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Technique for calculating technological parameters of non-Newtonian liquids injection into oil well during workover

Dmitry V. MARDASHOV, Anton V. BONDARENKO✉, Inzir R. RAUPOV
Saint Petersburg Mining University, Saint Petersburg, Russia

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Abstract. Technique for automated calculation of technological parameters for non-Newtonian liquids injection into a well during workover is presented. At the first stage the algorithm processes initial flow or viscosity curve in order to determine rheological parameters and coefficients included in equations of rheological models of non-Newtonian fluids. At the second stage, based on data from the previous stage, the program calculates well design and pump operation modes, permissible values of liquid flow rate and viscosity, to prevent possible hydraulic fracturing. Based on the results of calculations and dependencies, a decision is made on the necessity of changing the technological parameters of non-Newtonian liquid injection and/or its composition (components content, chemical base) in order to prevent the violation of the technological operation, such as unintentional formation of fractures due to hydraulic fracturing. Fracturing can lead to catastrophic absorptions and, consequently, to increased consumption of technological liquids pumped into the well during workover. Furthermore, there is an increased risk of uncontrolled gas breakthrough through highly conductive channels.

Keywords: mathematical modelling; calculation algorithms; well killing; well workover; polymer composition; rheological investigations; technological parameters; critical viscosity; hydraulic fracturing pressure

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Introduction. In the course of oil field development, the energy potential of a formation is gradually decreasing. At the same time, well operation is accompanied by occasional complications, which include deterioration of permeability and porosity properties of the near-bottomhole zone, gas or water breakthrough via highly permeable channels from worked-out formation intervals, mechanical wear of downhole equipment, etc. In order to eliminate them and maintain the target level of oil production, current and overhaul repair works are required [1, 2]. The preparation stages of such works include well killing, consisting in the injection of technological liquid (TL) into wellbore in order to prevent the gas, oil and water influx.

One of the main conditions for successful well killing is proper selection of technological liquids for specific conditions, which are limited by geophysical parameters (for example, permeability and porosity) and technical characteristics of pumping units (flow rate or pressure). For this purpose a set of laboratory experiments is carried out, which includes physical, chemical, rheological and filtration investigations [3-5]. The analysis of the results allows a comprehensive study of the properties and selection of the most effective liquid for the considered conditions.

Based on many years of well killing practice in Russia and worldwide, there is the following variety of liquids, which can be classified according to application conditions (Table 1) [6-8].

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Table 1

Field of application for the main types of well killing liquids

Technological liquid	Application conditions							
	Water-cut ≥ 60 %	Water-cut < 60 %	Low formation pressure (abnormally low formation pressure, undercompensation)	Abnormally high formation pressure	High-temperature formations (>80 °C)	Water-sensitive (clay) reservoirs	Highly permeable formations, natural or artificial fractures	Gas and gas condensate deposits, high gas-oil ratio (>200 m^3/m^3)
Water systems								
Technical water	+	–	–	–	+	–	–	–
Formation mineralized water	+	–	–	–	+	+	–	–
Water solutions of inorganic salts	+	–	–	+	+	+	–	–
Clay suspensions	+	–	–	+	+	–	–	–
Foam compositions	+	+	+	–	+	+	–	+
Hydrocarbon systems								
Commercial oil	–	+	+	–	+	+	–	–
Thickened oil	–	+	+	–	–	+	–	–
Blocking systems								
Invert-emulsion	+	+	+	+	+	+	+	+
Lime-bitumen	+	+	+	+	+	+	+	+
Polymer	+	+	+	+	+	+	+	+

According to Table 1, blocking compositions (polymer, invert-emulsion and lime-bitumen systems) proved to be efficient TL for well killing in the broad range of work conditions. Their application is most economically expedient in the conditions of high gas-oil ratio, presence of hydrogen sulphide, natural or artificial (hydraulic fracturing conducted earlier) fracturing of reservoirs, abnormally low formation pressure. In this case the risk of possible gas breakthrough into the well and absorption of killing liquid into the near-bottomhole zone is decreased [12, 13].

Statement of the problem. Development of chemical reagents for oil production objects, in particular for specific objects with given geological and physical conditions, should be carried out by conducting thorough laboratory investigations, including physical, chemical, rheological and filtration experiments [14]. Incorrect selection of technological liquid can lead to uncontrolled blow out of formation fluid, loss of a part of fluid as a result of filtration into formation, deterioration of permeability of productive formation, etc.

When killing wells under the conditions of workover operations it is also important to meet the technological requirements of liquid injection into the well [15]. The violation of work regulations can lead to more expensive technology because of long equipment downtime, increase in time of well development and putting it into operation. In addition, it is important to prevent the formation of new technogenic fractures caused by non-compliance of injection parameters with the set values [16].

An advanced solution in the development of blocking liquids is the use of linear and non-linear (cross-linked) polymer compositions with time-controlled gelation. The rate of change in viscosity of such compositions can be controlled over a wide range for more efficient technological operations [17, 18].

Compared to other types of TL (Table 1), polymer-based technologies have demonstrated to be the most reliable means of isolating highly permeable formation intervals, which are used to prevent water and gas breakthrough into production wells [19].

This article considers the theoretical and practical aspects of rheological investigations of polymer compositions, including those used for killing oil wells during their underground workover [20, 21]. The developed algorithm of calculation and subsequent control of basic technological parameters of polymer compositions injection into the well according to the results of rheological investigations is presented.

