1999 VOL. X(XVIII)

SATTAROV R.M., MAMEDOV R.M.

SOME SINGULARITIES OF FLOW OF RHEOLOGICAL COMPLEX MEDIUMS WITH FRACTAL STRUCTURE

Abstract

Existing in oils of resin, asphalt and paraffin components and also in technological liquids of surface active and polymer dopes predefinirtes their complexity, variety of innerphase and interphase interaction and processes.

A very effective method of construction of models of the mentioned liquids taking into account internal microstructures can be considered the fractal or skayling ideas used widely in rheological complex liquids at motion in porous mediums and tubes.

Some results of modeling of rheological complex liquids with fractal structure are presented in this work.

As a very effective method of construction of models of the mentioned liquids taking into account internal microstructures can be considered the fractal or skayling ideas used widely in rheological complex liquids at motion in porous mediums and tubes [1-4].

To the rheologic investigations of thixotrop systems of type of drill and clay solutions and also to investigations highparaffin and resin-asphalt oils a series of works [5-7] were devoted, where quantifiable estimations of the parameters were given, which characterize the thixotrop and relaxation properties.

For description of above mentioned dispersion systems, as a rule, the complex rheological models are used which contain great quantity of parameters and it restricts their practice using.

Probably, the most perspective for description of such complex liquid consideration of their fractal properties can serve.

Below some results are given on modeling of rheologic complex liquids with the fractal structure.

1. Rheologic investigations of stress relaxation in liquid systems are carried out by two methods. Both methods are reduced to measuring tangent or normal stresses at the time before the equilibrium condition in the first case for the given constant velocity of deformation and in the second case for the given constant deformation.

The experimental investigations with real and technological liquids of oil-gas production allow to consider, that stress kinetics has a complex character. For practice the instantly applied gradients of velocity the stress curve as a rule has incident branch.

In fig. 1 characteristic rheologic curves of kinetics of development of tangent stresses are represented by continuous lines for resin-asphalt-paraffin oils (deposit Varik-I, Boston-2, Uzbekistan Republic). The data were obtained [7] on the equipment Reotest-2 for various constant velocities of deformation of the considered oil. As it was shown [7] the given curves can be described by spectrum of different times of relaxation, moreover with increase of the spectrum the precision of the model gets better. Attempts to consider all discrete spectrums of relaxation times reduce to the complexity of rheologic model as far as the degree of the differential type equation rises.

In such situation probably the more advisable one is using the integral type models, considering the fractality of the structure of rheologic complex liquids. Analysis of graphics given in fig. 1 shows, that their behavior is analogous to behavior of the hyperbolic type curves with asymptotes for $x \le 0$ which can be described by the equation of following view:

$$\tau = A\left[1 + \frac{B}{(t-C)^{\nu}}\right], \tag{1.1}$$

where τ is shear stress, t is time, A is the parameter characterizing the stress for $t \to \infty$, B is constant which is analogous to relaxation time, C is time of lag, ν is a parameter characterizing the fractality.

Supposing, that for $t \to \infty$ it takes place the stationary viscous flow, then we can take $A = \mu\dot{\gamma}_0$ (μ is viscosity of the medium, $\dot{\gamma}_0$ is constant gradient of velocity). Equation (1.1) can be obtained from the rheologic integral of type

$$\tau = \mu\left[\dot{\gamma} + \frac{\lambda^{\nu}}{\Gamma(1-\nu)}\frac{d}{dt}\int_c^t (t-t')^{-\nu}\dot{\gamma}(t')dt'\right], \tag{1.2}$$

where the hermidarity nuclear was represented proportionally to the degree law with negative fractional exponent: λ is a relaxation time.

Taking $\dot{\gamma} = \dot{\gamma}_0 = const$ (the experiments in fig.1 were carried out for constant gradient of velocity) solution of (1.2) has a view

$$\tau = \mu\dot{\gamma}_0\left[1 + \frac{\lambda^{\nu}}{\Gamma(1-\nu)}\frac{1}{(t-C)^{\nu}}\right]. \tag{1.3}$$

Comparison of (1.1) and (1.3) shows their complete analogy

$$A = \mu\dot{\gamma}_0, B = \frac{\lambda^{\nu}}{\Gamma(1-\nu)}.$$

For big times from equation $\tau_{\infty} = \mu\dot{\gamma}_0$ for the given velocity of deformation and measured stress of shear it is not difficult to calculate $\mu = \tau_{\infty}/\dot{\gamma}_0$.

