AN EVALUATION OF DRAG REDUCTION EFFECT IN TURBULENT FLOWS OF FLUIDS WITH POLYMER ADDITIVES

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This presentation will review the way in which polymer solutions may reduce drag. Many complex fluids solutions exhibit phase transitions or dynamic instabilities under shear flow. The introduction of dilute polymers in a turbulent flow changes some mean characteristics of the flow .This phenomena is very complex and well known as Toms effect in pipe flow. It represents the effect of drag reduction in turbulent flows of fluids with polymer additives. In order to describe the viscoelastic behaviour of this solutions it is usually necessary to be taken into account the elastic as well as viscous responses of these fluids. It is assumed that the elasticity of the macromolecule of polymer is essential in explaining Toms effect .In this connection the effect of different rheological properties of fluids on the near wall transient flow will be studied on the basis of the developed sinusoidal theory. We have advanced a theory which provide us to elucidate some new aspects regarding the way in which polymer may reduce drag.

Keywords: drag reduction, polymer additives, Toms effect, wall turbulence.

1. Introduction

By dissolving a small amount of long–chain polymer molecules in water or in organic solvents, the frictional drag of turbulent flow through pipes and channels can be reduced very much. In pipe flows for example, the drag can be reduced by up to 70% by adding just a few parts per million (ppm) of polymer. The discovery of this phenomenon of turbulent drag reduction by polymer additives is attributed to Toms (1949). He discovered when investigated the mechanical degradation of polymer molecules using a simple pipe flow apparatus that a polymer solution offered less resistance to flow ,under constant pressure, than the solvent itself. The drag reduction effect is extremely interesting from practical point of view and for this reason was attentively studied during the last years due to its importance in technique. This effect is well known to fluid dynamists, chemists, specialists in oil industry etc. The most spectacular success in polymer applications for drag reduction has been the use of oil-soluble polymers in the trans-Alaska pipeline system. In spite of the numerous hypotheses

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advanced, there exists not yet a unitary theory which can explain this effect. This is caused by the fact that not only it is necessary to consider the turbulence processes that are present in the flow, but also the influence of the rheological properties of the fluid. Here one touches on two essentially areas within fluid dynamics, turbulence and rheology. This is why the existing studies are more or less empirical. We propose a theoretical approach based on the linear stability theory.

2. Physical aspects of the polymers solution

From a chemical point of view, the class of polymers we consider for drag reduction are formed by long linear chains of monomers. For a dilute solution in equilibrium condition , these chains assume the aspect of statistically spherical random coils due to thermal agitation. In flow fields of interest where a substantial deformation rate is present, the coils are elongated. Their interaction with the solvent originates a component of the stress in addition to that of the solvent , the so-called extra-stress, which gives rise to the non-Newtonian behaviour of the solution. In particular a viscoelastic response is observed which is characterized by a relaxation phenomena. The processes leading to such behaviour are very complex and to study the rheological properties of this solution is a very difficult task because of the great number of freedom of this polymers chains.

The polymer we used in our experiments is a partially hydrolysed romanian polyacrylamide and polyethylene oxide(Solacril RPC, Prestol, Medasol), which have a molecular weight around of 6-8$\times 10^6$ g/mol according to the manufacturer. The advantage of this polymer over other type of polymer encountered in the literature (Polyox WSR301, Union Carbide, or Separan AP 273, Dow Chemical Company)is that it is relatively resistant to mechanical degradation. Mechanical degradation denotes the breaking of the polymers by mechanical actions, which reduces the molecular weight of the polymers and thus reduces its drag reduction capability. This is very important because our experimental setup was a re-circulatory one so that the polymers are continuously subjected to deformations in the which might cause the scission of the polymers , especially in the pump.

The drag reduction at a constant flow rate Q, DR_Q is defined as :

$$DR_Q=\frac{\Delta P_N-\Delta P_P}{\Delta P_N}\times 100\% \qquad (1)$$

where ΔP_N is the pressure loss per unit length of the pipe for the Newtonian solvent alone and ΔP_P is the same quantity for the polymer solution.

