PERM JOURNAL OF PETROLEUM AND MINING ENGINEERING
ВЕСТНИК ПНИПУ. ГЕОЛОГИЯ. НЕФТЕГАЗОВОЕ И ГОРНОЕ ДЕЛО
ISSN 2224-9923
Volume / Том 19 №2 2019
http://vestnik.pstu.ru/geo/

UDC 622.276+522.52:622.24.063

Article / Статья

COMPLEX OF METHODS TO EVALUATE INHIBITING PROPERTIES OF MUDS IN RELATION TO CLAY SWELLING ROCKS (AT EXAMPLE OF "REACTIVE" CLAYS OF MONTMORILLONITE GROUP OF KAZANIAN, TATARIAN AGES IN PERMIAN SYSTEM)

Irina L. Nekrasova, Pavel A. Khvoshchin, Dmitriy A. Kazakov
Olga V. Garshina, Gennadiy V. Okromelidze, Denis V. Tiron[1]

PermNIPIneft branch of LUKOIL-Engineering LLC in Perm (29 Sovetskoy Armii st., Perm, 614066, Russian Federation)
[1]LUKOIL-Komi LLC (31 Neftyanikov str., Usinsk, 169712, Russian Federation)

КОМПЛЕКС МЕТОДОВ ОЦЕНКИ ИНГИБИРУЮЩИХ СВОЙСТВ БУРОВЫХ РАСТВОРОВ ПО ОТНОШЕНИЮ К ГЛИНИСТЫМ НАБУХАЮЩИМ ГОРНЫМ ПОРОДАМ (НА ПРИМЕРЕ «РЕАКТИВНЫХ» ГЛИН МОНТМОРИЛЛОНИТОВОЙ ГРУППЫ КАЗАНСКОГО, ТАТАРСКОГО ЯРУСОВ ПЕРМСКОЙ СИСТЕМЫ)

И.Л. Некрасова, П.А. Хвощин, Д.А. Казаков,
О.В. Гаршина, Г.В. Окромелидзе, Д.В. Тирон[1]

Филиал ООО «ЛУКОЙЛ-Инжиниринг» «ПермНИПИнефть» (614066, Россия, г. Пермь, ул. Советской Армии, 29)
[1]ООО «ЛУКОЙЛ-Коми» (169712, Республика Коми, г. Усинск, ул. Нефтяников, 31)

Received / Получена: 12.02.2019. Accepted / Принята: 01.06.2019. Published / Опубликована: 28.06.2019

Key words:
inhibiting ability of muds, rocks of Kazanian, Tatarian age, litho-mineralogical rock composition, degree of rock swelling, degree of rock erosion, colloidal particles concentration.

One of complication happening during construction of significant amount of wells in deposits of Denisovian basin of Timan-Pechora oil and gas province is loss of wellbore walls stability in intervals of "reactive" clays of Kazanian and Tatarian ages of Permian system. Complex lithological characterization of falling rocks within the named drilling intervals was performed using X-ray phase, X-ray fluorescence and litho-mineralogical analysis. In result of the study singularities of mineral and chemical composition of rocks and their clay component are determined. The article reviews the results obtained in diversified set of studies of muds inhibiting properties, including the following kinds of tests: study of rock swelling degree; tests to determine erosion of argillaceous slates in mud medium; evaluation of dispersing ability of muds; tests of fracture formation in rock samples in mud medium; study of character and intensity of ion exchange processes behavior in system «rock – mud»; study of alteration of rocks physical and chemical properties after influence of mud.
According to results of the study gradation of different mud types according to their inhibiting ability in relation to clay swelling rocks is proposed.

Ключевые слова:
ингибирующая способность буровых растворов, породы казанского, татарского ярусов, литолого-минералогический состав пород, степень набухания пород, степень эрозии пород, концентрация коллоидных частиц.

Одним из видов осложнений, возникающих при строительстве значительного количества скважин месторождений Денисовской впадины Тимано-Печорской нефтегазовой провинции, является потеря устойчивости стенок ствола в интервалах «реактивных» глин казанского и татарского ярусов пермской системы. С применением рентгенофазового, рентгенофлуоресцентного и литолого-минералогического анализов приведена комплексная литологическая характеристика обвальных пород указанных интервалов бурения. В результате изучения определены особенности минерального и химического состава горных пород и их глинистой составляющей. Рассмотрены результаты, полученные в ходе проведения разноплановового комплекса исследований ингибирующих свойств буровых растворов, включающего следующие виды испытаний: исследование степени набухания пород; проведение теста на определение эрозии глинистых сланцев в среде буровых растворов; оценка диспергирующей способности буровых растворов; проведение теста на образование трещин в образцах породы в среде буровых растворов; изучение характера и интенсивности протекания ионообменных процессов в системе «порода – буровой раствор»; изучение изменения физико-механических свойств пород после воздействия буровых растворов.
По результатам исследований предложена градация различных типов буровых растворов по ингибирующей способности по отношению к глинистым набухающим горным породам.

Irina L. Nekrasova (Author ID in Scopus: 56704818100) – PhD in Engineering, Senior Researcher at the Department of Muds and Process Fluids (tel.: +007 342 233 67 63, e-mail: Irina.Nekrasova@pnn.lukoil.com). The contact person for correspondence.
Pavel A. Khvoshchin (Author ID in Scopus: 54410568400) – PhD in Engineering, Head of the Department of Muds and Process Fluids (tel.: +007 342 233 67 62, e-mail: Pavel.Khvoschin@pnn.lukoil.com).
Dmitriy A. Kazakov (Author ID in Scopus: 57204942626) – PhD in Engineering, Researcher at the Department of Muds and Process Fluids (tel.: +007 342 233 67 63, e-mail: Dmitrij.Kazakov@pnn.lukoil.com).
Olga V. Garshina (Author ID in Scopus: 56705664700) – PhD in Engineering, Head of the Department of Well Construction Technology (tel.: +007 342 233 67 61, e-mail: Olga.Garshina@pnn.lukoil.com).
Gennadiy V. Okromelidze (Author ID in Scopus: 54780426700) – PhD in Engineering, Deputy Director of the Branch for Research in the Field of Well Construction (tel.: +007 342 233 67 40, e-mail: Gennadij.Okromelidze@pnn.lukoil.com).
Denis V. Tiron (Author ID in Scopus: 57194233664) – PhD in Engineering, Leading Specialist (tel.:+007 821 445 77 29, e-mail: Denis.Tiron@lukoil.com).

