NAFTA-GAZ

Nafta-Gaz 2024, no. 8, pp. 488–494, DOI: 10.18668/NG.2024.08.03

Increasing efficiency of technological processes in oil production based on innovative rheotechnologies

Zwiększenie wydajności procesów technologicznych w produkcji ropy naftowej w oparciu o innowacyjne technologie reologiczne

Yevgeniya V. Mammadova

Azerbaijan State Oil and Industry University

ABSTRACT: Numerous studies by various authors have been devoted to gas lift wells. The scientific literature has addressed issues of increasing production of both Newtonian and non-Newtonian oils. Despite these efforts, the efficiency of the gas lift method remains relatively low, necessisating novel approaches. One of the methods to increase the productivity of gas lift wells may be the use of innovative rheotechnologies. Rheotechnology laverages knowledge about the rheological properties of formation fluids to address specific technological problems. This paper describes studies of non-Newtonian oils, their rheological properties, and their impact on the technical and economic indicators of gas lift wells. The analysis showed that by studying the formation of the non-Newtonian structure of oil, it is possible to influence its relaxation properties, and thus obtain the movement of an abnormal oil (anomalous fluid), both in the bottom-hole zone of the well and in the lifting pipes. The results of experimental studies showed that viscoelastic crude oil flowing into the wellbore contains an increased volume of reservoir gas, which, along with the injected working agent, perform additional work in lifting gas-liquid mixtures to the surface. During gas lifting operations, phenomena such as breakthrough and slippage of the working agent can be observed. Addressing all these factors enables better control over gas lift well operations and, consequently, improves the efficiency of the tecnological processes.

Key words: abnormal oil, reservoir oil viscosity, structural properties, gas lift, velocity, efficiency, rheophysical characteristic.

STRESZCZENIE: Wielu autorów poświęciło swoje prace tematyce odwiertów eksploatowanych z wykorzystaniem metody sprężonego gazu. W literaturze naukowej poruszono kwestie zwiększenia wydobycia zarówno ropy o właściwościach newtonowskich, jak i nienewtonowskich. Pomimo tych wysiłków wydajność metody z zastosowaniem sprężonego gazu pozostaje stosunkowo niska, co wymaga opracowania nowych rozwiązań. Jedną z metod zwiększenia wydajności odwiertów eksploatowanych za pomocą sprężonego gazu może być zastosowanie innowacyjnych technologii reologicznych. Technologia reologiczna wykorzystuje wiedzę o właściwościach reologicznych płynów złożowych do rozwiązywania konkretnych problemów technologicznych. W artykule opisano badania nad ropą o właściwościach nienewtonowskich, jej właściwościami reologicznymi oraz ich wpływem na wskaźniki techniczne i ekonomiczne odwiertów eksploatowanych metodą sprężonego gazu. Przeprowadzona analiza wykazała, że badając proces formowania się nienewtonowskiej struktury ropy naftowej można wpływać na jej właściwości relaksacyjne, a tym samym uzyskać ruch nietypowej ropy naftowej („cieczy anomalnej”), zarówno w strefie przyodwiertowej, jak i w rurach wydobywczych. Wyniki badań eksperymentalnych wykazały, że lepkosprężysta ropa naftowa wpływająca do odwiertu charakteryzuje się zwiększoną objętością gazu złożowego, który wraz z wtryskiwanym czynnikiem roboczym pomaga wypychać mieszaniny gazu i cieczy na powierzchnię. Podczas operacji z zastosowaniem gazodźwigu można zaobserwować zjawiska takie jak przebicie i poślizg czynnika roboczego. Uwzględnienie wszystkich tych czynników umożliwia lepszą kontrolę nad operacjami podnoszenia gazu, a w konsekwencji poprawia efektywność procesów technologicznych.

Słowa kluczowe: nietypowa ropa naftowa, lepkość ropy w złożu, właściwości strukturalne, gazodźwig sprężarkowy, prędkość, wydajność, charakterystyka reo-fizyczna.

Introduction

Reserves of high-viscosity abnormal oils are one of the components of the raw material base of the oil industry.

The production of hard-to-recover oils in Azerbaijan is particularly significant for the country's fuel and energy balance. The fields of Western Absheron contain more than 100 million tons of undeveloped reserves of anomalous oil.

Corresponding author: Y.V. Mammadova, e-mail: *mammadova.yevgeniya.59@mail.ru*

Article contributed to the Editor: 21.02.2024. Approved for publication: 18.07.2024.

