Ramiz A. ISMAILOV

INFLUENCE OF VISCOELASTIC PROPERTIES OF PIPES MATERIAL ON TRANSMISSION OF WAVES OF PRESSURE DISTURBANCE AT MOVEMENT OF NONEQUILIBRIUM GASES

Abstract

Use of pipes from a viscous and elastic material at construction of oil pipelines and gas pipelines puts before the researchers questions of study elastic-viscous properties of a material of a pipe on distribution of waves of indignation of pressure in the pipeline at the unsteady movement nonequilibrium gases. This influence is especially brightly shown at occurrence of non-regular situations in pipelines (having dug pipes and as a consequence outflow of gas, sharp changes in a mode of submission of gas, hydraulic impacts, etc.)

When movement of rheological complex fluids in pipes [1, 2, 3] is studied, oils of various deposits, containing tar, asphaltene, and paraffinaceous components are generally considered as nonequilibrium relaxation medium. In the existent models for description of gas movement in pipelines, gas is considered as equilibrium and viscous medium. However, natural gases which are mixtures of various gases (propane, ethane, methane, butane, butylenes, carbon- dioxide gas, inactive gases, etc.) under the certain conditions especially which are characteristic for filtering process in porous media in the presence of argillaceous components, can display elastic and plastic properties parallel with viscous ones. Along with this it should be noted that by virtue of above mentioned circumstances, at small inclusions of fluid components (water, condensed fluid, etc.) and at rapidly proceeding processes natural gases display nonequilibrium properties. On the other hand, material of pipe can also display elasto-viscous properties, which are especially typical when pipes of polymeric materials are used in gas distribution networks.

In view of aforesaid, study of influence of nonequilibrium properties of medium and elasto- viscous characteristics of pipe's material on propagation of waves of pressure disturbance at movement of nonequilibrium gases is of great interest.

Model of nonsteady motion of nonequilibrium gases in pipes of elasto- viscous materials was obtained similarly to the paper [4]:

$$\left\{\begin{array}{l} \dfrac{\partial P}{\partial x}=-\rho\left(\dfrac{\partial\omega}{\partial t}+m_0 f_0\omega\right), \\ \displaystyle\sum_{i=0}^{n}\left[\begin{array}{c} b_i\dfrac{\partial^i}{\partial t^i}\left(\dfrac{\partial\omega}{\partial x}\right)+\theta\dfrac{K_c^\infty}{K_c^0}b_i\dfrac{\partial^{i+1}}{\partial t^{i+1}}\left(\dfrac{\partial\omega}{\partial x}\right)+ \\ +\left(\dfrac{2R}{\delta_0}a_i+\dfrac{b_i}{K_c^0}\right)\dfrac{\partial^{i+1}P}{\partial^{i+1}}+\left(\dfrac{2R}{\delta_0}\theta\dfrac{K_c^\infty}{K_c^0}a_i+\theta\dfrac{b_i}{K_c^0}\right)\dfrac{\partial^{i+2p}}{\partial t^{i+2}} \end{array}\right]=0 \end{array}\right. . \quad (1)$$

At first we consider Voigt pipe, whose rheological model is written in the following form

$$\sigma=E\varepsilon+\eta\dot{\varepsilon}. \quad (2)$$

From the generalized rheological equation for elasto- viscous pipe [5]

$$\sum_{i=o}^{n}a_i\frac{\partial^i\sigma}{\partial t^i}=\sum_{i=o}^{n}b_i\frac{\partial^i\varepsilon}{\partial t^i} \quad (3)$$

relation (2) is obtained for the following values of the coefficients

$$a_0 = 1,\ a_1 = 0,\ b_0 = E,\ b_1 = \eta. \tag{4}$$

Taking them into account, system (1) for Voigt pipe can be written in the form of one relation

$$C^2\left(\lambda_T\frac{\partial}{\partial t}+1\right)\left(1+\theta\frac{C_\infty^2}{C_0^2}\frac{\partial}{\partial t}\right)\frac{\partial^2 P}{\partial x^2} = \beta_1\frac{\partial^3 U}{\partial t^3}+\beta_2\frac{\partial^2 U}{\partial t^2}+\frac{\partial U}{\partial t}, \tag{5}$$

where

$$U = \frac{\partial P}{\partial t} + m_0 f_0 P;\quad \beta_1 = \theta\lambda_T\frac{C^2}{C_0^2} + \theta\frac{C_\infty^2}{C_0^2}\frac{C^2}{\tilde{C}^2},\ C^2 = \frac{K_c^0}{\rho\left(1+\dfrac{2R}{\delta_0}\dfrac{K_c^0}{E}\right)};$$

$$C_0^2 = \frac{K_c^0}{\rho};\ C_\infty^2 = \frac{K_c^\infty}{\rho};\ \tilde{C}^2 = \frac{K_c^\infty}{\rho\left(1+\dfrac{2R}{\delta_0}\dfrac{K_c^\infty}{E}\right)},$$