Некрасова Ирина Леонидовна – кандидат технических наук, ведущий научный сотрудник отдела буровых растворов и технологических жидкостей (тел.: +007 342 233 67 63, e-mail: Irina.Nekrasova@pnn.lukoil.com). Контактное лицо для переписки.
Хвощин Павел Александрович – кандидат технических наук, начальник отдела буровых растворов и технологических жидкостей (тел.: +007 342 233 67 62, e-mail: Pavel.Khvoschin@pnn.lukoil.com).
Казаков Дмитрий Александрович – кандидат технических наук, научный сотрудник отдела буровых растворов и технологических жидкостей (тел.: +007 342 233 67 63, e-mail: Dmitrij.Kazakov@pnn.lukoil.com).
Гаршина Ольга Владимировна – начальник управления технологии строительства скважин (тел.: +007 342 233 67 61, e-mail: Olga.Garshina@pnn.lukoil.com).
Окромелидзе Геннадий Владимирович – заместитель директора филиала по научной работе в области строительства скважин (тел.: +007 342 233 67 40, e-mail: Gennadij.Okromelidze@pnn.lukoil.com).
Тирон Денис Вячеславович – кандидат технических наук, ведущий специалист (тел.:+007 821 445 77 29, e-mail: Denis.Tiron@lukoil.com).

Introduction

One of most often complications during construction of wells in deposits of Denisovian basin of Timan-Pechora oil and gas province is loss of wellbore stability in intervals of Kazanian and Tatarian ages of Permian system. Well drilling through these intervals using fresh water acrylic muds, and also intended density increase in order to increase wellbore walls stability does not permit to fully resolve this problem.

With purpose to understand reasons of wellbore instability in intervals of Kazanian and Tatarian ages studies were performed to determine litho-mineralogical composition and physical and chemical characteristics of rocks, and a complex of methods for evaluation of mud inhibiting properties is proposed, with purpose to establish inhibition mechanism being most effective for the studied rocks.

Characteristic of "reactive" clays of montmorillonite group of Kazanian, Tatarian ages of Permian system

Rock of Kazanian, Tatarian ages of upper division of Permian system is presented by consolidated bondless clay, according to physical signs being at late diagenesis substage. Presence of psammite loose ingredients in rock composition demonstrates its low hardness. According to results of X-ray phase analysis in rocks of Kazanian, Tatarian ages presence of large concentrations of chlorite, hydromicas and montmorillonite is established, while in pellite rock fraction montmorillonite prevails (78,9 wt. %) [1]. According to results of X-ray fluorescent analysis it is established that rocks of Kazanian, Tatarian ages is characterized by increased contents of silica and reduced contents of magnesium. Sodium and potassium in rock composition are apparently presented by exchangeable ions, which in contact with water medium may cause alteration of composition, structure and stability of rocks [2, 3].

Prevailing content of montmorillonite in clay fraction determines high degree of swelling and rock dispersing – its high water sensitivity (so-called «reactivity») [4–6]. Characteristic feature of montmorillonite is weak attraction between packages in its structure, as only van der Waals forces act between them (weak intermolecular interactions of dispersion, induction and orientation character). As result, water dipoles are able to freely penetrate into interplanar space of montmorillonite and expand it. In process of water saturation montmorillonite rocks loose strength, obtain plasticity and gradually transit to flowing state. Another important factor influencing strength and deformational properties of weakly lithified clay rocks are forces of interaction between mineral particles – structural bonds. The higher is strength of structural bonds between separate elements of clay minerals, the higher is rock stability against hydrodynamic action of mud [7, 8].

Objects of study

The performed complex of litho-mineralogical studies of rocks in the studied intervals permitted to substantiate methods of study necessary for reliable evaluation of inhibiting ability of muds. Complex methods being proposed provide for subsequent performance of six stages of study: comparative evaluation of inhibiting properties of muds at argillaceous slates linear swelling tester, evaluation of dispersing ability of muds by degree of clay rocks erosion and MBT (Methylene Blue Test) parameter, study of ion exchange processes in system «rock – mud» using inductively coupled plasma mass spectrometry method, evaluation of alteration of strength properties of clay rocks under influence of muds.

Table 1

Types of muds studies (mud density – 1230 kg/m^3)

Mud #	Mud type	Sources describing peculiarities of mud usage
1	Fresh polymer clay mud on base of acrylic polymers ($FP_{0,7MPa}$ = 4,5 cm^3/30 min, pH = 8,7)	[9–12]
2	Fresh polymer clay mud on base of acrylic polymers with addition of organosilicon fluid ($FP_{0,7MPa}$ = 4,5 cm^3/30 min, pH =8,6)	[13, 14]
3	Fresh biopolymer mud on base of polymer lignite reagent and glycols ($FP_{0,7MPa}$ = 6,8 cm^3/30 min, pH = 10,4)	[15–18]
4	Potassium chloride biopolymer mud with inhibitor from polyamine class ($FP_{0,7MPa}$ = 4,6 cm^3/30 min, pH = 8,4)	[19–23]
5	Invert-emulsion mud (IEM) using as water phase calcium chloride solution with density 1,28 g/cm^3 (FP_{HPHT} = 0,3 cm^3/30 min, ES = 860 V, hydrocarbons/water ratio = 77/23)	[12, 24, 25]
6	IEM using as water phase $CaCl_2$ solution with density 1,39 g/cm^3 (FP_{HPHT}= 0,3 cm^3/30 min, ES = 467 B, hydrocarbons/water ratio = 60/40)	[26–28]

During evaluation of inhibiting properties of muds in relation to hydration of clays of Kazanian, Tatarian ages of Permian system following muds being currently used were studied, and also those muds considered promising for usage in well construction at deposits of Denisovian basin (table 1). As basis for comparison during evaluation of inhibiting properties of muds values of rock samples swelling and dispersing in technical and formation waters.

Results and discussion

Consolidated data on comparative evaluation of inhibiting properties of above stated types of muds in relation to red "reactive" clay of Kazanian, Tatarian ages of upper division of Permian system are given in table 2. Muds are designated according to table 1.

Main factors determining loss of stability in studied type of rock are processes of wetting, dispersing and weakening structural bonds between rock particles. In water saturation process montmorillonite rocks loose strength, acquire plasticity and gradually transit to flowing state. One of most demonstrative parameters in evaluation of hydration degree of clay rocks with increased content of smectite (montmorillonite) minerals is degree of their swelling in medium of liquids under study. It is known that volume increase during swelling clay rocks depends on combination of adsorption, osmotic and capillary forces [14, 29–31]. That is why usage of this method permits to evaluate action of the above forces depending on mud component composition.

