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Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

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EFFICIENCY DIAGNOSTICS OF POLYMER INJECTION FOR ENHANCED OIL RECOVERY

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Abstract. *Relevance.* Increasing the oil recovery factor in heterogeneous and mature reservoirs remains a critical challenge. Conventional waterflooding often suffers from low sweep efficiency, leading to premature water breakthrough and bypassed oil. This paper addresses the problem by investigating the diagnostic efficiency of polymer injection as an Enhanced Oil Recovery (EOR) method, specifically focusing on how polyacrylamide (PAA) modifies reservoir flow dynamics. *Methods.* The methodology is based on a retrospective analysis of field data from an oil field in Azerbaijan, utilizing the Group Method of Data Handling (GMDH) and neural network modeling. A comparative diagnostic approach evaluated a “pilot” area (PAA injection) against a “control” area (standard waterflooding). Mathematical models were constructed to describe the relationship between cumulative oil and liquid production, allowing for the extrapolation of performance indicators and technological efficiency. *Results.* The research results indicate that polymer injection significantly enhances oil displacement efficiency compared to conventional methods. Specifically, the application of PAA resulted in an average increase of the oil recovery factor by 7–10%. Correlation analysis revealed that the thickening effect of the polymer solution improves the sweep efficiency by creating a “screening effect,” diverting flow to previously unswept low-permeability zones. The study identified optimal conditions: oil viscosity of 10–100 mPa·s, oil saturation above 50%, permeability exceeding 0.1 μm², and reservoir temperatures up to 90 °C. High clay content and excessive water hardness were found to be limiting factors. These findings confirm that the integrated diagnostic modeling approach effectively quantifies the benefits of polymer EOR, providing a scientific basis for its implementation in mature fields to maximize hydrocarbon extraction.

Keywords: oil, polymer, oil recovery factor, displacement, rock, heterogeneous rocks

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МҰНАЙ ӨНДІРУДІ АРТТЫРУ ҮШІН ҚАБАТҚА ПОЛИМЕР АЙДАУДЫҢ ТИІМДІЛІГІН ДИАГНОСТИКАЛАУ

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Аннотация. *Өзектілігі.* Әртекті және игерілуі кеш сатыдағы қабаттардан мұнай алу коэффициентін (МАК) арттыру қазіргі мұнай-газ инженериясының маңызды міндеті болып табылады. Дәстүрлі су айдау әдісі кеңінен қолданылғанымен, айдалатын су мен қабаттағы мұнайдың тұтқырлығы арасындағы айтарлықтай айырмашылыққа байланысты мұнайды толық ығыстыра алмайды. Бұл судың ерте серпілуіне және мұнайға қаныққан аймақтардың қамтылмай қалуына әкеледі. Бұл жұмыста мұнай өндіруді арттырудың (EOR) әдісі ретінде полимер айдаудың тиімділігін диагностикалық бағалау мәселесі қарастырылған. Зерттеудің мақсаты — суда еритін полимерлердің, атап айтқанда полиакриламидтің (ПАА), өндіру көрсеткіштерін жақсарту үшін қабаттағы сүзілу динамикасын қалай өзгертетінін негізделген сандық тұрғыдан бағалау. *Әдістері*. Зерттеу әдістемесі Әзірбайжандағы мұнай кен орындарының бірінің кен орнындағы деректерін ретроспективті талдауға негізделген. Талдау барысында аргументтерді топтық есепке алу әдісі (МГУА) және нейрондық желілік модельдеу қолданылды. «Тәжірибелік» учаскені (ПАА айдалған) және «бақылау» учаскесін (дәстүрлі су айдалған) салыстырмалы диагностикалық бағалау жүргізілді. Зерттеу барысында ай сайынғы мұнай мен сұйықтық өндіру динамикасы, айдау ұңғымаларының жұмыс көрсеткіштері және ұңғымалардың өзара әрекеттесу коэффициенттері талданды. Жиынтық мұнай мен сұйықтық өндіру арасындағы байланысты сипаттайтын математикалық модельдер құрылып, бұл технологиялық тиімділікті анықтауға мүмкіндік берді. *Нәтижелер.* Зерттеу нәтижелері полимер айдаудың дәстүрлі әдістермен салыстырғанда мұнайды ығыстыру тиімділігін айтарлықтай арттыратынын көрсетті. ПАА қолдану МАК-ты орта есеппен 7–10%-ға арттыруды қамтамасыз етті. Корреляциялық талдау полимер ерітіндісінің қоюлану әсері «экрандау эффектісін» жасау арқылы қабаттың қамтылуын жақсартатынын анықтады. Бұл ағындарды бұрын қамтылмаған төмен өткізгішті аймақтарға бағыттайды. Жұмыс барысында әдісті қолданудың оңтайлы жағдайлары анықталды: мұнай тұтқырлығы 10–100 мПа·с, мұнайға қанықтылығы 50%-дан жоғары, өткізгіштігі 0,1 мкм²-ден жоғары және қабат температурасы 90 °C-қа дейін. Саз мөлшерінің көп болуы және судың қаттылығы шектеуші факторлар екені дәлелденді. Алынған қорытындылар диагностикалық модельдеуге кешенді көзқарастың полимерлік EOR артықшылықтарын тиімді бағалайтынын растайды және оны кеш сатыдағы кен орындарына енгізу үшін ғылыми негіз болады.