The school of Academician A. Kh. Mirzajanzadeh has amassed extensive field and experimental experience in studying the rheophysical properties of non-Newtonian hydrocarbons produced by the gas-lift method.

This article presents calculations aimed at determining the rate of pressure change in both porous mediums and wellbores. The "formation-well" system's response delay to the injected working agent, compressed gas, necessitates consideration of relaxation times for the gas-liquid mixture within both the formation and in the wellbore. In this regard, it is relevant and of interest to determine the relaxation time and search for ways to regulate this parameter.

Numerous studies have proposed using physical fields such as thermal, magnetic, and electric fields to regulate relaxation times and consequently alter the properties of Newtonian fluids to anomalous viscoelastic oils (Mirzadzhanzade et al, 2002; Khasanov and Bulgakova, 2003; Salavatov and Mamedova, 2012).

Thus, in oil field practice, pressure treatment of well products is employed to rapidly alter this parameter. Solving this problem enables control over the rheological properties of formation fluids by choosing appropriate technological production mode. Experimental work was carried out on the treatment of non-Newtonian oils by sequential unloading of the system. As a result of pressure unloading treatment, the test fluid began to exhibit Newtonian properties while preserving nonlinear viscoelasticity (Mirzadzhanzade et al., 1999; Balmforth et al., 2009; Mamedov and Manafov, 2012). The assessment of rheological properties before and after the experiment in the PVT bomb was carried out using a "Reotest-2" rotational viscometer with the sequential use of computer data processing.

Methodology

To study changes in the rheophysical properties of viscoelastic oil, field samples of well products underwent treatment. Thermal and pressure treatments revealed that oils acquired Newtonian properties. Experiments were also carried out to study the effect of the presence of resin in oil on the efficiency of gas lift and relaxation time. Resin was introduced into the formation fluid at a temperature above the crystallization temperature, and relaxation times were determined by analyzing pressure recovery curvse in capillaries. It was observed that increasing resin concentration prolonged relaxation time.

Considering the "reservoir-well-pipeline" system as a single hydrodynamic system allows us to attribute non-equilibrium phenomena to both well production characteristics and formation properties. Non-equilibrium processes in the reservoir result in the phenomenon of the initial pressure gradient of physical fields. This approach legitimizes exploring methods to regulate physical fields.

Various oils with different asphaltene and resin content were subjected to heat treatment. The experiments were carried out using «NESLAB» cooling apparatus with subsequent viscometric measurements. The equipment used made it possible to perform heat treatment of the fluid, both during movement and relaxation. It was possible to achieve different cooling rates from –272.15°K/min (1°C/min) to –1269.15°K/min (4°C/min), which influenced the resulting effect.

When testing oils with resin content of 50% and higher and a low resin and asphaltene content (1–2%), no improvement in rheological parameters was noted. The possibility of heat treatment of oils at relatively low temperatures (323°K) due to the multiplicity of processing was established.

One of the conventional ways to obtain information about the state of the "reservoir-saturating fluid" system is to measure the pressure build-up curve, which can be influenced by the properties of both formation rock and oil. During the experiment, samples of hydrophilic (permeability $0.35 \cdot 10^{-12}$ m^2) and hydrophobic (permeability $1.12 \cdot 10^{-12}$ m^2) rocks were used.

The following models of liquid were used:

- transformer oil + 5% resin;
- transformer oil + 10% resin;
- transformer oil + 15% resin.

The system temperature was maintained constant ($T = 313$°K), which is higher than the crystallization temperature of resin. Studies on gas-liquid mixture filtration processes were carried out under constant pressure drawdown ($\Delta p = 1.0$ MPa).

Experimental results showed that the pressure build-up time in a hydrophobic medium is significantly longer than in a hydrophilic rock, although the permeability of a hydrophobic medium is 3 times greater than that of a hydrophilic one.

As the outlet back pressure increases, the pressure build-up time decreases. Notably, in the presence of resin in transformer oil, pressure in hydrophobic porous media restored to inlet pressure by 0.1–0.15 MPa upon pressure built-up removea, a phenomenom not observed in other cases.

These observed effects are attributed to surface phenomena and the relaxation properties of the liquid.

It is known that non-Newtonian oils exhibit anomalous properties, primarily characterized by their viscosity variability in response to applied shear stress.

The viscosity of oil depends on the presence of high molecular weight compounds, gaseous and solid substances, and their degree of dispersion. An increase in the content of high-molecular compounds in hydrocarbon liquids, such as resins and asphaltenes, leads to the formation of structural spatial networks (Balmforth et al., 2009; Darbouli et al., 2013; El-Hoshoudy, et al., 2016; Frigaard et al., 2017).