Methodology. The sequence of rheological investigations with further evaluation of the technological parameters of polymer compositions [4, 22] is as follows:

• preparation of the polymer solution;

• rheological investigation of the polymer composition (viscosity and flow curve plotting; evaluation of the initial shear stress (static yield point);

• selection of the rheological model that most accurately describes the flow or viscosity curve according to a coefficient of determination R^2, which is as close to 1 as possible;

• determination of the rheological characteristics included in the equations of the rheological models (plastic viscosity; yield point; finite viscosity; Newtonian (initial) viscosity; maximum measured shear stress; consistency factor; yield index);

• calculation of technological parameters for injection of polymer composition into the well (friction loss considering coefficients of hydraulic resistance during visco-elastic fluids flow; bottomhole pressure for direct and reverse injection; effective viscosity of the polymer solution during its movement along different elements of the well; total volume of killing liquid; time of filling the well);

• calculation of hydraulic fracturing parameters (fracturing pressure; minimum horizontal stress; critical solution viscosity for given pump flow rates, at which fracturing will occur).

This algorithm (Fig.1) is presented in the form of program code written in Object Pascal programming language [23]. In order to reduce time spent on calculations and expert evaluation of obtained results, a visual interface, composed in Delphi 10 Seattle, was also developed (Fig.2). The algorithm for calculating the main parameters of fluid injection into the well developed by the authors is based on standard conventional equations.

The program is designed to process input data, calculate technological parameters of the process and plot the dependence of the current bottomhole pressure on various characteristics of the pumping unit. The input parameters for this calculation are well design, injection pump operating modes (pressure and flow rate), density of the fluid under study and data from rotary viscometers (rate and shear stress, liquid viscosity) (Fig.1).

Preparation of the polymer solution. To prepare the polymer solution, an accurate analytical scale, top-driven mixer is used. To prevent mechanical destruction of the polymer macromolecules, the rotation frequency of the mixer shaft should be set to the lowest possible value. Chemical dishes with the same geometry are used each time the solution is mixed, which prevents the Reynolds number and flow mode from changing. Complete hydration of the polymer in the solvent is considered to be the end of the preparation, as indicated by the absence of polymer crystals.

Conducting rheological investigations of the polymer composition. Rheological investigations are carried out using a rotary viscometer according to the following stages [24, 25]:

• The initial rheological curve of compositions (at a given formation temperature) is constructed in Controlled Rate mode (CR test). The essence of research method is to obtain dependence of shear stress on shear rate with gradual increase of the latter parameter from 0 to 300 s^{-1} (liquid flow curve).

