GENERAL RHEOLOGICAL MODEL OF MAXWELL-TYPE ELASTIC VALUABLE FLUIDS

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Annotation: ***The article formulates a generalized model of an elastic-viscous fluid, in particular, from this model one can obtain Newtonian, generalized Newtonian, Maxwellka and other models. Basically, the generalized model of a viscoelastic fluid is built on the basis of the topological hypothesis of Astarit and Marrucci and the axiomatic principles of Truesdell and Knoll. The developed generalized model of a viscoelastic fluid is convenient for solving engineering problems and thus is easily implemented for studying the flow of non-Newtonian fluids in a flat channel and in a circular cylindrical tube.***
Key words: ***Elastic, viscous, Newton's model, Maxwell's model, axiom, flat channel, cylindrical tube.***

Most fluids have the property of elasticity, which makes up the mechanical memory. In solids, this memory is determined relative to the initial deformation. In fluids, however, there is no concept of initial deformation. That is why in liquids it is studied to "remember" the preservation of the previous deformation in relation to the state of a moment in time. This in turn greatly complicates the construction of the rheological equation from a phenomenological point of view in finitely deformable elastic viscous fluids. In general, the concept of "memory" in liquids is characterized by the fact that the deformation of the environment creates a relaxation process. Therefore, in elastic viscous liquids, their elastic properties are reflected in the nostatial flow more than in other liquids. In stationary flow, the elastic property does not affect the flow. In this case, the elastic viscous liquids are converted into Newtonian liquids, i.e., viscous liquids [23-30]. In elastic viscous fluids, depending on the type of fluid, the "hereditary factor" can be significantly expressed in these fluids, if the length of the "memory" corresponds to the length of the relaxation process, recalls the area and other hydrodynamic characteristics. Basically, the "hereditary" factor is determined by the number of Deborah. This number is characterized by the ratio of the time of the relaxation process to the time characterizing the main hydrodynamic phenomena, ie: $De = \frac{\lambda}{T}$ where λ is the relaxation time; T is the time characterizing the hydrodynamic phenomena. Typically, this ratio can be from 10^{-2} to 10^{2} seconds for high-molecular substances, including colloids, dispersion biological substances (elastic viscous liquids) [15-20]. The motion of elastic viscous fluids is fundamentally different from the motion of fluids that do not have elastic properties. In the development of the motion of elastic adhesive (polymer) fluids under the influence of a pressure gradient, the longitudinal velocity profile is not monotonous like a Newtonian fluid, but rises sharply at the beginning, then decreases after reaching a maximum value, oscillates around a steady-state amplitude does. In elastic viscous fluids as a result of cessation of impact force, deformation causes a unloading process. For example, in a polymer liquid flowing in a pipe, it can be observed that as a result of removing the pressure gradient or equalizing it to zero, a reverse flow is formed in the direction opposite to the main flow direction of the liquid. In this regard, it is important to study the movement of elastic adhesive (polymer) fluids in pipes. To date, rheological models of elastic viscous fluids have been proposed by many scientists for different models of fluids of different types [1- 26]. However, among the models proposed so far, there is no single universal model that generalizes all models [2, 16-20]. Therefore, the theoretical study of convective migration processes of elastic viscous fluids is becoming a complex process. Among the proposed models, we can say that the model, which generalizes the models in a certain sense, is determined by the following nonlinear integral equation [2, 18-21]:

$$T=\int_{-\infty}^{t} m\left[(t-t'),\ S_D(t')\right]\left[\left(1+\frac{\varepsilon}{2}\right)\left(C_t^{-1}(t')-E\right)+\frac{\varepsilon}{2}\left(C_t(t')-E\right)\right]dt' \qquad (1)$$

where $m\left[(t-t')S_D(t')\right]=\sum_{k=1}^{\infty}\frac{\eta_k}{\lambda_k^2}f_k\left[S_D(t')\right]\exp\left[-\int_0^t\frac{g_k\left(s_D(t'')\right)}{\lambda_k}dt''\right],\quad S_D^2=2trD^2$

$C_t(t')$- Koshi tensor; $C_t^{-1}(t')$- Finger tensor; E - unit tensor.