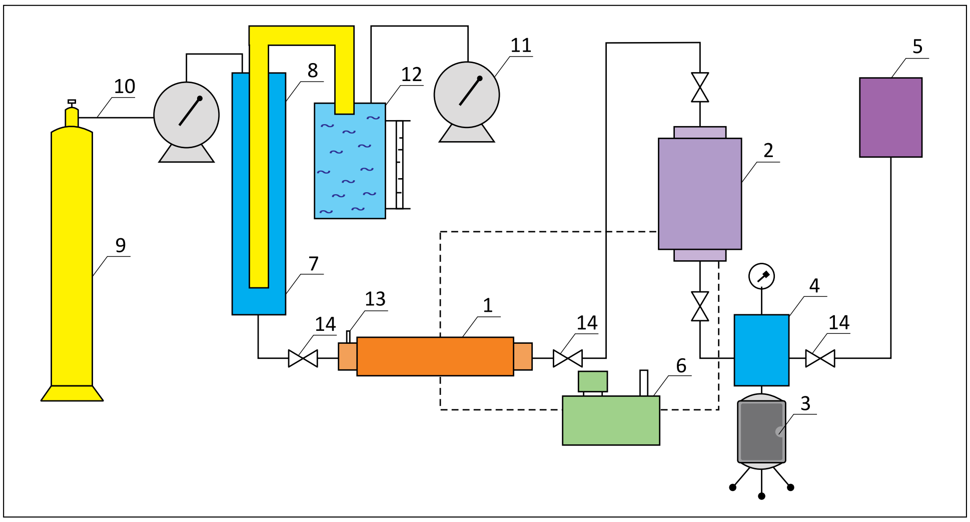


Figure 1. The experimental setup (scheme); 1 – column with a porous medium (reservoir model); 2 – high-pressure bomb; 3 – hand press; 4 – manifold; 5 – fluid displacement vessel; 6 – thermostat; 7 – gas-liquid lift model, consisting of a pipe with diameter $d = 8 \cdot 10^{-3}$ m, length 3.4 m; 8 – outer pipe with diameter $d = 20 \cdot 10^{-3}$ m, length 3.5 m; 9 – gas cylinder; 10 – pressure regulator; 11 – gas meter; 12 – measuring vessel; 13 – exemplary manometer; 14 – adjustment valves

Rysunek 1. Układ doświadczalny (schemat); 1 – kolumna z medium porowatym (model zbiornika); 2 – bomba wysokociśnieniowa; 3 – prasa ręczna; 4 – kolektor; 5 – naczynie wyporowe; 6 – termostat; 7 – model gazodźwigu, składający się z rury o średnicy $d = 8 \cdot 10^{-3}$ m, długości 3,4 m; 8 – rura zewnętrzna o średnicy $d = 20 \cdot 10^{-3}$ m, długości 3,5 m; 9 – butla gazowa; 10 – reduktor ciśnienia; 11 – miernik gazu; 12 – naczynie pomiarowe; 13 – przykładowy manometr; 14 – zawory regulacyjne

To study the issue of increasing efficiency of gas lift when producing non-Newtonian oils, laboratory experiments were carried out using the setup outlined in Figure 1. The experimental setup consists of the following main components: transformer oil with a density of 820 kg/m^3 and a 10% solution (resin and transformer oil) were used as test liquids.

It is known that when high molecular weight resin compounds are added to viscous liquids, they transform into a non-Newtonian system. After establishing the operating mode of the gas lift, both the productivity of the well and the readings of gas meters are measured.

To obtain the relationships between the productivity of the lift, the flow rate of the working agent $Q = Q(V_g)$, and the specific consumption of the working agent $R_0 = R_0(V_g)$, the operating mode of the well was changed several times, and the necessary measurements were taken for each mode.

Results and Discussion

Analysis of the results of the experiments shows that when the rate of pressure change is consistent in both the porous medium and the lift, degassing of viscoelastic oil in the reservoir experiences difficulties due to process imbalances, and the oil entering the well receives an increased amount of reservoir gas. This phenomenon contributes beneficially to the lifting process. When lifting viscoelastic oils, such phenomena as breakthrough and slippage of compressed gas are excluded, with gas working effectively until the moment of oil piston displacement. Consequently, gas-lift wells producing viscoelastic oils exhibit lower specific agent consumption compared to gas-lift wells with conventional viscous oils.

The results of experiments on lifting mixture graphical dependencies are presented in Figure 2 and Table 1.