Түйін сөздер: мұнай, полимер, мұнай алу коэффициенті, ығыстыру, жыныс, әртекті жыныстар

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ДИАГНОСТИКА ЭФФЕКТИВНОСТИ ЗАКАЧКИ ПОЛИМЕРА ДЛЯ ПОВЫШЕНИЯ НЕФТЕОТДАЧИ

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Аннотация. *Актуальность.* Повышение коэффициента извлечения нефти (КИН) в условиях высокой неоднородности пластов и на поздних стадиях разработки остается актуальной проблемой нефтегазовой отрасли. Традиционное заводнение часто оказывается недостаточно эффективным из-за формирования преимущественных путей фильтрации воды и ее преждевременного прорыва к добывающим скважинам. В данной работе рассматриваются диагностическая оценка и количественный анализ эффективности полимерного воздействия как метода интенсификации добычи. *Цель*. Изучить механизмы изменения реологических свойств вытесняющего агента и оценить их влияние на фильтрационные потоки и эффективность повышения нефтеотдачи. *Методы*. Методологическая база исследования основана на ретроспективном анализе промысловых данных месторождения Азербайджана с использованием метода группового учета аргументов (МГУА) и искусственных нейронных сетей. Применение данных алгоритмов позволило минимизировать погрешности при экстраполяции показателей и более точно оценить технологический эффект. В рамках исследования проведено сопоставление пилотного участка, где осуществлялась закачка полиакриламида (ПАА), и контрольного участка со стандартным заводнением. Анализировались динамика обводненности, темпы падения добычи и коэффициенты корреляции между скважинами. *Результаты и выводы.* Результаты анализа показывают, что применение полимеров позволяет выровнять профиль приемистости и увеличить охват пласта воздействием. Установлено, что повышение вязкости закачиваемой воды минимизирует риск прорыва по высокопроницаемым пропласткам. В исследуемых условиях внедрение ПАА позволило достичь прироста КИН на 7–10% по сравнению с базовым сценарием. Кроме того, использование полимеров способствует снижению объема попутно добываемой воды. Определены критические параметры успешного применения метода: вязкость нефти 10–100 мПа·с, нефтенасыщенность не менее 50% и температура пласта до 90 °C. Также выявлено негативное влияние высокой минерализации и содержания глинистых фракций на стабильность раствора. Полученные выводы служат научным обоснованием для масштабирования технологии на зрелых месторождениях со сложной геологической структурой.

Ключевые слова: нефть, полимер, коэффициент нефтеизвлечения, вытеснение, порода, неоднородные коллекторы

Introduction. The rapid pace of development in the oil and gas industry occurs both through the exploitation of new fields and by intensifying the extraction of hydrocarbon reserves from existing ones. For this reason, the enhancement of hydrocarbon recovery ranks among the primary challenges of the petroleum industry.

One of the important measures aimed at increasing oil recovery is water injection into oil reservoirs, the first positive result of which is an increase in the average flow rate of wells, which has always been the focus of attention of specialists in this field. Therefore, various methods of water injection into reservoirs have been proposed and implemented. Water injection into reservoirs, sufficiently counteracting the drop in reservoir pressure in them, allows fields to operate with a high flow rate and maintain this flow rate for a long time, until about half of the recoverable oil reserves are extracted. Water injection into reservoirs at the initial stage of field development has become a major step forward in solving the problem of increasing oil production from reservoirs. Water injection into reservoirs is used mainly in fields with low-viscosity oil.

In modern times, the study of works carried out to enhance oil recovery shows that these methods can be conditionally grouped: physical-hydrodynamic-cyclic water injection, vibration-impact, magnetic and acoustic methods of action; physical-chemical micellar, micellar-polymer and alkaline injection of water, water-soluble polymer sealants, surfactants (surfactants) and polymer mixtures, gas, water-gas injection, methods of regulating filtration with chemical reagents; thermal methods - steam injection, hot water and in-situ combustion.

Laboratory and theoretical studies conducted in the course of reservoir development have shown that in reservoirs where the crude oil viscosity ranges between 15–17 mPa·s, significant results can be achieved by injecting conventional water.

Due to the diverse physical and geological characteristics of oil-bearing formations and the evolving practice of waterflooding, several types of flooding processes have emerged. Accumulated experience makes it possible to classify and determine optimal conditions for each flooding type. It should be noted, however, that even after waterflooding, approximately 40–50% of the initial oil reserves remain trapped within the formation. This residual oil persists because the injected water does not fully sweep the reservoir or because oil cannot be completely displaced from water-swept zones.

