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DEVELOPMENT OF THE DIAGNOSTIC METHOD FOR DETERMINATION OF DENSITY OF «WATER-OIL-SAND» TYPE MIXTURES

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A B S T R A C T

In this article has been proposed empirical dependencies for the direct determination – without mathematical calculations or experimental measurements of density of "water-oil-sand" type rheological complex mixtures resulting from arbitrary mixing of oil with water and sand in the processes of production, collection and transportation of well products. Also, based on the application of «Colour characteristics», a new diagnostic method that allows to explain the dependence of density, which is one of the main quality indicators of heterogeneous liquids transported by pipeline, on watering and temperature factors, as well as the concentration of filler element, leads to new trivial solutions in the processes of production and transportation. Given its practical significance and expediency for use in hydraulic calculations, its application prospects have been commented.

K E Y W O R D S

Granular filler;
Dispersed systems;
Heterogeneous liquids;
Suspension;
Density factor;
Empirical dependence.

Introduction

It is known that rheological complex dispersed systems – «water-oil-sand» based mixtures are formed as a result of arbitrary mixing of oil with water and granular filler component (sand, shale, mineral salts, porphyrin, mechanical mixtures and etc.) in the processes of its production, collection and transportation. The study of the basic physical properties of fluids, especially their density and viscosity, is very important when performing hydraulical calculations that are necessary in the process of pipeline flow of these heterogeneous fluids [1].

Also, the correctness of the choice of pumps used to ensure the flow of suspension, sludge and pulp generated by these mentioned mixtures through pipes is directly related to the hydraulical resistance in the pipeline [2].

Formulation of the problem

Usually, the density of process liquids is determined by experimental (with a pycnometer and hydrometer) and mathematical (using known formulas) methods in field conditions [3]. In some cases, even if the mass fraction x of granular filler – solid particles that form dispersed phase is known, the density of mixtures can also be determined using following additivity condition [4]:

$$\frac{1}{\rho_{mix}} = \frac{x}{\rho_{s.p.}} + \frac{(1-x)}{\rho_{liquid}} \quad (1)$$

here: ρ_{mix}, $\rho_{s.p.}$, ρ_{liquid} – are the densities of a mixture, solid particle (for example, sand) and liquid which is dispersion medium (for example, water-oil emulsion in the case under consideration) kg/m^3(or g/sm^3), respectively.

However, the solution to this problem requires consideration of many important factors, and often the proposed solutions do not justify themselves. For example, in the analysis of multicomponent systems, the use of linear dependencies, which characterize the dynamics of change of only one of the constituent elements, is considered unacceptable [5]. The studies show that the determination of density by additivity rule requires numerous analyzes in order to study the quantitative and qualitative composition of the granular element that is part of this mixture, which is accompanied by a number of material and time costs [6].

According to the authors, the generally accepted additivity rules and various empirical formulas, as well as mathematical models used to determine the quality indicators of emulsions in calculations do not always allow to predict the density and viscosity factors of heterogeneous systems with the required accuracy [7].

For this reason, the issue of easier and more accurate determination of the density parameter of "water-oil-sand" rheological complex mixtures transported by technological pipelines in the field is of great importance. The possibility of developing a new diagnostic method with the application of empirical dependence in order to solve the problem mentioned in the article, the exact determination of the density of «water-oil-sand» mixtures, has been investigated.

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Research and analysis of the results

In the first stage, the rheology and physico-chemical features of mixtures transported by pipeline have been taken into account. And, given the great practical importance of the determination of the dependence of hydraulic characteristics of pipelines on the above mentioned features, the impact of added sand on the rheological properties of water-oil systems of different compositions has been studied on the basis of rotoviscosimetric studies.

In the example of mixed oils in the laboratory, by adding granular filler element, sieved quartz sand in d = 0.1 mm fraction, in different calculated amounts (C = 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 5.0; 6.0; 7.0%) to water-oil mixture samples that taken from «Muradkhanli» oilfields oil storage station, of which initial watercut rate is β = 52% and mechanically stirring in a homogenizer for 10-15 minutes, rheological properties of free of sand and «water-oil-sand» suspensions has been identified in «Rheotest-2.1» viscometer and obtained rotoviscosimetric indicators for β = 52% watercut rate has been given in table 1.

Based on this table, $\tau = f(\dot{\gamma})$ flow curves for different percentages of sand in «water-oil-sand» mixtures are shown in figure 1.

