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G. Zh. Moldabayeva[*1],
orcid.org/0000-0001-7331-1633,
G. M. Effendiyev[2],
orcid.org/0000-0002-4875-5782,
Z. B. Imansakipova[1],
orcid.org/0000-0002-6000-6477,
Sh. R. Tuzelbayeva[1],
orcid.org/0000-0002-1749-6511,
S. V. Abbasova[3],
orcid.org/0000-0002-4120-8452

1 – Satbayev University, Almaty, the Republic of Kazakhstan
2 – Azerbaijan National Academy of Sciences, Baku, the Republic of Azerbaijan
3 – Azerbaijan State Oil and Industry University, Baku, the Republic of Azerbaijan
[*] Corresponding author e-mail: moldabaeyva@gmail.com

INFLUENCE OF POLYMER SOLUTION CONCENTRATION AND MEDIA PERMEABILITY ON THE RESIDUAL RESISTANCE FACTOR

Purpose. Determination of the required concentration of polymer solution, providing the maximum well insulation effect, depending on the filtration characteristics of the medium.

Methodology. The research was conducted by experimental method using the methodology of planning the experiment. The theory of rational planning was used by varying two variables on five levels. Media permeability and polymer solution concentration were used as variables. Methods of mathematical statistics were used in processing the results.

Findings. Experimental studies made it possible to build a model expressing the dependence of the residual resistance factor on the permeability of the medium and the concentration of the polymer solution. By further statistical processing the connection between permeability and necessary concentration of polymer solution was obtained.

Originality. The experimental studies have substantiated the possibility of evaluating the influence of medium permeability and concentration of polymer solution on the residual resistance factor and determined its dependence on the concentration of polymer solution and medium permeability. The main point of polymer solutions application is justification and choice of the reagent concentration. The concentration should be selected in such a way that it provides the maximum value of the residual resistance factor and the viscosity of the solution necessary to level out permeability heterogeneity of the environment to some extent. To achieve this, a relationship has been obtained that allows determining the concentration of the polymer solution at a given permeability of the environment that provides the maximum residual resistance factor.

Practical value. The conducted experimental studies allow developing the ideas about the regularities of water manifestations. The results of the research allow selecting purposefully both the formulations of composite systems and the technology of their application to improve the efficiency of oil production and to limit water inflows in specific geological and physical conditions.

Keywords: *water inflow, oil, permeability, polymer solution, well, formation, gel-forming composition*

Introduction. Currently, the degree of depletion of oil reserves of industrial category in various regions has increased significantly and makes, approximately, more than 70 %. Since there is a high water content in them, scientific and technical solutions for blocking permeable areas of the reservoir become crucial. In this regard, ways to use effective water insulation compositions are being investigated. A considerable number of compositions is known and great experience of their application in various geological and physical conditions has been accumulated. However, their technological efficiency is low and does not exceed 40–50 %. There are a number of drawbacks of applied technologies based on sediment-gel-forming compositions for water insulation works. As a rule, these are low stability of compositions in formation environment, insignificant permeability in pore channels, high sensitivity to mineralization of formation water, temperature, type of reservoir, lack of effective technological methods used for regulating the processes of gelling the composition, etc. In connection with the mentioned above, it is necessary to conduct studies aimed at blocking of highly permeable flushed formation zone with gel-forming composition having high strength characteristics and adjustable gel-forming time.

Water inflows, whose mechanism of which is the subject of separate studies, play an important role. In this case, it is necessary to conduct special experimental research to study the influence of geological conditions and properties of the gel-forming compositions used.

Materials and methods. The purpose of this article is to develop a method for determining the required concentration of a polymer solution that provides the maximum isolation effect, depending on the filtration characteristics of the medium.

Analysis of the results of studies on water inflows into the well and combating them. The problem of water inflows has always remained in the center of attention, and in recent years, especially more often began to attract the attention of researchers [1, 2]. Theoretical and experimental studies aimed at study on mechanism of origin of water inflows, reasons of their origin, and also search of methods of struggle against this phenomenon, were carried out. At the same time the influence of various compositions, in particular, on a polymeric basis, was studied. Thus, in [3], by means of field and laboratory observations Manichand, R. and Seright, R. S. studied polymer retention capacity during polymer flooding in Tambarejo field (Suriname). The key parameter in this polymer flooding design process, as well as permeability changes due to retention or adsorption (e.g., clogging), is viscosity under reservoir conditions. Laboratory work is performed to determine the physical properties of polymer solutions as they flow through a porous medium, such as the presence of permeability reduction/clogging of the micromodel. Statistical analysis of the distribution and area of plugged zones is performed, and the study is supplemented by a study on the pressure response at various stages of injection. The results show that approximately half of the retention of the biopolymer xanthan (a gel-forming agent used to control viscosity) used was due to adsorption and the other half to mechanical trapping. Moreover, about 35.2 % of the retention caused by hydrolyzed polyacrylamide was due to adsorption and the remaining 64.8 % was due to mechanical trapping. The results obtained and the workflow presented in this paper provide a better understanding of the mechanism of polymer solutions in waterflooding. In addition, the definition of optimized workflows to evaluate any solutions in porous media and changes in permeability is supported.