At present, numerous studies and technological improvements are aimed at increasing the degree of reservoir filling by injected water and enhancing the density of the injection well pattern itself. The main challenge during water injection (artificial reservoir pressure maintenance) is to ensure full coverage of the productive zones by the displacing agent (Avdonin et al., 1967; Kerimov and Abdullaev, 2000).

Enhanced oil recovery (EOR) and complete reservoir coverage by waterflooding can be achieved by creating artificial physicochemical conditions that promote efficient oil displacement by water (Abdullaev, 1982).

The application of surface-active agents (surfactants, SAA) has mainly evolved from the conventional water injection process. The addition of small quantities of surfactants (0.05–0.1 wt%) to injected water reduces the interfacial tension between oil, water, and solid particles, leading to the breakdown of oil clusters, lowering the pressure gradient required for oil percolation through porous media, and improving the rheological properties of crude oil.

Surfactants influence the wettability of pore surfaces by reservoir fluids, intensify water saturation in low-permeability formations, and enhance oil displacement from capillaries. The efficiency of surfactant-based methods for improving oil recovery depends largely on the physicochemical and geological–operational characteristics of both the formation and the fluids present within it.

Surfactant injection is considered effective when reservoir oil saturation exceeds 30%, viscosity surpasses 60 mPa·s, the oil contains no natural surfactant components such as asphaltenes or resins, the formation permeability is around 0.1 μm^2, porosity is 10%, clay content does not exceed 5–10%, formation thickness is up to 15 m, and reservoir temperature exceeds 30°C. Increasing clay content, fracture density, and water saturation make the application of surfactant flooding more challenging.

Furthermore, in reservoirs with high-viscosity and paraffinic oils, when the injected water temperature is considerably lower than that of the formation, the process becomes less effective. Under such conditions, heavy components of oil precipitate, blocking pore channels and reducing water injectivity until it eventually ceases. In these cases, combined stimulation methods–involving sequential or simultaneous application of thermal agents and surfactants–are more practical and efficient.

Scientific studies and field experience demonstrate that the implementation of new thermochemical recovery methods significantly improves the development efficiency of high-viscosity oil reservoirs. The continuous growth of hard-to-recover oil reserves underscores the importance of these high-viscosity reservoirs and highlights the crucial role of thermochemical methods in their effective exploitation.

In productive formations containing zones of varying porosity, and where reservoir fluids differ greatly in viscosity, the high-permeability layers under artificial water drive tend to absorb most of the injected water, leaving medium- and low-permeability layers partially or completely unswept, and thus inactive in oil recovery.

In artificial water drive systems, injected water quickly channels through high-permeability layers, leading to premature water breakthrough in production wells. As a result, not only does the production fluid become water-saturated, but the contact of the displacing agent or chemical reagents with the formation diminishes, leaving unswept oil zones. One of the causes of this phenomenon is the much lower viscosity of injected water compared to that of the reservoir oil. Therefore, increasing the viscosity of the displacing water to match that of the reservoir oil has proven effective in improving displacement efficiency. For this reason, numerous technologies have been developed in this direction, among which polymer flooding plays a particularly significant role.

As noted, the conditions under which these individual methods are used must also be different. Therefore, it is possible to further clarify the problem by giving a separate explanation of some methods. Therefore, one of such methods was studied below - polymer injection into the reservoir. Increasing oil production at developed fields is a problem of great scientific importance, since increasing oil production even by a few percent gives a significant economic effect.

In recent years, various methods for increasing oil production have been developed and widely used, which under certain conditions significantly affect the increase in the final oil recovery of formations. One of such measures is the use of formation stimulation methods (polymer solutions, surfactants, micellar, alkaline solutions, etc.).

One of the important issues is the correct assessment of the effectiveness of the applied formation stimulation methods. A large number of methods based on hydrodynamic or static methods are known in the literature. In practice, it is common to compare "pilot" and control fields. These assessment methods often give contradictory results (sometimes even opposite) and require the fulfillment of various conditions for the used field data, both in terms of the volume of data and in terms of the technological features of the development of pilot and control fields (Ivakhnenko and Stepashko, 1976; Mirzajanzade et al., 1996; Sulaimon et al., 2014).

This article presents a retrospective analysis of the polymer injection efficiency at one of the oil fields.

Method. The work uses methods for diagnosing the efficiency of polymer injection based on a neural network model. Comparative quantitative estimates of the polymer injection efficiency are given based on a comparison of the development indicators of the pilot and control fields.

The article presents studies of the effect of the rate of selection during water and polymer injection on the oil recovery factor and the effect of the polymer on the formations.