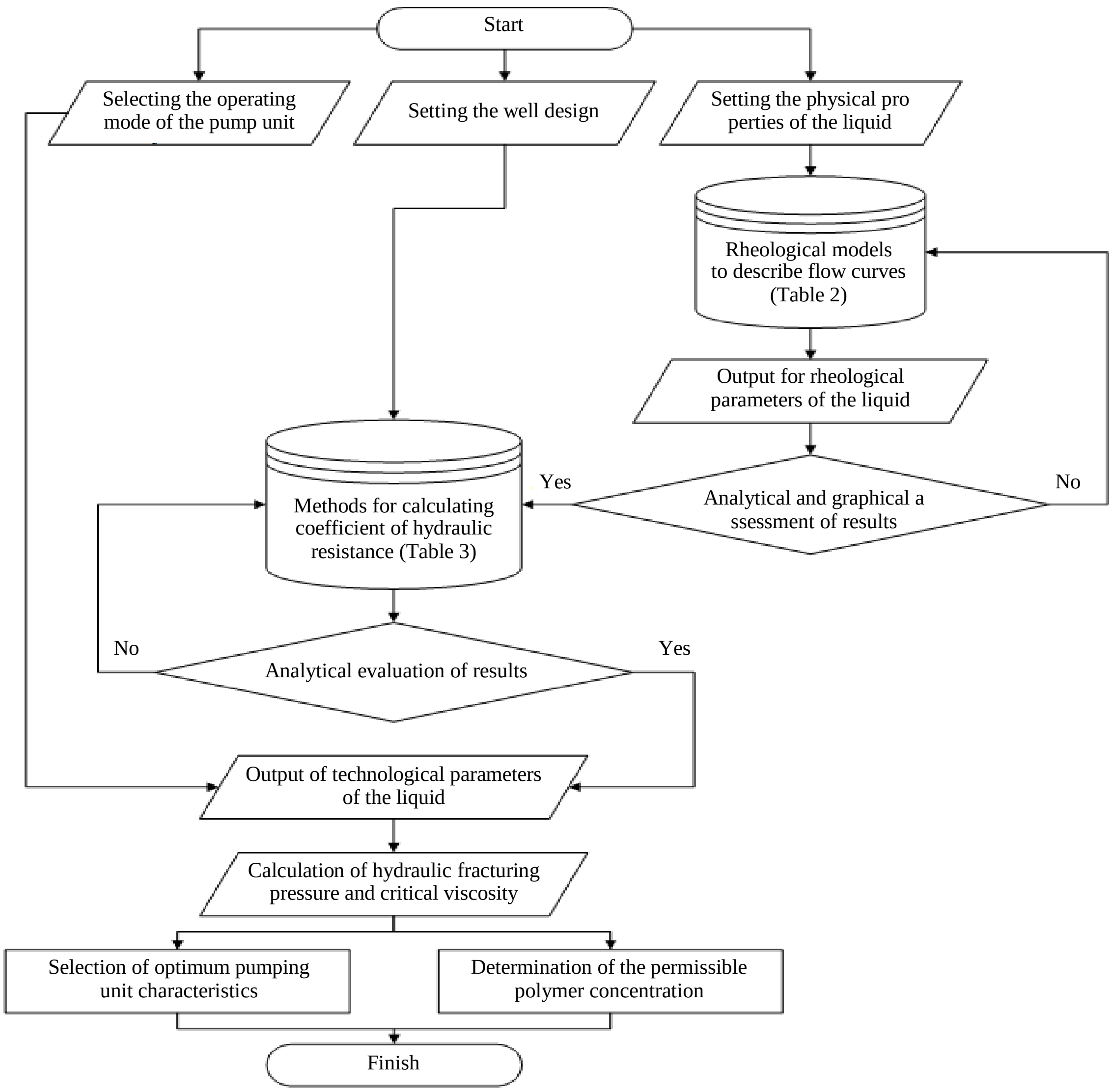

Fig.1. Calculation algorithm for technological parameters of non-Newtonian liquids

• The static yield point (initial shear stress) (at a given formation temperature) is determined in Controlled Stress mode (CS test) with increasing step of shear stress over a given time interval, and the longer the time of investigation, the more accurate the static yield point value is obtained. The initial shear stress is the maximum stress value, after which the measuring system moves and the shear rate increases.

Selection of a rheological model. At this stage, the rheological model that best describes the flow curve of the investigated liquid is selected graphically (Table 2). In addition, the coefficient of determination R^2 is calculated, which characterizes the proportion of variation for the dependent variable and allows evaluating the quality of the rheological model selection [20, 26, 27].

Determination of rheological characteristics. The result of the investigations and calculations with the proposed algorithm is the determination of rheological characteristics that describe the nature and behaviour of the studied liquid (values of plastic viscosity, yield point, finite viscosity, Newtonian (initial) viscosity, maximum measured shear stress, consistency index and fluidity index) [4, 28].

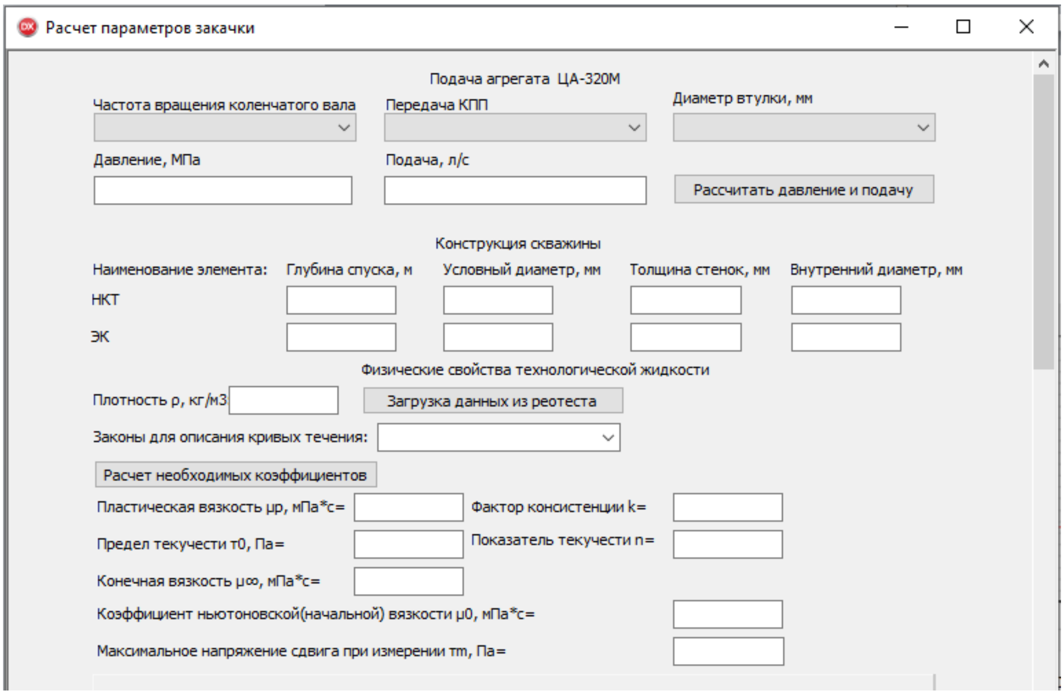

Fig.2. Interface of the developed algorithm

Table 2

Formulas for determining the viscosity and shear stress depending on shear rate for different types of liquids