Table 2

Comparative evaluation of inhibiting properties of muds

Mud	Swelling degree, %	Erosion parameter, %	Weakening coefficient	Rock dispersing degree, kg/m^3	Current wetting speed, cm/h
1	29,1	68,2	0,0067	7,6	0,298
2	27,7	36,8	0,0303	0,8	0,366
3	31,2	93,0	Complete destruction of sample	4,3	0,385
4	17,0	10,0	0,550	2,5	0,24
5	2,5	0	0,655	–	0,062
6	1,4	0	1,320	–	0,054
Technical water	45,8	Complete destruction of sample		7,7	Complete destruction of sample
Formation water	32,1	Complete destruction of sample		4,3	Complete destruction of sample

Results of study of rocks swelling dynamics in medium of muds in dynamic conditions at T = 55 °C (maximal formation temperature of Kazanian, Tatarian ages in deposits of Denisovian basin) confirmed that these rocks are prone to swelling and dispersing under action of water medium (within 72 h of experiment average value of longitudinal swelling of rocks from Kazanian, Tatarian age in technical water medium was 45,8 %). Presence of inorganic salts in water medium permits to significantly reduce rock swelling degree (swelling degree in formation water medium within 72 h of contact was 32,1 %). According to results of study it is established that at other equal conditions least inhibiting ability in relation to red "reactive" clays by swelling parameter is characteristic for fresh muds on base of acrylic polymers and glycols (muds 1 and 3 in table 1), addition of organosilicon compounds to mud recipe permits to somewhat increase inhibiting properties of fresh mud systems. *The lowest parameter of swelling degree from the studied water-based muds is noted for potassium chloride mud (mud 4 in table 1).*

Another important factor influencing strength and deformational properties of weakly lithified clay rocks are forces of interaction between mineral particles – structural bonds [32–34]. The higher is strength of structural bonds between separate elements of clay minerals, the higher is rock stability to hydrodynamic action of mud. As prospective method of evaluation of wellbore walls stability in intervals of clay rocks at early and medium lithification stage to hydrodynamic action of specific types of muds may be separated test to determine erosion of argillaceous slates, which is performed at extended action of mud in dynamic conditions and permits to obtain information on mud ability to prevent dispersing, i.e., rock destruction in dynamic conditions [35]. During performing experimental studies with purpose to exclude eroding and dispersing water action during final washing which is made to determine loss of samples weight, washing rock samples from water-based mud rests was performed by saturated potassium chloride solution. It is necessary to note that this method of evaluation of mud inhibiting properties is not informative for hydrocarbon-based muds, as degree of clay rock particles dispersing in them, as a rule, does not exceed measurement error value.

In general, results of studies to determine erosion parameter of studied rocks fully agree with data on

their swelling degree in water-based muds medium (see table 2). In process of hydrodynamic action of fresh glycol-based mud (mud 3 in table 1), probably, due to increased system pH value (pH = 10,4), practically complete rock weakening is observed (degree of sample weight loss was 93 %).

It is known that swelling and dispersing process of clay rocks with preemptive contents of montmorillonite to a great extent depends on their specific surface amount, and also on quantity and kind of exchangeable ions [9, 36, 37]. Study of ion exchange processes in system «rock – mud» using inductively coupled plasma mass spectrometry permits to evaluate alterations undergoing in rock, related to destabilization of clay crystal structure: ions desorption or oppositely rock saturation with ions and so-called rock «drying» (loss of bound water).

Inductively coupled plasma mass spectrometry is a method based on ionization of sample atoms by inductively coupled plasma with subsequent division of ions formed according to their atomic weight. this method is widely used to determine microquantities of metals and nonmetals in solutions. within this work sample analysis was performed at inductively coupled plasma mass spectrometer Aurora M90 by Bruker (USA).

Evaluation of character and intensity of ion exchange processes in system «rock – mud» was performed according to the following procedure. To equal volume mud samples same amount of milled sludge of falling rocks of Kazanian, Tatarian age was added. After this muds were hot rolled in roller-heart furnace at temperature 55 °C for 16 h. Character and intensity of ion exchange processes were evaluated according to difference in elements content in mud filtrate before and after placement of milled rock samples into muds. As base for comparison data on alteration of elements content in technical and formation waters before and after rock contact were used. Results of studies are given in table 3.

According to results of study it is established that clays of Kazanian, Tatarian age are characterized by undersaturation with main studied cations, which is demonstrated by direction of ion exchange processes between salt-containing liquids (formation water, potassium chloride mud) and studied rock, namely process of preemptive ion consumption by rock. To inhibit hydration of studied rocks promising are muds with increased electrolyte concentration, suppressing montmorillonite swelling processes and aiding to its transition to less hydrophilic varieties, and also reagents decreasing clay sorption capacity. Usage of the named mud types will aid to transit clay mineral present in rock into less hydrated potassium forms.

Table 3

Content of cations in mud filtrates before and after contact with rock of Kazanian, Tatarian age

Mud	Rock contact	Content of main cations, mg/dm^3			
		K^+	Na^+	Mg^{2+}	Ca^{2+}
Distilled water	Before	Less than 0,5	2,89	0,265	2,51
	After	52,4	309,0	1,36	20,0
Formation water	Before	864,0	75170,0	4462,0	17618,0
	After	907,0	69625,0	3939,0	16872,0
Mud 1	Before	197,0	1017,0	11,8	15,6
	After	280,0	1479,0	12,5	Less than 0,5
Mud 2	Before	141,0	1435,0	8,5	Less than 0,5
	After	94,3	1610,0	11,2	Less than 0,5
Mud 3	Before	219,0	2028,0	4,78	Less than 0,5
	After	604,0	3290,0	13,0	35,6
Mud 4	Before	55500,0	2318,0	87,5	319,0
	After	53510,0	2666,0	124,0	477,0

According to results of study ion desorption in the maximal degree from clays of Kazanian, Tatarian age is noted for fresh glycol-based mud (mud 3), intensity of desorption of ions present in rock exceeds this parameter even for distilled water. Most probably, this fact is related to increased pH value of this mud recipe (pH = 10,4). Strongly alkaline reaction of environment aids in intensification of process of salts leaching from rock to contacting water medium.

At mud contact with rock alteration of alteration of rock strain-stress state, and consequently reduction of rock strength characteristics. First of all this is related to hydration swelling of clay minerals in composition of rock being drilled. But not less important are other mechanisms of weakening action of mud liquid phase, for example. its wedging action during penetration to surface micro fractures of monolith formation or its separate structural elements [38, 39].

Different methods are used for evaluation of rock strength properties and their alteration under influence of muds, most often measurement of rock sample surface hardness measurement by penetrometer, determination of rock strength by monoaxial compression using mechanical presses

[40, 41]. These methods are rather effective for evaluation of mud inhibiting properties in case of availability of unbroken core material samples, but are seldom applicable for evaluation of alteration of strength properties of falling rocks sludge under influence of muds.

