ENVIRONMENT PROTECTION, CHEMICAL AND BIOTECHNOLOGY

UDC 622.323:622.276.344(045)
DOI: 10.18372/2306-1472.87.15686

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REGULATION OF THE RATE OF GEL FORMATION BY ADDING CHEMICAL COMPOUNDS INTO SILICATE COMPOSITIONS

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Abstract

Purpose: *The purpose of this article is to determine the dependence of the rate of gel formation on the type of reagent-inhibitor of the gel formation process, and to study the kinetic dependences of gel formation of silicate compositions in the presence of compounds that regulate the rate of gel formation.* ***Research methods:*** *Direct and reverse titration, potentiometric titration, pH-metry, determination of the dynamic viscosity on a rotational viscometer, axial compression method to determine the elastic modulus were used to study the possibility of using chemical reagents as gelation inhibitors.* ***Results:*** *The possibility of using inorganic and organic additives to slow down the gel formation process and the effect of these additives on the strength of the gel, their thermodynamic parameters have been researched.* ***Discussion:*** *The adding of organic acids into the silicate composition as "crosslinking agents" slows down the gel formation process, while replacing hydrochloric acid with other gel acids that slow down the gel formation process does not lead to a decrease in the strength characteristics of these systems compared to the standard. It was found that with an increase in the gelation time, the strength of the gels decreases, and the syneresis increases; the adding of inhibitor additives insignificantly worsens the filterability of silicate compositions, which in general have bad filterability, leading to an increase in resistance during filtration at the inlet section of the sample. Observations have shown that the addition of additives-inhibitors does not affect the thermal stability of gels, regardless of the additives' nature.*

Keywords: gel formation, kinetics, oil extraction, reagent-inhibitor, silicate-gel composition, thermal stability, filterability.

1. Introduction

Preliminary researches carried out by the authors have shown that some inorganic and organic acids are able to slow down significantly the gel formation process in comparison with the standard silicate system, where hydrochloric acid is used as a "crosslinking " agent [1-3]. There are new data on the selection of new inhibitor additives in this work, as well as the results of studying the kinetic dependences of gel formation and evaluation the effect of additives on the physicochemical characteristics of silicate compositions.

2. Analysis of the latest investigations and publications, problem statement

The efficiency of oil extraction from oil deposits using modern, industrially developed methods is considered unsatisfactory in all oil-producing countries. Residual or non-extractable by industrial methods oil reserves reach on average 55-75% of the initial geological oil reserves in the bowels. According to expert estimates, residual oil reserves (100%) by types are quantitatively distributed as follows [4]:

- oil remaining in low-permeability layers and areas not covered by water – 27%;

- oil in stagnant zones of homogeneous layers – 19%;
- oil remaining in lenses and at impermeable screens not drilled by wells – 24%;
- capillary-retained and film oil – 30%.

Capillary-retained and film oil remains in flooded reservoirs due to their microheterogeneity and can only be extracted as a result of the impact of various physical and physicochemical processes and phenomena.

Technologies aimed at blocking the washed zones of the reservoir by using effective waterproofing compositions are very actual considering the fact that most of the deposits are at a late stage of development and are characterized by low well flow rates, a high degree of watering of the extracted products. A significant number of such compositions is known and there is a colossal experience of their implementation in various geological and physical conditions [5].

The use of gel-forming compositions to regulate flows and filtration resistance in the bottomhole zone and in the depth of the reservoir is one of the promising methods of physicochemical action on the reservoir in order to increase oil recovery.

Silicic acid releases when sodium silicate interacts with acidic agents and it forms a sol, which turns into a gel over time. Silicate gel has a spatial structure in which silicic acid molecules are linked by valence and hydrogen bonds, which determines the strength of the gel, its formation in the entire volume of the working solution and prevents the precipitation of silicic acid as a separate phase.

The strength of the gel and the rate of its formation depend on the concentration of the components in the system, the temperature of the deposit, water salinity and the contact time. The increase of the rate of gel formation causes the increase of its strength properties.