Table 1. The results of experimental studies of lifting Newtonian (transformer oil) and non-Newtonian (a mixture of transformer oil and resin) liquids

Tabela 1. Wyniki badań eksperymentalnych podnoszenia cieczy newtonowskich (olej transformatorowy) i nienewtonowskich (mieszanina oleju transformatorowego i żywicy)

Transformer oil				10% resin solution in transformer oil			
Gas consumption, $V_{g0}10^{-6}$	Fluid flow rate, Q_f10^{-6}	Gas flow rate, Q_g10^{-6}	Specific gas consumption, R_0	Gas consumption, V_g10^{-6}	Fluid flow rate, Q_f10	Gas flow rate, Q_g10^{-6}	Specific gas consumption, R_0
[m^3/s]	[m^3/s]	[m^3/s]	[m^3/m^3]	[m^3/s]	[m^3/s]	[m^3/s]	[m^3/m^3]
100	0.078	3.2	1252	100	0.1	4	1000
200	0.800	15.7	250	200	1.3	17	153
300	2.000	45.0	150	300	2.5	70	120

cont. Table 1/cd. Tabela 1

Transformer oil				10% resin solution in transformer oil			
Gas consumption, $V_g 10^{-6}$	**Fluid flow rate, $Q_f 10^{-6}$**	**Gas flow rate, $Q_g 10^{-6}$**	**Specific gas consumption, R_0**	**Gas consumption, $V_g 10^{-6}$**	**Fluid flow rate, $Q_f 10$**	**Gas flow rate, $Q_g 10^{-6}$**	**Specific gas consumption, R_0**
[m^3/s]	**[m^3/s]**	**[m^3/s]**	**[m^3/m^3]**	**[m^3/s]**	**[m^3/s]**	**[m^3/s]**	**[m^3/m^3]**
400	2.500	76.0	160	400	3.1	85	129
500	3.000	98.0	169	500	3.1	87	161
600	3.300	100.0	181	600	3.0	81	160
700	2.800	80.0	250	700	2.4	68	240
800	2.000	41.0	400	800	1.8	16	144

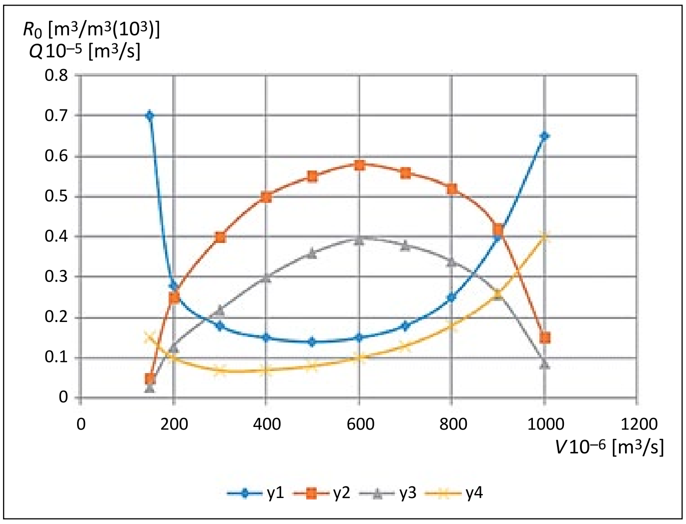


Figure 2. The dependence of the specific consumption of the working agent R_0 and the lift performance Q_f from the consumption of the working agent V_g; 1, 3 – transformer oil; 2, 4 – transformer oil + 10% resin

Rysunek 2. Zależność jednostkowego zużycia czynnika roboczego R_0 i wydajności podnoszenia Q_f od zużycia czynnika roboczego V_g; 1, 3 – olej transformatorowy; 2, 4 – olej transformatorowy + 10% żywica

Interpretation results

The obtained results show that lifting the same volume of viscoelastic fluid (a mixture of resin and transformer oil) requires less gas consumption than the same volume of Newtonian fluid (Frigaard et al., 2017).

Analysis of the obtained results of experimental studies shows that the viscoelastic properties of liftable liquids can be used to improve technological processes of oil production.

The rheological properties of non-Newtonian oils were studied using the Reotest-2 rotational viscometer. A resin solution in transformer oil (at varying percentages) served as a model for non-Newtonian oil, with shear rates in the range $\gamma = 100/1300$ s^{-1} and corresponding values of the tangential shear stress τ.

The research results are given in Table 2. The corresponding values of effective viscosity can be determined from the relationship ($\eta_{eff} = \tau/\gamma$).