A 24-month field test in the Yarigui Cantagallo field in Colombia using hydrolyzed polyacrylamide resulted in a residual resistivity factor close to 3. With a total water cut of up to 5 %, polymer flooding was considered both technically and economically feasible for the field. A sand formation with permeability of 1.279 mD was used as a reservoir model [2, 4]. Knobloch, L. O. and Peter Mora [2, 5] give the results of a series of experiments in which at higher ranges of permeability retention does not change anymore. In addition, AL-Obaidi S. H., et al. [2, 6] showed that when the permeability is increased from 12 to 137 mD, the retention decreases significantly. Permeability appears to be an important characteristic at values below 100 mD and becomes less important at higher values. In [7] special attention is paid to polymer injection [partially hydrolyzed polyacrylamide] as a part of chemical method of influence. Experiments were conducted under laboratory conditions using water and brine in the sand after injection of polymer solution. The purpose of the experiments was to study the effect of polymer solution adsorption on permeability reduction by analyzing the values of the residual resistance factor at different concentrations of polymer solutions. The rheological properties of the polymer were also investigated. Experimental results as well show that the adsorption properties of polymer are strongly influenced by salinity, solution pH and polymer concentration. To study the effect of polymer adsorption and mobility control on additional oil recovery, polymer flooding experiments with different polymer concentrations were conducted. It was obtained that with increasing polymer concentration oil recovery increases.

In [2] the results of experimental studies on polymer waterflooding are given. The polymers varied in type and concentration. "Tracer" particles combined with fluorescein sodium salt helped visualize polymer flow through a glass-silica-glass micromodel resembling a low permeability reservoir. The images were taken during the flooding process, and the results provided additional insight into polymer flow through such micromodels and the principle of retention mechanisms. Here [2] there was mechanical capture as opposed to Scleroglucan, where there was adsorption. Quantitative analysis gave information that adsorption is not seen in experiments of this sort. In addition, scleroglucan resulted in a higher residual resistance factor in both experiments, although Flopaam was tested with a higher resistance factor. Furthermore, increasing the concentration resulted in a higher resistance factor for both polymer and hydrolyzed polyacrylamide. Qualitative analysis showed that most of the polymer solutions exhibited a filtration process on the injection side. Moreover, while Flopaam 1000 ppm (0.1 %) showed almost no visible clogging, visible clogging increased dramatically at 1500 ppm (0.15 %). Apparently, as the authors note, there is a critical concentration for Flopaam at which the drop in permeability increases dramatically. Scleroglucan, on the other hand, provides the same degree of adsorption at low concentrations. Adsorption has a greater effect on the resistivity factor than mechanical capture. At such low flow rates, none of the polymers used showed hydrodynamic retention. Moreover, the paper shows that the workflow presented in this study can be used to evaluate any type of fluid to determine the potential effects of permeability reduction or plugging.

Experimental studies on the effect of polymer compositions on their insulating ability in a porous medium. To improve the effectiveness of fighting against complications, it is necessary, taking into account the classification of rocks by filtration-capacitive characteristics given in the works of recent years [8], to create an impermeable screen, or significantly reduce the permeability of rocks in the area where water inflows are observed (or are expected).

Currently, a huge number of plugging solutions with different properties have been developed to create water-proof screens and block water inflow into the well.

Obviously, it is practically impossible to consider all developed compositions within the framework of one research project. In our case, taking into account earlier studies, we considered reagents that are able to create a waterproof screen and reduce several times the permeability of the rock in the horizontal section of the well in the shortest possible time.

Additionally, based on the conditions at the present stage, the selected reagents must be as economical as possible (relatively low cost) and their production is desirable to have within the area of oilfield operations.

Recently, in a number of works, along with the use of polymers in the secondary methods of enhanced oil recovery, they are used to prevent the escape of drilling mud into the formation [9].