There are two generally accepted approaches to analyzing the technological efficiency of injecting aqueous polymer solutions to enhance oil recovery:

a) the polymer hydration process began at the initial stage of development. In this case, the technological efficiency indicators of the "pilot" field (where the PAA solution was injected) and the "control" field (where water was injected). In this case, the pilot and control fields should be identical in geological and mining indicators.

b) the polymer solution injection process began at a relatively late stage of development. In this case, the analysis is based on extrapolation of compression characteristics obtained before the use of polymer injection and comparison with the characteristics (Tsai et al., 2009; Upadhyaya and Lu, 2004). This method was applied at the Balakhany-Sabunchi-Romania fields and the Pirallahi onshore field.

At one of the experimental sites under consideration, the first approach is used, that is, two sites are compared - the control and experimental (Table 1 and Fig. 1, 2).

In this area, the geological and reservoir characteristics are identical; the development stages, the commencement of production, and the initiation of waterflooding were carried out simultaneously (Abbasov et al., 2016).

Table 1 (Figure 1) and Figure 2 present the development data of the experimental and control areas. These zones were operated intensively for four years without any water injection. At the beginning of the second quarter of the fourth year, injection of an aqueous solution of polyacrylamide (PAA) with a hydrolysis degree of 26-28% was initiated in two wells of the experimental area, followed by the addition of two more injection wells. Simultaneously, water injection into the formation was also started in the control area.

Table 1. Monthly oil and liquid production data of the control area used for diagnostic analysis.

Time	Q_{oil} min.m^3	$\sum Q_{oil}$ m^3	Q_{liq} m^3	$\sum Q_{liq}$ m^3
1	5091	5091	5633	5633
2	7030	12121	7603	13236
3	7743	19864	8524	21760
4	7218	27082	7979	29739
5	6799	33881	7369	37108
6	7605	41486	8421	45529
7	7142	48628	7772	53301
8	7327	55955	7963	61264
9	6667	62622	7167	68431
10	7827	70449	8626	77057
11	8370	78819	9106	86163
12	8348	87167	9260	95423
13	9132	96299	9871	105294
14	8619	104918	9211	114505
15	9153	114071	9811	124316
16	8649	122720	9192	133508
17	8293	131013	8902	142410
18	6935	137948	7528	149938
19	7612	145560	7998	157936
20	7722	153282	8102	166038
21	7284	160566	7767	173805
22	7845	168411	8550	182355
23	9753	178164	11144	193499
24	9416	178580	10807	204306
25	11168	198748	12262	216568
26	10089	208837	11986	228554
27	9315	218152	11758	240312
28	10175	228327	13677	253989
29	8354	236681	12054	266043
30	6418	243099	8992	275035
31	7552	250651	10541	285576
32	8140	258791	10931	296507
33	7664	266455	10569	307076
34	7406	273861	10665	317741
35	7429	281490	11040	328781
36	7426	288916	11722	340504
37	7853	296769	12829	353333
38	8132	304901	12556	365889
39	19019	313920	13946	379835

40	10644	324564	18934	398769
41	9890	334454	18279	417048
42	9760	344214	18806	435854
43	8643	352857	17636	453490
44	10888	363745	20925	474415
45	9411	373156	19475	493890
46	7289	380445	17527	511417
47	7505	387950	16408	527825
48	7521	395471	14466	542291
49	7396	402867	16313	558604
50	8223	411090	16471	575075
51	7684	418774	20728	595803
52	7712	426486	21039	616842
53	5540	432026	18830	635672
54	5876	437902	18788	654460
55	5336	443238	18785	673245
56	4784	448022	15769	689014

Table 2. Experimental Area (PAA Injection).

Time	Q_{oil} min.m^3	$\sum Q_{oil}$ m^3	ΔQ_{oil} min. m^3	Q_{liq} m^3	$\sum Q_{liq}$ m^3	ΔQ_{liq} м^3	Q_{inj} m^3	$\sum q_{liq}$ m^3	Δq_{liq} m^3
1	2	3	4	5	6	7	8	9	10
1									
2									
3									
4									
5									
6									
7	6,1	6,1		9,5	9,5				
8	5,3	11,4	-0,8	6,8	16,3	-2,7	-	-	-
9	4,5	15,9	-0,8	6,0	22,3	-0,8	-	-	-
10	4,9	20,8	0,4	6,3	28,6	0,3	-	-	-
11	5,2	26,0	0,3	6,7	35,3	0,4	-	-	-
12	5,7	31,7	0,5	7,3	42,6	0,6	-	-	-
13	6,3	38,0	0,6	7,4	50,0	0,1	-	-	
14	5,7	43,7	-0,6	7,3	57,3	-0,1	-	-	--
15	6,3	50,0	0,6	8,1	65,4	0,8	-	-	-
16	6,0	56,0	-0,3	7,8	73,2	-0,3	-	-	-
17	6,7	62,7	0,7	8,7	81,9	0,9	-	-	-
18	6,7	69,4	0,0	8,8	90,7	0,1	-	-	-
19	9,2	78,6	2,5	11,5	102,2	2,7	-	-	-
20	8,3	86,9	-0,9	9,8	112,0	-2,7	-	-	-
21	8,1	95,0	-0,2	9,2	121,2	-0,6	-	-	-
22	7,2	102,2	-0,9	8,9	130,1	-0,3	-	-	-
23	8,7	110,9	1,5	10,8	140,9	1,9	-	-	-
24	12,4	123,3	3,7	14,9	155,8	3,1	-	-	-
25	17,0	140,3	4,6	19,3	175,1	4,4	-	-	-
26	17,6	157,9	0,6	19,7	194,8	0,4	-	-	-
27	19,5	177,4	1,9	21,9	216,7	2,2	-	-	-
28	20,4	197,8	0,9	22,9	239,6	1,0	-	-	-
29	21,0	218,8	0,6	21,7	261,3	-1,2	-	-	-