As can be seen from the figure, the rheology of the systems varies significantly depending on the weight of the sand. At all flow velocities studied, structural instability - dilatation (n > 1) - is observed with an increasing percentage of sand in the mixture. Reynolds number was the first to claim that the possibility of dilatant properties in suspensions could be observed. This is once again confirmed in the "water-oil-sand" mixtures.

The above demonstrates once again that in order to increase the efficiency of in-field storage and pipelines, oil collection, preparation, and transportation systems in general, and to reduce additional energy costs during transportation of mixture of different oils with each other, as well as with mechanical particles, including sand,as well as factors such as watering must be taken into account,and rheological and physicochemical studies must be carried out separately, and the existing hydraulic criteria,especially density and viscosity, must be further clarified.

Taking this into consideration, in the second stage

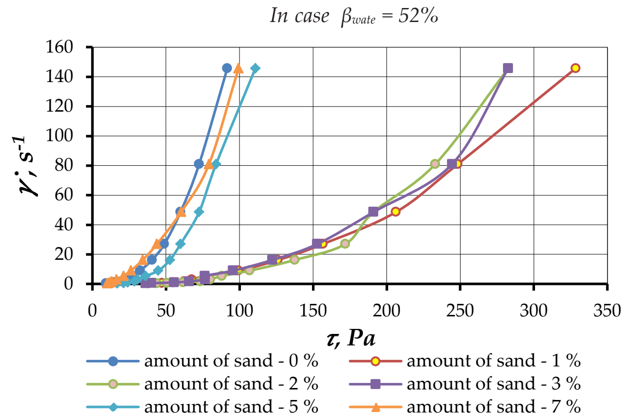

Fig.1. Flow curves for various percentages of sand in mixtures

of research,in order to forecast directly, without doing measurements, the mechanism of change of density, depending on temperature and watering factors of «water-oil-sand» mixtures, as well as the concentration (mass or percentage) of the granular element (sand, shale, mineral salts, corrosion products, etc.) that is mixed with it, a new empirical formula for determining the density index in a 3-dimensional system has been proposed as a result of experimental and mathematical study of the obtained suspensions with a pycnometer (or hydrometer) by using «MatLab R-2010a», one of the mathematical software packages of the world-famous «Microsoft» Corporation.

As a result of experimental and mathematical study of the obtained suspensions with a pycnometer (or hydrometer) a new empirical formula for determining the density index in 3D-dimensional system has been proposed.

The proposed empirical formula for the diagnosis of the density of an arbitrarily formed «water-oil-sand» mixture in the processes of production, storage and transportation is given below:

$$z = \frac{a + bx + cx^2 + dy + ey^2}{1 + fx + gx^2 + hx^3 + iy} \qquad (2)$$

here: x, y, z – parameters that indicate water cut , concentration of sand within, and density of water-oil-sand mixtures, respectively; $a, b, c, d, e, f, g, h, i$ – constant factors.

As a result of the relevant calculations performed at

Table 1

Rheological parameters of oil in various sand percentage(in β_{water} = 52%)

$\dot{\gamma}$, s^{-1}	τ, Pa											
0.33	9.27	26.98	37.94	40.65	43.84	39.4	36.24	30.33	29.51	16.86	14.33	10.12
0.6	12.22	34.56	47.21	52.21	50.58	36.25	40.21	36.37	35.41	21.08	17.7	10.96
1	15.17	44.68	54.8	55.64	61.54	49.52	55.63	49.12	46.37	24.03	21.08	11.8
1.8	19.39	51.42	62.38	69.97	73.34	53.53	65.75	46.37	53.11	28.66	25.29	13.07
3	23.18	60.7	67.44	77.56	80.09	61.12	76.71	57.32	60.7	30.77	28.66	16.44
5.4	27.82	73.34	76.4	80.22	87.86	75.87	76.4	69.97	72.5	36.25	34.56	21.08
9	32.46	76.4	99.32	87.86	106.96	80.22	95.5	8.09	81.77	44.68	42.99	26.13
16.2	40.47	103.14	126.06	114.6	137.52	103.14	122.24	99.32	95.5	52.69	50.58	34.14
27	48.9	129.88	156.62	137.52	171.9	133.7	152.8	126.06	114.6	59.85	57.32	43.84
48.6	59.85	171.9	206.28	183.36	191	175.72	191	168.08	145.16	72.5	67.44	60.28
81	72.5	217.74	248.3	236.84	233.02	225.38	244.48	217.74	198.64	84.04	78.4	79.24
145.8	91.68	290.32	328.52	313.24	282.68	282.68	282.68	282.68	259.76	110.78	95.5	99.32
	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
	Amount of sand, % (mass)											

