DRAG REDUCTION BY POLYMER ADDITIVES IN A TURBULENT PIPE FLOW

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Introduction

The phenomenon of drag reduction by additives was discovered in 1946 by B.A.Toms.He was actually investigating the mechanical degradation of polymers using a pipe flow apparatus and noticed that the polymer solution offered less resistance to flow in turbulent conditions under constant pressure, than the solvent itself. Drag reduction by polymer additives is known as Toms effect and is well known to fluid dynamicists, chemists, specialists in oil transport industry etc.By dissolving a minute amount of long-chain polymer molecules in water or in organic solvent, the frictional drag of turbulent flow through pipes and channels can be very much reduced. In pipe flows for example the drag can be reduced by up to 70% by adding just few parts per milion(ppm) of polymer. Liquids are mostly transported through pipes and a drag reduction by adding a small amount of polymers can offer large economic advantages and a greater effectiveness.

Drag reduction mechanism

Since the discovery of the drag reducing effect a lot of theories have been proposed in order to describe this phenomenon. In spite of the numerous hypotheses advanced there exists not yet a unitary theory of this effect. It is assumed that the elasticity of the macromolecules of polymer is essential in explaining Toms effect. The elasticity of the polymer could during extension inhibit vortex stretching in the flow, thereby changing the flow characteristics. Many studies have concentrated more on the interaction which takes place between the polymer and the flow. But the non-Newtonian character of the flow implies cumbersome algebra. In fact is not necessary to consider the turbulence processes that are present in the flow, but also the influence of the rheological properties of the fluids. Here one touches on two essentially incomplet areas within fluid dynamics, turbulence and rheology. We propose a theoretical approach based on the linear stability theory.

Basic equations

We consider a fluid that consists of a Newtonian solvent to which a minute amount of polymer is added. In turbulent flow the turbulence is directly influenced by the presence of the pipe wall. So, the study of the wall turbulence is very important in order to understand the drag reduction mechanism.

To describe the flow and transport phenomena in fluids we need the equations of continuity, motion and energy, together with the expressions for the fluxes of mass, momentum and energy.It is well known that liquids with complex structure ,such as macromolecular fluids, soap solutions and two-phase fluids are not describe by Newton's law of viscosity.

To describe these various effects of non-Newtonian fluids flow is necessary to use constitutive relation, or rheological equation of state, or non-Newtonina model.

The basic equations that describe the incompressible flow of such fluid are given by: continuity equations, Cauchy equation of motion and constitutive equations. During the last decades a large number of constitutive equations have been proposed to describe the nonlinear viscoelastic behavior of polymer melts and solution. We used the Maxwell model that is base for more sophisticated nonlinear models, which try to capture all observed nonlinear viscoelastic phenomena.

The system of equations is:

$$\text{div } \vec{v} = 0, \quad (1)$$

$$\frac{d\vec{v}}{dt} = \rho\vec{F} + div\sigma, \quad (2)$$

$$\sigma + \Lambda\frac{\delta\sigma}{\delta t} = 2\mu D, \qquad \text{where } \frac{\delta}{\delta t} \text{ is the Jaumann derivative} \quad (3)$$

$$\sigma + \Lambda\left[\frac{\partial\sigma}{\partial t} + (\vec{v}grad)\sigma - grad\vec{v}\sigma - (grad\vec{v}\sigma)^T\right] = \mu\left[grad\vec{v} + (gradv)^T\right]. \quad (4)$$

μ represents the coeficient of dynamic viscosity, λ is the relaxation time, D is the rate -of- strain tensor, T= -pI + σ is the symmetric stress tensor, I stands for the unit tensor, p represents the isotropic pressure, $\vec{v}$ is the velocity .