30	20,4	239,2	-0,6	23,5	284,8	1,8	-	-	-
31	17,6	256,8	-2,8	20,6	305,4	-2,9	-	-	-
32	18,3	275,1	0,7	21,9	327,3	1,3	-	-	-
33	18,1	293,2	-0,2	21,5	348,8	-0,4	-	-	-
34	16,4	309,6	-1,7	20,1	368,9	-1,4	-	-	-
35	16,7	326,3	0,3	20,7	389,6	0,6	-	-	-
36	16,0	342,3	-0,7	20,2	409,8	-0,5	-	-	-
37	17,7	360,0	1,7	22,5	432,3	2,3	-	-	-
38	15,5	275,5	-2,2	22,0	454,3	-0,5	-	-	-
39	16,5	392,0	1,0	25,5	479,8	3,5	-	-	-
40	14,7	406,7	-1,8	22,7	502,5	-2,8	1433	1433	-10483
41	15,4	422,1	0,7	26,1	528,6	5,4	11916	13349	9345
42	14,8	436,9	-0,6	23,1	551,7	-3,0	9345	22694	-1705
43	15,3	452,2	0,5	22,5	574,2	-0,6	2640	30334	4301
44	13,2	465,4	-2,1	22,0	596,2	-0,5	11941	42275	5789
45	12,8	478,2	-0,4	25,5	621,7	3,5	17730	60005	-8358
46	14,0	492,2	1,2	22,7	644,4	-2,8	9372	69377	2140
47	15,3	507,5	1,3	26,1	670,5	3,4	11512	80889	3320
48	17,6	525,1	1,3	23,1	693,6	-3,0	14832	95721	
49	12,3	537,4	-5,3	30,9	724,5	7,8	12567	108288	-2265
50	10,1	547,5	-2,2	25,6	750,1	-5,3	5890	114178	-6677
51	9,5	557,0	-0,6	24,2	774,3	-1,4	29099	143277	23209
52	9,4	566,4	-0,1	24,6	798,9	0,4	23774	167051	-5325
53	9,5	575,9	0,1	23,2	822,1	-1,4	22481	189532	670
54	9,2	585,1	-0,3	22,9	845,0	-0,3	22767	212299	-516
55	10,2	595,3	1,0	29,1	874,1	6,2	20399	232698	713
56	15,3	610,6	5,1	32,8	906,2	4,7	23940	256638	756
57	13,7	624,3	-1,6	30,4	936,6	-2,4	31349	287987	1960
58	16,3	640,6	3,4	30,9	967,5	0,5	36443	324430	-4399
59	13,9	654,5	-2,4	28,1	995,6	-2,7	36330	360760	3149
60	20,4	674,9	6,5	28,8	1024,4	0,7	43501	404261	7171
61	14,4	689,3	-6,0	29,3	1053,7	0,5	40334	444595	-3167
62	11,6	700,0	-3,8	21,8	1075,5	-1,5	32404	476999	-7939
63	15,7	716,6	4,1	26,2	1101,7	4,4	29730	506729	-2674
64	10,3	726,9	-5,4	21,2	1122,9	-5,0	33418	540147	3688
65	14,3	741,2	4,0	24,8	1147,7	3,6	33732	573879	314
66	12,3	753,5	-2,0	22,8	1170,5	-2,0	33330	607209	-402
67	11,8	765,3	-0,5	24,6	1195,1	1,8	38408	645617	5078
68	16,2	781,5	3,4	25,9	1221,0	1,3	36310	631927	-2098
69	16,8	798,3	0,6	25,7	1246,7	-0,2	34520	716447	-1790
70	20,5	918,8	3,7	30,8	1277,5	5,1	33489	749936	-1031
71	21,0	939,8	0,5	30,2	1307,7	-0,6	34108	784039	614
72	19,5	959,3	-1,5	27,9	1335,6	-2,3	34853	818892	750