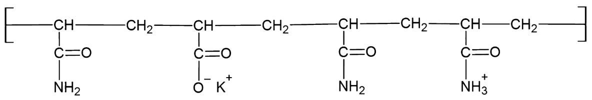
In [10] it was found that polymer filtration through cores with low permeability occurs with attenuation and at high pressure drops. Water permeability of cores after polymer solutions filtration sharply decreases, and the degree of permeability decrease depends on polymer concentration (polymer viscosity) and the initial permeability of the core. The core isolation coefficient depends on the type of polymer. For example, the core isolation coefficient during the filtration of a polymer solution containing 0.1 % of CS-6 type polymer is 11.1 %, while that of sedipur type polymer is 36.4–98.8 %. At 0.25 % polymer content the core isolation coefficient is 90.9–99.5 %, and at 0.5 % concentration the filtration almost completely stops [8].

In [9] it was shown that the efficiency of water inflow limitation by polymer solutions is also determined by a set of their physical and chemical, reservoir properties and formation water properties of the treated reservoir.

In the work [9] considered above, polymers produced outside the CIS were used, and in works [10, 11], properties of polymers were studied on the basis of the possibility of their use for limiting water inflow into oil wells.

To prevent water inflow, studies were conducted to understand the feasibility of creating an impermeable screen using a polyacrylamide (PAA)-based composition.

PAA – copolymer of acrylamide with acrylic acid and its salts [12, 13]



In industry, technical PAA is produced from acrylic acid nitrile (AAN) by replacing the nitrile group with the amide group followed by acrylamide polymerization in the presence of regenerative initiators.

The experiment was carried out using the theory of planning experiments while varying two factors at five levels. Medium permeability and polymer solution concentration were considered as factors. The residual resistance factor R_{RF}, which characterizes the insulating ability of polymer solutions, was taken as the output parameter.

To describe the effect of permeability reduction after contact of the porous medium with polymers [10, 14] we introduced the concept of the residual resistance factor R_{RF}, which is defined as a value representing the ratio of porous medium permeability by water before and after its treatment with a polymer solution

$$R_{RF} = k_w / k_p, \quad (1)$$

where k_w, k_p are respectively permeabilities of porous medium by water and polymer, μm^2.

The residual resistance factor is an important characteristic that shows the decrease in conductivity of the porous medium after its interaction with the polymer solution. To carry out laboratory research on the study of the residual resistivity factor and the influence of various parameters on it, the appropriate experimental setup simulating the porous medium was used. Such installations in different modifications are available in various scientific organizations and their description has been widely published in the press. The same setup was used in our experimental research. Description and scheme of one of such units are given in earlier publications [14], including ours [9]. Therefore, without dwelling on the scheme and a detailed description of the setup, we will give only a brief characteristic of it.

Brief description of the experimental setup. One of the units of the installation is a homogeneous linear reservoir model, which is a steel pipe with flanges welded at both ends, closed in turn by removable flanges, which have valves that allow connecting the model to the installation. The choice of the reservoir model length (1 m) was carried out in accordance with the recommendations on modeling the process of oil recovery by water [15, 16].

Ground quartz sand was used as a model of porous medium in the experiments. The necessary permeabilities of the porous medium were created by appropriate fractions of quartz sand obtained by grinding it in a ball mill.

Experiments to study the laws of formation of the residual resistance factor, the influence of various parameters on the process of formation of the residual resistance factor using polymer solutions were carried out in the following sequence.

The homogeneous reservoir model was vacuumized and then saturated with water. After that, permeability of porous medium by water at several pressure drops was determined.

The experiments in all cases were conducted in isothermal conditions. A constant reservoir temperature was maintained using an electric heater. Then, polymer solution was injected into the reservoir model at a certain pressure drop, after which the model was kept at rest for 24 hours [17, 18]. After that, water was injected into the reservoir model again at the same pressure drop as the polymer solution and at a given pressure drop in the steady-state filtration mode, the permeability of the porous medium treated with polymer solution was determined. The residual resistance factor was determined according to [19, 20] by (1).

Filtration characteristics were evaluated by the change in the residual resistance factor (R_{RF}) from the filtration rate, permeability, etc.

The insulating ability of the polymer solution was determined by formula in %

$$W = \frac{K_{perm} - K'_{perm}}{K_{perm}} \cdot 100\,\%, \quad (2)$$

where K_{perm}, K'_{perm} are permeability coefficients of porous medium by water before and after filtration of polymer solution, μm^2.

Results and discussion. The planning matrix with input and output variables and the results of the experiments are shown in the Table.

Each of the results shown in the table is the arithmetic average of 3–5 repeated experents. Using the experimental values, graphical dependences of the resistance factor on polymer solution concentration at average values of permeability coefficient and on permeability at average values of concentration were plotted, shown in Figs. 1, 2 and 3.