It is known gel forming composition of prof. A.T. Gorbunov based on sodium silicate and acidic reagent, which is successfully used to treat high-temperature deposits [6]. A gel-forming composition "Galka" based on soluble aluminum salts has developed under the guidance of prof. L.K. Altunina [7]. An aluminum hydroxide gel is formed in the result of hydrolysis of carbamide or urotropine due to change the pH of the medium.

Filtration studies have shown that the injection of the Galka gel-forming composition reduces the permeability by 4-100 times, and the degree of mobility decrease increases with the increase in permeability.

Interpolymer gel-forming composition based on high modulus liquid glass and polymers under the guidance of prof. S.V. Krupin [8]. It was proposed gel-forming compositions based on acidic solutions of nepheline and synthetic zeolite for use in deposits with highly mineralized waters, which are suitable for treating both injection and water-flooded extraction wells.

Sediment-gel-forming compositions are widely used to regulate the front of oil displacement from heterogeneous deposits, the action of which is based on the formation of gels and sediments in the result of mixing of two layers of gel and sediment-forming reagents inside the deposit [9].

Sediment-gel-forming compositions based on liquid glass and calcium chloride or mineralized water, sodium hydroxide and aluminum salts are the most widespread. Water-soluble polymers (PAA is the most effective) are added to the composition to regulate the properties of precipitates and gels, which imparts viscoelastic properties to the precipitates [10].

There are a number of disadvantages of the applied technologies based on sediment-gel-forming compositions for waterproofing works. As a rule, these are low stability of the compositions in the reservoir medium, insignificant penetrating ability into pore channels, high sensitivity to the salinity of reservoir waters, temperature, reservoir type, lack of effective technological methods for regulating the processes of gelation of the composition, etc. [11]. In this regard, there is a need for the development of new gel-forming compositions capable to create a durable water isolation barrier, stable for a long time, taking into account the peculiarities of specific geological and physical conditions of the reservoir.

3. Purposes and problems of a research

To determine the dependence of the rate of gel formation on the type of reagent. To study the kinetic dependences of gel formation of silicate compositions in the presence of compounds that regulate the rate of gel formation.

4. Materials and methods of a research

Methods of direct and reverse titration were used to determine the relative concentration of silicate in the supernatant; pH-metry was used to control the change in the pH of the silicate-gel composition during the experiment. Sodium silicate solution (4 mass %) is the research material; hydrochloric, hydrofluoric, oxalic, and citric acids were used as inhibitor reagents.

5. Research results

Replacement of the hydrochloric acid in hydrofluoric leads to slower gel formation process. Table 1 shows times of gel formation depending on the concentration of hydrochloric and hydrofluoric acids for a 4% silicate solution. The table 1 shows that the gel formation rate is significantly slowed down in the presence of hydrofluoric acid compared to the standard system at the same pH values.

Table 1

Time of gel formation in 4% silicate solution in the presence of hydrochloric and hydrofluoric acids

Hydrochloric acid				Hydrofluoric acid			
Concentration of an acid, %	pH	Time of gel formation, min.	Gel strength	Concentration of an acid, %	pH	Time of gel formation, min.	Gel strength
0.50	10.75	6240	Weak	0.20	10.59	9480	Str
0.60	10.63	1500	Mid	0.25	10.45	4620	Str
0.70	10.35	280	Mid	0.30	10.29	1920	Str
0.75	10.20	90	Str	0.40	9.89	165	Str
0.80	9.94	25	Str	0.50	8.53	2	Str
0.85	9.59	8	Str				
0.90	9.40	2	Str				
0.95	8.97	0,5	Str				

Table 1 shows the "strength" column, which reflects a qualitative assessment of the strength of the resulting gels. This assessment carried out visually, but the consistency of the gel included conditionally three gradations - weak, medium and strong gels. The same regularities are observed in the presence of hydrofluoric acid as in the standard system - with an increase in pH and, accordingly, gel formation time, the strength of the gel decreases. The use of oxalic and citric acids as "crosslinking agents" showed that, in the region of high pH values, the rate of gel formation decreases by about an order of magnitude in comparison with the standard system (Fig. 1 and Table 2).