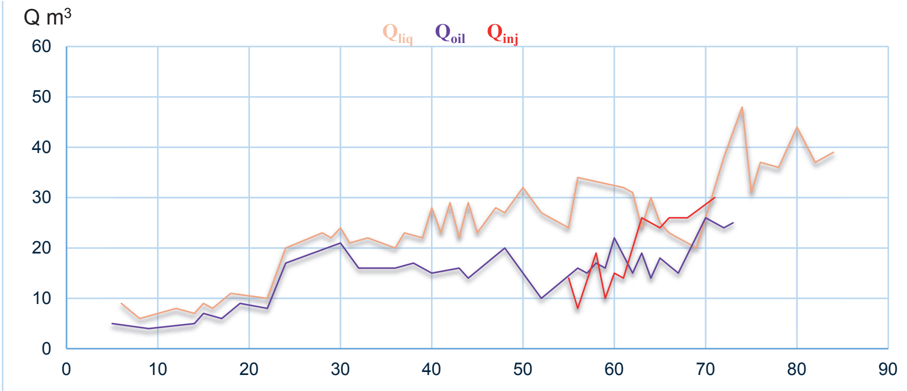

Figure 1. Development data of the experimental site.

At this site, the geological, geological and mining characteristics are the same, the development periods, the start of operation and the beginning of flooding are carried out simultaneously (Sulaimon et al., 2014).

Figure 1 and Figure 2 show the development data for the experimental and control sites. These sites were intensively developed without water injection for four years. At the beginning of the second quarter of the fourth year, injection of an aqueous solution of PAA into two wells was started at the experimental site, and then two more injection wells were added. At the same time, water injection into the formation was also started at the control site in parallel.

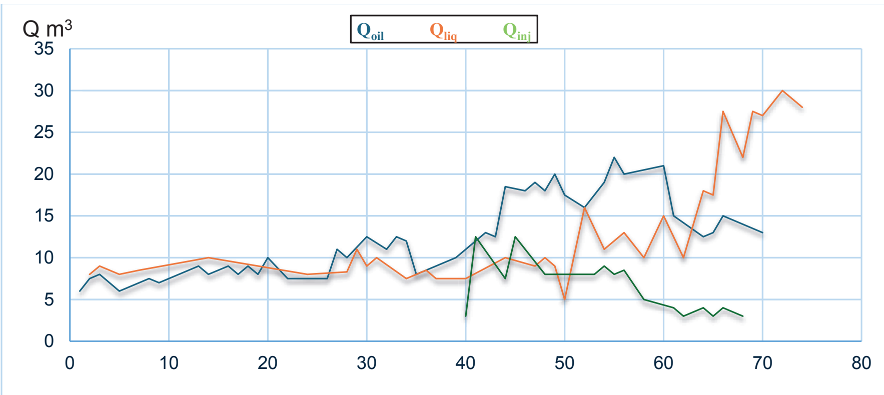

Figure 2. Control zone development data.

Results and discussions. The problem of diagnostics of polymer dilution efficiency based on model construction is considered.

It was found that total oil production in the period before injection of the working agent is well described by the model of dependence of liquid production on total oil production for both experimental and control fields. The degree of similarity of the initial data and the data obtained by the model is very high for all of them, approximately 1. Despite the different production levels at these fields, it can be said that the development in this period is the same, which once again confirms the validity of the comparison of the experimental and control fields (Tsai et al., 2009; Upadhyaya and Lu, 2004).

At the next stage, a model with the same structure was built only for the period of the beginning of the impact on the reservoir. A model of the structure $\sum Q_o = F(Q_o, Q_v, \sum Q_1)$ was built before liquid was injected into the reservoir.

The problem of diagnosing the efficiency of polymer flooding based on the construction of GMDH (Group Method of Data Handling) models has been examined. In the initial stage, models of the following type were developed for the pre-water-cut period (Vasilyev V.İ. and Lanqe T.İ.,2002; Muravina O.M., 2009):

$$\sum Q_{oil} = F(Q_{oil}, Q_{liq}, \sum Q_{liq}$$

Where:
$\sum Q_{oil}$ - total oil production;
Q_{oil}- average monthly oil production;
$\sum Q_{liq}$ – total liquid production;
1.For the control period

$$\sum Q_{oil} = 23+0,91 \cdot \sum Q_{liq}$$

When the similarity measure (identify measure) is 0,999,
For the initial 20-Month period

$$\sum Q_n = -363663 + 150 \frac{\sum Q_l}{Q_n} \sqrt{Q_n} + 456 \cdot 10^4 \frac{Q_n}{\sum Q_l}$$

When the measure of identify (similarity) is 0,997.
The results are provided in Tables 3.

Table 3. Control area (PAA injection) over a 20-month period.