Both partial dependences have been approximated and then combined into a common one using methods known from mathematical statistics, as a result the following expression has been obtained

$$R_{RFcalc.} = 19.959 \cdot C^{0.4287} \cdot K_{perm}^{-0.8453}.$$

The Table also shows the isolation capacity W of the PAA solution determined by (2). As can be seen from the table, the insulating capacity of the PAA solution is determined by the concentration and permeability of the porous medium. Based on such values and their correspondence to permeability coefficient values, as well as concentration of polymer solution, the concentration values corresponding to the medium permeability are determined. The dependence of necessary polymer

Table

Planning matrix with input and output variables and results of experiments

No.	C	K_{perm}	K'_{perm}	R_{RF}	$W = \frac{K_{perm} - K'_{perm}}{K_{perm}} \cdot 100\,\%$
1	0.005	0.05	0.0045	11	90.91
2	0.1	0.05	0.0008	62	98.39
3	0.5	0.05	0.0004	140	99.29
4	1	0.05	0.0003	200	99.5
5	2	0.05	0.0001	350	99.71
6	0.005	0.25	0.05	5	80
7	0.1	0.25	0.0167	15	93.33
8	0.5	0.25	0.005	50	98
9	1	0.25	0.0028	90	98.89
10	2	0.25	0.0021	120	99.17
11	0.005	0.45	0.15	3	66.67
12	0.1	0.45	0.045	10	90
13	0.5	0.45	0.0113	40	97.5
14	1	0.45	0.009	50	98
15	2	0.45	0.008	56	98.21
16	0.005	0.65	0.1625	4	75
17	0.1	0.65	0,0722	9	88.89
18	0.5	0.65	0,026	25	96
19	1	0.65	0.0163	40	97.5
20	2	0.65	0.013	50	98
21	0.005	1.2	0.8	1.5	33.33
22	0.1	1.2	0.15	8	87.5
23	0.5	1.2	0.08	15	93.33
24	1	1.2	0.05	24	95.83
25	2	1.2	0.0343	35	97.14

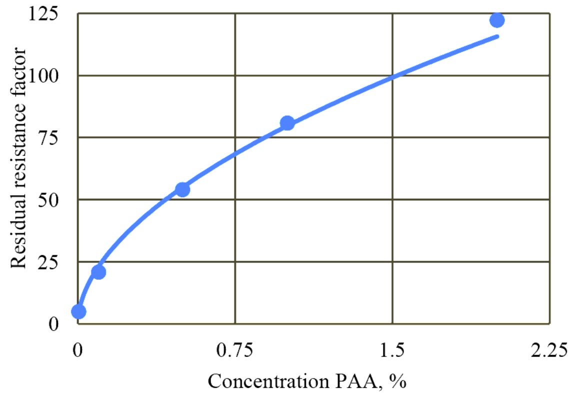


Fig. 1. Residual resistance factor dependence on solution PAA concentration

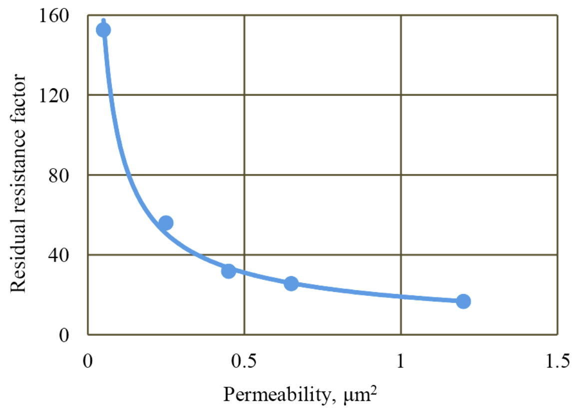


Fig. 2. Dependence of residual resistance factor on permeability of porous medium

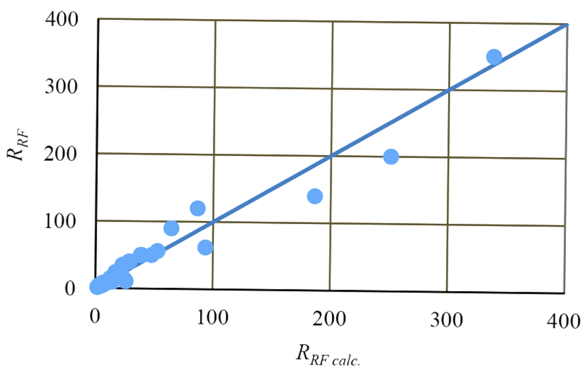


Fig. 3. Comparative graph of calculated and actual values of the residual resistance factor

concentration in the solution on porous medium permeability is plotted on the basis of the lowest concentration values at which the maximum insulation effect is observed (Table).