The phenomenon of turbulence can be explicitly introduced in the equations by decomposing the turbulent motion in a mean and fluctuating part. The equations (1) -(4) can be transformed into cylindrical coordinates which makes them more convenient for analysing pipe flow.

$$v_r = \bar{v}_r + V_r,\ v_\theta = \bar{v}_\theta + V_\theta,\ v_z = \bar{v}_z + V_z,\ p = \bar{p} + p,\ \sigma = \bar{\sigma} + \Sigma \quad (5)$$

Where the bar indicates the mean characteristic while the capital letters stand for fluctuation. If the fluctuation is a normal mode of the form $f(t,r,\theta,z)=\text{Re}[f(r),T]$ where $T=\sqrt{2}\exp(i\alpha z - i\alpha ct)$, $\alpha \in R^+$ and $\chi = 1 + i\alpha\Lambda[B(r^2 - R^2) - c]$.

We obtain finally after elimination of pressure and neglecting quadratic terms in fluctuations the following Orr-Sommerfeld equation for Maxwell fluids:

$$\rho\frac{(1-\chi)}{i\alpha\Lambda}\left[V_r'' + V_r'/r - (\alpha^2 - r^{-2})V_r\right] = -i\alpha\Sigma_{rr}' + (\alpha^2 r^2 - 1)r^{-2}\Sigma_{zr} - i\alpha\Sigma_{rr}r^{-1} + i\alpha\Sigma_{\theta\theta} + \Sigma_{rz}'' +$$
$$+ i\alpha\Sigma_{zz}' + \Sigma_{rz}'r^{-1}, \quad (6)$$

For $\lambda = 0$, $\chi = 1$ (the case of viscous incompressible fluids) equation takes the classical form

$$(U-c)(L-\alpha^2)\varphi = \nu(i\alpha)^{-1}(L-\alpha^2)^2\varphi\ , \quad (7)$$

where $\psi(t,r,z) = \varphi(r)\exp[i\alpha(z-ct)]$.

Imposing homogenous conditions at r=0 for V_r'/r numerical calculations lead to results ploted in fig.1.

Types of drag reducing additives

Drag reducing has been observed for several solvent/ additive systems, including dilute solutions of high molecular weight, soluble polimers, surfactants and micellar systems, suspension of insoluble particles such as fine grainsor fibers. The polymer solutions are the most widely studied and most often employed of the drag reducing systems.Some drag reducing water -soluble polymers very effective are: Polyethylene oxide, polyacrilamide, Guar gum.

Several characteristics of a polymer could be important for its effectiveness as a drag reducing additive: linearity, flexibility, molecular weight, the average end-to-end distance, the solubility and the radius of giration. We used in our experiments romanian polyacrilamide as SOLACRIL, PRESTOL, MEDASOL.

Gross flow measurements

Gross flow studies involve pressure drop versus flow rate measurements.We get a drag reduction coeficient of 70% for turbulent flow of water with additive as polyacrilamide(ppm) in metalic or plastic pipe with different diameters.