We propose the following complex method for evaluation of alteration of physical and chemical properties of rocks of Kazanian, Tatarian age under influence of various types of muds, including evaluation of muds wetting ability, alteration of fracture degree and strength of pressed samples of falling rock sludge. The method presumes pulverizing sludge samples to fraction size less than 160 μm, average sample preparation and pressing «tablets» using compactor included into longitudinal swelling tester set. The obtained «tablets» are placed into equal volumes of studied muds and are held in mud medium for 10 days (time of sample contact with muds should correspond to average time of rocks from problem drilling intervals staying in «uncased» condition). After that pressed samples are extracted from muds and following parameters are evaluated:

– current rock wetting speed (cm/h) in mud medium by alteration of sample weight according to formula stated in RD 39-00147001-773-2004 [42];

– visual test for alteration of degree of fractures in pressed samples after holding in mud medium;

– mechanical strength of pressed rock samples.

Evaluation of mechanical strength of pressed rock samples after contact with studied muds under action of external load on samples is proposed to perform using texture analyzer CT3 made by Brookfield (fig. 1).

a *b*

Fig. 1. Appearance (*a*) and schematic layout (*b*) of texture analyzer CT3 made by Brookfield

Study of mechanical strength of rock samples at texture analyzer CT3 provides for performance of the following: sample being studied is placed to analyzer support table; cylindrical spindle with certain geometric parameters is placed to the shaft (for all samples identical spindles should be used); experiment conditions set in instrument software; tests are performed in two sample compression cycles, with load measurement by dynamometric sensor. result of the experiment is dependency of load on sample/spindle in grams to experiment duration or to spindle travel (depth of penetration into rock sample), on basis of which using software following parameters are calculated: sample hardness (maximal load in first compression cycle) before and after mud influence, and peak stress corresponding to maximal load exerted per sample area unit in moment of its destruction. The latter parameter reflects compression strength of the studied sample. Influence of studied muds on strength of rock samples is proposed to be evaluated by value of weakening coefficient (K_p), being ratio of peak stress values for pressed rock sample after influence of studied mud and initial dry sample.

Instrument software permits to build diagrams of alteration of load on rock samples depending on spindle travel (depth of penetration into rock sample), which assist not only to evaluate character of sample integrity disturbance under external load action visually, but also to characterize additionally adhesion properties of sample softened by action of muds being studied (fig. 2).

For example, from the given diagrams it is seen that rock sample held in mud 1 medium was momentarily destroyed at application of small load (80 g), meanwhile travel of load graph below zero mark demonstrates occurrence of adhesive properties of softened surface of sample. In rock sample held in mud 5 medium, other destruction character under load is observed, accompanied with appearance of internal fractures and gradual sample destruction only after application of rather significant load (over 10 kg).

Results of study regarding evaluation of physical and mechanical properties of rocks of Kazanian, Tatarian ages under influence of studied muds are given in table 2 and fig. 3.

It is established that studied type of clay rocks is characterized with high sorption capacity in relation to mud water phase: increase of rock sample weight in medium of studied water-based

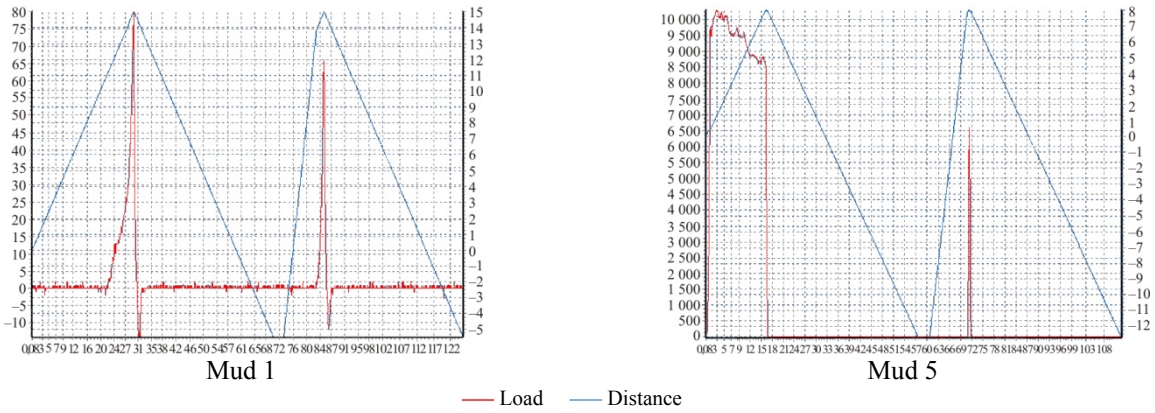

Fig. 2. Diagrams of alteration of load on rock samples depending on penetration depth

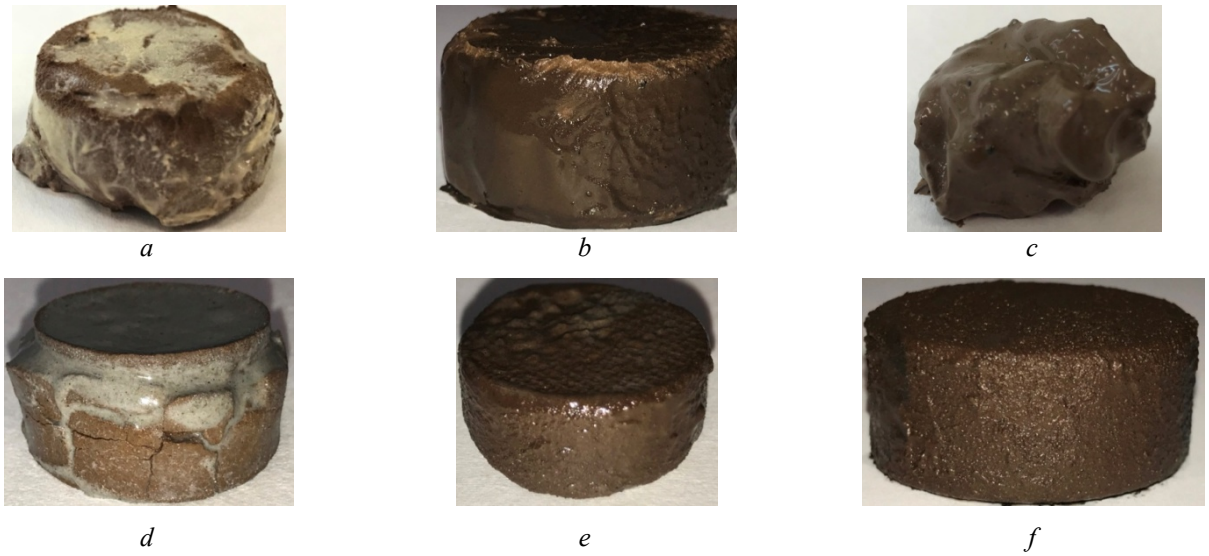

Fig. 3. Rock samples before and after mud influence: *a* – mud 1: significant sample softening with loss of initial form; *b* – mud 2: insignificant volume increase and sample softening; *c* – mud 3: significant sample softening with loss of initial form; *d* – mud 4: significant sample volume increase (swelling), appearance of several large fractures; *e* – mud 5: insignificant volume increase and sample surface softening; *f* – mud 6: no alteration of sample form and size is observed

muds is in range from 57 to 92 %. The lowest wetting ability from water system muds in relation to the studied rocks is with polyamine-based potassium chloride mud. This testifies that usage of this mud will aid to reduction of wetting intensity of near-wellbore area, and, as result, well walls stabilization. The most wetting ability is characteristic for fresh glycol-based mud. This permits to conclude that usage of glycols as clay hydration inhibitor will not help to preserve mechanical strength of studied rocks in near-wellbore area.

