Computer modeling of capillary flow with superimposed pulsations

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Abstract. Increasing efficiency of methods of oil production can be achieved by the influence of elastic vibrations. It is a well-known fact that shift viscosity of oil changes under the effect of elastic vibrations. This change depends on properties of the oil and exposure mode. Existing approaches to the research of the way wave exposure impacts on viscosity are based on measuring it after the processing. This article concerns development of methods to measure viscosity of liquid right during its exposure to elastic vibrations. The suggested approach is based on combining numerical and natural experiments. We investigated the pulsating flow of viscid liquid in a capillary numerically in this article. We received allocations of fields of average velocity and pressure in a capillary. It is demonstrated that imposed pulsations in a capillary do not impact on hydrodynamics of the flow. We offered the scheme of an experimental installation for a research of the impact that wave exposure has on the viscosity of liquids. The installation is based on a capillary viscometer.

1. Introduction

Current period of development of oilfields in the main oil-producing regions is characterized by the increase in proportion of reserves, which are hard to reach, and ineffective deposits. Therefore specialists of oil branch do not lose interest in practical use of new effective technologies, which would provide stable maintenance and growth of oil production in complicated geological and trading conditions. Applying wave method has a prospect in technologies of increasing efficiency of oil production [1-10]. Its essence lies in intensification of processes inside of a stratum by its exposure to elastic vibrations. However, there are questions to be answered, which concern applying it. One of the biggest ones is the investigation of an impact, which wave action has on the medium, and its mechanisms.

There are different ideas of mechanisms of the exposure [11-14]. One of them is changing permeability of a porous collector; another one is the release of the dissolved gas; also there is one which lies in decreasing viscosity of formation fluids, to name but a few. However, despite significant results in understanding basic mechanisms of the exposure, there is still a vacancy in our knowledge when it comes to the way elastic vibrations impact on viscosity of liquids. Changes of rheological behavior of liquids, which are characterized by existence of viscoelastic and viscoplastic properties of non-Newtonian liquids, were found in an experiment by authors of the article [14]. In particular, change of oil shift viscosity under the action of elastic vibrations was observed (figure 1). It was established that shift viscosity decreases by 20-30% right after the exposure and after some time (5-6 hours and more) it restores fully or partially.

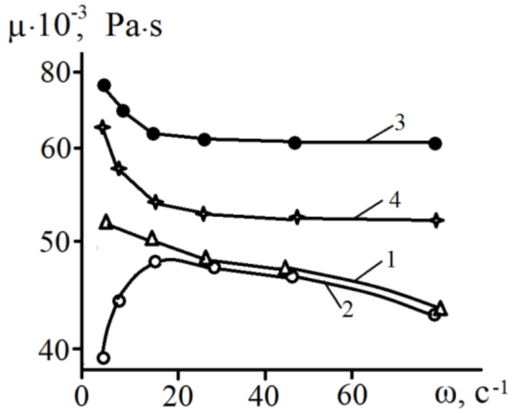

Figure 1. Dependence of dynamic viscosity of oil μ on frequency of rotor rotation ω with different time *t* after the acoustic treatment [14]: 1 – before the treatment; 2 – *t*=0; 3 – *t*=22 h; 4 – *t*=120 h.

The presented data do not give an answer to the question of the value of oil viscosity right in the middle of the exposure. It is important to know because in some cases wave impact on formation is performed permanently in the process of oil production. The main gap in our knowledge is absence of tools that would allow observing change of viscosity right in the process of the exposure. Thus, the aim of the article is development of method of measuring viscosity of liquid in the process of acoustic influence. To achieve this goal it is necessary to investigate hydrodynamics of the liquid in existing devices for measuring viscosity with imposed fluctuations.

2. Setting the task

Essence of the offered approach is the following. Wave exposure of liquid is performed right in the process of measuring it with viscometer. We can observe change of readings on the device which will testify some changes in rheological properties of the liquid. However, to isolate the change of viscosity from the other ones, it is necessary to know how elastic vibrations influence hydrodynamics of the liquid in a flow channel of the device. This task can be resolved by numerical modeling of the flow of liquid.