For curves given in fig.1 the parameters of viscosity have correspondingly the following values:

$$1 - \mu = 0.11 \text{ Pa c}, \quad 2 - \mu = 0.419 \text{ Pa c}.$$

Determination of λ, ν and C can be realized by the following way. First, C is taken equal to zero and experiments are worked out in the coordinates of the transformed equation (1.3)

$$\ln\frac{\tau}{\mu\dot{\gamma}_0} = \ln\frac{\lambda^{\nu}}{\Gamma(1-\nu)} - \nu\ln t. \tag{1.4}$$

By angle of inclination ν are determined in coordinates $\ln\frac{\tau}{\mu\dot{\gamma}_0} - \ln t$, and for value $\ln t = 0$ it is determined $\ln\frac{\lambda^{\nu}}{\Gamma(1-\nu)}$, that is λ. After that if the stress curve cuts across the axis of coordinate then taking equation (1.3) $t = 0$ it is not difficult to find the value by the following dependence

$$C = -\left[\frac{\lambda^{\nu}}{\Gamma(1-\nu)}\frac{1}{\tau_0/\mu\dot{\gamma}_0 - 1}\right]^{1/\nu}. \tag{1.5}$$

The working out of graphics given in fig. 1 by (1.4) was represented in fig.2.

As it is not difficult to notice the both curves are rectified in coordinates

$$\ln \tau/_{\mu\dot{\gamma}_0} - \ln t .$$

Determining by tangens of the angle of inpclination and the cuted across axis of the values of the fractality parameter and relaxation time the following quantities were obtained: for oils deposit Varik- $\nu = 0{,}605$, $\lambda = 27{,}96$ min; deposit Boston $\nu = 0{,}51$, $\lambda = 40{,}36$ min. As far as for deposit Varik the stress at initial moment of time $t = 0$ has the finite value τ_0, then the calculated by (1.5) parameter has value equal to 2,58 min. Curves of calculation (dash) were represented in fig.1 shows enough good convergence with experimental data.

2. In item 1 it was shown, that some oils containing resin-asphalt-paraffin inclusions for some conditions is enough satisfying described by the model of integral type (1.2), where function of heredity characterizes at some moment of time the system is subjected to deformation. It is clear that in general case in addition to relaxation function (retapdation) of gradient of velocity the strain relaxation function can have place, too.

Then analogous to (1.2) the following rheologic equation can be written

$$\frac{\theta^\alpha}{\Gamma(1-\alpha)}\int_e^t (t-t')^{-\alpha}\tau(t')dt' + \tau = \mu\left[\dot{\gamma} + \frac{\lambda^\nu}{\Gamma(1-\nu)}\int_c^t (t-t')^{-\nu}\dot{\gamma}(t')dt'\right]. \tag{2.1}$$

In case if $\theta = 0$, then (2.1) is identical to (1.2). And if suppose, that $\lambda = 0$ then (2.1) will be written in a view

$$\frac{\theta^\alpha}{\Gamma(1-\alpha)}\int_e^t (t-t')^{-\alpha}\tau(t')dt' + \tau = \mu\dot{\gamma}\,. \tag{2.2}$$

Following [8] the operation of differentiation of fractional index is introduced or more often named by fractional differentiation. The fractional derivative of order ν from the piece-wise continuous function $f(t)$ is determined by

$$D_c^\nu f(t) = \frac{d_c^\nu f(t)}{dt^\nu} = \frac{1}{\Gamma(1-\nu)}\frac{d}{dt}\int_c^t f(t')(t-t')^{-\nu}dt'\,; \quad -\infty < \nu < 1, \tag{2.3}$$

where c is a random real number (may be $c = \pm\infty$). In the particular case (2.3) for $c = 0$ index is omitted and the simplified denotations are introduced:

$$D_0^\nu \equiv D^\nu \quad \text{and} \quad \frac{d_0^\nu}{dt^\nu} \equiv \frac{d^\nu}{dt^\nu}.$$

Taking into account the introduced fractional differentiation operation the equation (2.1) will be written

$$\theta^\alpha D_e^\alpha \tau + \tau = \mu\left(\dot{\gamma} + \lambda^\nu D_c^\nu \dot{\gamma}\right)$$

or

$$\theta^\alpha \frac{d_e^\alpha \tau}{dt^\alpha} + \tau = \mu\left(\dot{\gamma} + \lambda^\nu \frac{d_c^\nu \dot{\gamma}}{dt^\nu}\right). \tag{2.4}$$

For $e = 0$, $c = 0$ equation (2.4) is represented as

$$\theta^\alpha D^\alpha \tau + \tau = \mu\left(\dot{\gamma} + \lambda^\nu D^\nu \dot{\gamma}\right)\theta D^\alpha$$

or

$$\theta^\alpha \frac{d^\alpha \tau}{dt^\alpha} + \tau = \mu\left(\dot{\gamma} + \lambda^\nu \frac{d^\nu \dot{\gamma}}{dt^\nu}\right). \tag{2.5}$$

3. The non-stationary motion of rheological complex dispersive liquid with fractal structure in the circle cylindrical tube with radius R along the axis z under action of pressure differential $-\dfrac{\partial P}{\partial z}=f(t)$ (particularly, pressure differential can change and take constant value $\dfrac{\Delta P}{L}$).

