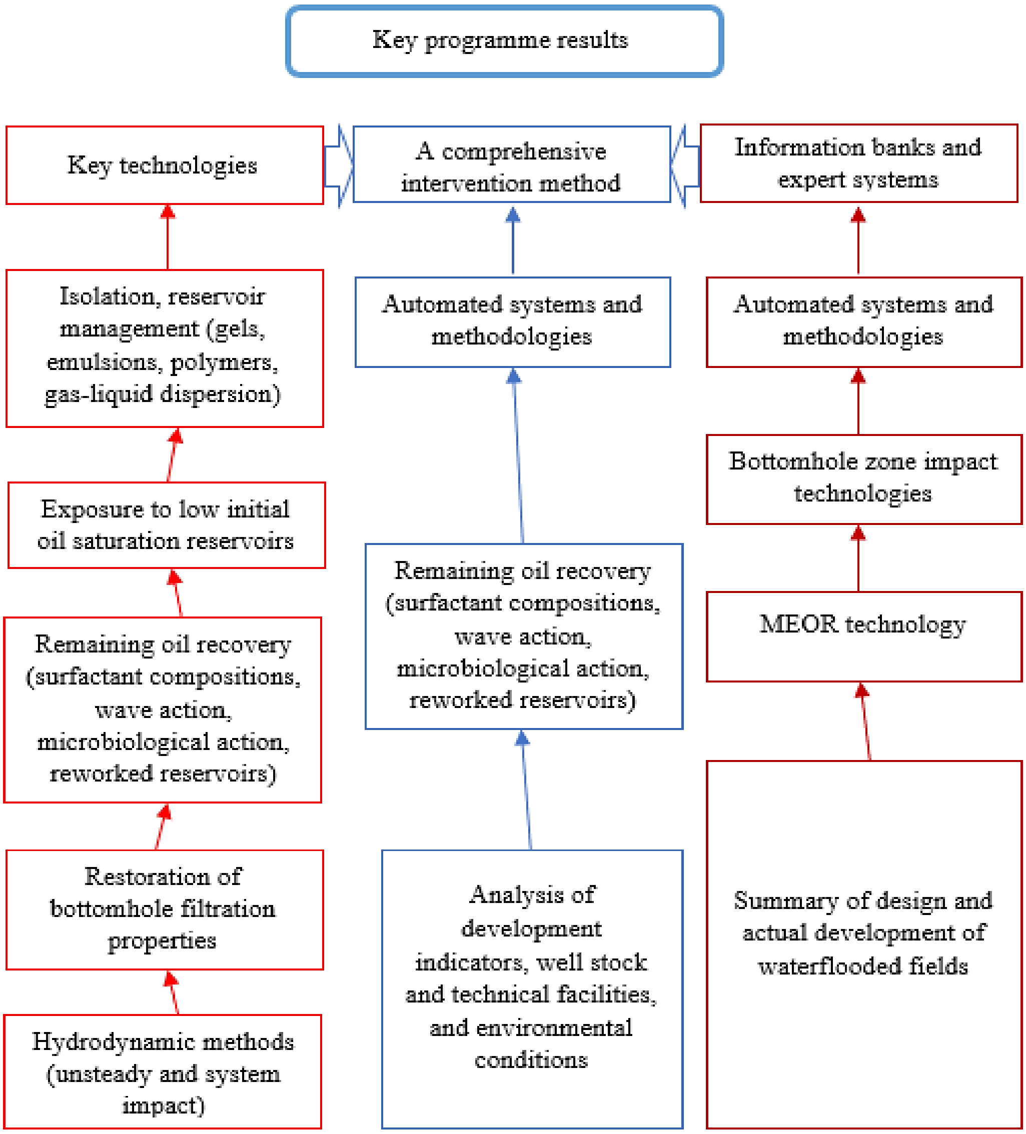

Fig.7 Comprehensive waterflood impact scheme.

Abdirazakov [13] studied that residual oil reserves (taken as 100%) are quantitatively distributed by types: the remaining oil reserves in the stagnant zones of homogeneous reservoirs – 19%; remaining oil reserves remaining in impermeable screens and lenses that did not reach the wells – 24%; remaining oil reserves in low-permeability interlayers – 27%; capillary-held and film oil fluid – 30%. The problem of optimising oil displacement using neural networks has been solved by Mukhanbet et al. [14]. The optimisation of the calculation was done by vectorising the calculations and implementing the algorithm using neural networks. The authors consider that the proposed method has the potential to provide a simple implementation of oil knowledge into artificial intelligence.

Tlegenov et al. [15] have put together a targeted programme of geological and technical measures that are designed to expand oil production potential and have proven their effectiveness. The authors of this article considered the designated target program as an example of the development of the Uzen field. Ren and Duncan [16] explored the effects of heterogeneity and low oil saturation in waterflooded reservoirs on the effectiveness of alternating gas and water injection strategies. As a result, it has been demonstrated that alternating gas and water injection in the residual oil zones does not maximise oil recovery.

Bottom water taper, gas and water injection, and uneven distribution of fractures and cavities are key factors affecting the heterogeneous distribution of residual oil in reservoirs. Zhai et al. [17] the dynamic interfacial tension between the simulated oil and the chemical solution, viscosity, rheology, emulsification and emulsion stability were measured [18]. The results demonstrated that large amounts of residual oil are contained in the non-core flow area and dead-end pores after waterflooding. Through these studies [17-19], the authors of the article studied the characteristics that affect the heterogeneous distribution of residual oil.

Zhang et al. [20] analysed oil displacement efficiency and determined the oil recovery factor, residual oil distribution and core flooding mechanism in a low-permeability reservoir. Han [21] conducted an oil displacement experiment to explore the interfacial tension of an alkaline surfactant polymer system. The main difference of this research on water-flooded fields is the establishment of a comprehensive method, which allowed a systematic review of the current state and the main objectives: technological, technical, economic and other development of a particular field, the selection and implementation of the most effective technologies, their solutions and improving the efficiency of oil deposit post-development.

6. CONCLUSION

The present study emphasises the establishment and subsequent use of resource-saving technologies for integrated impacts. Cyclic waterflooding with changes in filtration flows, systemic stimulation, chemical compositions, bottom-hole treatment and other technologies are used in waterflooded fields. New technologies for the isolation and regulation of reservoir water movement are being established by using silicate gels, emulsions, polymer solutions, gas-liquid dispersions and other agents.

The integrated method presented in this research involved the simulation of a particular waterflooded field being reworked using pre-selected technologies. The technical and economic analysis allowed the final selection of the most efficient option for the application of the set of technologies and measures. Using decision-making with technology and investment risk assessment was suggested. Economic efficiency in the implementation of a comprehensive program is achieved by saving the cost of drilling additional wells and the use of new technology that can simulate the filtration parameters of a porous medium, increase the residual resistance coefficient, and most accurately recognize residual reservoir oil. goals.

The originality of this article lies in the development of an integrated method to overcome the challenges associated with re-developing waterflooded oil fields. The findings of this study have practical value for the further development of fully or partially waterflooded fields, and its approach can be applied to other similar fields to increase the efficiency and economic viability of waterflood post-development.

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