Name of the rheological model	Dependence formula of τ on *γ*	Formula for determining μ
Ostwald – de Waale	$\tau = k\gamma^n$	$\mu = k\gamma^{n-1}$
Golub	$\tau = \mu_\infty\gamma + \frac{(\mu_0 - \mu_\infty)\gamma}{e^{k\cdot\gamma}}$	$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{e^{k\cdot\gamma}}$
De Haven	$\tau = \frac{\mu_0\gamma}{1 + \left(\frac{\tau}{\tau_m}\right)^n}$	$\mu = \frac{\mu_0}{1 + \left(\frac{\tau}{\tau_m}\right)^n}$
Krieger – Dougherty	$\tau = \mu_\infty\gamma + \frac{(\mu_0 - \mu_\infty)\gamma}{1 + \frac{\tau}{\tau_m}}$	$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{1 + \frac{\tau}{\tau_m}}$
Cross	$\tau = \mu_\infty\gamma + \frac{(\mu_0 - \mu_\infty)\gamma}{1 + \alpha\gamma^n}$	$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{1 + \alpha\gamma^n}$
Reiner – Filipov	$\tau = \mu_\infty\gamma + \frac{(\mu_0 - \mu_\infty)\gamma}{1 + \left(\frac{\tau}{\tau_m}\right)^2}$	$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{1 + \left(\frac{\tau}{\tau_m}\right)^2}$
Meter	$\tau = \mu_\infty\gamma + \frac{(\mu_0 - \mu_\infty)\gamma}{1 + \left(\frac{\tau}{\tau_m}\right)^n}$	$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{1 + \left(\frac{\tau}{\tau_m}\right)^n}$
Ellis	$\tau = \mu_0\gamma + k\gamma^n$	$\mu = \mu_0 + k\gamma^{n-1}$
Herschel – Bulkley	$\tau = \tau_0 + k\gamma^n$	$\mu = \mu_p + k\gamma^{n-1}$
Casson	$\tau^{\frac{1}{n}} = \tau_0^{\frac{1}{n}} + (\mu_p\gamma)^{\frac{1}{n}}$	$\mu^{\frac{1}{n}} = \mu_p^{\frac{1}{n}} + \left(\frac{\tau_0}{\gamma}\right)^{\frac{1}{n}}$

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End of Table 2

Name of the rheological model	Dependence formula of τ on γ	Formula for determining μ
Shvedov – Bingham	$\tau = \tau_0 + \mu_p \gamma$	$\mu = \mu_p + \frac{\tau_0}{\gamma}$

Note. μ – effective viscosity; τ – shear stress; γ – shear rate; *k* – consistency index; *n* – yield index; μ_0 – Newtonian (initial) viscosity; μ_∞ – finite viscosity; τ_m – maximum measured shear stress; τ_0 – yield point; μ_p – plastic viscosity; α, *e* – constants.

The search for rheological values takes place in several stages. The first step is a linear regression analysis of the viscosity and shear stresses resulting from the rheological investigations carried out. The result of this analysis is a relationship of the form: $y = a + bx$. The parameters of this regression equation are estimated by the least-squares method [29]. In this case according to Shvedov-Bingham equation (Table 2), the value of coefficient *a* corresponds to the value of yield point τ_0, coefficient *b* – to plastic viscosity μ_p.

The initial viscosity μ_0 is defined as the highest value of the viscosity of the solution resulting from the investigations and corresponds to the yield point τ_0. At the same time, the minimum value of the viscosity (at $\gamma \to \infty$) corresponds to the finite viscosity μ_∞. Based on the initial and final viscosity values the following calculation is carried out:

$$\mu_{mid} = \frac{\mu_0 - \mu_\infty}{2} + \mu_\infty. \quad (1)$$

The maximum measured shear stress τ_m corresponds to the viscosity value obtained from formula (1) and can be found from the summary table of the research results [30].

The next step is to find the values of the consistency index *k* and the yield index *n*. Namely, based on the obtained values of viscosity and shear stress, a power dependence of the following form is constructed: $y = ax^b$. Estimation of parameters of the power-law regression is also carried out by the least-squares method [29]. The coefficient a corresponds to the consistency index *k*, and the coefficient *b* to the yield index, according to the Ostwald – de Waale equation (Table 2).

Calculation of the technological parameters for injecting the polymer composition into the well. Then the technological parameters of polymer composition injection into the well are calculated in the considered algorithm: friction pressure loss, bottomhole pressure for direct and reverse injection methods, effective viscosity for different elements of the well design, as well as total volume of killing liquid and filling time of the well [31, 32].

The bottomhole pressure is calculated from the wellhead pressure, hydrostatic pressure and pressure friction loss:

$$P_{\text{bh}} = P_{\text{wh}} + \rho g L - \lambda \frac{L}{d} \cdot \frac{w^2}{2} \rho, \quad (2)$$

where P_{wh} – wellhead pressure, MPa; ρ – density of the technological liquid, kg/m^3; *L* – depth of the well, m; λ – hydraulic resistance coefficient; *d* – diameter of the tubing string, m; *w* – flow velocity of the technological liquid through the tubing string, m/s.

Application of standard methods for calculating pressure loss can lead to errors due to their inapplicability for viscoplastic liquids flowing through pipes. The most correct way of calculating the pressure loss is to use methods, which take into account the properties of the liquids and the nature of their flow. That is why on the basis of Reynolds number the method for calculation of hydraulic resistance coefficient in case of liquid movement in tubing, annular space and wellbore interval from the depth of tubing end to the bottomhole is selected.

This paper uses the methods for calculating the hydraulic resistance coefficient shown in Table 3 [33].

Table 3

Methods for calculating the hydraulic resistance coefficient for viscoplastic liquids flowing through pipes