θ, λ_T are relaxation times for the medium and pipe's material, respectively. If the pressure at the beginning of pipe is a harmonic time-varying function of the given frequency, then we find solution of equation (5) in the form $P(x,t) = P_0 e^{\alpha x + \omega t}$. Taking this representation into account in equation (5), we obtain the following relation for α:

$$\alpha = \frac{1}{C}\sqrt{K_1 + i\omega K_2}, \tag{6}$$

where

$$\begin{gathered} K_1 = \frac{R_1R_2+\omega^2 S_1 S_2}{R_2^2+\omega^2 S_2^2}, K_2 = \frac{S_1R_2 - S_2R_1}{R_2^2+\omega^2S_2^2};\ R_1 = \beta_1\omega^4 - (1+\beta_2 m_0 f_0)\,\omega^2; \\ S_1 = m_0 f_0 - (\beta_1 m_0 f_0 + \beta_2)\,\omega^2;\ R_2 = 1 - \lambda_T\theta\frac{C_\infty^2}{C_0^2}\omega^2;\ S_2 = \lambda_T + \theta\frac{C_\infty^2}{C_0^2}. \end{gathered} \tag{7}$$

Let us separate real and imaginary parts in relation (6), and we reserve only the root with the negative real part. Then solution of (5) can be written in the form

$$P = P_0 e^{-\xi\frac{x}{c}} e^{i\omega\left(t-\nu\frac{x}{c}\right)}, \tag{8}$$

where

$$\xi = \frac{1}{\sqrt{2}}\sqrt{\rho_1 + K_1};\ \nu = \frac{K_2}{2\xi};\ \rho_1 = \sqrt{K_1^2+\omega^2K_2^2}. \tag{9}$$

Parameter ξ characterizes the attenuation, and parameter ν defines the lag or phase displacement of boundary value of pressure harmonics.

Now we consider Maxwellian pipes in the form of the following rheological model:

$$\dot{\varepsilon} = \frac{\dot{\sigma}}{E} + \frac{\sigma}{\eta}. \tag{10}$$

Similarly to the above mentioned procedure for Maxwellian pipe described by relation (10) the following equation for motion of nonequilibrium gases was obtained

$$C^2\left(\frac{\partial}{\partial t}+\theta\frac{C_\infty^2}{C_0^2}\frac{\partial^2}{\partial t^2}\right)\frac{\partial^2 P}{\partial x^2} = \beta_1\frac{\partial^3 U}{\partial t^3}+\beta_2\frac{\partial^2 U}{\partial x^2}+\beta_3\frac{\partial U}{\partial t}. \tag{11}$$

The following calculated relations were obtained for determination of attenuation and lag parameters for relations (6), (7):

$$R_1 = \beta_1\omega^4 - (m_0 f_0 \beta_2 + \beta_3)\,\omega^2;\ S_1 = \beta_3 m_0 f_0 - (\beta_1 m_0 f_0 + \beta_2)\,\omega^2;$$
$$R_2 = -\theta\frac{C_\infty^2}{C_0^2}\omega^2;\quad S_2 = 1, \tag{12}$$

where

$$\beta_1 = \theta\frac{C^2}{\tilde{C}^2}\frac{C_\infty^2}{C_0^2};\ \beta_2 = 1 + \frac{2R}{\delta_0}\frac{\theta}{\lambda_T}\frac{C_\infty^2}{C_0^2}\frac{C^2}{C_T^2};\ \beta_3 = \frac{2R}{\delta_0}\frac{1}{\lambda_T}\frac{C^2}{C_T^2}. \tag{13}$$

Now we investigate influence of relaxation parameters θ and λ_T for medium (nonequilibrium gases) and pipe's materials, respectively, distribution of parameters ζ and ν on frequency ω.

To this end according to relations (7), (9), (12) and (13), computer program on QBASIC was prepared and realized for calculating values ζ and ν for Voigt and Maxwellian pipe, respectively. On the basis of the calculated values curves of qualitative distribution on attenuation parameter ζ and lag ν on frequencies ω were constructed for values $m_0 f_0 = 0,1\,\mathrm{sec}^{-1}$, $R = 0,2m$, $\delta = 0,01m$ and for the following estimates

$$\frac{C_\infty^2}{C_0^2} = 1,1;\ \frac{C^2}{C_0^2} = 0,9;\ \frac{C_\infty^2}{C_0^2}\frac{C^2}{\tilde{C}^2} = 1,1;\ \frac{C^2}{C_T^2} = 1.$$

These curves for Voigt and Maxwellian pipe at values $\theta = 1,\ \lambda_T = 1$ are given in fig. 1 and fig. 2, respectively. Analysis of these curves shows that for Maxwellian pipe starting with value $\omega = 86\,\mathrm{sec}^{-1}$ further increase of frequency does not cause the attenuation of pressure disturbance (fig.1).