Usage of organosilicon compounds in the fresh mud recipe, seemingly, due to their hydrophobizing effect, permits to somewhat reduce degree of weakening pressed rock samples in mud medium.

According to results of study it is established that the proposed complex method permits to substantiate component composition not only for water system muds used to drill-in clay sediments being studied, but for invert-emulsion muds also. Despite the fact that majority of methods confirmed practically complete IEM inertness in relation to clays of Kazanian, Tatarian age, it is discovered that component composition of mud water phase effects significant influence on its inhibiting ability in relation to hydration of clay rocks (see table 2). Most prominently differences between inhibiting ability of IEM on base of saturated (mud 6) and non-saturated calcium chloride solution (mud 5) showed themselves during study of alteration of physical and mechanical rock properties in mud medium.

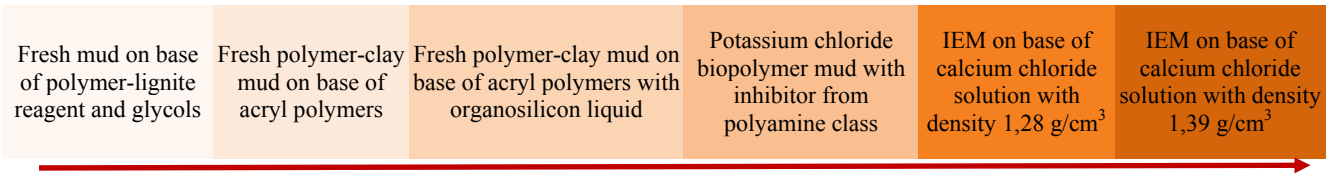

Fig. 4. Scale of inhibiting ability of studied types of muds in relation to red "reactive" clay of Kazanian, Tatarian ages of upper division of Permian system (arrow direction points increase of inhibiting properties of muds)

In particular, strengthening of rock samples is observed in medium of IEM based on saturated calcium chloride solution. This result, most probably, is related to partial filling of voids in samples by oil phase of mud, which due to its low compressibility takes a part of load during compression and permits more even distribution of skeletal stresses on the whole area of rock [43]. Usage solution saturated with calcium ions as water phase permits to obtain IEM with low water phase activity (a_w = 0,39) and to minimize osmotic processes in system «mud – rock». According to results of study it is established that in order to drill a well through clay sediments of Kazanian, Tatarian ages in deposits with difficult geological drilling conditions, where most severe complications are registered, related to loss of stability of wellbore walls, it is possible to recommend usage of water-based invert-emulsion muds, saturated with calcium ions.

Conclusions

Consequently, complex of methods for evaluation of inhibiting properties of muds, presented in the article, permits to perform all-around analysis of physical and chemical interaction in system «rock – mud» with regard to lithological composition and properties of clay rocks in problem drilling intervals. Complex of methods most closely resembles well conditions due to modeling temperature, exposure time, and usage of natural core material in studies.

Method of evaluation of rock strength parameters using texture analyzer CT3 may be used as indicator of alterations in physical and chemical rock properties under influence of studied liquids and is recommended for usage as one of advanced methods for evaluation of inhibiting properties of muds when it is possible to use only desegregated sludge of falling rocks as core material.

By aggregate of data received using the discussed complex method, gradation of muds per their inhibiting ability in relation to red "reactive" clays of Kazanian, Tatarian ages is proposed, which will be further considered during selection of mud type for drilling wells through the studied clay rocks (fig. 4).

References

1. Rentgenograficheskii kolichestvennyi fazovyi analiz osadochnykh gornykh porod [X-ray quantitative phase analysis of sedimentary rocks]. Metodicheskie rekomendatsii MP-03/RF-2015. Perm', Izdatel'stvo Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta, 2015.

2. Novikov V.S. Ustoichivost glinistykh porod pri burenii skvazhin [The stability of clay rocks during drilling]. Moscow, Nedra, 2000, 270 p.

3. Berry S.L., Boles J.L., Brannon H.D., Beall B.B. Performance evaluation of ionic liquids as a clay stabilizer and shale inhibitor. *SPE International Symposium and Formation Damage Control held in Lafayette*. Louisiana, 2008. DOI: 10.2118/112540-MS

4. Gaidarov M.M.-R. et al. Ustoichivost stenok skvazhiny v glinistykh otlozheniiakh [The stability of the borehole walls in clay deposits]. *Nefteservis*, 2013, no.2, pp.28-32.

5. Gaidarov M.M.-R. et al. Ustoichivost glinistykh porod pri burenii skvazhin [Clay rock stability while well drilling]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2013, no.7, pp.20-30.

6. Patel A. et al. Highly inhibitive water-based fluid system provides superior chemical stabilization of reactive shale formations. *AADE 01-NC-HO-55/AADE National Drilling Conference, held at the Omni Houston Westside*. Houston, 2001.

7. Kuznetsov V.G. Litologiia. Osadochnye gornye porody i ikh izuchenie [Lithology.

Sedimentary rocks and their study]. Moscow, Nedra-Biznestsentr, 2007, 511 p.

8. Bol G.M. et al. Borehole stability in shales. *SPE Drilling & Completion*, 1994, vol.9, iss.02, pp.87-94. DOI: /10.2118/24975-PA

9. Koshelev V.N., Rastegaev B.A., Dobrosmyslov A.S. Obespechenie ustoichivosti glinistykh otlozhenii za schet primeneniia ingibirovannykh burovykh rastvorov [Ensuring the stability of clay deposits through the use of inhibited drilling fluids]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2008, no.3, pp.30-34.

10. Vasiliev M. et al. A drilling fluid with high inhibitory characteristics, based on freshwater, contributing to increased drilling efficiency in more than 600 wells at the Salym oil fields. *SPE 160675. SPE Russian Oil and Gas Exploration and Production Technical Conference and Exhibition*. Moscow, 2012. DOI: 10.2118/160675-RU

11. Fetsenets R.M., Mosin V.A., Riabtsev P.L. Opyt sovershenstvovaniia inkapsuliruiushchikh burovykh rastvorov pri burenii skvazhin na Iuzhno-Priobskom mestorozhdenii [The experience of improving encapsulating drilling fluids in wells drilling in the South Priobskoye field]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2011, no.9, pp.45-50.