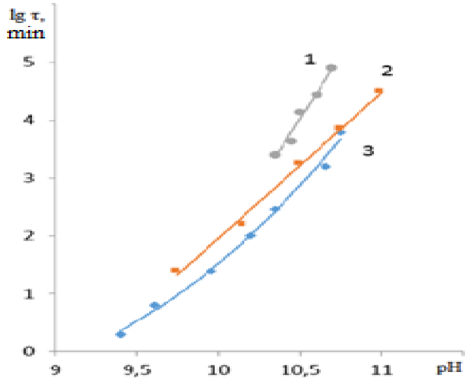

Fig. 1. The influence of different acids on kinetics of gel formation. The used acids are: 1 – citric acid; 2 – oxalic acid; 3 – hydrochloric acid

Table 2

Time of gel formation in 4% silicate solution in the presence of citric and oxalic acids

Citric acid				Oxalic acid			
Concentration of an acid, %	pH	Time of gel formation, min.	Gel strength	Concentration of an acid, %	pH	Time of gel formation, min.	Gel strength
0,70	10,69	79200	Weak	0.60	11.03	37440	Weak
0.80	10.63	50400	Weak	0.70	10.90	17280	Weak
1.00	10.60	31680	Mid	0.80	10.76	8340	Weak
1.10	10.55	25920	Str	0.85	10.65	5400	Weak
1.20	10.50	14400	Str	0.90	10.51	300	Mid
1.30	10.44	5580	Str	0.95	10.38	1920	Mid
1.40	10.35	2340	Str	1.00	10.28	540	Mid
1.50	10.38	660	Str	1.05	10.17	210	Str
				1.10	9.94	70	Str
				1.15	9.78	20	Str

The technology can use not pure organic acid, but its mixture with hydrochloric acid. Experiments show that the gelation process proceeds more smoothly in such systems than in standard solutions.

Table 3 and Fig. 2 show the data on the kinetics of gel formation for a mixture of hydrochloric and citric acids, at two fixed values of the HCl concentration - 0.25 and 0.5%.

Two standard systems were used to study the "strength properties":

1. 4% silicate with 0.6% HCl. This system has a gel formation time of about 1 day, and the resulting gel can be attributed to strong.
2. 4% silicate with an acid concentration of 0.5%. This composition is characterized by the gel formation time of 3 days, and the gel strength corresponds to the term "weak".

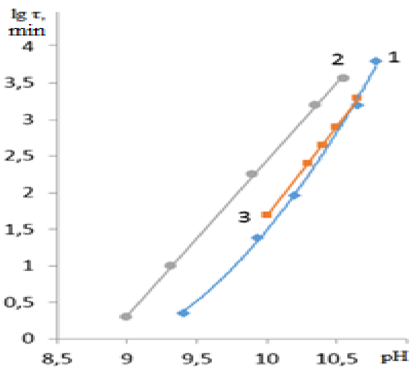

Fig. 2. Kinetics of the formation of silicate gel an the presence of a mixture of hydrochloric and citric acids. Citric acid concentration in the mixture is: 1 – 0 (standard system); 2 – 0,25 %; 3 – 0,50 %

Table 3

The combined influence of hydrochloric and citric acids on the kinetics of gel formation in 4% silicate solution

Concentration of HCl, %	Concentration of citric acid, %	pH	Time of gel formation, min	Gel strength
0.25	0.70	10.57	4620	Weak
0.25	0.80	10.45	2820	Middle
0.25	0.90	10.35	1170	Middle
0.25	1.00	9.90	450	Strong
0.25	1.10	9.61	60	Strong
0.25	1.20	9.34	10	Strong
0.25	1.30	9.01	2	Strong
0.5	1.25	10.65	1900	Middle
0.5	0.50	10.30	255	Strong
0.6	0.25	9.94	345	Middle
0.75	0.25	9.23	5	Strong

Silicate compositions based on other acids were selected so that the gel formation time in them was 1 and 3 days, respectively. The results are shown in Table 4 and Fig. 3.