The resulting graphical dependence $\tau = f(\gamma)$ does not make it possible to evaluate the presence of viscoelastic properties of the fluid (Figure 3), which led to the decision to create a technique for identifying the rheological properties of the fluid.

Estimation of relaxation time

To assess the relaxation properties, data were processed according to the method proposed by Cross and developed by Brill and Mukherjee (1999) and Mamedova (2016). The essence of this approach is to determine the relationship between the values of the tangential shear stress (τ) and the values of the effective viscosity (η_{eff}) in the following form:

Table 2. Properties of rheological fluid at different percentages (a mixture of transformer oil and resin)

Tabela 2. Właściwości płynu reologicznego o różnej zawartości procentowej (mieszanina oleju transformatorowego i żywicy)

System	Density, ρ [kg/m^3]	Viscosity, μ [mPa·s]	Measurement interval		η_{eff} [Pa·s]	$1/\eta_{eff}^2$ [Pa^{-2}s^{-2}]	τ^2 [Pa^2]
			T [Pa]	Γ [s^{-1}]			
Transformer oil	878	10.0	–	–	–	–	–
Transformer oil +5% resin	890	12.6	9.5 11.1 16.3 17.5	364.5 437.4 656.0 729.0	0.0261 0.0255 0.0248 0.0240	1470 1538 1639 1736	90 123 266 306

cont. Table 2/cd. Tabela 2

System	Density, ρ [kg/m^3]	Viscosity, μ [mPa·s]	Measurement interval		η_{eff} [Pa·s]	$1/\eta_{eff}^2$ [Pa^{-2}s^{-2}]	τ^2 [Pa^2]
			T [Pa]	Γ [s^{-1}]			
Transformer oil	878	10.0	–	–	–	–	–
Transformer oil +10% resin	900	17.2	31.2	1312.0	0.0238	1770	973
			12.5	364.5	0.0342	855	156
			13.7	437.4	0.0313	1021	188
			17.7	656.0	0.0270	1371	313
Transformer oil +15% resin	915	20.5	18.9	729.0	0.0259	1492	357
			32.5	1312.0	0.0248	1639	1056
			12.7	218.7	0.0580	294	161
			13.2	243.0	0.0543	344	174
			14.5	364.5	0.0398	633	210
			15.2	437.4	0.0347	833	231
			20.3	656.0	0.0309	1048	412
			21.2	729.0	0.0291	1182	449
			35.4	1312.0	0.0270	1371	1253

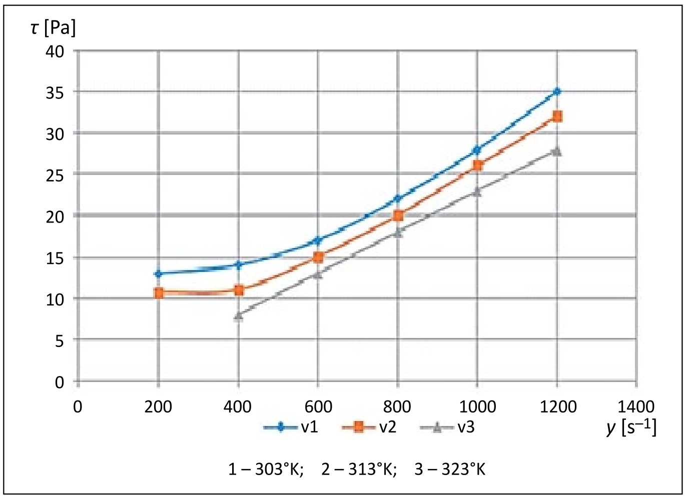


Figure 3. Dependence $\tau = \tau(\gamma)$ for transformer oil + 10% resin solution at different temperatures

Rysunek 3. Zależność $\tau = \tau(\gamma)$ dla oleju transformatorowego + 10% roztwór żywicy w różnych temperaturach

$$\frac{1}{\eta_{eff}^2} = \frac{1}{\eta_t^2} + \frac{\tau^2}{4G^2\eta_t^2} \tag{1}$$

where:

G – modulus of shear elasticity of the studied liquid,

η_t – proper viscosity.

It should be noted that equation (1) will take place if η_t and G take constant values. i.e. provided that the system is linear. The indicators of the curves (Figure 3) of the dependence $\tau = f(\gamma)$ were recalculated in coordinates $1/\eta_{eff}^2 = f(\tau^2)$.

Based on the results of the calculation using the above formula, a new dependence was constructed, and the resulting curves are presented in Figure 4. The system is linear in the straight section of the graph.

