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Satbayev University

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STUDY OF INTERRELATIONS BETWEEN COMPOSITION AND PROPERTIES OF HIGH-VISCOUS OIL

Abstract. Under the real geological-physical conditions of displacement of viscous oil, the related anomalies are additionally strengthened also due to the content of asphaltenes, resins and paraffins therein, inhomogeneity of collectors with various properties, in particular, permeability; therewith, the displacement ratio is reduced with increase in viscosity. All that is complicated by insufficient knowledge of the mechanism of generation of asphalt, resin, and paraffin depositions, their impact on the properties of oils, in particular, temperature of saturation of oil with paraffin, surveys of the regularities of which do not provide the consensus as shown by the study. As it is known, a feature of development of oil and gas industry is the exploration of deposits of heavy high-viscous oil in order to increase the resource base of hydrocarbon raw materials, which is possible due to the development of energy-efficient and resource-saving technologies for its development.

That is explanation for the attention of the researchers to the problems related to production of the hard to recover and viscous oils in structurally complex strata. Therefore, this article is an attempt to analyze the interrelations between the composition and properties of oils and estimation of the temperature of saturation with paraffin subject to the experience gained by now. Prior to proceed with the results of the studies, it is necessary to analyze knowledge of this problem, pre-obtained results.

Key words: high-viscosity oil; hard-to-recover reserves; oil composition; oil properties; conditions of occurrence; classification; complex indicator of oil quality; oil saturation temperature with paraffin.

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ТҰТҚЫРЛЫҒЫ ЖОҒАРЫ МҰНАЙДЫҢ ҚҰРАМЫ МЕН ҚАСИЕТТЕРІ АРАСЫНДАҒЫ БАЙЛАНЫСТЫ ЗЕРТТЕУ

Аннотация. Мақала күрделі қабаттардағы қиын алынатын, тұтқыр майларды өндіруге байланысты проблемаларға арналған. Мұнайдың құрамы мен қасиеттері арасындағы өзара байланысты зерттеу нәтижелерін талдау және жинақталған тәжірибені ескере отырып, парафинмен қанықтыру температурасын бағалау жүргізілді. Мұнайдың парафинмен қанығу температурасының есептік деректері алынды, бұл әртүрлі кен орындарының мұнайын салыстыруға сапалы баға беруге мүмкіндік береді. Мұнайдың парафинмен қанығу температурасы қолайсыз температура аралығын анықтауға және АШПШ түзілуінің алдын алу және алдын алу бойынша уақтылы шешімдер қабылдауға мүмкіндік беретін маңызды көрсеткіштердің бірі болып табылады. Ұңғыманың бойындағы температураның өзгеруіне байланысты қарқынды парафин түзілу тереңдігін бағалауға болады. Мұнайдың парафинмен қанығу температурасын бұрын жүргізілген зерттеу нәтижелеріне жүргізілген статистикалық талдау осы параметрді болжамды бағалауды жеңілдету үшін пайдаланылған жеке тәуелділіктерді алуға мүмкіндік берді. Мұнайдың парафинмен қанығу температурасының асфальтендер, шайырлар мен парафиндердің құрамына, сондай-ақ тұтқырлық қатынасына тәуелділігі құрылды. Мұнай және газ саласын дамытудың ерекшелігі көмірсутегі шикізатының ресурстық базасын ұлғайту мақсатында тұтқырлығы жоғары мұнай кен орындарын игеру болып табылады, бұл оны игерудің энергиялық тиімді және ресурс үнемдейтін технологияларын әзірлеу есебінен мүмкін болып отыр. Есептелген және эксперименттік деректерді салыстыру олардың жеткілікті жақындығын көрсетті, сондықтан тәуелділікті зерттеу аймағы үшін қолайлы деп санауға болады. Мақалада мұнайдың парафинмен қанығу температурасының кейбір аймақтар үшін асфальтендер, шайырлар мен парафиндердің концентрациясына тәуелділігі көрсетілген. Қарастырылған кен орындары шегінде алынған модельдердің қателіктерін бағалау және салыстырмалы талдау жүргізілді.