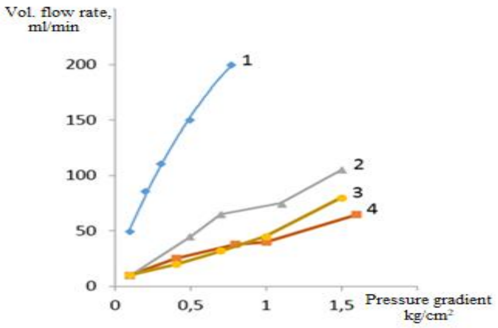

Fig. 3. Dependence of the volumetric flow rate of water on pressure gradient when filtration through the sample, impregnated with silicate gel. Gels are based on of 4 % silicate with the time of gel formation of 3 days. Crosslinking agents are 1 – hydrochloric acid; 2 – hydrofluoric acid; 3 – citric acid; 4 – oxalic acid

It is shown the dependence of volumetric water flow on pressure gradient (some analogy of the injectivity coefficient or the productivity coefficient).

Experiments on the study the effect of additives-inhibitors on the rheological properties of silicate gels were carried out in filled two-section models with a length of each section of 11 cm and an area of 5.31 cm^2. The sample permeability is 0.5 darcy in average. A gel-forming composition was injected into the model, kept for 3 days, and after the formation of the gel, a desalinated water model containing 0.5 g/dm^3 NaCl was injected into the sample. The filtration rate varied in the range of 0.5 - 11.7 m/day. It should be noted right away that no significant effect of additives such as sodium nitrate, potassium iodide, and thiourea on the rheology of gels was found.

The results of studying the effect of additives of inhibitors on the rheological properties of silicate gels are shown in Table 5 and in Fig. 4-5.

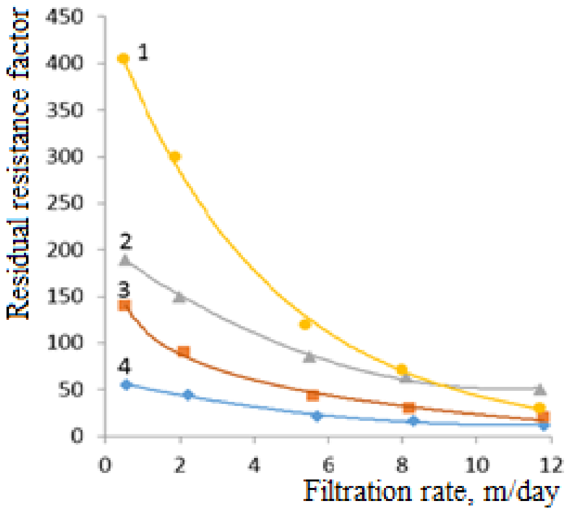

Fig. 4. The influence of sodium nitrate on the rheology of silicate gels. Two section model, permeability is 1.5 darcy. 1 – standard system, 1st section; 2 – sodium nitrate content is 0,05%, 1st section; 3 – sodium nitrate content is 0,05%, 2nd section; 4 – standard system, 2nd section.

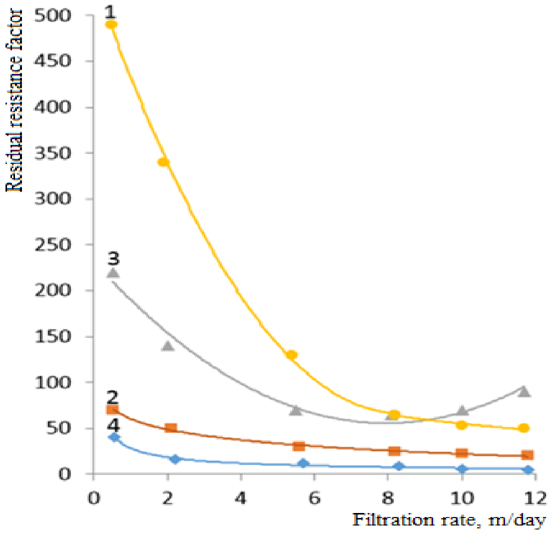

Fig. 5. The influence of potassium iodide on rheological properties of silicate gels. Two section model, permeability is 1.5 darcy. Potassium iodide concentration in a mixture is 0.05 %. 1 – standard system, 1st section; 2 – standard system, 2nd section;
3 – in the presence of potassium iodide, 1st section;
4 – in the presence of potassium iodide, 2nd section