Based on the nature of the curve, the range of shear rates can be estimated and the region of nonlinearity can be highlighted.

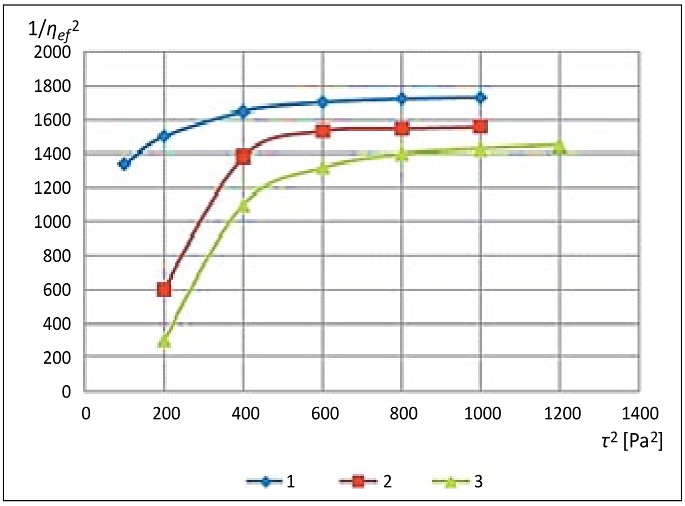


Figure 4. Dependence $1/\eta_{eff}^2 = \tau^2$ for transformer oil + resin content at various temperatures: 1 – 303°K; 2 – 313°K; 3 – 323°K

Rysunek 4. Zależność $1/\eta_{eff}^2 = \tau^2$ dla oleju transformatorowego + zawartość żywicy w różnych temperaturach: 1 – 303°K; 2 – 313°K; 3 – 323°K

The results of viscometric studies for a solution (transformer oil + resin) at different temperatures show that those sections of the dependences that are parallel to the τ^2 axis correspond to the viscous flow of the liquid and are linear in nature. The other part of the dependencies which corresponds to nonlinear sections expresses the manifestation of the viscoelastic properties of the test fluid.

As oil moves towards the bottom of the well, the pressure in its volume drops, causing gas to be released. The rate of changes in reservoir pressure values is determined from the expression shown below:

$$\left|\frac{dp}{dt}\right| = \left|\frac{dp}{dr}\frac{dr}{dt}\right| = \frac{dp}{dr}\frac{1}{m}\upsilon = \left(\frac{dp}{dr}\right)^2 \frac{k}{\mu m} = \frac{\mu}{km}\upsilon^2 = $$
$$= \frac{\mu}{km}\left(\frac{Q}{2\pi hr}\right)^2 \tag{2}$$

Using the Cross's method and data from viscometry studies, it is possible to determine the relaxation time of the tested solution at different temperatures. Assuming that $x = \tau^2$ and $y = 1/(\eta_t^2)$, the following dependence can be written:

$$Y = aX + b$$

$$a = \frac{1}{4G^2\eta_t^2}; \quad b = \frac{1}{\eta_t^2}1$$

Let φ be the angle of inclination of the straight line to the abscissa axis and b to be the segment that is cut off by the straight line along the ordinate axis. Then:

$$G = \sqrt{\frac{b}{4\,\mathrm{tg}\varphi}}\ [\mathrm{Pa}] \tag{3}$$

$$\eta_t = \sqrt{\frac{1}{b}}\ [\mathrm{Pa \cdot s}] \tag{4}$$

By dividing the value of the elastic modulus by the viscosity of the solution, the relaxation time of the solution at a certain temperature can be found. The research results are presented in Table 3, showing that with increasing temperature, the relaxation time of anomalous oils decreases.

The rate of pressure change in the reservoir model can be estimated from the expression:

$$\frac{dp}{dt} = \frac{\mu}{km}\left(\frac{Q}{2\pi hr}\right)^2 \tag{5}$$

Studies have shown that the velocity of fluid movement in a porous medium takes on the greatest value in the bottomhole zone of the well. However, the fluid gains its maximum velocity value near the walls of the lift.

Table 3. The results of studies on the evaluation of relaxation time (for different composition of the studied solution)

Tabela 3. Wyniki badań oceny czasu relaksacji (dla różnych składów badanego roztworu)

b	Temperature, *T*	Slope, *φ*/tg *φ*	True viscosity, *η*	Elastic modulus, *G*	Relaxation time, *t*
	[°C]		[mPa·s]	[Pa]	[s]
0.3	30	30/0.57	1.30	0.36	3.6
1.1	40	45/1.00	0.95	0.50	1.9
2.3	50	60/1.73	0.65	0.57	1.1
9.0	60	70/2.74	0.33	0.90	0.4

Calculation of pressure rate changes when lifting Newtonian and non-Newtonian oils

Calculations were made to assess the influence of the rheological properties of the lifted liquids on the parameters of the gas lift. Based on the calculation results it was determined that the shear rate (γ) in the near-wellbore zone does not exceed the value (10^{-1}–10).