Motion differential equations taking into account rheological correlation (2.4) will be written

$$\rho\frac{\partial\vartheta_z}{\partial t}=-\frac{\partial P}{\partial z}+\frac{\partial\tau_{rz}}{\partial r}+\frac{\tau_{rz}}{r},$$

$$\theta^{\alpha}\frac{\partial_e^{\alpha}\tau_{rz}}{\partial t^{\alpha}}+\tau_{rz}=\mu\left(\frac{\partial\vartheta_z}{\partial r}+\lambda^{\nu}\frac{\partial_c^{\nu}}{\partial t^{\nu}}\frac{\partial\vartheta_z}{\partial r}\right), \tag{3.1}$$

where $\vartheta_z(t,r)$ is the velocity of motion;

τ_{rz} is a shear strain.

Solving (3.1) with respect to $\vartheta_z(t,r)$, we obtain

$$\rho\theta^{\alpha}\frac{\partial_e^{\alpha+1}\vartheta_z}{\partial t^{\alpha+1}}+\rho\frac{\partial\vartheta_z}{\partial t}=-\theta^{\alpha}\frac{\partial_e^{\alpha+1}}{\partial t^{\alpha}}\frac{\partial P}{\partial z}-\frac{\partial P}{\partial z}+\mu\frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\frac{\partial\vartheta_z}{\partial r}+\lambda^{\nu}\frac{\partial_c^{\nu}}{\partial t^{\nu}}\frac{\partial\vartheta_z}{\partial r}\right)\right]. \tag{3.2}$$

If we assume that in initial moment of time the liquid was in rest and $e=0$, $c=0$, then (3.2) will be written in the following view:

$$\rho\theta^{\alpha}\frac{\partial^{\alpha+1}\vartheta_z}{\partial t^{\alpha+1}}+\rho\frac{\partial\vartheta_z}{\partial t}=-\theta^{\alpha}\frac{\partial_e^{\alpha+1}P}{\partial t^{\alpha}\partial z}-\frac{\partial P}{\partial z}+\mu\frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\frac{\partial\vartheta_z}{\partial r}+\lambda^{\nu}\frac{\partial_c^{\nu+1}\vartheta_z}{\partial t^{\nu}\partial r}\right)\right], \tag{3.3}$$

and the initial and boundary conditions as

$$\vartheta_z(0,r)=0,\quad \vartheta_z(t,R)=0,\quad \frac{\partial\vartheta_z(t,0)}{\partial r}=0. \tag{3.4}$$

Solution of the differential equation (3.3) under the conditions (3.4) in the plane of Laplace transformants has a view:

$$Q(S)=\frac{\pi F(S)R^2}{\rho S}\left[1-\frac{2}{\beta\sqrt{\rho S}R}\frac{I_1\left(\beta\sqrt{\rho S}R\right)}{I_0\left(\beta\sqrt{\rho S}R\right)}\right]. \tag{3.5}$$

Immediate conversion of dependencies (3.5) is conjugate with significant difficulties of finding of the originals of functions

$$I_0\left(\beta\sqrt{\rho S}R\right),\quad I_1\left(\beta\sqrt{\rho S}R\right).$$

So it can be advisable obtaining of the approximate correlations for the small and big times.

On the base of well-known properties of limit passings of Laplace transformation the asymptotic behavior of the original for $t\to 0$ and $t\to\infty$ is determined by behavior of transform for $S\to\infty$ and $S\to 0$ correspondingly. First case $t=0$ is consider, that is $S\to\infty$. Then from (3.5) it follows

$$Q(S)\sim\frac{\pi R^2}{\rho}\left(S^{-1}-\frac{2\sqrt{\mu}}{\sqrt{\rho}R}\theta^{-\frac{\alpha}{2}}\lambda^{\frac{\nu}{2}}S^{\frac{\nu-\alpha-3}{2}}\right)F(S) \tag{3.6}$$

for $0<\nu<1$, $0<\alpha<1$

$$Q(S) \sim \frac{\pi R^2}{\rho}\left(S^{-1} - \frac{2\sqrt{\mu}}{\sqrt{\rho R}} S^{-3/2}\right) F(S) \qquad (3.7)$$

for $\nu \le 0$, $\alpha \le 0$.