Table 2

Values of the factors of the formula for determining the density of the mixture in accordance with the watering and temperature factors

t, °C	**Factors of formula (2)**								
	a	*b*	*c*	*d*	$e \cdot 10^{-5}$	*f*	*g*	*h*	*i*
5	1.232	- 0.355	0.092	- 0.008	2.505	- 0.393	0.094	- 0.002	- 0.004
20	1.065	- 0.244	0.048	- 0.007	0.097	- 0.317	0.065	- 0.002	- 0.006
40	1.066	-0.278	0.059	-0.009	2.688	- 0.359	0.077	- 0.002	- 0.006

different temperatures, the real calculated values obtained for the constant factors of the mathematical formula (1) were determined and are shown in table 2.

Considering the values in the table on dependence (2), with the application of the regression equation at different temperatures – t = 5; 20; 40 °C, respectively, the system of empirical formulas below has been proposed:

$$\rho_{mix} = \begin{cases} \dfrac{1.232 - 0.355x + 0.092x^2 - 0.008y + 2.505y^2}{1 - 0.393x + 0.094x^2 - 0.002x^3 - 0.004} \\ \\ \dfrac{1.065 - 0.244x + 0.048x^2 - 0.007y + 0.097y^2}{1 - 0.3166930x + 0.065x^2 - 0.002x^3 - 0.006} \\ \\ \dfrac{1.066 - 0.278x + 0.059 - 0.009y + 2.688y^2}{1 - 0.359x + 0.077x^2 - 0.002x^3 - 0.006} \end{cases} \quad (3)$$

The calculated values of the density of the «water-oil-sand» mixture by the application of the practical and proposed system of empirical equations (3) at various water cut, temperatures and different concentrations of sand determined, as well as the estimate of the absolute error between these indicators are given in table 3. As can be seen from the table, the absolute errors are around $\Delta\rho$ = ±3%, which is the allowable and indicates the parametric accuracy of the selected mathematical model [8].

Also, as the correlation coefficients are high enough – R_1^2 = 0.9867, R_2^2 = 0.9806 and R_3^2 = 0.9866 ($R_i^2 \approx 1.0$),

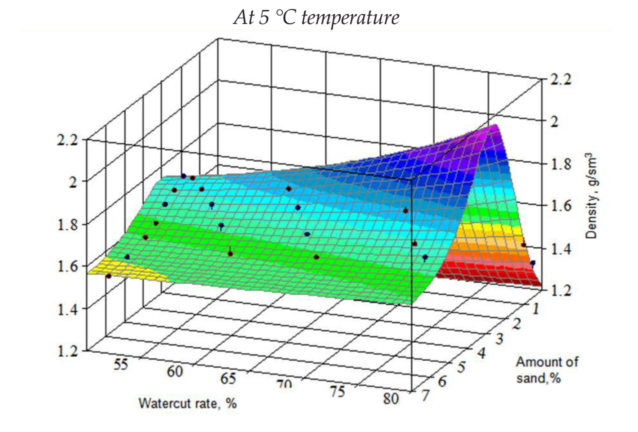

Fig.2. Diagnostic curve of density of «water-oil-sand» type mixtures in 3D

Table 3

Practical and calculated values of the density of «water-oil-sand» mixture at various watering rate, temperature and different concentration of sand