Let us consider an example of changing the rate of pressure reduction when lifting Newtonian oil (Table 2) with the following well parameters:

$$Q = 3.5 \cdot 10^{-6}\ \mathrm{m^3/s};\ d = 4.5\ \mathrm{cm} = 4.5 \cdot 10^{-2}\ \mathrm{m};\ \mu = 10\ \mathrm{mPa/s};$$
$$k = 1.1 \cdot 10^{-12}\ \mathrm{m^2};\ m = 0.23$$

$$\frac{dp}{dt} = \frac{10\ \mathrm{mPa \cdot s}}{1.1 \cdot 10^{-12} \cdot 0.23\ \mathrm{m^2}}\left(\frac{3.5 \cdot 10^{-6}\,\mathrm{m^3/s}}{23.14 \cdot 2.25 \cdot 10^{-2}\,\mathrm{m^2}}\right)^2 = \\ = 2.4 \cdot 10^{-5}\ \mathrm{MPa/s}$$

For the flow of a viscoelastic fluid ($\mu = 20.5$ mPa/s; $Q = 2.5 \cdot 10^{-6}$ m^3/s), the rate of pressure decrease will be:

$$\frac{dp}{dt} = \frac{20.5\ \mathrm{mPa \cdot s}}{1.1 \cdot 10^{-12} \cdot 0.23\ \mathrm{m^2}}\left(\frac{2.5 \cdot 10^{-6}\,\mathrm{m^3/s}}{23.14 \cdot 2.25 \cdot 10^{-2}\,\mathrm{m^2}}\right)^2 = \\ = 2.3 \cdot 10^{-5}\,\mathrm{MPa/s}$$

When lifting liquid, hydraulic resistance can be neglected as it represents a small fraction of the difference between the wellhead and the bottom of the well. Therefore:

$$dp/dt = dp/dh \cdot dh/dt$$

Velocity gradients as oil moves through the wellbore will also be small. Calculations of the rate of pressure reduction when lifting Newtonian fluid along the lifting pipes showed the following results:

$$\gamma_f = \rho_f g = 878\ \mathrm{kg/m^2} \cdot 9.81\ \mathrm{m/s^2} = 8613\ \mathrm{Pa/m}$$

$$\upsilon_* = \frac{4Q}{\pi d^2} = \frac{43.5 \cdot 10^{-6}\,\mathrm{m^3/s}}{3.14 \cdot 64 \cdot 10^{-6}\,\mathrm{m^2}} = 7 \cdot 10^{-2}\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$dp/dt = 8613\ \mathrm{Pa/m} \cdot 7 \cdot 10^{-2}\ \mathrm{m/s} = 6 \cdot 10^{-4}\ \mathrm{MPa/s}$$

When lifting a viscoelastic fluid:

$$\gamma_f = \rho_f g = 915\ \mathrm{kg/m^2} \cdot 9.81\ \mathrm{m/s^2} = 8976\ \mathrm{Pa/m}$$

$$\upsilon_* = \frac{4Q}{\pi d^2} = \frac{42.5 \cdot 10^{-6}\,\mathrm{m^3/s}}{3.14 \cdot 64 \cdot 10^{-6}\,\mathrm{m^2}} = 5 \cdot 10^{-2}\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$dp/dt = 8976\ \mathrm{Pa/m} \cdot 5 \cdot 10^{-2}\ \mathrm{m/s} = 4.5 \cdot 10^{-4}\ \mathrm{MPa/s}$$

As is known from rheological studies, intensive changes in the viscoelastic properties of oil will occur at a shear rate $\gamma = 10\ \mathrm{s^{-1}}$. Analysis of the results of the experiments shows that at the same rate of pressure drawdown in the porous medium and the lift, degassing of viscoelastic oil in the reservoir experiences difficulties due to the non-equilibrium of this process. Oil entering a gas lift well releases an additional amount of reservoir gas, which performs useful work when lifting the liquid (Darbouli et al., 2013). Therefore, in wells producing viscoelastic oils, the specific consumption of the working agent will be less than the value of this parameter in wells with conventional viscous oils.