Table 4

Dependence of the water flow rate on pressure gradient when filtering through the sample impregnated by gel. Gels are based on 4 % silicate and various acids

Pressure drop, kg/cm^2	Weak gels		Time of gel formation is 3 days		Strong gels		Time of gel formation is 1 day	
	Water flow rate, cm^3/min				Water flow rate, cm^3/min			
	HCl	Citric acid	Oxalic acid	Hydrofluoric acid	HCl	Citric acid	Oxalic acid	Hydrofluoric acid
0.1	5	1	1	1	1	1	1	1
0.2	18	3	5	4	5	1	2	2
0.3	30	6	7	6	10	4	3	2.5
0.4	40	8	9	13	14	6	4	3.5
0.5	70	12	12	24	18	8	7	6
0.6	110	17	16	32	26	10	10	8
0.7	120	23	22	48	34	20	14	13
0.8	160	32	27	58	48	26	16	16
0.9	-	38	42	66	58	34	18	20
1.0	-	45	50	72	70	40	20	25
1.1	-	56	60	78	85	48	25	28
1.2	-	80	75	106	105	50	28	32
1.3	-	90	90	132	-	65	32	34
1.4	-	102	100	154	-	72	38	38
1.5	-	122	114	165	-	82	40	45
1.6	-	-	-	-	-	90	50	50
1.7	-	-	-	-	-	108	58	52
1.8	-	-	-	-	-	-	64	60

Table 5

Influence of additives-inhibitors on the rheological properties of silicate gels. Two-section model, permeability is 1.5 darcy, mixture volume is 0,5 V_{por}

№	Injected additive	pH	Resistance factor when uploading a mixture		Rate of water filtration, m/day	Residual resistance factor	
			R_1	R_2		$R_{1\ res}$	$R_{2\ res}$
1	standard system	9.3	2.1	1.0	11.7 5.6 2.1 0.5	37 107 337 412	12.5 24 47 53
2	standard system	9.5	1.9	1.0	11.7 5.6 2.1 0.5	51 101 325 490	22 28 53 69
3	0.05% thiourea	9.3	2.8	1.0	11.7 5.6 2.1 0.5	30 77 125 231	2 6 9 14
4	0.05% thiourea	9.5	2.1	1.0	11.7 5.6 2.1 0.5	24 35 188 265	3 6 9 12
5	0.05% sodium nitrate	9.3	3.2	1.0	11.7 5.6 2.1 0.5	59 79 162 189	16 35 124 135
6	0.05% sodium nitrate	9.5	2.8	1.0	11.7 5.6 2.1 0.5	60 126 248 333	11 15 19 29
7	0.05% potassium iodide	9.3	5.7	1.0	11.7 5.6 2.1 0.5	23 30 149 314	4 10 13 17
8	0.05% potassium iodide	9.5	4.7	1.0	11.7 5.6 2.1 0.5	93 61 117 223	6 10 12 18

Filterability experiments were carried out on the same models as the rheology experiments. 10 V_{pores} of the mixture of various composition were injected into the sample at a constant rate of 5.3 m/day, and the resistance factor was calculated using the pressure change in both sections of the sample. The results are shown in Table 6 and Fig. 6, from which it can be seen that pure silicate compositions have poor filterability in general, leading to an increase in resistance during filtration at the inlet section of the sample. The addition of additives-inhibitors insignificantly worsens the filterability of the mixture.

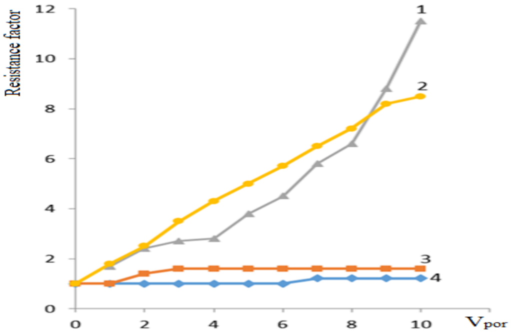

Fig. 6. Dependence of the resistance factor on the volume of injected mixture. Two section model, permeability is 1.5 darcy. 1 – mixture contains 0,05% $NaNO_3$, 1st section; 2 – standard system, 1st section; 3 – standard system, 2nd section; 4 – mixture contains 0,05% $NaNO_3$, 2nd section