Temperature, °C														
5					20					40				
x	*y*	$z_{practical}$	$z_{calculated}$	*absolute error, Δz, %*	*x*	*y*	$z_{practical}$	$z_{calculated}$	*absolute error, Δz, %*	*x*	*y*	$z_{practical}$	$z_{calculated}$	*absolute error, Δz, %*
0.5	52	1.227	1.261	2.74	0.5	52	1.114	1.136	1.98	0.5	52	1.015	1.024	0.89
0.5	60	1.261	1.272	0.91	0.5	60	1.151	1.143	0.66	0.5	60	1.025	1.024	0.06
0.5	70	1.326	1.298	2.08	0.5	70	1.166	1.156	0.90	0.5	70	1.032	1.036	0.40
0.5	80	1.365	1.339	1.87	0.5	80	1.179	1.173	0.55	0.5	80	1.077	1.065	1.09
1.0	52	1.396	1.371	1.80	1.0	52	1.217	1.232	1.20	1.0	52	1.091	1.101	0.95
1.0	60	1.405	1.395	0.70	1.0	60	1.253	1.254	0.10	1.0	60	1.113	1.111	0.14
1.0	70	1.424	1.443	1.35	1.0	70	1.308	1.294	1.09	1.0	70	1.165	1.143	1.86
1.0	80	1.482	1.518	2.41	1.0	80	1.343	1.354	0.85	1.0	80	1.193	1.211	1.43
1.5	52	1.528	1.505	1.50	1.5	52	1.382	1.345	2.66	1.5	52	1.226	1.199	2.16
1.5	60	1.565	1.549	1.06	1.5	60	1.426	1.394	2.22	1.5	60	1.245	1.228	1.34
1.5	70	1.612	1.631	1.20	1.5	70	1.455	1.488	2.24	1.5	70	1.279	1.302	1.78
2.0	52	1.636	1.638	0.09	2.0	52	1.479	1.465	0.93	2.0	52	1.315	1.307	0.61
2.0	60	1.687	1.702	0.88	2.0	60	1.492	1.512	2.89	2.0	60	1.34	1.364	1.76
2.5	52	1.723	1.728	0.30	2.5	52	1.579	1.566	0.81	2.5	52	1.375	1.395	1.43
3.0	52	1.767	1.756	0.64	3.0	52	1.646	1.621	1.52	3.0	52	1.465	1.433	2.16
3.5	52	1.734	1.735	0.07	3.5	52	1.612	1.623	0.67	3.5	52	1.411	1.423	0.87
4.0	52	1.701	1.695	0.37	4.0	52	1.578	1.589	0.74	4.0	52	1.383	1.388	0.34
4.5	52	1.645	1.653	0.51	4.5	52	1.525	1.545	1.33	4.5	52	1.345	1.348	0.24
5.0	52	1.613	1.619	0.41	5.0	52	1.502	1.505	0.21	5.0	52	1.31	1.315	0.41
6.0	52	1.587	1.579	0.48	6.0	52	1.479	1.458	1.44	6.0	52	1.286	1.277	0.71
7.0	52	1.567	1.569	0.12	7.0	52	1.446	1.452	0.44	7.0	52	1.265	1.268	0.20

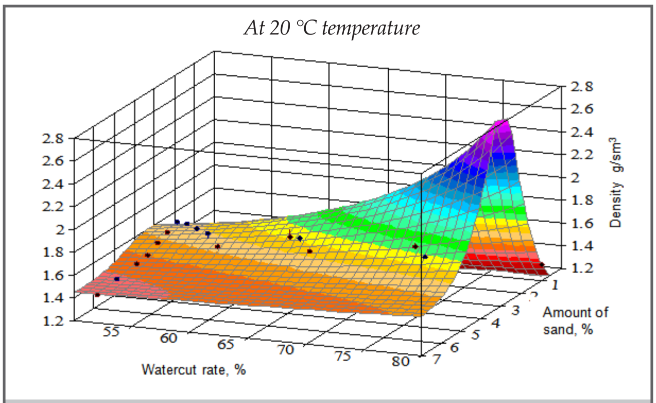

Fig.3. Diagnostic curve of density of «water-oil-sand» type mixtures in 3D

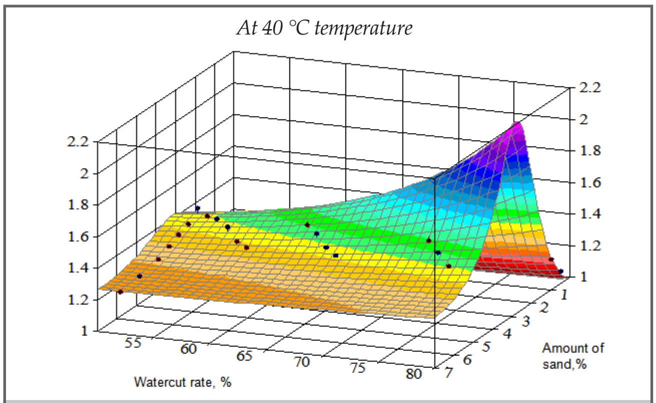

Fig.4. Diagnostic curve of density of «water-oil-sand» type mixtures in 3D

respectively, once again emphasizes the correct choice of empirical dependence. With the application of the system of equations (3) diagnostic curves that evaluate the change in the density profile of «water-oil-sand» mixtures in 3D at different (t = 5, 20 and 40 °C) temperatures are given in figures 2-4.

As can be seen from curves, the different shades of color reflected on the surface (profile) of spatially structured figures show change activity depending on the degree of water cut, temperature and amount of sand by percentage.