12. Uliasheva N.M. et al. Zadachi upravleniia adgezionnymi svoistvami burovykh rastvorov pri uglublenii skvazhiny v glinistykh porodakh [A management of adhesive drilling fluid properties on a well sinking into clay deposits]. *Neftegazovoe delo*, 2014, no.6, pp.103-119. DOI: 10.17122/ogbus-2014-6-103-119

13. Petrov N.A. et al. Otritsatelnye i polozhitelnye posledstviia obrabotki burovykh rastvorov zhidkostiami GKZh-10 i GKZh-11 [Negative and positive effects of drilling fluid treatment with GKZh-10 and GKZh-11 fluids]. *Neftegazovoe delo*, 2006, no.2, p.7.

14. Petrov N.A., Konesev G.V., Davydova I.N. Issledovanie spetsialnykh svoistv reagentov, primeniaemykh v promyvochnykh zhidkostiakh [Research of special properties of reagents, applied in bore solution liquids]. *Neftegazovoe delo*, 2012, no. 5, pp.397-401. DOI: 10.17122/ogbus-2017-3-6-25

15. Reid P.I., Dolan B., Cliffe S. Mechanism of shale inhibition by polyols in water based drilling fluids. *SPE 28960. SPE International Symposium on Oilfield Chemistry*. San Antonio, 1995. DOI: 10.2118/28960-MS

16. Samaei S.M., Tahmasbi K. The possibility of replacing oil-based mud with the environmentally acceptable water-based glycol drilling mud for the Iranian fields. *SPE 106419. SPE Environmental and Safety Conference*. Texas, 2007. DOI: 10.2118/106419-MS

17. Gaifutdinov G.Sh. et al. Poliglikolevyi modifikator burovykh rastvorov [Polyglycol drilling mud modifier]. Patent 2224780 Russian Federation, MPK^7 C09K7/02, no.2002119246/03; 2004.

18. Perricone A.C. Modifitsirovannyi ekologicheski bezopasnyi ingibiruiushchii burovoi rastvor i metod ego ispolzovaniia [Modified non-polluting liquid phase shale swelling inhibition drilling fluid and method of using same]. Patent US 4830765, kl. C09K8/06, no.US219870128798, 1987.

19. Paten A. et al. Advances in inhibitive water-based drilling fluids – can they replace oil-based muds? *SPE 106476. SPE International Symposium on Oilfield Chemistry*. Houston, 2007. DOI: 10.2118/106476-MS

20. Guerrero X., Guerrero M., Warren B. Use of amine/PHPA system to drill high reactive shales in the Orito field in Colombia. *SPE 104010. First International Oil Conference*. Mexico, 2006. DOI: 10.2118/104010-MS

21. Rosa R.C. et al. A new inhibitive water-based fluid: a completely cationic system. *SPE 94523. SPE Latin American and Caribbean Petroleum Engineering Conference*. Rio de Janeiro, 2005. DOI: 10.2118/94523-MS

22. Gaidarov M.M.-R. et al. Kationnoingibiruiushchii burovoi rastvor [Cationic Inhibitant Drilling Mud]. Patent 2534546 Russian Federation, MPK^7 C09K8/24, no.2013133733/03, 2014.

23. Dye W. et al. New water-based mud balances high-performance drilling and environmental compliance. SPE 92367. *IADC/SPE Drilling Conference*. Amsterdam, 2005. DOI: 10.2118/92367-MS

24. Vitvitskii E.I., Antonchik R.L., Demidov R.N. Primenenie burovogo rastvora na sinteticheskoi osnove “Rheliant Plus” dlia stroitelstva skvazhin v nesovmestimykh gorno-geologicheskikh usloviiakh [Application “Rheliant Plus” drilling fluid system for drilling wells in uncompatible geological conditions]. *Burenie i neft*, 2016, no.32-33, pp.32-33.

25. Makarova Ia.A., Egorova A.S. Universalnyi rastvor na uglevodorodnoi osnove dlia bureniia gorizontalnykh skvazhin [Universal hydrocarbon based fluid for drilling horizontal

wells]. *Bulatovskie chteniia*, 2017, vol.3, pp.162-165.

26. Khvoshchin P., Lyadova N., Iliasov S. et al. The results of horizontal well drilling using invert-emulsion fluid at Kharyaginskoe field. *SPE Russian Oil and Gas Exploration & Production Technical Conference and Exhibition*. Moscow, 2014. DOI: 10.2118/171283-MS

27. Nekrasova I.L., Garshina O.V., Khvoshchin P.A. Teoriia i praktika ispolzovaniia invertno-emulsionnykh rastvorov v protsesse stroitelstva skvazhin [Theory and practice of using invert-emulsion solutions in the process of well construction]. Perm, Aster, 2016, 148 p.

28. Khvoshchin P.A. et al. Utiazhelennyi invertnyi emulsionnyi rastvor s reguliruemym reologicheskim profilem dlia stroitelstva gorizontalnykh skvazhin [Weighted invert emulsion drilling fluid with controlled rheology profile for horizontal well construction]. *Neftegazovoe delo*, 2015, vol.13, no.1, pp.35-44.

29. Labenski F., Reid R., Santos H. Drilling fluids approaches for control of wellbore instability in fractured formations. *SPE/IADC Middle East Drilling Technology Conference and Exhibition*. Abu Dhabi. DOI: 10.2118/85304-MS

30. Ivenina I.V. Povyshenie effektivnosti ingibirovaniia glinistykh porod putem upravleniia mineralizatsiei burovykh rastvorov [Improving the effectiveness of inhibition of clay rocks by controlling the salinity of drilling fluids]. Abstract of Ph. D. thesis. Ukhta, 2011, 25 p.

31. Vafin R.M. et al. Vybor burovogo rastvora dlia provodki skvazhin v oslozhnennykh gorno-geologicheskikh usloviiakh [Choosing drilling fluid for well making in complicated mining and geological conditions]. *Oil industry*, 2013, no.1, pp.53-55.

32. Ivanov D.Iu. et al. Ekspress-metod otsenki ingibitorov glin [Express method for evaluating clay inhibitors]. *GeoInzhiniring*, 2014, no.1 (21), pp.78-83.

33. Balaba V.I. et al. Mekhanizm razuprochneniia glinistykh porod burovymi tekhnologicheskimi zhidkostiami [The mechanism of softening of clay rocks by drilling fluids]. *Inzhener-neftianik*, 2008, no.2, pp.19-22.

34. Gomez S., He W. Fighting wellbore instability: customizing drilling fluids based on laboratory studies of shale-fluid interactions. *IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition*. Tianjin, 2012. DOI: 10.2118/155536-MS

35. GOST 33696-2015 (ISO 10416:2008) Rastvory burovye. Laboratornye ispytaniia [Drilling fluids. Laboratory tests]. Moscow, Standartinform, 2016, 100 p.