The general-view elastic viscous fluid model given above (1) includes many models of polymer fluids and other elastic viscous fluids. Basically, the difference between these models is in the assignment of functions $f_k\left(S_D(t')\right)$ and $g_k\left(S_D(t')\right)$, which are part of the integral equation (1). Especially in small deformations $f_k=g_k=1$, in which case the model of elastic viscous fluids becomes linear. In numerical accounting, λ_k and η_k are quantities, in particular

$$\lambda_k=\frac{\lambda}{k^{\alpha}},\qquad \eta_k=\frac{\eta}{\xi(\alpha)k^{\alpha}}$$

taken in the form of, where η is the dynamic viscosity coefficient of the Newtonian fluid in the initial state; λ – relaxation time, α – a number that characterizes the spectrum of relaxation time distribution; $\xi(\alpha)$ – Riman zeta function. It is determined by the expression in the form $\xi(\alpha)=\sum_{k=1}^{\infty}\frac{1}{k^{\alpha}}$. The fact that the integral equation in the form of an elastic viscous fluid (1) is equivalent to the differential equation in this form is given in the research work of Z.P.Shulman and B.M.Husid [18-20]:

$$T=\sum_{k=1}^{\infty}\left(1+\frac{\varepsilon}{2}\right)' T_k^{(1)}+\frac{\varepsilon}{2}T_k^{(2)},\quad \overset{\nabla}{T}{}_k^{(1)}+\frac{g_k}{\lambda_k}T_k^{(1)}=2p_kD,$$
$$\overset{\Delta}{T}{}_k^{(2)}+\frac{g_k}{\lambda_k}T_k^{(2)}=-2p_kD,\qquad \frac{Dp_k}{Dt}+\frac{g_k}{\lambda_k}p_k=\frac{2_k}{\lambda_k^2}f_k. \tag{2}$$

where the high convective product is through this expression

$$\overset{\nabla}{T}{}_k^{(1)}=\frac{DT_k^{(1)}}{Dt}-T_k^{(1)}\nabla V^T-\nabla V\cdot T_k^{(1)}$$

the lower convective product is defined by the following expression

$$\overset{\Delta}{T}{}_k^{(2)}=\frac{DT_k^{(2)}}{Dt}+T_k^{(2)}\nabla V+\nabla V^T\cdot T_k^{(2)}$$

Yaumann's product is defined as follows

$$\frac{DA}{Dt}=\frac{\partial A}{\partial t}+V\nabla A+WA-AW$$

Where $\nabla V=D+W,\quad D=\frac{1}{2}\left(\nabla V^T+\nabla V\right),\quad W=\frac{1}{2}\left(\nabla V-\nabla V^T\right);$

ε –is introduced as a parameter representing the second normal voltage difference other than zero, which is determined by the following formula $\frac{\varepsilon}{2}=\frac{\Psi_2}{\Psi_1}$. Where $\Psi_1=(\sigma_{11}-\sigma_{22})/\gamma^2,\qquad \Psi_2=(\sigma_{22}-\sigma_{33})/\gamma^2$. It should be noted that the upper convective product, the lower convective product, and the Yaumann product are obtained in the arbitrary coordinate system, which are transformed into ordinary products in the orthogonal system Cartesian and cylindrical coordinate systems.

Three types of rheological models of this type are widely used in practice for numerical calculations in specific cases:

1. Meyster (M) model $f_k=1,\quad g_k=1+\left(c/\sqrt{2}\right)\lambda_k S_D;$

2. Berd-Carro (BK) model $f_k=1\left(1+\lambda_k^2 S_D^2\right),\quad g_k=1;$

3.McDonald-Baird-Carro(MBK) model $f_k=\frac{1+\lambda_k^1 S_D}{1+\lambda_k S_D},\quad g_k=\frac{\left(1+\lambda_k^1 S_D\right)^{3/2}}{\left(1+\lambda_k S_D\right)^{1/2}},\quad \lambda_k^1=\lambda^1/k^\alpha$

where $\lambda_k^1=x\lambda_k,\ 0\le x\le 1$

for all three models:

$$\lambda_k^1=\frac{\lambda^1}{k^\alpha},\quad \eta_k=\frac{\eta}{\xi(\alpha)k^\alpha},\quad S_D^2=2trD^2;\quad \lambda_k^1=x\lambda_k,\ 0\le x\le 1$$