If to take

$$F(S) \equiv \frac{\Delta P}{SL},$$

then originals (3.6) and (3.7) correspondingly have a view:

$$q(t) \sim \frac{\pi R^2}{\rho}\left[t - \frac{2\sqrt{\mu}}{\sqrt{\rho R}} \theta^{-\frac{\alpha}{2}} \lambda^{\frac{\nu}{2}} \frac{t^{\frac{3+\alpha-\nu}{2}}}{\Gamma\left(\frac{5+\alpha-\nu}{2}\right)}\right] \frac{\Delta P}{L}, \qquad (3.8)$$

$$q(t) \sim \frac{\pi R^2}{\rho}\left[t - \frac{2\sqrt{\mu}}{\sqrt{\rho R}} \frac{t^{3/2}}{\Gamma\left(\frac{5}{2}\right)}\right] \frac{\Delta P}{L}. \qquad (3.9)$$

It is seen from (3.8) and (3.9) that for small times the function of consumed for values $0 < \nu$, $\alpha < 1$ depends on the parameters of fractality and relaxation and reteradation times and there is not such dependence for $\nu, \alpha < 0$.

Now consider the case ,when $t \to \infty$, that is $S \to 0$. For that from (3.5) we obtain

$$Q(S) \sim \frac{\pi R_4}{4\mu} \frac{1+\theta^\alpha S^\alpha}{1+\lambda^\nu S^\nu} \frac{F(S)}{1 + \frac{\rho S}{4\mu} R^2 \frac{1+\theta^\alpha S^\alpha}{1+\lambda^\nu S^\nu}}. \qquad (3.10)$$

Original (3.10) can be represented in a view

$$q(t) \sim \frac{\pi R^4}{4\mu} \sum_{n=0}^{\infty} (-1)^n \left[\lambda^{\nu n} D^{\nu n} + \theta^\alpha \lambda^{\nu n} D^{\nu n+\alpha}\right] f(t) \qquad (3.11)$$

for $\nu < 0$ and $\alpha < 0$.

Knowing the concrete value of $f(t)$ from (3.11) the quantity of expense $q(t)$ is calculated. If we assume $f(t) = \frac{\Delta P}{L}$, then (3.11) is written as

$$q(t) \sim \frac{\pi \Delta R R^4}{4\mu L} \sum_{n=0}^{\infty} (-1)^n \left[\frac{\lambda^{\nu n}}{\Gamma(1-\nu n)} t^{-\nu n} + \frac{\theta^\alpha \lambda^{\nu n} t^{-\nu n-\alpha}}{\Gamma(1-\nu n-\alpha)}\right]. \qquad (3.12)$$

For big times original (3.10) can be written correspondingly in a view of the following differential equation

$$\frac{\rho R^2}{4\mu} \theta^\alpha \frac{d^{\alpha+1} q}{dt^{\alpha+1}} + \lambda^\nu \frac{d^\nu q}{dt^\nu} + \frac{\rho R^2}{4\mu} \frac{dq}{dt} + q = \frac{\pi R^4}{4\mu}\left[f(t) + \theta^\alpha \frac{d^\alpha f}{dt^\alpha}\right]. \qquad (3.13)$$

Giving the concrete value of $f(t)$ the differential equation (3.13) can be solved with respect to $q(t)$ and on the contrary knowing $q(t)$ equation (3.13) is solved with respect to $f(t)$. Moreover, having experimental measures $q(t)$ and $f(t)$ we can determine the parameters of the model.

Supposing that at initial moment $q(0) = q_0$, and $f(t) \equiv 0$, that is, the flowing process is considered after discharge of pressure differential we can obtain solution of (3.13) if the condition is fulfilled:

$$\frac{4\mu}{\rho R^2} = \frac{\lambda^{\frac{\nu}{\alpha-\nu}}}{\theta^{\frac{\alpha}{\alpha-\nu}}},$$

which has a view

$$q(t) = q_0 \exp\left(-\frac{\lambda^{\frac{\nu}{\alpha-\nu}}}{\theta^{\frac{\alpha}{\alpha-\nu}}} t \right). \tag{3.14}$$

Analysis of (3.14) shows that after discharge the pressure differential the liquid continues to flow for some time, moreover duration of flowing depends on relaxation times and the fractality parameters.

4. At motion of real liquids in tubes as a rule the integral parameters are used such as mean velocity by cross-section, density and pressure. According to the obtaining of the averaged differential equations of motion of rheological complex liquid with fractal structure represent interest. For that multiplying the first equation of (3.1) by $2\pi r dr$ and integrating by radius from 0 to R taking into account the correlation

$$w = \frac{1}{\pi R^2} \int_0^R 2\pi r \vartheta_z dr$$

we have

$$\rho \frac{\partial w}{\partial t} = -\frac{\partial P}{\partial z} + \frac{2}{R} \tau_z, \tag{4.1}$$

where τ_z is strain of friction on the tube wall.