36. Simpson J.P. Studies dispel myths, give guidance on formulation of drilling fluids or shale stability. IADC/SPE 39376. *IADC/SPE Drilling Conference*. Dallas, 1998. DOI: 10.2118/39376-MS

37. Carminati S., Del Gaudio L., Del Piero G., Brignoli M. Water-based muds and shale interactions. SPE 65001. *SPE International Symposium on Oilfield Chemistry*. Houston, 2001. DOI: 10.2118/65001-MS

38. Baidiuk B.V., Shits L.A., Talakhadze M.G. Otsenka snizheniia mekhanicheskoi prochnosti gornoi porody pod vozdeistviem burovogo rastvora [Evaluation of the reduction of mechanical strength of rock under the influence of drilling mud]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2008, no.9, pp.10-14.

39. Riley M. et al. Wellbore stability in unconventional shale – the design of a nano-particle fluid. *SPE 153729. SPE Oil and Gas India Conference*. Mumbai, 2012. DOI: 10.2118/153729-MS

40. Jienian Y. et al. Design of water-based drilling fluids for an extended reach well with a horizontal displacement of 8000 m located in Liuhua oilfield. SPE 130959. *SPE International Oil&Gas Conference*. Beijing, 2010. DOI: 10.2118/130959-MS

41. Bradbuty A. et al. Development of new, environmentally friendly, salt-free shale inhibitors for water based drilling fluids. *AADE National Technical Conference and Exhibition*. Oklahoma City, 2013.

42. RD 39-00147001-773-2004. Metodika kontrolia parametrov burovykh rastvorov [Method of monitoring parameters of drilling fluids]. Moscow, Standartinform, 2004, 110 p.

43. Nekrasova I.L., Khvoshchin P.A., Garshina O.V., Konesev G.V. Novye podkhody k otsenke ingibiruiushchikh svoistv invertno-emulsionnykh burovykh rastvorov [New approaches to inhibitory properties evaluation of invert emulsion drilling fluids]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2017, no.2, pp.28-33.

Библиографический список

1. Рентгенографический количественный фазовый анализ осадочных горных пород: методи-ческие рекомендации МП-03/РФ-2015. – Пермь: Издательство Пермского государст-венного национального исследовательского университета, 2015.
2. Новиков В.С. Устойчивость глинистых пород при бурении скважин. – Москва: Недра, 2000. – 270 с.
3. Performance evaluation of ionic liquids as a clay stabilizer and shale inhibitor / S.L. Berry, J.L. Boles, H.D. Brannon, B.B. Beall // SPE International Symposium and Formation Damage Control held in Lafayette. – Louisiana, 2008. DOI: 10.2118/112540-MS
4. Устойчивость стенок скважины в глинис-тых отложениях / М.М.-Р. Гайдаров [и др.] // Нефтесервис. – 2013. – № 2. – С. 28–32.
5. Устойчивость глинистых пород при бурении скважин / М.М.-Р. Гайдаров [и др.] // Строительство нефтяных и газовых скважин на суше и на море. – 2013. – № 7. – С. 20–30.
6. Highly inhibitive water-based fluid system provides superior chemical stabilization of reactive shale formations / A. Patel [et al.] // AADE 01-NC-HO-55/AADE National Drilling Conference, held at the Omni Houston Westside. – Houston, 2001.
7. Кузнецов В.Г. Литология. Осадочные горные породы и их изучение: учебное пособие для вузов. – Москва: Недра-Бизнесцентр, 2007. – 511 с.
8. Borehole stability in shales / G.M. Bol [et al.] // SPE Drilling & Completion. – 1994. – Vol. 9, iss. 02. – P. 87–94. DOI: /10.2118/24975-PA
9. Кошелев В.Н., Растегаев Б.А., Добросмыслов А.С. Обеспечение устойчивости глинистых отложений за счет применения ингибированных буровых растворов // Строительство нефтяных и газовых скважин на суше и на море. – 2008. – № 3. – С. 30–34.
10. A drilling fluid with high inhibitory characteristics, based on freshwater, contributing to increased drilling efficiency in more than 600 wells at the Salym oil fields / M. Vasiliev [et al.] // SPE 160675. SPE Russian Oil and Gas Exploration and Production Technical Conference and Exhibition. – Moscow, 2012. DOI: 10.2118/160675-RU.
11. Феценец Р.М., Мосин В.А., Рябцев П.Л. Опыт совершенствования инкапсулирующих буровых растворов при бурении скважин на Южно-Приобском месторождении // Строительство нефтяных и газовых скважин на суше и на море. – 2011. – № 9. – С. 45–50.
12. Задачи управления адгезионными свойствами буровых растворов при углублении скважины в глинистых породах / Н.М. Уляшева [и др.] // Нефтегазовое дело. – 2014. – № 6. – С. 103–119. DOI: 10.17122/ogbus-2014-6-103-119
13. Отрицательные и положительные последствия обработки буровых растворов жидкостями ГКЖ-10 и ГКЖ-11 / Н.А. Петров [и др.] // Нефтегазовое дело. – 2006. – № 2. – С. 7.
14. Петров Н.А., Конесев Г.В., Давыдова И.Н. Исследование специальных свойств реагентов, применяемых в промывочных жидкостях // Нефтегазовое дело. – 2012. – № 5. – С. 397–401. DOI: 10.17122/ogbus-2017-3-6-25
15. Reid P.I., Dolan B., Cliffe S. Mechanism of shale inhibition by polyols in water based drilling fluids // SPE 28960. SPE International Symposium on Oilfield Chemistry. – San Antonio, 1995. DOI: 10.2118/28960-MS
16. Samaei S.M., Tahmasbi K. The possibility of replacing oil-based mud with the environmentally acceptable water-based glycol drilling mud for the Iranian fields // SPE 106419. SPE Environmental and Safety Conference. – Texas, 2007. DOI: 10.2118/106419-MS
17. Полигликолевый модификатор буровых растворов: пат. 2224780 Российская Федерация, МПК7 C09K7/02 / Гайфутдинов Г.Ш. [и др.]; заявитель и патентообладатель ОАО «Нижне-камснефтехим». – № 2002119246/03; заявл. 16.07.2002; опубл. 27.02.2004.
18. Модифицированный экологически безопас-ный ингибирующий буровой раствор и метод его использования: пат. US 4830765, США, кл. C09K8/06 / Perricone A.C. [и др.]; заявитель и патентообладатель Baker Hughes Inc. – № US219870128798, заявл. 04.12.1987.
19. Advances in inhibitive water-based drilling fluids – can they replace oil-based muds?/ A. Paten [et al.] // SPE 106476. SPE International Symposium on Oilfield Chemistry. – Houston, 2007. DOI: 10.2118/106476-MS