Name of method	Calculation of the coefficient
Shishchenko R.I. and Mirzadzhanzade A.Kh.	at $Re' = 80 \div 1000$ $\lambda = \frac{32}{Re'}$; at $Re' = 1000 \div 2300$ $\lambda = \frac{0{,}13}{\sqrt[6]{Re'}}$, where $Re' = \frac{vd\rho}{\mu}$
Shishchenko R.I. and Ibatulov K.A.	at $Re' = 2300 \div 40000$ $\lambda = \frac{0{,}075}{\sqrt[8]{Re'}}$; at $Re' > 40000$ $\lambda = 0{,}02 = \text{const}$, where $Re' = \frac{vd\rho}{\mu}$
Filatov B.S.	at $Re' \geq 2800 \div 4000$ $\lambda = 0{,}017 \div 0{,}025$, where $Re' = \frac{vd\rho}{\mu_p\left(1+\frac{\tau_0 d}{6\mu_p v}\right)}$; at $Re' < 2000 \div 3000$ $\lambda = \frac{64}{Re'}$; at $Re' > 2000 \div 3000$ $\lambda = \frac{0{,}08}{\sqrt[7]{Re'}}$, where $Re' = \frac{vd\rho}{\mu_p\left(1+\frac{\tau_0 d}{6\mu_p v}\right)}$
Mitelman B.I.	for annular space: at $Re' < 1600$ $\lambda = \frac{80}{Re'}$; at $Re' \geq 1600 \div 2000$ $\lambda = \frac{0{,}012}{\sqrt[7]{Re'}}$, where $Re' = \frac{v(D-d')\rho}{\mu_p\left(1+\frac{\tau_0 (D-d')}{6\mu_p v}\right)}$
Metzner A. and Reed J.	at $Re' < 2100$ $\lambda = \frac{64}{Re'}$; at $Re' > 2100$ $\lambda = c(Re')^{-m}$, where $Re' = \frac{v^{2-n}d^n\rho}{\frac{k}{8}\left(\frac{6n+2}{n}\right)^n}$

End of Table 3

Name of method	Calculation of the coefficient
Soloviev E.M.	For annular space: at Re′ < 1600 $\lambda = \frac{64}{\mathrm{Re}'}$ at Re′ ≥ 1600 ÷ 2000 λ = 0,014 ÷ 0,019, where $\mathrm{Re}' = \frac{v d_{\text{экв}} \rho}{\mu_p \left(1 + \frac{\tau_0 (D - d')}{\mu_p v} \psi\right)}$; $\psi = \frac{D^2 + Dd' + d'^2}{3(D^2 - d'^2)^2} - \frac{1}{2 \ln \frac{D}{d'}}$; $d_{\text{eqv}} = 2\sqrt{D^2 + d'^2 + \frac{D^2 - d'^2}{\ln \frac{D}{d'}}}$

Note. λ – hydraulic resistance coefficient; Re′ – generalized Reynolds number; *c*, *m* – coefficients depending on the effective viscosity of the liquid; *v* – average flow velocity; *d* – internal diameter of the pipe; *d*′ – external diameter of the pipe; *D* – internal diameter of the production casing; ρ – density of the liquid.

Calculation of hydraulic fracturing parameters. To control the injection process, the hydraulic fracturing pressure has been calculated, which, according to [34], is determined by the following relationship:

$$P_{\text{fr}} = 3\sigma_h - \sigma_H - P_p + T, \tag{3}$$

where T – uniaxial tensile durability limit of the rock , MPa; P_p – pore pressure, MPa; σ_h – minimum horizontal stress, MPa; σ_H – maximum horizontal stress, MPa.

The horizontal stress values are calculated using the following formulas [35]:

$$\sigma_H = \frac{\nu}{1-\nu}\sigma_V - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_H + \frac{\nu E}{1-\nu^2}\varepsilon_h; \tag{4}$$

$$\sigma_h = \frac{\nu}{1-\nu}\sigma_V - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_h + \frac{\nu E}{1-\nu^2}\varepsilon_H, \tag{5}$$

where ν and E – Poisson's ratio (units) and Young's modulus (GPa) respectively; σ_V – vertical stress, MPa; α – Bio coefficient, units; ε_H and ε_h – maximum and minimum strain values respectively, units.

The solution viscosity, at which hydraulic fracturing will occur, is determined by the formula [36]:

$$\frac{P_{\text{fr}}}{P_{\text{h}}}\left(\frac{P_{\text{fr}}}{P_{\text{h}}} - 1\right)^3 = 5.25\frac{1}{(1-\nu)^2}\left(\frac{E}{P_{\text{h}}}\right)^2 \frac{Q\mu}{P_{\text{h}}}, \tag{6}$$

where P_{h} − horizontal component of rock pressure, MPa; Q – flow rate of liquid, m^3/s; μ – effective viscosity of liquid, mPa·s.

With the viscosity value obtained, the permissible concentrations for the components of the polymer composition can be determined based on rheological investigations of the solution.

Discussion. As a result of the investigation, an algorithm and software on its basis were developed to calculate the technological parameters of liquid injection into the well, using data obtained from rotary viscometers.

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Let us consider a typical calculation in Delphi 10 Seattle. The first step is to set the technological parameters of the pumping unit, diameter and running depth of the casing. Next, the values of polymer composition density and the data obtained earlier from rheological investigations are entered. The rheological model for description of flow curves, for example, De Haven law (Table 2) is selected and rheological characteristics of studied liquid are calculated (Fig.3). To analyze the results a graph of viscosity dependence on shear rate is drawn (Fig.4).

The rheological model of De Haven incorrectly describes rheological behaviour of the considered polymer composition (Fig.4, *a*), as the curves constructed differ from each other considerably, while a rather low coefficient of determination ($R^2 = 0.18$) is observed. However when the model for rheological curves description is changed, for instance to Reiner – Filipov law (Table 2), similar curves with higher value of determination coefficient $R^2 = 0.62$ are observed (Fig.4, *b*).