If we suppose the quasi-stationary condition is fulfilled on the tube wall analogously to viscous liquid, that is

$$\left. \frac{\partial \vartheta_z}{\partial r} \right|_{r=R} = -\frac{4}{R} w,$$

then the second equation of (3.1) can be written as

$$\theta^\alpha \frac{\partial_e^\alpha \tau_z}{\partial t^\alpha} + \tau_z = -\frac{4\mu}{R} \left(w + \lambda^\nu \frac{\partial_c^\nu w}{\partial t^\nu} \right). \tag{4.2}$$

Excluding from equations (4.1) and (4.2) τ_z, we will have

$$\theta^\alpha \frac{\partial_e^{\alpha+1} w}{\partial t^{\alpha+1}} + 2a\lambda^\nu \frac{\partial_c^\nu w}{\partial t^\nu} + \frac{\partial w}{\partial t} + 2aw = -\frac{\theta^\alpha}{\rho} \frac{\partial_e^{\alpha+1} P}{\partial t^\alpha \partial z} - \frac{1}{\rho} \frac{\partial P}{\partial z}, 2a = \frac{8\mu}{\rho R^2}. \tag{4.3}$$

Equation (4.3) contains two unknown parameters w, P. For closure of the system let's use the equation of continuity of poorcompressible liquid [9]

$$\rho c^2 \frac{\partial w}{\partial z} = -\frac{\partial P}{\partial t}. \tag{4.4}$$

Solving the system (4.3) and (44) with respect to P we obtain:

$$\theta^\alpha \frac{\partial_e^{\alpha+2} P}{\partial t^{\alpha+2}} + 2a\lambda^\nu \frac{\partial_c^{\nu+1} P}{\partial t^{\nu+1}} + \frac{\partial^2 P}{\partial t^2} + 2a \frac{\partial P}{\partial t} = \theta^\alpha c^2 \frac{\partial_e^{\alpha+2} P}{\partial t^\alpha \partial z^2} + c^2 \frac{\partial^2 P}{\partial z^2}. \tag{4.5}$$

In processes of start or sudden stops of pipe-lines the arising on that passing processes are described by the system of differential equations motion and continuity. Suppose, that at initial moment of time in the halfinfinite pipe- line the rheologic complex liquid with fractal structure is in rest and pressure is equal to zero. At some moment of time pressure in cross-section $z=0$ begins to change by law $P=P_0(t)$, particularly pressure can take constant value equal to P_{00}.

In this case non-established motion for the above pointed liquid is described by the system of differential equations (4.3) and (4.4) for the following initial and boundary conditions

$$w(0,z)=0,\quad P(0,z)=0; \tag{4.6}$$

$$P(t,0)=P_0(t),\quad P(t,\infty)=0. \tag{4.7}$$

The system (4.3) and (4.4) written with respect to P under the condition $e=0$ and $C=0$ has a view

$$\theta^\alpha \frac{\partial^{\alpha+2} P}{\partial t^{\alpha+2}} + 2a\lambda^\nu \frac{\partial^{\nu+1} P}{\partial t^{\nu+1}} + \frac{\partial^2 P}{\partial t^2} + 2a\frac{\partial P}{\partial t} = c^2\left(\theta^\alpha \frac{\partial^{\alpha+2} P}{\partial t^\alpha \partial z^2} + \frac{\partial^2 P}{\partial z^2}\right). \tag{4.8}$$

Write the initial and boundary conditions for P as

$$P(0,z)=0,\quad \frac{\partial P(0,z)}{\partial t}=0; \tag{4.9}$$

$$P(t,0)=P_0(t),\quad P(t,\infty)=0. \tag{4.10}$$

Using Laplace transform to (4.8)-(4.10) we obtain the following value of velocity in initial cross- section of the tube

$$\hat{w}(S)=\frac{\sqrt{S}}{\rho C^2}\sqrt{\frac{1+\theta^\alpha S^\alpha}{2a+S+2a\lambda^\nu S^\nu+\theta^\alpha S^\alpha}}\,\hat{P}_0(S). \tag{4.11}$$

Asymptotic solutions for $0<\alpha;\ \nu>1+\alpha$, for $t\to 0$ and $t\to\infty$ are obtained from (4.11) and correspondingly have view

$$w(t)\sim \frac{1}{\rho C^2}\sqrt{\frac{\theta^\alpha}{2a\lambda^\nu}}\,D^{\frac{1+\alpha-\nu}{2}}P_0(t), \tag{4.12}$$

$$w(t)\sim \frac{1}{\rho C^2\sqrt{2a}}\left[D^{1/2}-\frac{1}{2\cdot 2a}D^{3/2}-\frac{1}{2}\left(\lambda^\nu D^{\nu+\frac{1}{2}}-\theta^\alpha D^{\alpha+\frac{1}{2}}\right)\right]P_0(t). \tag{4.13}$$