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 gyration. Drag reduction has been observed for several solvent/additive systems, but the most widely studied and employed is water/ soluble polymers ,very effective are : polyethylene oxide, polyacrilamide and Guar gum.

3. 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.

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 solutions. 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:

$$div\vec{v} = 0 \tag{2}$$

$$\frac{d\vec{v}}{dt} = \rho\vec{F} + div\sigma \tag{3}$$

$$\sigma + \Lambda\frac{\delta\sigma}{\delta t} = 2\mu D \tag{4}$$

where $\frac{\delta\sigma}{\delta t}$ is Jaumann derivative

$$\frac{\delta\sigma}{\delta t} = \frac{\partial\sigma}{\partial t} + (\vec{v}grad)\sigma - grad\vec{v}\cdot\sigma - (grad\vec{v}\cdot\sigma)^T \tag{5}$$

σ is the Cauchy stress tensor, D the rate of deformation tensor, $\vec{v}$ is the velocity vector, $\vec{F}$ is the external force vector, ρ is the density , μ represents the coefficient of dynamic viscosity, Λ is the relaxation time. Further it is assumed that $\vec{F}$ =0, $T = -pI + \sigma$ is the symmetric stress tensor, I stands for the unit tensor, p represents the isotropic pressure.

The phenomenon of turbulence can be explicitly introduced in the equations by decomposing the turbulent motion in a mean and fluctuating part. We use cylindrical coordinates for writing the equations of flow because they are more convenient for analysing pipe flow.

$$v_r = \overline{v}_r + V_r,\ v_\theta = \overline{v}_\theta + V_\theta,\ v_z = \overline{v}_z + V_z,\ p = \overline{p} + P,\ \sigma = \overline{\sigma} + \Sigma \tag{6}$$

where the bars indicates the means characteristics ,while the capital letters stand for fluctuations. If we assume that fluctuation as a normal mode of the form

$f(t,r,\theta,z)=\mathrm{Re}[f(r),T]$, where $T=\sqrt{2}\exp(i\alpha z-i\alpha ct),\alpha\in R^{+}$ and $\chi=1+i\alpha\Lambda[B(r^2-R^2)-c]$, $B=\frac{1}{4\mu}\frac{d\overline{p}}{dz}$.

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

$$\rho\frac{(1-\chi)}{i\alpha\Lambda}\left[V_r''+\frac{V_r'}{r}-\left(\alpha^2-r^{-2}\right)V_r\right]=$$

$$=-i\alpha\Sigma_{rr}'+\left(\alpha^2r^2-1\right)r^{-2}\Sigma_{zr}-i\alpha\Sigma_{rr}r^{-1}+i\alpha\Sigma_{\theta\theta}+\Sigma_{rz}''+i\alpha\Sigma_{zz}'+\Sigma_{rz}'r^{-1} \quad (7)$$

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

$$(U-c)\left(L-\alpha^2\right)\varphi=\frac{\nu}{i\alpha}\left(L-\alpha^2\right)^2\varphi \quad (8)$$

where $\psi(t,r,z)=\varphi(r)\exp[i\alpha(z-ct)]$ is the perturbation stream function, $U=\overline{v}_z, L=\frac{d}{dr^2}-\frac{1}{r}\frac{d}{dr}$.

Imposing homogenous conditions at r = 0 for $\frac{V_r'}{r}$ numerical simulation in particular would be very useful.

4. Conclusions

As the phenomenon of drag reduction has not a unitary explanation all the existing theories are highly speculative and contain many semi-empirical data. So, the study of linear dynamics of polymer solutions is very important. It is very important to study the optimal perturbations regime in a turbulent flow with polymer additives in order to get the determination of regions of absolute stability in which no perturbation growth is possible.

Most of experiences suggests an increase in maximum streamwise turbulence intensity, a decrease in normal (or radial) turbulence intensity and the occurrence of Reynolds stress deficit, which is evident of an extra elastic stress contribution, in drag reduced flow.

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