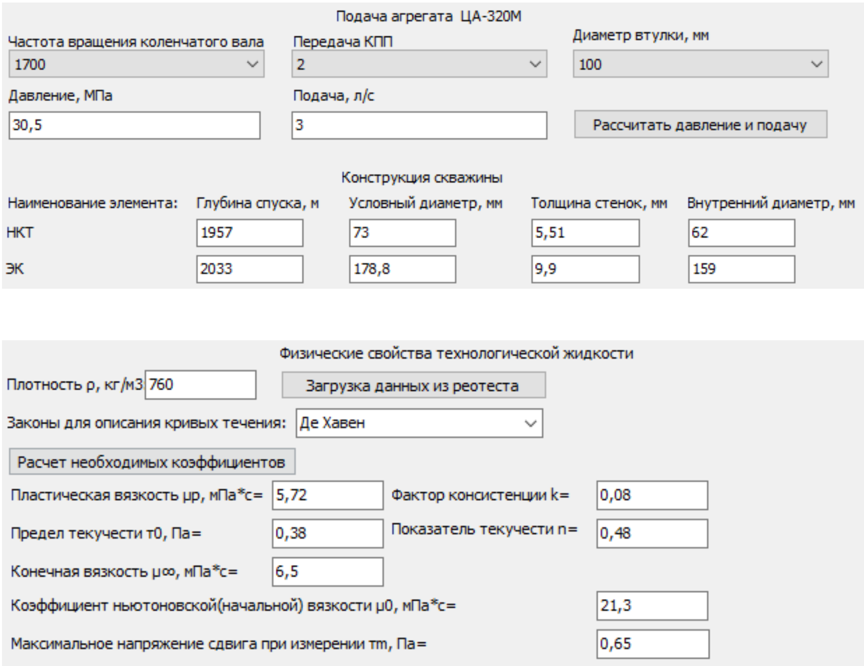

Fig.3. Initial data and results of rheological calculations

a *b*

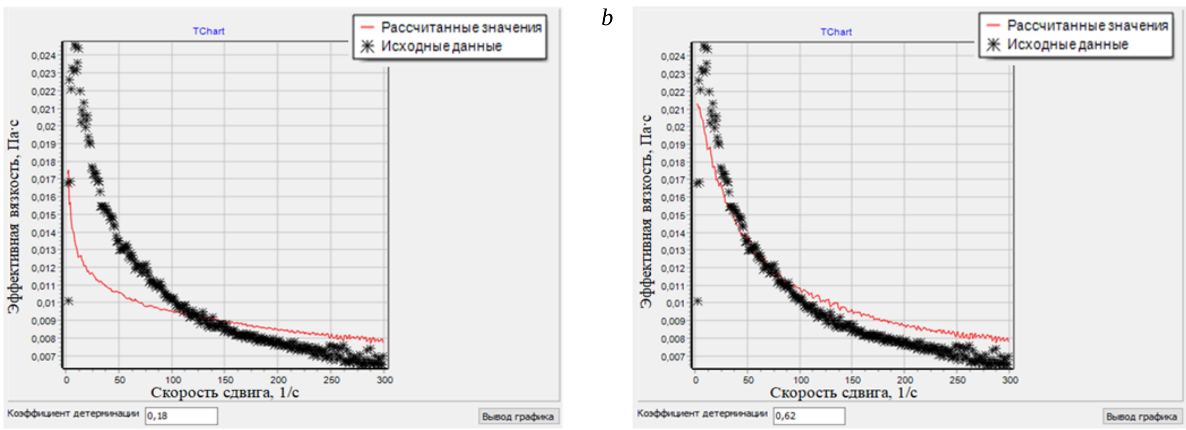

Fig.4. Viscosity curve plots based on initial data and values calculated by De Haven (*a*) and Reiner – Filipov (*b*) laws

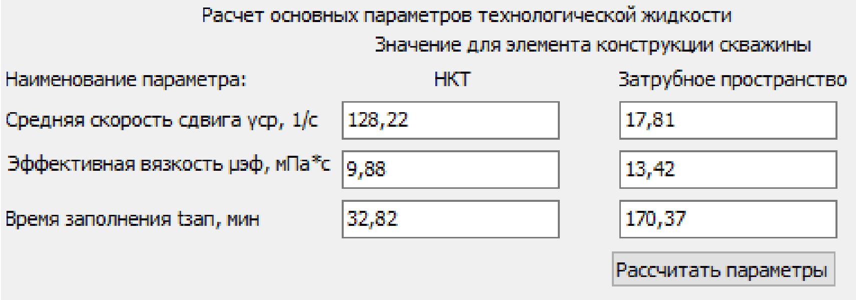

Fig.5. Calculated parameters of the polymer composition

After selecting a suitable rheological model to describe the flow curves, the average shear rate, effective viscosity of the polymer composition and filling time are calculated for the different elements of the well design (Fig.5).

Knowledge of the rheological properties of liquids for different elements of the well design is important for predicting liquid behaviour and preventing possible complications when flowing through the wellbore. Such complications include the inability to flow due to excessively high viscosity [37].

The next step is to calculate injection parameters of the polymer composition (Fig.6, *a*, *b*). For this purpose, methods of calculation of hydraulic resistance coefficient for tubing and annular space of well are selected beforehand (Table 3).

When analyzing the obtained results (Fig.6, *a*), it can be seen that the Reynolds number for tubing is too high in relation to the Reynolds number calculated for the annulus and perforation interval. This indicates incorrect selection of methods for calculating hydraulic resistance coefficient, which leads to errors, for example, in determining bottomhole pressure (–437.7 MPa). Changing the calculation methods for the hydraulic resistance coefficient results in correct values of polymer injection parameters (Fig.6, *b*).