The flow of liquid in a capillary is used as a viscometer in this article. The modeling is based on methods of computing hydrodynamics, including the numerical solution to Navier–Stokes equations and continuity equations. Calculation is performed in steady state and with imposed fluctuations and is followed by the analysis of the results. In numerical modeling properties of the medium stay permanent, i.e. the impact of wave exposure does not affect rheological properties of the medium, thereby we investigate only exposure of hydrodynamics of the flow to elastic vibrations.

The three-dimensional geometric model of a flow passage of a capillary is devised to prepare for modeling in the system SolidWorks, which is intended for solid-state parametrical associative modeling of complex pieces. Modeling was carried out using the program complex for research of flows of liquids and gases FlowVision. Calculation area was internal flow area of a capillary with the one that adjoins at the entrance and the exit of a capillary (figure 2). In our case the needle of a medical syringe was used as a capillary; geometric sizes of the needle were the following: L=42 mm, R=0.51 mm. The liquid that we investigated was glycerol at 20 °C.

Results of calculations were compared to known analytical relation that is Poiseuille equation, which describes steady-state motion of the liquid:

$$Q = \pi\rho \frac{P_1 - P_2}{8\mu L} R^4 \qquad (1)$$

where Q represents volume flow of liquid, m^3/s; μ represents viscosity coefficient, Pa·s; ρ represents density of the liquid, kg/m^3; P_1 and P_2 are pressures at the entrance and the exit respectively, Pa; L is length of a capillary, m; R is radius of a capillary, m.

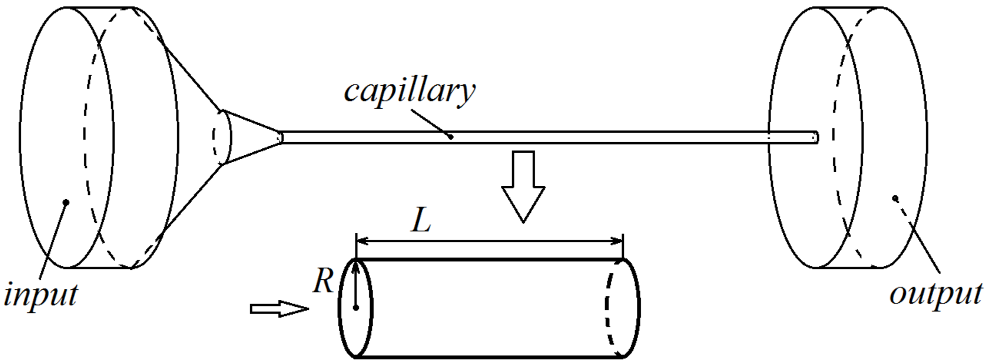

Figure 2. Calculation area.

3. Results of the modeling

Comparison of the results of the numerical experiment with the laminar steady-state flow to the one with imposed pulsations of the flow was carried out according to the change of average pressure difference on a region of the capillary as well as the change of velocity profile in a capillary section.

As a result of numerical modeling of steady-state flow we received the allocation of velocity through a capillary section (figure 3). Direction of the flow is from the left to the right. Value of velocity is established on 800 iteration of calculation.

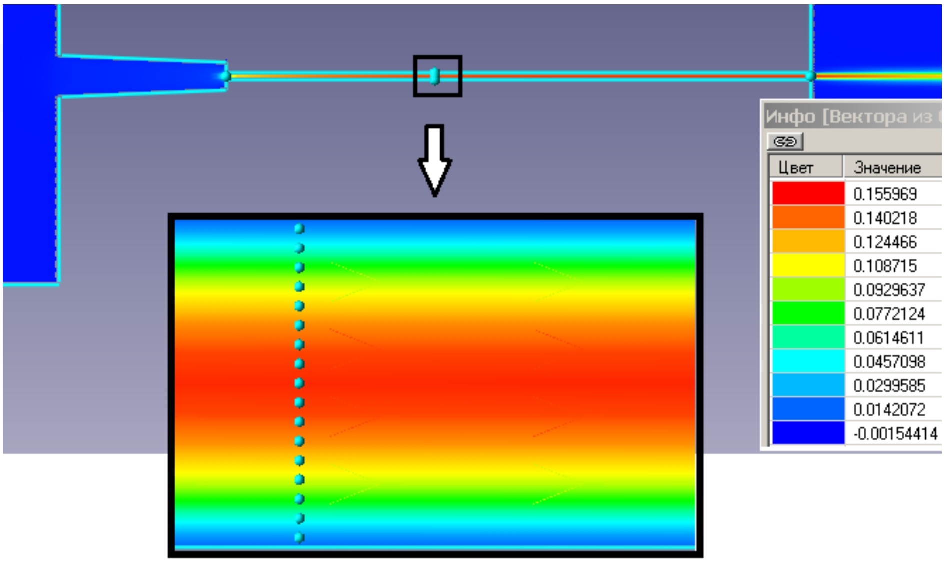

Figure 3. Allocation of velocity of the liquid in a capillary.