Түйінді сөздер: тұтқырлығы жоғары мұнай; алынуы қиын қорлар; мұнайдың құрамы; мұнайдың қасиеттері; орналасу жағдайлары; жіктелуі; мұнай сапасының кешенді көрсеткіші; мұнайдың парафинмен қанығу температурасы.

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ИССЛЕДОВАНИЕ ВЗАИМОСВЯЗЕЙ МЕЖДУ СОСТАВОМ И СВОЙСТВАМИ ВЫСОКОВЯЗКИХ НЕФТЕЙ

Аннотация. Статья посвящена проблемам, связанным с добычей трудноизвлекаемых, вязких нефтей в сложнопостроенных пластах. Выполнен анализ результатов исследований взаимосвязей между составом и свойствами нефтей и оценка температуры насыщения парафином с учетом накопленного опыта. Получены расчетные данные температуры насыщения нефти парафином, которые позволяют дать качественную оценку сравнения нефтей различных месторождений. Отметим, что температура насыщения нефти парафином является одним из важных показателей, позволяющих определять интервал неблагоприятных температур и принимать своевременные решения по предотвращению и профилактике образования АСПО. В зависимости от изменения температуры по стволу скважины можно оценить глубину интенсивного парафинообразования. Проведенный статистический анализ результатов ранее выполненных исследований температуры насыщения нефти парафином позволил получить частные зависимости, которые были использованы для облегчения прогнозной оценки этого параметра. Построена зависимость температуры насыщения нефти парафином как от содержания асфальтенов, смол и парафина, так и соотношения вязкостей. Как известно, особенностью развития нефтегазовой отрасли является освоение месторождений тяжелых высоковязких нефтей с целью увеличения ресурсной базы углеводородного сырья, что представляется возможным за счет разработки энергоэффективных и ресурсосберегающих технологий ее освоения. Проведенное сравнение расчетных и экспериментальных данных показало их достаточную близость, и зависимость, таким образом, можно считать приемлемой для района исследований. В статье получены зависимости температуры насыщения нефти парафинами от концентрации асфальтенов, смол и парафинов для некоторых регионов. Выполнены оценка и сравнительный анализ погрешностей полученных моделей в пределах рассматриваемых месторождений.

Ключевые слова: высоковязкая нефть; трудноизвлекаемые запасы; состав нефти; свойства нефти; условия залегания; классификация; комплексный показатель качества нефти; температура насыщения нефти парафином.

Introduction. Analysis of results of studies of interrelations between composition and properties of oils. It should be noted that, in their studies, the authors pay the great attention to definition of the concept of the hard to recover reserves, their classification, estimation of degree of oil recovery hardness. For the analysis, it should be noted that the concept of "hard to recover reserves" (HRR) has been greatly changed (Yaschenko et al., 2020:5), (Guler et al., 2001), (Negin et al.,2016:9).

As it is known, a feature of development of oil and gas industry is the exploration of deposits of heavy high-viscous oil in order to increase the resource base of hydrocarbon raw materials, which is possible due to the development of energy-efficient and resource-saving technologies for its development.

One of the main negative factors of the characteristics of heavy oil is the high content of paraffin, resins and asphaltenes. Changes in the properties of fluids during oil production can induce the deposition of asphaltenes. At their large thickness such consequences are possible, as a violation of the flow and production stoppage as a result of accumulation in various parts of the system from the formation pores to various pumping well equipment, as well as obstructed oil trunk transportation due to the manifestation of clogging ability. In addition, the studies carried out show a great influence of asphaltenes on the stability of oil-water emulsions and the wettability of the formation. The problem of studying the influence of the content of paraffin, resins and asphaltenes in oil is also relevant in the processes of heavy oil processing. The problem of developing deposits with reserves of heavy high-viscosity oils is considered in the work (Paul et al., 2009:32), (Planckaert, (2005:16). The results of research on the study of physical effects, among which ultrasonic, ultra-high-frequency and magnetic methods are distinguished, on the rheological properties of oil. The essence and main ways of application of thermal methods of extraction of hard-to-recover oils are analyzed. The main directions for extension of the study of this direction in order to eliminate the existing shortcomings in the previously conducted experiments are proposed.