In the case when $P_0(t)\equiv P_\infty$, (4.12) and (4.13) correspondingly will be written as

$$w(t)\sim \frac{P_\infty}{\rho C^2\Gamma\left(\frac{1+\nu-\alpha}{2}\right)}\sqrt{\frac{\theta^\alpha}{2a\lambda^\nu}}\,t^{-\frac{1+\alpha-\nu}{2}}, \tag{4.14}$$

$$w(t)\sim \frac{P_\infty}{\rho C^2\sqrt{2a}}\left\{\frac{t^{-1/2}}{\Gamma\left(\frac{1}{2}\right)}-\frac{t^{-3/2}}{\Gamma\left(-\frac{1}{2}\right)}-\frac{1}{2}\left[\lambda^\nu\frac{t^{-\left(\nu-\frac{1}{2}\right)}}{\Gamma\left(\frac{1}{2}-\nu\right)}-\theta^\alpha\frac{t^{-\left(\alpha+\frac{1}{2}\right)}}{\Gamma\left(\frac{1}{2}-\alpha\right)}\right]\right\}. \tag{4.15}$$

From analysis of (4.12)- (4.15) it is seen, that for small times the velocity of the flow depends on relaxation times θ, λ and on the fractality parameters α, ν multiplicatively, and for big times it depends additive.