At the next stage of numerical research the velocity with imposed pulsations of different frequencies in the range from 1 kHz to 10 kHz was set at the entrance to a capillary. Step of time was $1.25 \cdot 10^{-5}$ s. Measurements of velocity were carried out at different points along the radius of the capillary (figure 4). Value of velocity was noted at every point. Typical change of velocity by time is depicted in figure 5. It should be mentioned that pulsations of velocity were imposed on the average velocity of the steady-state flow. Dependence of average velocity on distance to the axis of a capillary is depicted in figure 5. Such allocation of profile fits the theory that says the farther away from the wall a point is located, the higher velocity of the flow is.

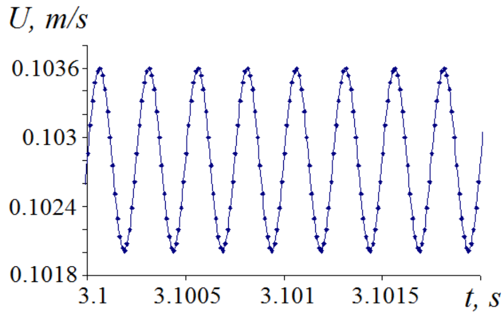

Figure 4. Change of velocity of the flow in a capillary.

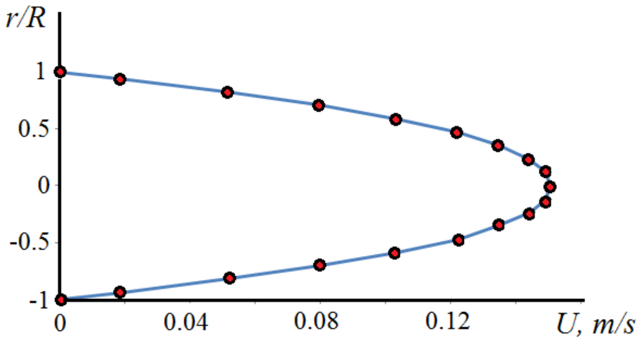

Figure 5. Profiles of velocity of the flow in a capillary (the line is for stationary conditions, the points are for when applying fluctuations 2 kHz).

Difference between average velocities of the steady-state flow, the flow with imposed pulsations and theoretical numbers calculated according to equation (1) is less than 0.4%, which is less than the error of the numerical experiment. Thus, we can conclude that presence of pressure pulsations in a capillary does not affect hydrodynamics of the flow. It means that for research of the way wave exposure impacts on viscosity of liquid we can use the capillary method, installation of which includes a device for generation of elastic fluctuations. We developed a scheme for an experimental installation for a research of the impact that wave exposure has on viscosity of liquid, which is based on a capillary viscometer. The scheme is depicted in figure 6. The installation includes the following components: a capillary that the tested liquid comes through; a fluctuations oscillator, which carries out wave exposure; a system of measuring the flow rate through a capillary and pressure difference in it.