Research Material and methods. As shown by the studies, there is no unified classification of hard to recover reserves. The specialists distinguish the common criteria: the hard to recover reserves are the "reserves contained in the geologically complex strata and deposits or represented by slow-moving (heavy, high-viscosity) oil". As a rule, the hard to recover reserves are characterized by relatively low well outputs and slow development rates due to low productivity of strata, unfavorable conditions of oil occurrence and its abnormal physical-chemical properties. Estimation of the results of recovery is affected also by the insufficient level of the appropriate technologies. The studies of the hard to recover oils have resulted in formation of two groups of works: the works devoted to study of the properties and conditions of oil occurrence and the works devoted to study of the compositions of oils. In recent years, works of improving the classification of hard-to-recover oils have attracted specialists. In this case, it should be noted the use of modern methods of mathematical statistics in conjunction with the methods of fuzzy logic (Aliev et al., 2014). The analysis shows that, pursuant to (Askarova, 2017), (Lissovksiy et al., 2009:2), (Yaschenko et al., 2015:5) the hard to recover reserves are the reserves represented by slow-moving oil due to high viscosity

and density, oil with high (more than 500 m^3/t) or low (less than 200 m^3/t) gas saturation, or with presence of aggressive components (hydrogen sulfide, carbon dioxide) in dissolved and/or free gas. Oils included into this group are commonly called as oils with abnormal physical-chemical properties. This group also includes oils with high content of metals (firstly vanadium and nickel), due to increase in degree of their environmental hazard. The second group of the hard to recover oils consists of oils with complicated conditions of occurrence, as wells as oils located in the territory of perpetually-frozen ground and sea offshores (Purtova et al., 2011:5). In order to identify the oil reserves as to degree of recovery hardness, the work proposes the complex index of oil quality at various temperatures and regression equation for calculation of this index. Later, it has been proposed to use such complex index for estimation of qualitative characteristics of oils in oil deposits of fields and oil basins (Planckaert, 2005:16).

The work (Raupov et al., 2014:15) presents the results of the studies of the optical properties of oil of various oil-gas-bearing regions of Russia and correlation dependences of density and viscosity on the light absorption factor correspondingly. The abnormally viscous properties of oils containing asphalt-resinous substances are strengthened by cooling of oil not only due to weakening of Brownian motion, but also due to generation of new phase – paraffin. Thereat, it must be understood that the medium temperature shall be lower than the temperature of saturation of oil with paraffin. Pursuant "… according to, the link between the temperature of saturation with paraffin and weight content of asphalt-resinous substances and paraffin in oil has been detected. The value of the temperature of saturation of oil with paraffin is closely related to the weight content of asphaltenes and paraffins and is weakly related to presence of resins". The same work researches the impact of the composition of high-molecular components on the temperature of saturation of oils of the Ural-Volga region deposits with paraffin (Amerkhanov, 1980:49). Based on the studies of oils of five fields of Kazakhstan and comparative analysis of the results of the study of fusion temperatures of paraffins extracted from oil, the work defines that this index for Uzen Field corresponds to 48°C, and Botakhan Field – 44°C. Paraffins with such fusion temperature are transformed naturally upon heating from the solid state into the liquid state. Pursuant to the data presented in (Askarova, 2017) the fusion temperature of paraffins of East Makat Field, Kumkol Field and Akshabulak Field is equal to 62, 55 and 44°C correspondingly; for Botakhan Field and Uzen Field, the fusion temperature of resins is equal to 62°C (Askarova, 2017). Based on processing of the data of the temperature properties of paraffins extracted from oil, as well as rheological parameters of oil, the temperature of saturation of oil with paraffin has been calculated. The authors of the work (Akhmetov et al., 2018:7), (Karazhanova et al., 2021a:11), (Ogolo et al., 2012:9) propose to use the following formula of VNIIneft as equation for calculation of the temperature of saturation of oil with paraffin:

$$t_o = 11.398 + 34.084 \cdot \lg C_p, \quad (1)$$

where t_o–temperature of saturation of oil with paraffin under surface conditions; C_p -

concentration of paraffin in oil, wt.%. Also the references contain the similar empirical dependences of the temperature of saturation on the content of paraffins in the form of:

$$t_o = 19.457 \cdot \ln(C_p) - 0.8117 . \quad (2)$$

The works (Ogolo et al., 2019:9), (Santos et al., 2014:19) make the conclusion that the temperature of saturation of oil with paraffin depends not only on the content of paraffin therein, but also on presence of resins and asphaltenes, fusion temperature of paraffin extracted from oil, kinematic viscosity at 20°C and 50°C:

$$t_o = [\sigma] \cdot (K * \ln(T_{fusion}) + \mu 20/\mu 50), \quad (3)$$

where $[\sigma]$ –correction factor (°C/%); μ_{20} - kinematic viscosity of oil at 20°C (mm/s^2), μ_{50}– kinematic viscosity of oil at 50°C (mm/s^2), K – total content of paraffins, resins and asphaltenes (%), T_{fusion} – fusion temperature of paraffin extracted from oil (°C). The work presents the results of calculations of the temperature of saturation of oil with paraffin by such formulas (Amerkhanov, 1980:49).

The design data of the temperature of saturation of oil with paraffin enables to perform the qualitative estimation during comparison of oils from different fields. The temperature of saturation of oil with paraffin is one of the important indexes; its knowing enables to determine the interval of unfavorable temperatures in the process of production of well products, as well as to make timely decisions for prevention of generation of asphalt, resin, and paraffin depositions. Depending on change in the temperature along the well bore, the depth of intensive paraffin-generation may be estimated.

Results of studies. In order to facilitate the forecast estimation, the statistical analysis of the results of the previously performed studies of the temperature of saturation of oil with paraffin has been performed to disclose the particular dependences, which are summarized in the form: $t_{par}=f(C_a,C_{res},C_{par})$. Here, t_{par} – temperature of saturation of oil of the deposits with paraffin; C_a,C_{res},C_{par}- concentrations of asphaltenes, resins, high-molecular paraffins correspondingly, %. For the analysis, the initial data is the results of the studies of impact of the composition of high-molecular components on the temperature of saturation of oil of the Ural-Volga region deposits with paraffin presented in the work of I.M. Amerkhanov (Amerkhanov,1980:49).

Transformations have resulted in the following formula:

$$t_s = 15.085 C_a^{-0.047} (11.21 * \ln(C_p) - 1)^{0.2199} e^{0.004464 C_r} \quad (4)$$

The calculations by this formula and comparison with the experimental data have been carried out (Amerkhanov,1980:49). Table 1 presents the calculated and relevant actual data, as well as appropriate errors.

Table 1-Values of concentrations of asphaltenes, resins, high-molecular paraffins, related design and actual temperatures of saturation of oil with paraffins (Ural-Volga region)

C_a	C_r	C_p	$t_{s\ calculated}$	$t_{s\ actual\ av}$	$\Delta t_{s\ abs}$	$\Delta t_{s\ rel,\%}$
3.605	13.053	4.531	27.68	22.71	4.97	21.885
0.526	18.711	3.281	29.36	25.79	3.57	13.84
1.763	7.263	3.125	26.09	29.03	2.94	10.128
1.763	12.526	3.125	26.71	29.03	2.32	7.99
0.474	18.842	4.531	31.24	32.10	0.86	2.679
0.474	20.289	4.531	31.44	32.10	0.66	2.056
0.632	8.184	7.188	31.26	34.20	2.94	8.597

t_s – temperature of saturation of oil with paraffin; $\Delta t_{s\ abs}$ - absolute error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ abs} = |t_{s\ calculated} - t_s|$; $\Delta t_{s\ rel}$ - relative error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ rel} = \frac{|t_{s\ calculated} - t_s|}{t_s} * 100\%$.