Table 6

Influence of additives-inhibitors on the filterability of silicate compositions. Experiments on two-section models

№	Injected additive	The volume of the uploaded mixture, v_{por}	Filtration resistance factor by sections	
			R_1	R_2
1	standard system	1	1.9	1.1
		2	2.6	1.4
		3	3.5	1.6
		4	4.3	1.7
		5	5.0	1.7
		6	5.7	1.7
		7	6.5	1.7
		8	7.2	1.7
		9	8.2	1.7
		10	8.6	1.7
2	0.05% thiourea	1	1.3	1.2
		2	2.2	1.2
		3	3.4	1.3
		4	4.6	1.5
		5	5.3	1.5
		6	7.1	1.5
		7	8.0	1.5
		8	9.3	1.5
		9	10.6	1.5
		10	12.3	1.5
3	0.05% potassium iodide	1	1.5	1.0
		2	2.1	1.2
		3	3.7	1.7
		4	5.1	1.9
		5	7.5	1.9
		6	8.4	1.9
		7	9.3	1.9
		8	10.1	1.9
		9	12.0	2.0
		10	14.2	2.0
4	0.05% sodium nitrate	1	1.0	1.0
		2	2.5	1.0
		3	2.7	1.0
		4	2.8	1.0
		5	3.8	1.0
		6	4.5	1.2
		7	5.8	1.2
		8	6.6	1.2
		9	8.8	1.2
		10	11.6	1.2

The thermal stability of the gels was evaluated in a porous medium. A gel forming composition was pumped into a sample of 11 cm long and an area of 5.31 cm^2, containing a mixture of sand, clay and carbonate (permeability was 1.5 darcy). The method of non-stationary filtration from the pressure drop curve was used for calculation the residual resistance factor in the process of gel hardening (within 2 days). Then the sample holder was placed in an air thermostat with a temperature of 70 ± 1 ° C. Every month, the value of the residual resistance factor was estimated by the same method. The observation results for 4 months are shown in Table 7 and Fig. 7.

Table 7

The change in the residual resistance factor created by the silicate gel during storage at 70 °C. Gels are on the basis of 4% silicate, pH = 9.5

№	Additive-inhibitor	R_{res} value at time of storage (month)				
		0	1	2	3	4
1	Sodium nitrate	232	559	526	588	512
2	Potassium iodide	244	1162	909	833	794
3	Thiourea	29	143	112	156	134

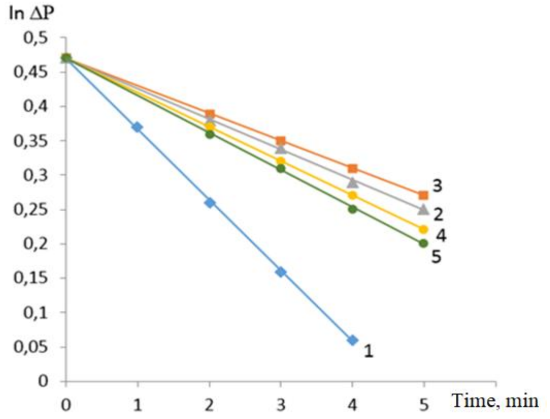

Fig. 7. Change of curves of pressure drop in the process of storage of silicate gel based on 4 % silicate at temperature 70 °C. Mixture contains 0,05% $NaNO_3$.
1 – after 4 hours; 2 – after 1 month; 3 – after 2 month; 4 – after 3 month; 5 – after 4 month

6. Discussion of results

The study of the influence of various organic fatty acids on the gel formation process showed that an increase in the length of the alkyl substituent in C_1-C_4 acids, and, correspondently, its size, leads to an increase in the rate of gel formation. Retention of the same pattern in relation to inorganic acids should mean that replacing hydrochloric acid with hydrofluoric acid should slow down the gel formation process.