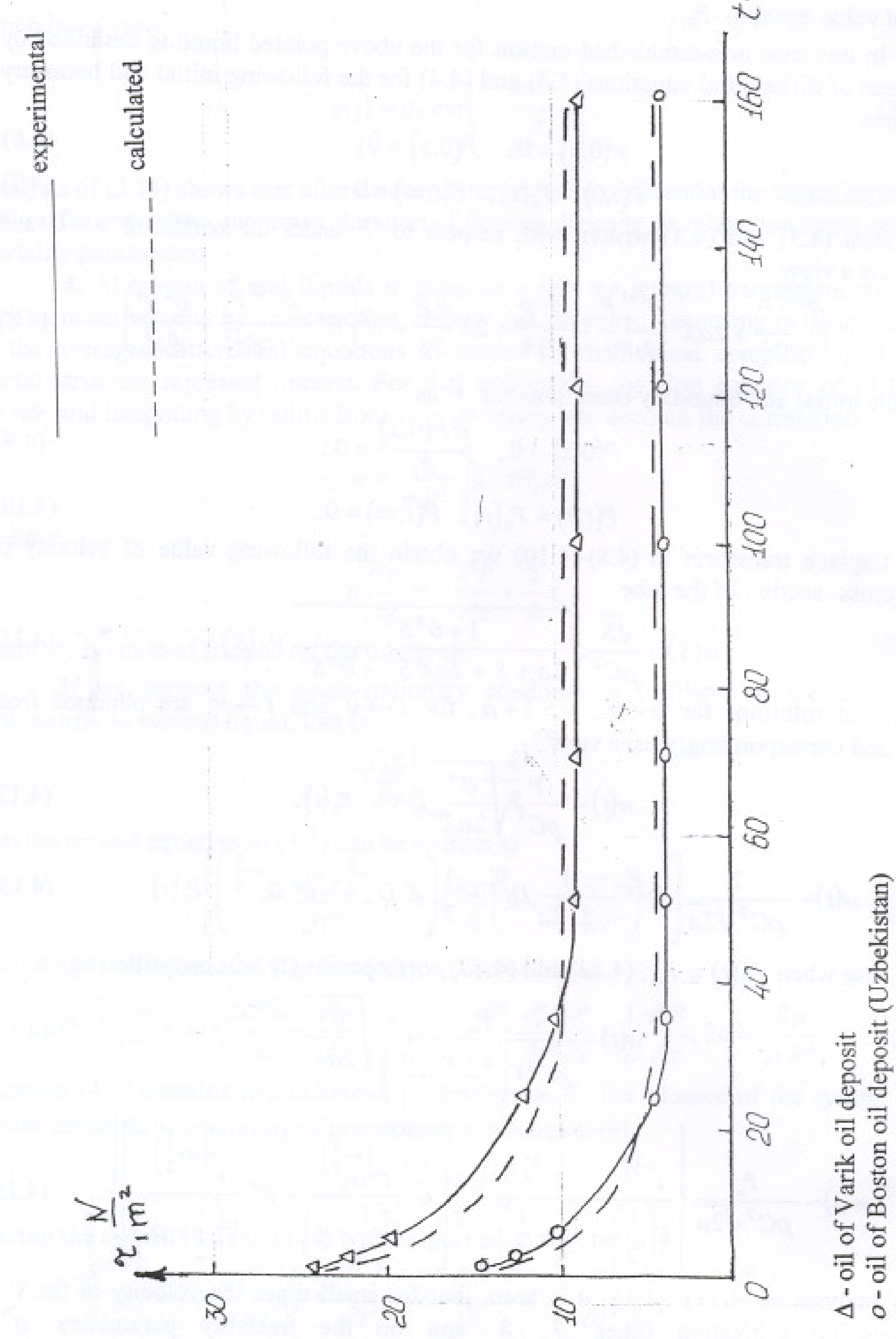
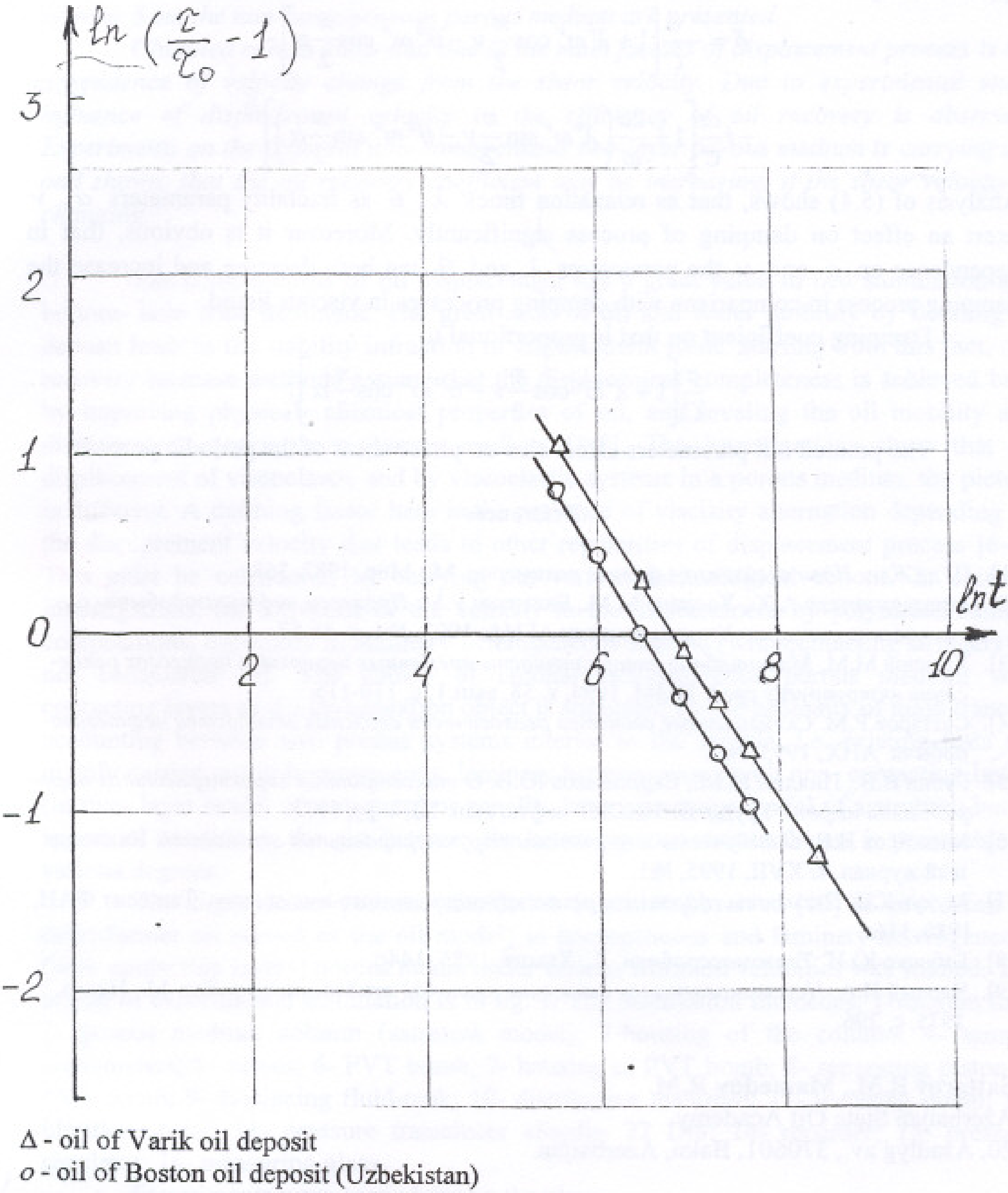

experimental
calculated
t·60, s
N/m²
τ,
30
20
10
0
20
40
60
80
100
120
140
160
Δ - oil of Varik oil deposit
o - oil of Boston oil deposit (Uzbekistan)

Fig. 1.