However, when the content of resin in transformer oil is more than 20%, it is necessary to increase the consumption of injected gas, due to the more significant influence of the increase in viscosity on the lifting process.

Conclusions

1. The article discusses the problems of identifying the features of the process of lifting anomalous oils that significantly affect the flow of the working agent, and assigning uniform modes for wells with similar geological and technical operating conditions.
2. Analysis of the results of the experiments showed the reason for the formation of an increased volume of the gas phase in the well fluid compared to the formation. When lifting viscoelastic oils, unlike viscous oils, phenomena such as slippage of the injected gas are excluded, bringing its operation closer to the moment of piston displacement.
3. Based on the data from the rotational viscometer, the dependence $1/\eta_{eff}^2 = f(\tau^2)$ was constructed, revealing the boundaries of the viscous (linear) and viscoelastic (nonlinear) properties of the test liquid at different temperatures.
4. The calculations indicate that the rate of change in pressure values for the porous medium and for the lift is small. Therefore, the properties of non-Newtonian oil under these conditions will not change, and they will retain their formation values when reaching the surface.
5. The relaxation time of oils was estimated using Young's modulus and true fluid viscosity.
6. When assessing the relaxation time in the process of lifting non-Newtonian oils, it was found that as the temperature increases (in the range considered in this article), there is a degeneration of viscoelastic properties. This, in turn, affects, the specific consumption of the working composition under the same conditions, which tends to increase.

References

Balmforth N.J., Forterre Y., Pouliquen O., 2009. The viscoplastic Stokes layer. *Journal Non-Newtonian Fluid Mechanics*, 158: 46–53. DOI: 10.1016/j.jnnfm.2008.07.008.

Brill J.P., Mukherjee H., 1999. Multiphase Flow in Wells. *Richardson Publ., Texas*, 384.

Darbouli M., Metivier C., Piau J.-M., Magnin A., Abdelali A., 2013. Rayleigh-Bénard convection for viscoplastic fluids. *Journal Physics of Fluids*, 25: 1–15. DOI: 10.1063/1.4790521.

El-Hoshoudy A.N., Desoukya S.E.M., Al-Sabagha A.M., Betiha M.A., El-kady M.Y., Mahmoud S., 2017. Evaluation of solution and rheological properties for hydrophobically associated polyacrylamide copolymer as a promised enhanced oil recovery candidate. *Egyptian Journal of Petroleum*, 26(3): 779–785. DOI: 10.1016/j.ejpe.2016.10.012.

Frigaard I.A., Paso K.G., de Souza Mendes P.R., 2017. Bingham's model in the oil and gas industry. *Rheologica Acta*, 56(3): 259–282. DOI: 10.1007/s00397-017-0999-y.

Khasanov M.M., Bulgakova G.T., 2003. Nelineynyye i ravnovesnyye effekty v reologicheski slozhnykh sredakh. *Moscow-Izhevsk, Institut Kompyuternykh Issledovahy*, 287.

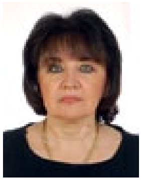
Mamedov A.V., Manafov I.S., 2012. Innovatsionnaya tekhnologiya dobychi vysokovyazkikh neftey. *Journal Oil and Gas Business*, 6: 251–257.

Mamedova Ye.V., 2016. Uchet reologicheskikh svoystv nen'yutonovskikh neftey tekhnologicheskikh protsessakh neftedobychi. *Journal Herald of the Azerbaijan Engineering Academy*, 8(4): 53–58.

Mirzadzhanzade A.Kh., Filippov V.T., Ametov I.A., 2002. Sovmestnyye metody v neftedobyche. *Tekhnika OOO "Tuma GRUP" Publ., Moscow*, 163.

Mirzadzhanzade A.Kh., Hasanov M.M., Baxtizin R.N., 1999. Etudi o modelirovanii slojnix system neftidobichi. *Gilem Publ., Ufa*, 464.

Salavatov T.S.H., Mamedova Ye.V., 2012. K voprosu povysheniya proizvoditel'nosti skvazhin. *Materialy Mezhdunarodnoy Nauchno-Prakticheskoy Konferentsii "Problemy razrabotki i ekspluatatsii mestorozhdeniy vysokovyazkikh neftey i bitumov", Ukhta*, 1: 13.



Yevgeniya V. MAMMADOVA, Ph.D.
Associate Professor at the Department of Oil and Gas Engineering
Azerbaijan State Oil and Industry University
34 Azadliq Ave., AZ1010 Baku, Azerbaijan
E-mail: *mammadova.yevgeniya.59@mail.ru*