The deceleration of the gel formation process in the presence of hydrofluoric acid is especially noticeable at high pH values, where gelation times are measured in days (at a temperature of 23-25 °C).

The possibility of using hydrofluoric acid as a "crosslinking" agent in technological processes is ambiguous. On the one hand, an advantage is the more flexible regulation of the gel formation process by hydrofluoric acid and its lower consumption in comparison with hydrochloric acid. On the other hand, the higher cost of hydrofluoric acid and its activity requires additional study of this question, including experiments, mathematical and economic calculations. The same applies to the possibility of using oxalic and citric acids, which have certain advantages over hydrochloric acid. It should be mentioned that the gel formation was noted after 4 and even 8 weeks under static conditions in the presence of these compounds and these gels are quite weak.

The syneresis proceeding of the formed gels was observed in the process of studying the kinetics. It is sufficient to restrict these observations to one conclusion - with an increase in the gel formation time, the strength of the gels decreases, and the syneresis increases.

The term "strength properties" does not quite accurately reflect the actual strength of the gels. The permeability of the sample without gel impregnation was approximately 20 darcy. This value was determined by the method of estimating the water flow rate as a function of the pressure gradient during filtration through an artificially cemented sample impregnated with a gel of a given composition.

Table 4 represents experimental data on the comparative assessment of the volumetric flow rate (i.e. the ratio of flow rate to pressure gradient) depending on the composition of the mixture in comparison with standard systems.

These data show that replacing hydrochloric acid with other acids that slow down the gel formation process does not lead to a decrease in the strength characteristics of these systems in comparison with the standard one. Moreover, we can confidently say that both inorganic hydrofluoric and organic oxalic and citric acids cause the formation of stronger gels. This conclusion is especially true in the case of the formation of weak gels.

Figure 3 clearly shows that under these filtration conditions, there is a deviation from Darcy's law. As follows from this law, the ratio of the flow rate to the pressure gradient should not depend on the pressure gradient. In this case, for almost all systems, the volumetric flow rate increases with an increase in the gradient. This phenomenon can be explained by the existence of an initial pressure gradient below which filtration does not occur. This parameter is found in experiments on filled models for silicate-polymer compositions. On the other hand, a deviation from Darcy's law may be a consequence of the rheology factor. In this case, it is a pseudoplastic flow of water through a porous medium treated with a gel.

Obtained data in the study of the effect of additive-inhibitors on the rheological properties of silicate gels (Table 5, Fig. 4, 5) show that the dependence of the residual resistance factor on the filtration rate for all systems follows similar regularities, although the absolute values of R_{res} may differ in 1.5 – 2.5 times. An exception is the system containing potassium iodide, for which the phenomena of dilatancy is charactarable in the inlet section (Fig. 5). Most likely, the occuring of rheology should largely depend on the presence of a high molecular weight polymer additive in the composition but not a low molecular weight.

The results of filterability of silicate solutions containing additives-moderators (Table 6, Fig. 6) showed that pure silicate compositions have poor filterability in general, leading to an increase in resistance during filtration at the inlet section of the sample. The addition of additives-inhibitors insignificantly worsens the filterability of the composition.

Observations of the thermal stability of silicate compositions showed that the stability of pure silicate gels remains at a high level (Table 7, Fig. 7) regardless of whether an inorganic additive is used as an inhibitor or not. A definite exception is the thiourea-containing system. The initial properties of the gels are retained in the presence of this compound; however, the absolute level of the residual resistance factor is inferior to R_{res} for mixtures of a different composition.

7. Conclusions

1. The addition of organic acids as "crosslinking agents" slows down the gel formation process, while replacing hydrochloric acid with other acids does not lead to a decrease in the strength characteristics of these systems in comparison with the standard.

2. The deceleration of the gel formation process in the presence of hydrofluoric acid is especially noticeable at high pH values, where gel formation times are measured in days. In addition, both inorganic hydrofluoric and organic oxalic and citric acids cause the formation of stronger gels. This conclusion is especially true in the case of the formation of weak gels.

3. With an increase in the gel formation time, the strength of the gels decreases and the syneresis increases.

4. The addition of inhibitor additives insignificantly worsens the filterability of silicate mixtures, which in general have poor filterability, leading to an increase in resistance during filtration at the inlet section of the sample.