Thus, the orange color in the «colour bar» characterize – «progressive», green – «active», and blue and navy blue – «super active» zones. Based on the «Colour characteristics», it is planned to further develop a more accurate diagnosis of the determining dependence of density of water-oil-sand based mixtures on watering and temperature factors, as well as direct determination of the amount of granular element, and research is currently underway.

Conclusion

Proposed new diagnostic method for the direct – without experimental measurements, determination of the "density" parameter, which is one of the main quality indicators of heterogeneous «water-oil-sand» mixtures transported by pipeline, depending on temperature and water cut factors, as well as the amount of sand volume is practically important, since it opens up new trivial solutions in oil production and transportation processes, and its application in hydraulic calculations is expedient, so it is worth to think about its future prospects. The above mentioned makes it necessary to reconsider and clarify the existing hydraulical criterias.

References

1. Ismayilov, G. G., Safarov, N. M. (2010). Reotechnology of visco-loose systems. *Baku: «MSM»*.

2. Lurye, M. V.(2003). Mathematical modeling of the processes of pipeline transportation of oil, oil products and gas. *Moscow: RGU.*

3. Safiyeva, R. Z., Sunyayev, R. Z. (2007). Physical and chemical properties of oil dispersed systems and oil and gas technologies. *Moscow-Ijevsk: ICR, Regular and Chaotic Dynamics*.

4. Safarov, N. M. (2014). On the need to take into account the rheophysical features of oil-water-sand mixtures during their collection and transportation. *Pipeline Transport (Theory and Practice)*, 3-4(43-44), 44-49.

5. Ismayilov, G. G., Ismayilova, F. B., Musayev, S. F. (2021). Prediction of viscosity properties of oil-water systems. *SOCAR Proceedings*, SI1, 109-115.

6. Evdokimov, E. N., Losev, A. P., Fesan, A. A. (2012). Lack of additivity of oil mixtures. *Drilling and Oil*, 1, 27-28.

7. Evdokimov, I. N., Fesan, A. A., Kronin, A. M., Losev, A. P. (2016). Common features of «Rag» layers in water-in-crude oil emulsions with different stability. Possible presence of spontaneous emulsification. *Journal of Dispersion Science and Technology*, 37(11), 1535–1543.

8. Shramm, G. (2003). Fundamentals of practical rheology and rheometry. *Moscow: ColosS.*

О разработке диагностического метода для определения плотности в смесях типа «вода-нефть-песок»

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Реферат

В статье, с целью прямого - без проведения математических расчетов или практических замеров, определения показателей плотности смесей типа «вода-нефть-песок», создающихся в результате произвольного смешения нефти с водой и песком при добыче, сборе и транспортировке реологически сложной скважинной продукции, предложена группа эмпирических зависимостей. Также, учитывая практическую значимость, целесообразность использования в вычислительных работах и возможностей создания новых тривиальных решений в процессах добычи и транспортировки, на основе применения «Цветовых характеристик» комментируются перспективы применения нового метода диагностики, позволяющего объяснить зависимости одного из основных качественных показателей- плотности гетерогенных жидкостей от водонасыщенности и температурного факторов, а также концентрации наполнителя.

Ключевые слова: сыпучий наполнитель; дисперсные системы; гетерогенные жидкости; суспензия; фактор плотности; эмпирическая зависимость.

«Su-neft-qum» tipli qarışıqların sıxlığının təyini üçün diaqnostik üsulun işlənilməsi

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Xülasə

Məqalədə quyu məhsulunun hasilatı, yığımı və nəqli proseslərində neftin su və qumla ixtiyari qarışmasından yaranan «su-neft-qum» tipli reoloji mürəkkəb qarışıqların sıxlıq göstəricisinin riyazı hesablamalar və ya təcrübü ölçmələr aparılmadan - birbaşa təyini məqsədilə empirik asılılıqlar təklif edilmişdir. Həmçinin, «Color xarakteristikası»-nın tətbiqi əsasında, boru kəmərilə nəql edilən heterogen mayelərin əsas keyfiyyət göstəricilərindən biri sayılan sıxlığın sulaşma və temperatur amillərindən, eləcə də doldurucu ünsürün konsentrasiyasından asılılığını izah etməyə imkan verən yeni diaqnostik üsulun, hasilat və nəql proseslərində yeni trivial həllərə yol açdığını, praktiki cəhətdən əhəmiyyətini və hidravliki hesablamalarda istifadəsinin məqsədəuyğunluğunu nəzərə alaraq, onun tətbiq perspektivləri şərh edilmişdir.

Açar sözlər: dənəvər doldurucu; dispers sistemlər; heterogen mayelər; suspenziya; sıxlıq amili; empirik asılılıq.