In order to determine the degree of compliance of the resulted formula (4) with the real conditions, the quantitative estimation called as identity index has been executed: $Q(t_s) = 0.697$.

As shown by comparison of the calculated and experimental data, in the sufficient extent, they may be deemed as similar; therefore, the dependence may be deemed as acceptable for the studied area. It is of interest to study the similar link for the conditions of Kazakhstan. For that, it is possible to try to identify the resulted formula as per the conditions of fields of Kazakhstan or to create the same dependence based on the data of the experimental studies for oils of fields of Kazakhstan. It should be noted that, of course, the results of the special studies are need for that. The work presents the summarized results for five fields of Kazakhstan with the reference to the performed works (Askarova, 2017). Using this data, we have tried to identify the resulted dependence for the conditions of Kazakhstan. Processing has resulted in the following formula:

$$t_s = 0.2996 \exp(2.2371 C_a^{-0.047} (11.21 * \ln(C_p) - 1)^{0.2199} e^{0.004464 C_r}) \qquad (5)$$

The experimental values of the temperature of saturation with paraffin for oils of some fields of Kazakhstan pursuant to in comparison with the ones calculated by the formula (2) are presented in Table 2.

Table 2-Values of temperature of saturation with paraffin for oils of fields of Kazakhstan in comparison with calculated data

Field	Structural-group composition, %			t_s, °C	$t_{s\ calculated}$, °C	$\Delta t_{s\ abs}$	$\Delta t_{s\ rel,\%}$
	Asphaltenes	Resins	Paraffins				
Uzen	2.36	16.2	21.1	56	43.978	12.022	21.468
Botakhan	0.44	4.3	3.1	22	17.534	4.466	20.3
East Makat	0.01	5.21	2.1	16.67	24.503	7.833	46.989
Kumkol	0.21	5.2	14.4	50	52.319	2.319	4.638
Akshabulak	0.23	6.3	16.1	53	55.091	2.091	3.945

t_s – temperature of saturation of oil with paraffin; $\Delta t_{s\ abs}$ - absolute error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ abs} = |t_{s\ calculated} - t_s|$; $\Delta t_{s\ rel}$ - relative error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ rel} = \frac{|t_{s\ calculated} - t_s|}{t_s} * 100\%$.

The results of comparative calculations show the ambiguity of accuracy of the model for various fields: for Kumkol Field and Akshabulak Field, the relative error is (3.9-4.6)%, for the other fields, it varies in the range of (20-47)%. Such circumstance requires arrangement of the special experimental studies.

Based on the resulted experimental data, the work presents the values of the temperatures of saturation of oil with paraffin (Askarova, 2017). Taking into account the above and the results presented in the references, the dependance of the temperature of saturation of oil with paraffin both on the content of asphaltenes, resins and paraffin and on the ratio of viscosities has been created:

$$t_s = 37.362 * C_a^{0.0855}(0.3363C_r - 1)^{0.4292} C_p^{0.2392} \left(0.6451\frac{\mu_{20}}{\mu_{50}} - 1\right)^{0.4292} \qquad (6)$$

Table 3 shows the initial data pursuant to (Askarova, 2017), as well as appropriate calculated values of the temperature of saturation of oil with paraffin. Identity index: $Q(t_s) = 0.873$.

As shown in the Table 3, the calculations by the formula (6) provide generally the sufficiently satisfactory results. Thereat, the relative error varies in the range of (6-20) %, enabling to use the formula (6). The noted results are summarized and presented in the form of bar charts (Fig.1), which clearly show the concentrations of asphaltenes, resins and paraffins, as well as the saturation temperature of oil with paraffin. In order to obtain more accurate forecast data on values of the temperature of saturation of oil with paraffin, it is necessary to arrange and to perform the more detailed, extended experimental studies. It should be noted that knowing of the temperature of saturation of oil with paraffin is required to control the products in the process of production and to make the appropriate decisions for prevention of generation of asphalt, resin, and paraffin depositions.