At the last stage, to determine the hydraulic fracturing pressure and the critical viscosity of the polymer composition, the values of stresses, strains, elastic and durability properties of the rock (Fig.6, *c*) are set [38, 39]. The calculated value of hydraulic fracturing pressure (27 MPa) turned out to be lower than the value of bottomhole pressure (45 MPa) (Fig.6, *b*) when injecting polymer composition. In this case, there is a high risk of hydraulic fracturing [40, 41].

The resulting critical viscosity value serves as an upper limit for the viscosity of the technological liquid, above which a technogenic fracture as a result of an autohydraulic fracture may occur, so the current viscosity value must be compared with the specified limit value [42].

In order to visually assess whether the current bottomhole pressure exceeds the hydraulic fracturing pressure, a graph of bottomhole pressure dependence on the pumping unit flow rate is constructed. In the graph (Fig.7), bottomhole pressure is represented as points corresponding to different injection methods and technical conditions of the pumping unit operation, while fracturing pressure is marked with a red horizontal line. The graph can be used as an aid in selecting the optimum pumping unit characteristics. In this case, direct injection means filling the wellbore with TL through the tubing string. Reverse injection means that the liquid enters the wellbore through the annular space.

The current bottomhole pressure, marked with a red square (point 1700/2, where 1700 is the crankshaft rotation frequency and 2 is the gearbox value), is above the hydraulic fracturing pressure (Fig.7, *a*).

In practice, the following methods are used to prevent hydraulic fracturing when injecting a polymer composition into a well: changing the technological parameters of liquid injection into the well and changing the concentration of the components in the polymer composition [43].

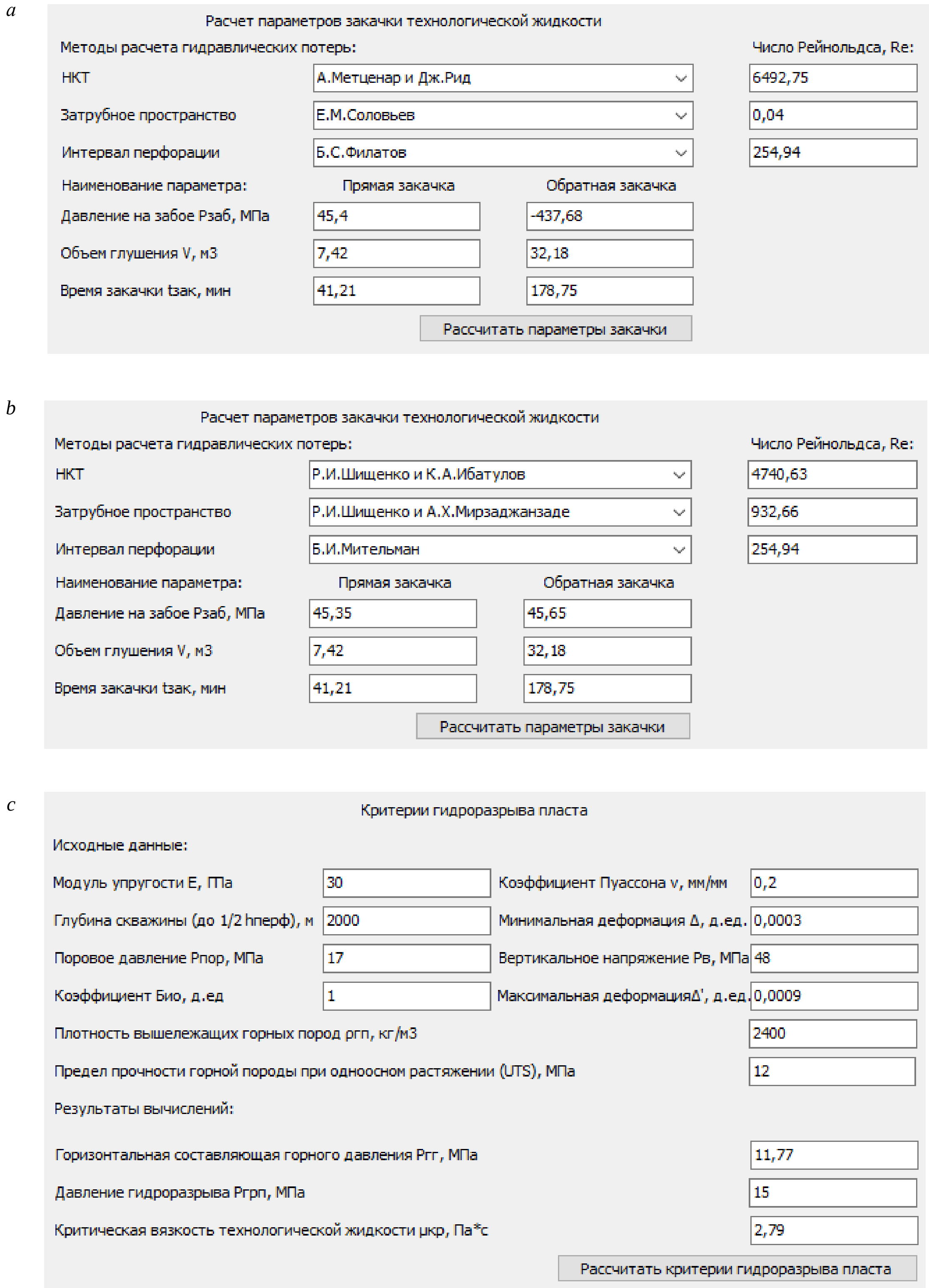

Fig.6. Parameters for polymer composition injection (*a*, *b*) and hydraulic fracturing criteria (*c*)

The results of this calculation, e.g. when changing the technological characteristics of the pump unit, are shown in Fig.7, *b*. The resulting current bottomhole pressure, marked with a blue square (point 1700/4, where 1700 is the crankshaft rotation frequency and 4 is the gearbox value), is below the hydraulic fracturing pressure (Fig.7, *b*).