№	$\sum Q_{n.init.}$, m^3	$\sum Q_n^*$, m^3	Δ,% error
1	160566	132912	17,2
2	168411	148336	11,9
3	178164	160076	10,1
4	187580	168317	10,3
5	198748	183881	7,5
6	208837	189944	9,0
7	218152	194580	10,8
8	228327	204706	10,3
9	236681	224137	5,3
10	243099	257714	5,7
11	250651	249852	0,3

12	258791	254386	1,7
13	266455	276295	3,6
14	273361	296450	7,6
15	281490	306778	8,2
16	288916	318486	9,3
17	296769	328762	9,7
18	304901	334296	8,8
19	313920	341548	8,1
20	324564	337831	3,9

2. For the experimental (test) area:
For the initial 20-month period:

$$\sum \hat{Q}_n = -1.257 + 0.7814 \sum Q_l + 10^{-5} \left(\sum Q_l\right)^2 \sqrt{\sum Q_l} - 0{,}05 \frac{\sum Q_l}{\sqrt{Q_n}}$$

When the measure of similarity=0,998.
Over the 20-Month period:

$$\sum Q_n = 268{,}6 + 29{,}6\sqrt{\sum Q_l}$$

When the model's measure of identify (similarity) θ=0,999.
The results are provided in Tables 4.

Table 4. Experimental Area over a 20-month period.

№	$Q_{n,}$ m^3	Q_{liq}, m^3	$\sum Q_{liq}$ m^3	$\sum Q_{n.init.,}$ m^3	$\sum Q^*_{n,}$ m^3	Δ,%
1	19,5	21,9	216,7	177,4	176,5	0,5
2	20,4	22,9	239,6	197,8	199,0	0,6
3	21,0	21,7	261,3	218,8	219,6	0,4
4	20,4	23,5	284,8	239,2	240,6	0,6
5	17,6	20,6	305,4	256,8	258,5	0,6
6	18,3	21,9	327,3	275,1	276,8	0,6
7	18,1	21,3	348,8	293,2	294,3	0,4
8	16,4	20,1	368,9	309,6	310,1	0,2
9	16,7	20,7	389,6	326,3	325,9	0,1
10	16,0	20,2	409,8	342,3	340,9	0,4
11	17,7	22,5	432,3	360,0	357,2	0,8
12	15,5	22,0	454,3	375,5	372,6	0,8
13	16,5	25,5	479,8	392,0	390,2	0,4
14	14,7	22,7	502,5	406,7	405,4	0,3
15	15,4	26,1	528,6	422,1	422,4	0,07
16	14,8	23,1	551,7	436,9	437,3	0,1
17	15,3	22,5	574,2	452,2	451,2	0,2
18	13,2	22,0	596,2	465,4	464,8	0,1

19	12,8	25,5	621,7	478,2	480,0	0,4
20	14,0	22,7	644,4	492,2	493,7	0,3

As observed from the models developed for both the experimental and control sectors during the pre-polymer injection period, the dependence of cumulative oil production on cumulative liquid production is well-described. The degree of identity between the raw data and the model outputs is exceptionally high for each case, approximately 1. Despite the varying production levels in these sectors, the development characteristics for this period remain consistent, which further confirms the legitimacy of comparing the experimental and control areas.

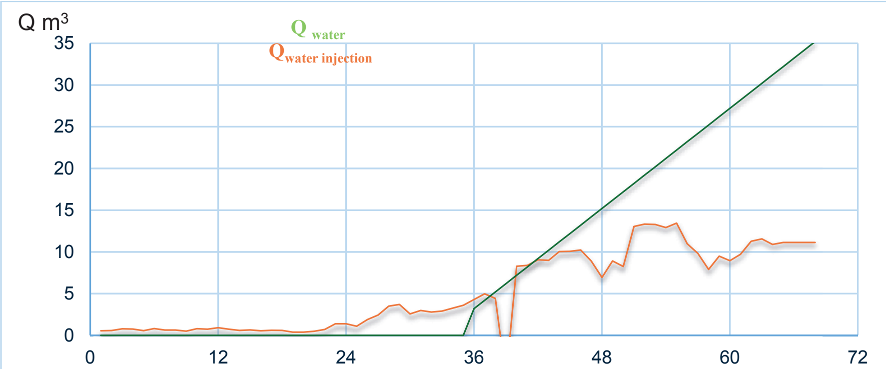

Figure 3. Dynamics of oil production in the control area (without impact).

Taking into account the data on injection wells № 5231 and 5232, into which the aqueous solution of PAA was injected, and production wells № 3777, 5160, 3786, 3750, 3771, 3787, located in the first row opposite these wells, a graph was constructed (Fig. 3), (Toma et al., 2017; Lu et al., 2021).

The correlation between the liquid withdrawal rate for each of the wells under consideration and the injection rate or flow rate for the others was assessed for three dates (Table 5).

Table 5. Correlation analysis of production and injection wells during polymer flooding.