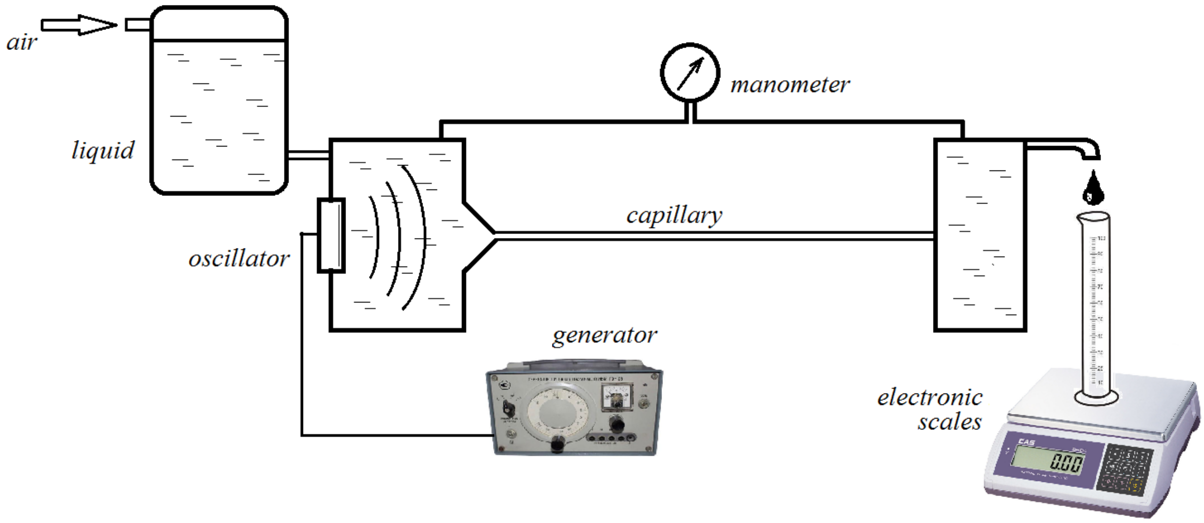

Figure 6. The scheme of upgraded experimental installation.

4. Conclusion

According to the results of the research it was established that imposed pulsations do not affect hydrodynamics of the flow of viscid liquid in a capillary. Thus, the method based on applying capillary viscometer can serve as a foundation for a way to research the impact of wave exposure on viscosity of the liquid. We developed a scheme for an experimental installation for measuring viscosity of the liquid right in the process of exposing it to elastic waves.

References

[1] Beresnev I A and Johnson P A 1994 *Geophysics* **59** 1000-17

[2] Marfin E A, Kravtsov Y I, Abdrashitov A A, Gataullin R N and Galimzyanova A R 2015 *Pet. Sci. Tech.* **33**(15) 1526-32

[3] Jeong C, Kallivokas L F, Kucukcoban S, Deng W and Fathi A 2015 *J. Pet. Sci. Eng.* **129** 205-220

[4] Marfin E A and Kravtsov Ya I 2005 *Izvestiya Akademii Nauk. Energetika* **6** 108-113

[5] Jankov M, Lovoll G, Knudsen H A, Maloy K J, Planet R, Toussaint R and Flekkoy E G 2010 *Transp. Porous Med.* **84**:3, 569-58

[6] Marfin E A, Kravtsov Ya I, Abdrashitov A A and Gataullin R N 2014 *Georesources* **2**(57) 14-16

[7] Marfin E A, Kravtsov Y I, Abdrashitov A A and Metelev I S *2015 Geomodel 2015 - 17th Sci.-Pract. Conf. on Oil and Gas Geol. Explor. and Devel.* doi: 10.3997/2214-4609.201413912

[8] Gataullin R N, Kravtsov Ya I and Marfin E A 2013 *Neftyanoe khozyaystvo - Oil Industry* **1** 90-93

[9] Marfin E A and Abdrashitov A A 2014 *6th Saint Petersburg Int. Conf. and Exhib. on Geosciences 2014: Investing in the Future*. doi: 10.3997/2214-4609.20140186

[10] Marfin E A, Abdrashitov A A and Kravtsov Y I 2016. *7th EAGE Saint Petersburg Int. Conf. and Exhib.: Understanding the Harmony of the Earth's Resources Through Integration of Geosciences.* doi: 10.3997/2214-4609.201600094

[11] Kravtsov J I, Marfin E A, Butorin E A and Gataullin R N 2009 *Georesources* **1**(29) 43-45

[12] Manga M, Beresnev I, Emily E, Brodsky E E, Elkhoury J E, Elsworth D, Ingebritsen S E, David C, Mays D C and Wang C-Y 2012 *Rev. Geophys.* **50** RG2004

[13] Hamidi H, Mohammadian E, Junin R, Rafati R, Manan M, Azdarpour A and Junid M 2014 *Ultrasonics* **54**:2 655-662

[14] Sokolov A V and Simkin E M 1981 Study of influence of acoustic treatment on rheological properties of some oils. *Topics in nonlinear geophysics* (*Voprosi nelineinoy geofiziki*) (Moscow: All-Union Research Institute of Nuclear Geophysics and Geochemistry) pp 137–142