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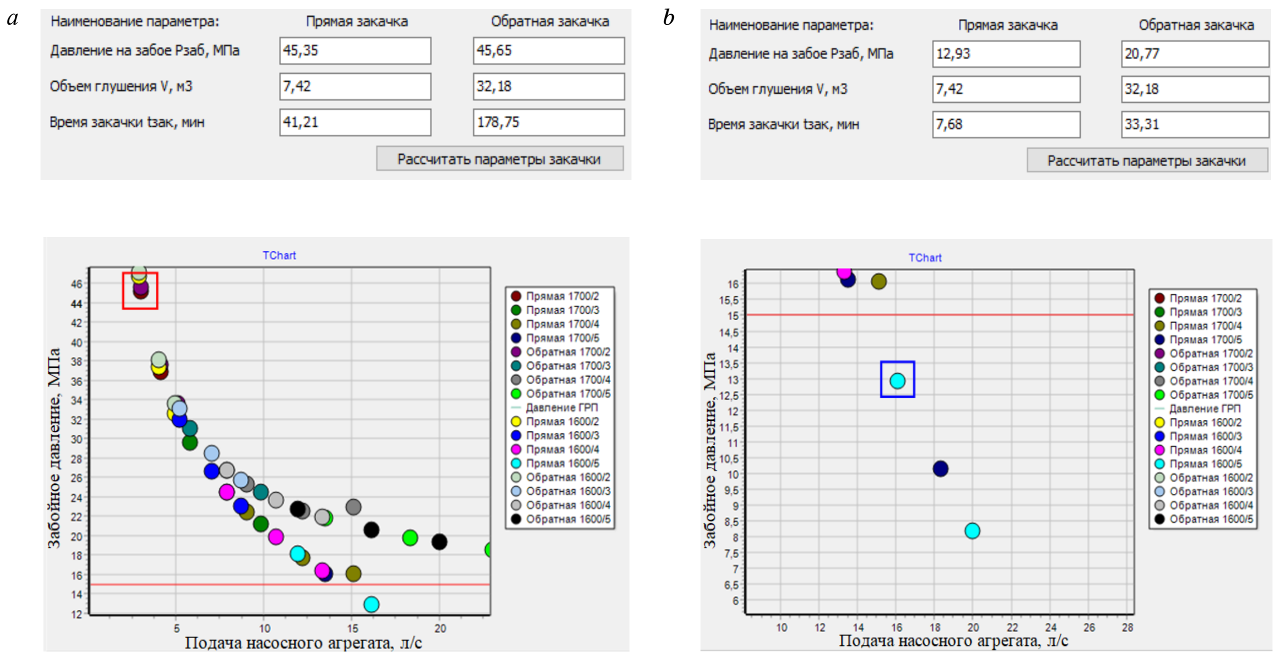

Fig.7. Bottomhole pressure (*a*) and hydraulic fracturing pressure (*b*) graph

The results of the investigation have shown that application of this program will allow a specialist to considerably accelerate obtaining information about basic parameters for the process of liquid injection into a well in the course of workover. This information is necessary for making regulations when planning preparatory and workover operations at a well.

The results of laboratory and theoretical investigations described in this work are important in modeling such processes in oil production as injection of polymer composition into the well, including killing of oil wells during their workover. When carrying out technological operations related to the injection of polymer compositions into a well, there is a need to obtain reliable viscosity values depending on geological and thermobaric conditions of the formation. The lack of consideration of the influence of the considered physical parameters on the viscosity or its incorrect determination can lead to negative results, such as uncontrollable formation of high-conductive fracture [44-46].

Conclusion. The algorithm developed by the authors involves calculation of the main parameters for the liquid injection process based on information about the design of the vertical well, pump operation modes, as well as the rheological characteristics of non-Newtonian liquid.

The software will allow optimizing the liquid injection mode. Namely, when calculating the critical viscosity, upon reaching which hydraulic fracturing is possible, the decision is made to change technological parameters of non-Newtonian liquid injection and/or its composition (components content, chemical base). The formation of fractures as a result of an autohydraulic fracturing can lead to catastrophic absorptions and, consequently, to an increased risk of bottomhole zone bridging and increased consumption of technological liquids pumped into the well during workover. Furthermore, there is an increased risk of uncontrolled gas breakthrough through highly conductive channels.

The proposed software prevents unintentional fracturing caused by hydraulic fracturing, reduces the high costs of downtime and possible post-repair complications, and increases the efficiency of well interventions by injecting polymer compositions.

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***Authors*: Dmitry V. Mardashov,** *Candidate of Engineering Sciences, Head of the Department, https://orcid.org/0000-0001-6193-9490* (*Saint Petersburg Mining University, Saint Petersburg, Russia*), **Anton V. Bondarenko,** *Postgraduate Student, s185060@stud.spmi.ru, https://orcid.org/0000-0002-2468-6807* (*Saint Petersburg Mining University, Saint Petersburg, Russia*), **Inzir R. Raupov,** *Candidate of Engineering Sciences, Associate Professor, https://orcid.org/0000-0002-9321-0626* (*Saint Petersburg Mining University, Saint Petersburg, Russia*).

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