This pattern is typical for so-called standing waves. Physical nature of this process for the considered case can be explained by nonequilibrium properties of moving medium. The similar pattern is observed for Voigt pipe but for higher frequency at values $\omega = 1074\,\mathrm{sec}^{-1}$ and higher. This shows the close connection of this phenomenon with the choice of model, which takes into account elasto- viscous characteristics of pipe's material. Analysis of curves, which are obtained for different values of relaxation parameters of medium and pipe's material, shows that when a certain value of relaxation parameter of pipe's material λ_T is achieved, its further increase does not change pattern of transmission of pressure disturbance in pipeline.

On the other hand, analysis of the curves in fig.1 shows that for Maxwellian model in comparison with Voigt model, we have abrupt branches of curve; this describes faster displaying of elasto-viscous characteristics of pipe's material. Analysis of curves for the lag parameter in fig.2 also shows narrower intervals of frequency variation at displaying elasto-viscous characteristics by Maxwellian pipe in comparison with Voigt one.

In conclusion the author is grateful to professor of "Oil and gas transfer and storage" chair of Azerbaijan State Oil Academy, doctor of Technical Science Sattarov R.M. for the problem statement and analysis of the obtained results.

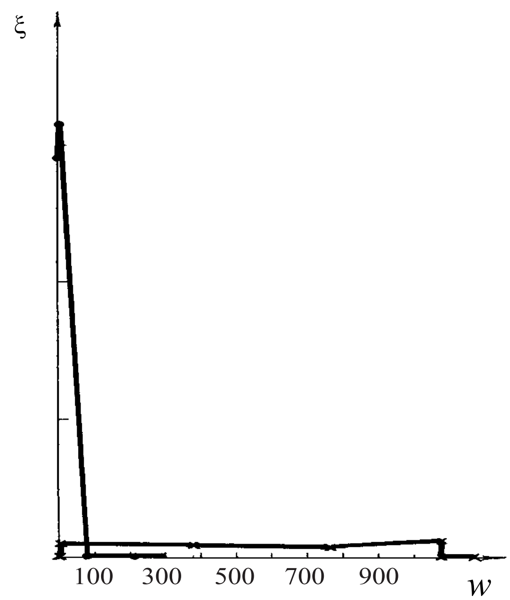
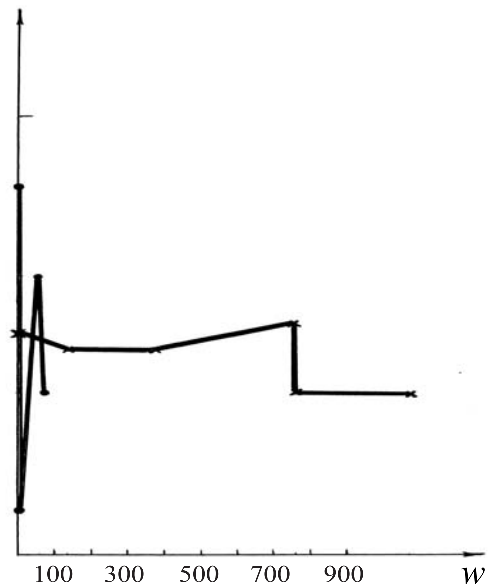


Fig 1.
Curve of qualitative distribution of attenuation parameter on frequencies
x - Voigt pipe
● - Maxwellian pipe



Fiq 2.
Curve of qualitative distribution of lag parameter on frequencies
x - Voigt pipe
● - Maxwellian pipe

References

[1]. Mirzadzhanzadekh A.Kh., Gallamov A.K., Maron V.I., Yupin V.A. *Hydrodynamics of pipeline transfer of oil and petroleum products*. M.: "Nedra", 1984, 287 p. (Russian)

[2]. Sttarov R.M. *Diagnostics of rheological properties of viscous elastoplastic media when they move in pipes.* // Inzhenerno-Fizicheskiy Zhurnal, 1981, v.41, No6, pp.1016-1026. (Russian)

[3]. Mukuk K.V. *The elements of hydraulics of relaxing anomalous system.* Tashkent: FAN, 1980, 116 p. (Russian)

[4]. Sattarov R.M. *Nonstationary motion of rheological complex fluids in pipes.* Baku, "Elm", 1999, 412 p. (Russian)

[5]. Wilkinson U.H. *Non- Newtonian fluids.* M.: "Mir", 1964, 216 p. (Russian)

Ramis A. Ismailov
Azerbaijan State Oil Academy.
20, Azadlyg av., AZ1010, Baku, Azerbaijan.
Tel.: (99412) 934 350(off.)

Received March 11, 2003; Revised June 24, 2003.
Translated by Azizova R.A.