20. Guerrero X., Guerrero M., Warren B. Use of amine/PHPA system to drill high reactive shales in the Orito field in Colombia // SPE 104010. First International Oil Conference. Mexico, 2006. DOI: 10.2118/104010-MS

21. A new inhibitive water-based fluid: a completely cationic system / R.C. Rosa [et al.] // SPE 94523. SPE Latin American and Caribbean Petroleum Engineering Conference. – Rio de Janeiro, 2005. DOI: 10.2118/94523-MS

22. Катионноингибирующий буровой раствор: пат. 2534546 Российская Федерация, МПК7 C09K8/24. / Гайдаров М.М.-Р. [и др.]; заявитель и патентообладатель ООО «Научно-исследовательский институт природных газов и газовых технологий – Газпром ВНИИГАЗ». – № 2013133733/03; заявл. 19.07.2013; опубл. 27.11.2014.

23. New water-based mud balances high-performance drilling and environmental compliance / W. Dye [et al.] // SPE 92367. IADC/SPE Drilling Conference. – Amsterdam, 2005. DOI: 10.2118/92367-MS

24. Витвицкий Е.И., Антончик Р.Л., Демидов Р.Н. Применение бурового раствора на синтетической основе «Rheliant Plus» для строительства скважин в несовместимых горно-геологических условиях // Бурение и нефть. – 2016. – № 32–33. – С. 32–33.

25. Макарова Я.А., Егорова А.С. Универсальный раствор на углеводородной основе для бурения горизонтальных скважин // Булатовские чтения. – 2017. – Т. 3. – С. 162–165.

26. The results of horizontal well drilling using invert-emulsion fluid at Kharyaginskoe field / P. Khvoshchin, N. Lyadova, S. Iliasov [et al.] // SPE Russian Oil and Gas Exploration & Production Technical Conference and Exhibition. – Moscow, 2014. DOI: 10.2118/171283-MS

27. Некрасова И.Л., Гаршина О.В., Хвощин П.А. Теория и практика использования инвертно-эмульсионных растворов в процессе строительства скважин: монография. – Пермь: Астер, 2016. – 148 с.

28. Утяжеленный инвертный эмульсионный раствор с регулируемым реологическим профилем для строительства горизонтальных скважин / П.А. Хвощин [и др.] // Нефтегазовое дело. – 2015. – Т. 13, № 1. – С. 35–44.

29. Labenski F., Reid R., Santos H. Drilling fluids approaches for control of wellbore instability in fractured formations // SPE/IADC Middle East Drilling Technology Conference and Exhibition. – Abu Dhabi. DOI: 10.2118/85304-MS

30. Ивенина И.В. Повышение эффективности ингибирования глинистых пород путем управления минерализацией буровых растворов: автореферат диссертации на соискание ученой степени кандидата технических наук. – Ухта, 2011. – 25 с.

31. Выбор бурового раствора для проводки скважин в осложненных горно-геологических условиях / Р.М. Вафин [и др.] // Нефтяное хозяйство. – 2013. – № 1. – С. 53–55.

32. Экспресс-метод оценки ингибиторов глин / Д.Ю. Иванов [и др.] // ГеоИнжиниринг. – 2014. – № 1 (21). – С. 78–83.

33. Механизм разупрочнения глинистых пород буровыми технологическими жидкостями / В.И. Балаба [и др.] // Инженер-нефтяник. – 2008. – № 2. – С. 19–22.

34. Gomez S., He W. Fighting wellbore instability: customizing drilling fluids based on laboratory studies of shale-fluid interactions // IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition. – Tianjin, 2012. DOI: 10.2118/155536-MS

35. ГОСТ 33696-2015 (ИСО 10416:2008). Растворы буровые. Лабораторные испытания. – Москва: Стандартинформ, 2016. – 100 с.

36. Simpson J.P. Studies dispel myths, give guidance on formulation of drilling fluids for shale stability. IADC/SPE 39376. IADC/SPE Drilling Conference. – Dallas, 1998. DOI: 10.2118/39376-MS

37. Water-based muds and shale interactions / S. Carminati, L. Del Gaudio, G. Del Piero, M. Brignoli // SPE 65001. SPE International Symposium on Oilfield Chemistry. – Houston, 2001. DOI: 10.2118/65001-MS

38. Байдюк Б.В., Шиц Л.А., Талахадзе М.Г. Оценка снижения механической прочности горной породы под воздействием бурового раствора // Строительство нефтяных и газовых скважин на суше и на море. – 2008. – № 9. – С. 10–14.

39. Wellbore stability in unconventional shale – the design of a nano-particle fluid / M. Riley [et al.] // SPE 153729. SPE Oil and Gas India Conference. – Mumbai, 2012. DOI: 10.2118/153729-MS

40. Design of water-based drilling fluids for an extended reach well with a horizontal displacement

of 8000 m located in Liuhua oilfield / Y. Jienian [et al.] // SPE 130959. SPE International Oil&Gas Conference. – Beijing, 2010. DOI: 10.2118/130959-MS

41. Development of new, environmentally friendly, salt-free shale inhibitors for water based drilling fluids / A. Bradbuty [et al.] // AADE National Technical Conference and Exhibition. – Oklahoma City, 2013.

42. РД 39-00147001-773-2004. Методика контроля параметров буровых растворов. – Москва: Стандартинформ, 2004. – 110 с.

43. Новые подходы к оценке ингибирующих свойств инвертно-эмульсионных буровых растворов / И.Л. Некрасова, П.А. Хвощин, О.В. Гаршина, Г.В. Конесев // Строительство нефтяных и газовых скважин на суше и на море. – 2017. – № 2. – С. 28–33.

Please cite this article in English as:
Nekrasova I.L., Khvoshchin P.A., Kazakov D.A., Garshina O.V., Okromelidze G.V., Tiron D.V. Complex of methods to evaluate inhibiting properties of muds in relation to clay swelling rocks (at example of “reactive” clays of montmorillonite group of Kazanian, Tatarian ages in Permian system). *Perm Journal of Petroleum and Mining Engineering*, 2019, vol.19, no.2, pp.150-161. DOI: 10.15593/2224-9923/2019.2.5

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Комплекс методов оценки ингибирующих свойств буровых растворов по отношению к глинистым набухающим горным породам (на примере «реактивных» глин монтмориллонитовой группы казанского, татарского ярусов пермской системы) / И.Л. Некрасова, П.А. Хвощин, Д.А. Казаков, О.В. Гаршина, Г.В. Окромелидзе, Д.В. Тирон // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2019. – Т.19, №2. – С.150–161. DOI: 10.15593/2224-9923/2019.2.5