5. Observations have shown that the addition of additives-inhibitors does not affect the thermal stability of gels, regardless of the additives nature. Observations of the thermal stability of silicate compositions have shown that the stability of pure silicate gels remains at a high level, regardless of whether an inorganic inhibitor is used or not. The thiourea system is a definite exception.

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Регулювання швидкості гелеутворення введенням хімічних сполук у силікатні композиції

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Мета: Метою даної статті є визначення залежності швидкості гелеутворення від типу реагенту-сповільнювача процесу гелеутворення, а також дослідження кінетичних закономірностей гелеутворення силікатних композицій в присутності сполук, що регулюють швидкість гелеутворення. **Методи дослідження:** Для визначення можливості використання хімічних реагентів у якості сповільнювачів гелеутворення застосовували наступні методи дослідження: пряме і обернене титрування, потенціометричне титрування, pH-метрію, визначення динамічної в'язкості на ротаційному віскозиметрі, метод одновісного стиснення для визначення модуля пружності. **Результати:** Досліджено можливість використання неорганічних і органічних добавок для уповільнення процесу гелеутворення і вплив цих добавок на міцність гелю, їх термодинамічні показники. Проводилися дослідження з визначення впливу добавок-сповільнювачів на фільтруємість і синерезис композицій у стані гелю. **Обговорення:** Введення у силікатну композицію додатково органічних кислот в якості «зшиваючих агентів» уповільнює процес гелеутворення, при цьому заміна соляної кислоти на інші кислоти, не приводить до зменшення міцності цих систем у порівнянні зі стандартною. Встановлено, що зі збільшенням часу гелеутворення міцність гелів зменшується, а синерезис збільшується; введення добавок-сповільнювачів незначним чином погіршує фільтруємість силікатних композицій, які в цілому характеризуються поганою фільтрацією, що приводить до зростання опору під час фільтрації на вхідній ділянці керна. Спостереження показали, що введення добавок-сповільнювачів не позначається на термостабільності гелів незалежно від природи добавок.

Ключові слова: гелеутворення, кінетика, нафтовидобуток, реактив-сповільнювач, силікатно-гелева композиція, термостабільність, фільтруємість.

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Регулирование скорости гелеобразования введением химических соединений в силикатные композиции

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Цель: Целью данной статьи является определение зависимости скорости гелеобразования от типа реагента-замедлителя процесса гелеобразования, а также исследование кинетических закономерностей гелеобразования силикатных композиций в присутствии соединений, регулирующих скорость гелеобразования. **Методы исследования:** Для определения возможности использования химических реагентов в качестве замедлителей гелеобразования применяли следующие методы исследования: прямое и обратное титрование, потенциометрическое титрование, pH-метрию, определение динамической вязкости на ротационном вискозиметре, метод одноосного сжатия для определения модуля упругости. **Результаты:** Исследована возможность использования неорганических и органических добавок для замедления процесса гелеобразования и влияние этих добавок на прочность геля, их термодинамические показатели. Проводились исследования по определению влияния добавок-замедлителей на фильтруемость и синерезис композиций в состоянии геля. **Обсуждение:** Введение в силикатную композицию дополнительно органических кислот в качестве «сшивающих агентов» замедляет процесс гелеобразования, при этом замена соляной кислоты на другие кислоты гелей, замедляющие процесс гелеобразования, не приводит к уменьшению прочностных характеристик этих систем по сравнению со стандартной. Установлено, что с увеличением времени гелеобразования прочность гелей уменьшается, а синерезис увеличивается; введение добавок-замедлителей незначительно ухудшает фильтруемость силикатных композиций, которые в целом обладают плохой фильтруемостью, приводящей к возрастанию сопротивления при фильтрации на входном участке керна. Наблюдения показали, что введение добавок-замедлителей не сказывается на термостабильности гелей независимо от природы добавок.

Ключевые слова: гелеобразование, кинетика, нефтедобыча, реактив-замедлитель, силикатно-гелевая композиция, термостабильность, фильтруемость.

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