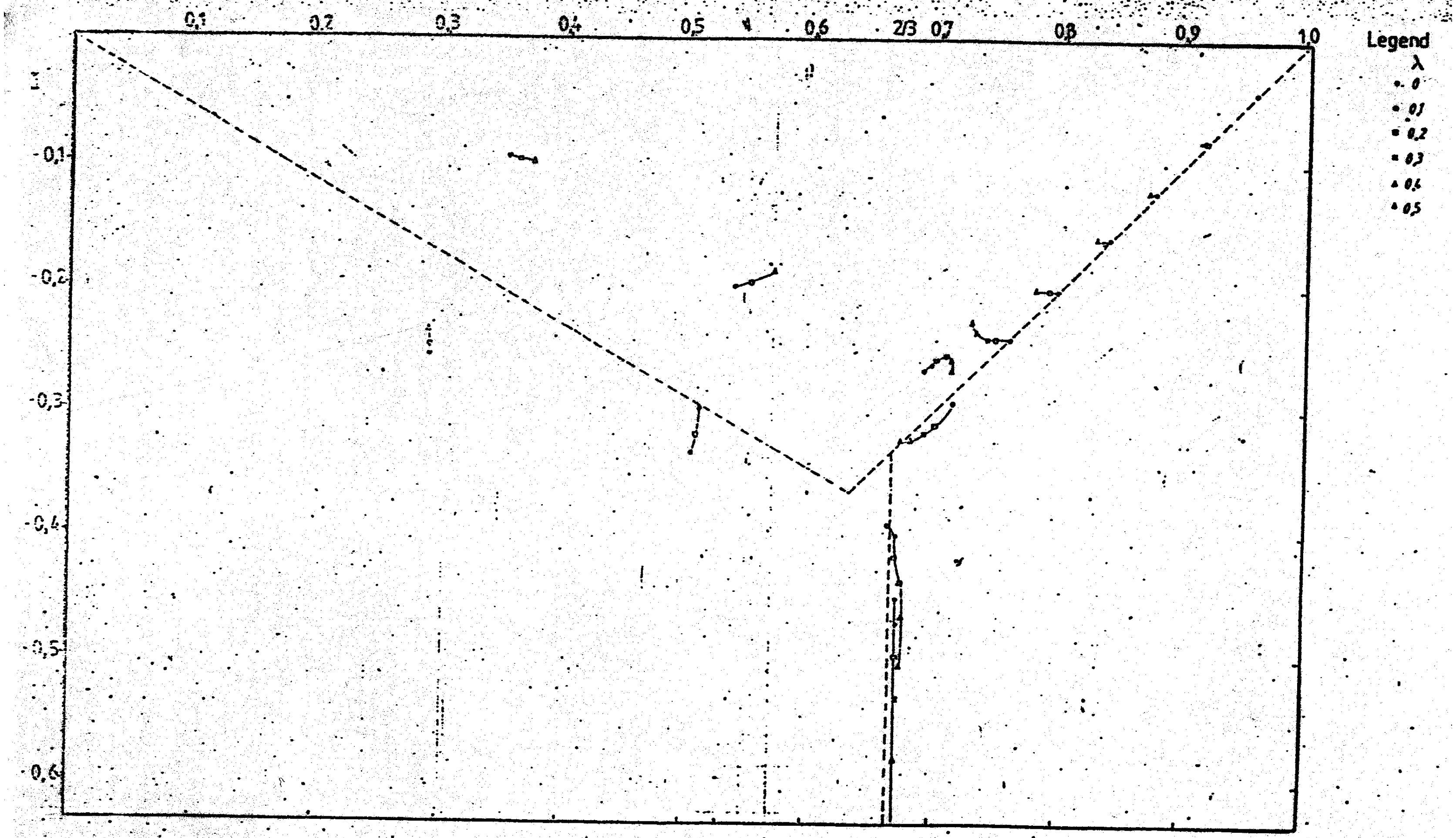
From our experimental studies can be seen as laminar regime and newtonian regime are regimes without drag reduction, the friction factor relation is the same as for solvent. Polymeric regime is a regime in which the friction factor depends on the nature of the polymer solution and the concentration. Maximum drag reduction regime is a regime of maximum possible drag reduction then the friction factor is insensitive to the polymer solution.

Conclusions

All experiments agree on the fact that drag reduction in pipes or channels occurs only in turbulent flow and the existence of an universal maximum drag reduction asymptote known as Virk's asymptote. In fact ,the proper correlation between macromolecular properties and drag -reduction effect remains unknown. The existing theories concerning drag reduction are inadequate of explaining the phenomenon exhibits itself in the experiments. We believe that the research in this area has to continue.

REFERENCES

1. Josef, D., D., Fluid Dynamics of Viscoelastic Liquids, Springer -Verlag,1990.
2. Georgescu, A., Hydrodynamic stability theory, Kluwer Dordrecht, 1985.
3. Chiujdea,C., M., and Georgescu, A., On the mechanism of drag reduction in dilute polymer solution , Proceedings of ICCHMT, Famagusta, N.Cyprus, 1999 pp.407
4. Chiujdea, C.,M., Georgescu, A., and Florea, R., Linear stability of a turbulent flow of Maxwell fluids in pipes, Universitè de Metz, Departement de mathematiques et d'information de Metz no21/ 91.



Values of c for $\alpha = 1$, $Re = 5000$ and $\lambda \in [0; 0.5]$