The formula obtained as a result of dependence processing is as following

$$C = 0.5 \cdot K_{perm},$$

where K_{perm} is the permeability coefficient, μm².

Using the formula obtained, it is possible to calculate the concentration of polymer solution, which provides the highest value of isolation coefficient that can be obtained at a given reservoir permeability.

The impact of polymer solution on waterflood results in fields with hard-to-recover oil has been studied and are being studied by many researchers, oil companies and scientific organizations; by now, a large number of different results and opinions have been accumulated. Therefore, in the present work an attempt has been made to study the influence of polymer composition concentration and medium permeability on the mobility characteristic, which is the resistivity factor. The results of experimental studies allowed obtaining the dependence of the resistance factor on the permeability of the medium and the concentration of polymer solution, which will make it possible to create conditions for the isolation of water inflows using polymer compositions in the considered medium. Application of methodology of rational planning of experiments allows one to get maximum information during realization of the experiment plan. Reduction in water mobility can be achieved even at minimum polymer concentrations. In this regard, the expression for determining the necessary concentration depending on the permeability of the medium is obtained. Application of appropriate methods of data processing and information analysis makes it possible to justify the choice of polymer solution concentration.

Conclusions:

- as a result of the experiment using the theory of mathematical planning, the dependence of the residual resistance factor on the concentration of the polymer solution and the coefficient of permeability has been established;
- analytical expression of dependence of resistivity factor on medium permeability and concentration of polymer solution has been obtained according to the results of statistical data processing;
- in the considered range of values, the increase in the residual resistance factor has been observed in case of concentration increase, while the increase in permeability leads to decrease in its values;
- the expression for determining the concentration of polymer solution has been proposed, based on the condition of providing the maximum value of the residual resistance factor;
- the expression obtained allows us to determine the necessary concentration in accordance with the permeability of the reservoir;
- the possibility of creating filtration resistances by polymer solutions in the filtration channels of rocks has been experimentally confirmed;
- the results of the research can be used in the development of oil fields using polymer solutions.

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Вплив концентрації полімерних розчинів і проникності середовища на залишковий фактор опору

Г.Ж. Молдабаєва[*1], *Г.М. Еффендієв*[2], *З.Б. Імансакіпова*[1], *Ш.Р. Тузелбаєва*[1], *С.В. Аббасова*[3]

1 – Satbayev University, м. Алмати, Республіка Казахстан
2 – Національна Академія Наук Азербайджану, м. Баку, Азербайджанська Республіка
3 – Азербайджанський державний університет нафти та промисловості, м. Баку, Азербайджанська Республіка
[*] Автор-кореспондент e-mail: moldabaeyva@gmail.com

Мета. Визначення необхідної концентрації полімерного розчину, що забезпечує максимальний ефект ізоляції свердловини, у залежності від фільтраційної характеристики середовища.

Методика. Дослідження проводилися експериментальним методом із застосуванням методики планування експерименту. Була використана теорія раціонального планування при варіюванні двох змінних на п'яти рівнях. В якості змінних служили проникність середовища й концентрація полімерного розчину. При обробці результатів використовувалися методи математичної статистики.

Результати. Експериментальні дослідження дозволили побудувати модель, що виражає залежність фактору залишкового опору від проникності середовища й концентрації полімерного розчину. Шляхом подальшої статистичної обробки отримано зв'язок між проникністю та необхідною концентрацією полімерного розчину.

Наукова новизна. Експериментальними дослідженнями обґрунтована можливість оцінки впливу проникності середовища й концентрації полімерного розчину на фактор залишкового опору, встановлена його залежність від концентрації полімерного розчину та проникності середовища. Основним моментом застосування полімерних розчинів є обґрунтування й вибір концентрації реагенту. Концентрацію необхідно вибрати таким чином, щоб вона забезпечувала максимальне значення фактору залишкового опору та в'язкість розчину, необхідну для вирівнювання в тій чи іншій мірі неоднорідності середовища по проникності. Для цього отримана залежність, яка дозволяє визначити концентрацію полімерного розчину при заданій проникності середовища, що забезпечує максимум фактору залишкового опору.

Практична значимість. Проведені експериментальні дослідження дозволяють розвинути уявлення про механізм водопроявлень. Результати досліджень дозволяють цілеспрямовано вибирати як рецептури композиційних систем, так і технологію їх застосування для підвищення ефективності видобутку нафти та обмеження водопритоків у конкретних геолого-фізичних умовах.

Ключові слова: *водоприток, нафта, проникність, полімерний розчин, свердловина, пласт, гелеутворюючий склад*

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