5. It is considered the non-established motion of rheologic complex liquid with fractal structure in the halfinfinite tube when pressure P represents the harmonic function of time of the given frequency in the initial cross-section of the tube.

In that case the problem is reduced to solution of the differential equation (4.8). Supposing, that in the enough further moment from the initial moment of time influence of initial conditions is not exerted on distribution of pressure, then solution of (4.8) can be found in view

$$P(z,t) = P_0 \exp(i\omega t + \delta z). \qquad (5.1)$$



Δ - oil of Varik oil deposit
o - oil of Boston oil deposit (Uzbekistan)

Fig. 2

Substituting (5.1) into (4.8) for determination δ we will obtain

$$-\theta^{\alpha} i^{\alpha} \omega^{\alpha+2} + 2a\lambda^{\nu} i^{\nu+1} \omega^{\nu+1} - \omega^2 + 2ai\omega = \delta^2 C^2 \left(\theta^{\alpha} i^{\alpha} \omega^{\alpha} + 1\right). \tag{5.2}$$

Whence we have

$$\delta = \frac{i\omega}{C} \sqrt{\frac{\theta^{\alpha} i^{\alpha} \omega^{\alpha} - 2a\lambda^{\nu} i^{\nu} \omega^{\nu+1} - 2ai\omega^{-1} + 1}{1 + \theta^{\alpha} i^{\alpha} \omega^{\alpha}}} \quad . \tag{5.3}$$

If we assume that θ, λ, ω, $2a$ are small then for $0 < \alpha$, $\nu < 1$, we will obtain approximately

$$\begin{gathered} \delta = -\frac{a}{C}\left[1 + \lambda^{\nu}\omega^{\nu} \cos\frac{\pi}{2}\nu - \theta^{\alpha}\omega^{\alpha} \cos\frac{\pi}{2}\alpha\right] - \\ -i\frac{\omega}{C}\left[1 + \frac{2a}{\omega}\left(\lambda^{\nu}\omega^{\nu} \sin\frac{\pi}{2}\nu - \theta^{\alpha}\omega^{\alpha} \sin\frac{\pi}{2}\alpha\right)\right]^{1/2}. \end{gathered} \tag{5.4}$$

Analysis of (5.4) shows, that as relaxation times λ, θ as fractality parameters α, ν exert an effect on damping of process significantly. Moreover it is obvious, that in dependence on α and ν the parameters λ and θ can both decrease and increase the damping process in comparison with damping processes in viscous liquid.

Damping coefficient on that is proportional to

$$\frac{a}{C}\left[1 + \lambda^{\nu}\omega^{\nu} \cos\frac{\pi}{2}\nu - \theta^{\alpha}\omega^{\alpha} \cos\frac{\pi}{2}\alpha\right].$$

The pointed out parameters effect also on phase shear of the periodic process.

References

[1]. П. де Жен. *Идеи скейлинга в физике полимеров.* М.: Мир, 1982, 368с.

[2]. Мирзаджанзаде А.Х., Хасанов М.М., Бахтизин Р.М. *Процессы нефтегазодобычи- динамическая система.* Ученые записки АГНА, 1992, №1, с. 45-57.

[3]. Хасанов М.М. *Масштабная инвариантность временных иерархий в процессах релаксации вязкоупругих сред.* ПММ, 1994, т. 58, вып.1, с. 110-115.

[4]. Саттаров Р.М. *Скейлинговые свойства реологически сложных жидкостей нефтегазодобычи.* АНХ, 1993, №9.

[5]. Губин В.В., Пиядин М.М., Скрипников Ю.В. *О тиксотропных характеристиках парафинистой нефти.* Труды ВНИИСПТ нефть, вып. XI, Уфа, 1973.

[6]. Михайлов Н.В. *О текучести и прочности структурированных жидкостей.* Каллоидный журнал, т. XVII, 1995, №1.

[7]. Мукук К.В. *Элементы гидравлики релаксирующих аномальных систем.* Ташкент ФАН, 1980, 116с.

[8]. Бабенко Ю.И. *Тепломассообмен.* Л., Химия, 1986, 144с.

[9]. Чарный И.А. *Неустановившееся движение реальной жидкости в трубах.* М., Недра, 1975, с. 296.

Sattarov R.M., Mamedov R.M.
Azerbaijan State Oil Academy.
20, Azadlyg av., 370601, Baku, Azerbaijan.

Received June 7, 1999; Revised August 31, 1999.
Translated by Soltanova S.M.