№	**Well**	**I Date (Duration)**	**III Date (Duration)**
1	3777	0,51	0,82
2	3750	0,38	0,7
3	3771	0,26	0,45
4	3786	0,88	0,58
5	3787	0,1	0,29
6	5160	0,75	0,31

Dates 1; II; III were assessed as the process of injecting the aqueous polymer solution into the formation continued. The increase in the correlation coefficient (C.C.), and then the decrease in the value of the correlation coefficient for most wells (for example, 3777, 5169, 3786, 3787) can be explained by the fact that on dates 1 and 2 these wells were located at a distance from the polymer joint (C.C. increases as they approach the outer boundary of the joint) - on date 3 the joint is located directly at the bottom of these wells (C.C. decreases due to the screening effect of the joint). The most pronounced properties of the change in C.C. are manifested for wells 5160-3787 (Suleymanov et al., 2017; Firoozjaee and Saghafi, 2020). For wells 3750 and 3771, the change in C.C. is monotonic, with a constant decrease in the mobility of this fluid (in the area of well 3750) and approaching the outer boundary of the joint (well 3771). Based on the analysis of the obtained results, it is possible to evaluate the configuration of the area covered by the thickener and diagnose the predominant development of the process in the direction of wells №. 3750, 3787.

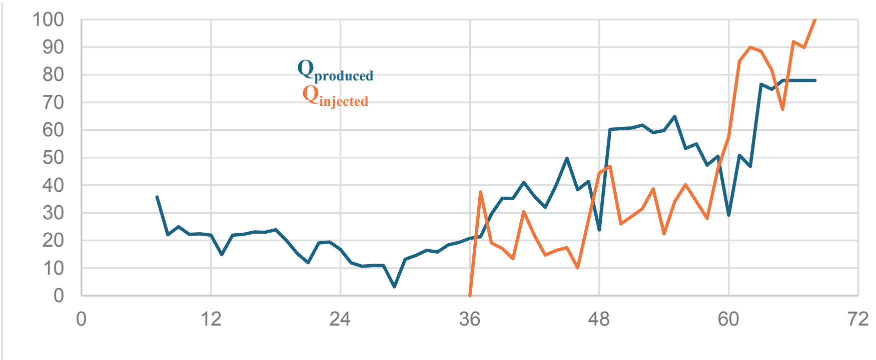

Figure 4. Data in the control zone (water injection).

Then the correlation coefficient between the water cut of each well and the flow rate on the first and last dates, respectively, was studied.

Thus, for all wells this indicator decreases sharply, which is associated with the effective thickening of the formed water and, as a consequence, the limitation of the water inflow from the injection wells.

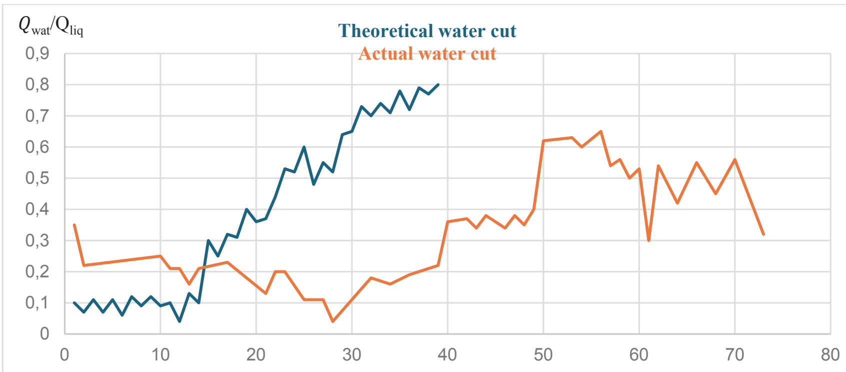

Figure 5. Control, practical (comparative) areas.

In Figure 5, no clear decrease in water cut is observed when injecting an aqueous solution of PAA into the formation. The values of the coefficient of correlation given in Table 1 clearly confirm the tendency to decrease water cut when injecting PAA (Toma et al., 2017; Lu et al., 2021). At the same time, a study of water cut depending on the injection rate on the 1st and 3rd dates showed an increase in the correlation coefficient for wells № 3777, 3750, 3771, 3787.

Conclusions. For clarity and conciseness, the original monthly production dataset was analyzed in full, while the article presents representative time windows corresponding to key technological stages of field development. This approach preserves the dynamic response of the reservoir to polymer injection without loss of diagnostic information. The complete time-series data used in the analysis are available in the Supplementary material.

– Analysis of models based on the development data of the pilot and control fields showed that the oil production models for the period before well injection describe the initial data well, whereas for the period after injection, the effect of injection at the pilot field is significantly greater than at the control site.

– Study of well interaction at the pilot field showed that well interaction is enhanced by injection of an aqueous polymer solution.

– Overall, the results support the conclusion that polymer flooding leads to a more stable production regime, with improved oil recovery, especially in reservoirs characterized by high permeability contrast or heterogeneity. These findings align with previous literature and reinforce the applicability of polymer injection as a cost-effective enhanced oil recovery (EOR) method.

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