Table 3- Initial data and appropriate calculated values of the temperature of saturation of oil with paraffin

Field	Structural-group composition, %			Viscosity of oil, mm/s²		Ratio of viscosities	t_s, °C	$t_{s\ calculated}$, °C	$\Delta t_{s\ abs}$	$\Delta t_{s\ rel,\%}$
	Asphaltenes	Resins	Paraffins	at 20°C	at 50°C					
Uzen	2.36	16.2	21.1	1800	105.9	17	56	-	-	-
Botakhan	0.44	4.3	3.1	12.82	6.04	2.12	22	21.052	0.948	4.309
East Makat	0.01	5.21	2.1	11.2	4.98	2.25	16.67	18.919	2.249	13.4913
Kumkol	0.21	5.2	14.4	8.93	3.91	2.28	50	42.647	7.353	14.706
Akshabulak	0.23	6.3	16.1	13.11	4.66	2.81	53	61.557	8.557	16.1452

t_s – temperature of saturation of oil with paraffin; $\Delta t_{s\ abs}$ - absolute error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ abs} = |t_{s\ calculated} - t_s|$; $\Delta t_{s\ rel}$ - relative error of the temperature of saturation of oil with paraffin, $\Delta t_{s\ rel} = \frac{|t_{s\ calculated} - t_s|}{t_s} * 100\%$.

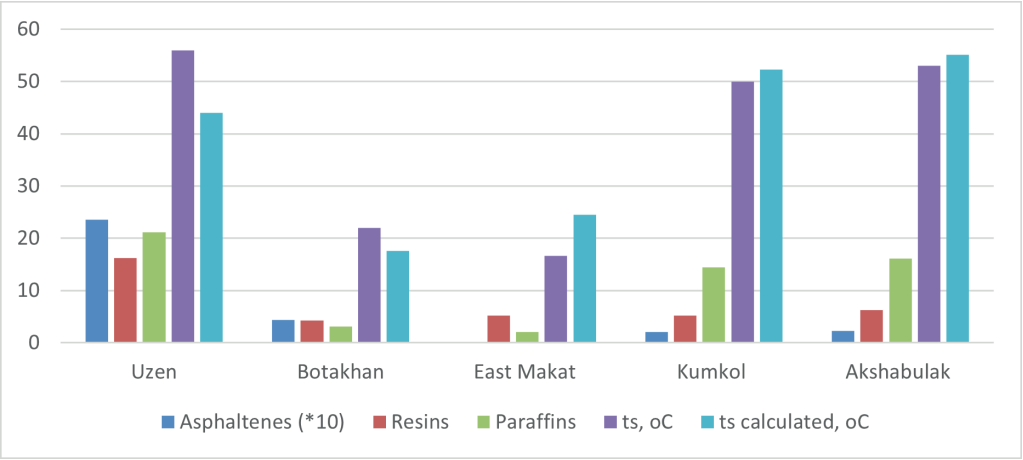

Figure 1. Structural-group composition the temperature of saturation of oil with paraffin in five fields of Kazakhstan

Conclusion. Thus, we have performed the analysis and summarization of the results of the studies for forecast estimation of the temperature of saturation of oil with paraffin. The statistical processing of the experimental data of different researchers has resulted in the dependence of the temperature of saturation of oil with paraffins on the concentration of asphaltenes, resins and paraffins for some regions. Estimation and comparative analysis of the uncertainties of the resulted models within the studied fields have been carried out. The performed studies on the classification of oils in various companies continued with studies devoted to finding methods for influencing the reservoir and increasing oil recovery (Santos et al., 2014:19), (Khasanov et al., 2018:5), (Purtova et al., 2011:5), (Ogolo et al.,2012:9), (Karazhanova et al., 2019 b:5).

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