Where $c^2 = (2 - 2\varepsilon - \varepsilon^2)/3$; in some cases it is taken as $\lambda^1 = 0,2\lambda$. If $\lambda^1 = \lambda$, then the McDonald-Bird-Carro model corresponds to the Meister model; $k = 1,2,...,\infty$

The Meyster model here takes into account the relaxation time effect of the deformation rate. In the BK model, the deformation rate is related to the shear model, while in the MBK model, it is a generalized model that takes into account changes in relaxation time, as well as the shear model. The formulas for determining the coefficient of dynamic viscosity in a stationary shear are determined in the following form with respect to the Weisenberg number:

$$\eta_k(\dot{\gamma}) = \frac{\eta}{\xi(\alpha)} \sum_{k=1}^{\infty} \frac{k^\alpha}{\left(k^\alpha + We\right)^2}, \qquad We = \frac{c\lambda\dot{\gamma}}{\sqrt{2}}$$

$$\eta_k(\dot{\gamma}) = \frac{\eta}{\xi(\alpha)} \sum_{k=1}^{\infty} \frac{k^\alpha}{k^{2\alpha} + We^2}, \qquad We = \lambda\dot{\gamma} \tag{3}$$

$$\eta_k(\dot{\gamma}) = \frac{\eta}{\xi(\alpha)} \sum_{k=1}^{\infty} \frac{k^\alpha}{\left(k^\alpha + We\frac{\lambda^1}{\lambda}\right)^2}, \qquad We = \lambda\dot{\gamma}$$

Where $\dot{\gamma}$ –is the shear deformation velocity or velocity gradient;

$\eta(\dot{\gamma})$ – Newtonian coefficient of adhesion depending on the rate of deformation.

At a small value of the shear rate, i.e. $|\lambda\dot{\gamma}| << 1$, when $f_k \to 1, \quad g_k \to 1$ is sought, the model under consideration is the same as the spectrum of relaxation time. When $We = 0$, the coefficient of adhesion of the three states in formula (3) above is equal to $\eta_k(\dot{\gamma}) = \frac{\eta}{\xi(\alpha)k^\alpha}$.

However, it is not possible to derive a viscous plastic fluid model from this model in a special way, because in the hydrostatic (quiescent) state the maxwell fluid cannot maintain the noisotropic stress state indefinitely. That is, with a change in voltage, of course, fluid motion or deformation occurs. Therefore, the nonstationary state of plastic fluids cannot be expressed by a generalized elastic adhesive model. The above model can be applied to the fluid flow when the velocity gradient $\dot{\gamma} \geq 0,1 сек^{-1}$ is present. However, plasticity properties can occur in non-Newtonian fluids when $\dot{\gamma} \leq 0,1 сек^{-1}$ accept small values. The creation of a generalized model of such liquids is carried out by conducting separate scientific research. We can cite this in our next research work. Specifically from the model proposed above, it is possible to derive the Newtonian model for the viscous fluid and the Maxwell models for the viscous elastic fluid.

If $\lambda_k = 0$, then the equation corresponding to the Newtonian model is derived from the system of equations (2). In fact, being $\lim(\lambda_k \to 0)\lambda_k p_k = \eta$, equation (2) becomes a Newtonian equation in one-dimensional space. That is $T = \eta\frac{\partial u}{\partial y}$, which is the Newtonian mod. By performing the same steps, it is possible to form an equation corresponding to the Maxwell model when $\alpha \to \infty$ is attempted (2) from the system of equations

$|\lambda\dot{\gamma}| << 1$ $\quad f_k \to 1, \quad g_k \to 1$ and when $p_k = \dfrac{\eta_k}{\lambda_k}$ is satisfied. In conclusion, it can be said that the system of equations in the form (2) is a generalized model of elastic viscous fluids in a certain sense.

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