FLOW OF NON-NEWTONIAN FLUIDS IN A PIPE AND CONSIDERATIONS REGARDING DYNAMICS OF DILUTE POLYMER SOLUTIONS

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The classical linearly viscous Navier-Stokes fluid cannot adequately describe the behavior of many real fluids, which exhibit phenomena as shear thinning or shear thickening. Dilute polymer solutions are well known to be non-Newtonian fluids. During the last decades various constitutive equations have been proposed to describe the behavior of such fluids. Because of the great diversity in the chemical and physical structure of non-Newtonian fluids because of the wide variety of flows it is not possible to recommend a single constitutive equation as the equation for use in all rheological calculations.

In this paper we present the Toms effect in pipes flow, the effect of drag reduction in turbulent flows of fluids with polymer additives. The elastic as well as viscous responses in these experiments have to be taken in account. It is assumed that the elasticity of the macromolecules of polymer is essential in explaining Toms effect.

Here we shall discuss about constitutive equations as Ostwald law, about Metzner - Reed equations and Rabinowitch-Money equations and possibilities of calculations of the mean pressure drop over the pipe and the flow rate for Newtonian and non-Newtonians fluids , in our case dilute polymer solutions.

In this connection the drag reductions effect is evident and extremely interesting from practical point of view, because liquids are mostly transported through pipes and a drag reduction by adding a small amount of polymer can offer large economic advantages and a larger effectiveness of this transportations.

Key words: Non-Newtonian fluid, polymer additive, Toms effect, Rabinowitch-Mooney equation

1. Introduction

The flow of non-Newtonian fluids in pipes occurs in wide range of practical applications in the process industries. The drag reduction effect using small amount of long-chain polymer molecules in water or in organic solvents there are advantages in operating pipe flow because the specific energy consumption is lowest there. Some interesting applications for drag reduction has been the use of small amount of dilute polymer- the polymer concentrations are of the order of 10 ppm- to oil being pumped from offshore platforms to shore

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facilities. In addition to a drag reduction, the polymer can causes a reduction in heat transfer, which is advantageous in maintaining low oil viscosity.

Polymeric drag reduction is interesting in many ways, also from a fundamental fluid dynamics point of view because the structure of the characteristics of the flow present spectacular changes. As the flow index becomes smaller for the same Reynolds number, the flow deviates further from Newtonian profile and the results suggest that transition is delayed. But the non-Newtonian character of the flow implies cumbersome algebra. In fact is not only necessary to consider the turbulence processes that are present in the flow, but also the influence of the rheological properties of the fluids. General theories of turbulence are lacking for non-Newtonian fluids and the development of mathematical and computational models is not well advanced.

Computational modelling of non-Newtonian flows especially using direct numerical simulation (DNS), show promises in helping to understand the dynamics of this phenomena. There have been some DNS studies of the turbulent flow of polymer solutions with the aim to understand the causes of drag reduction. [1]. In those studies, dilute polymer solutions were considered in which shear thinning behaviour was negligible end elongational (visco-elastic) effects were taken into account using different methods. However, for a wide range of important materials, the non-Newtonian rheology is primarily of a shear-thinning nature. This is why the present studies are more or less empirical.

Turbulence intensities are lower by 20%-40% for a non-Newtonian fluid. As in figures 1.1,1.2 and 1.3,1.4 are depicted. The polymer used in these experiments is Superfloc A110 type A and B, which is a partially hydrolysed polyacrylamide. The advantage of this polymer over other types of polymer used in the literature (as Polyox WSR301, Union Carbide or Separan AP273, Dow Chemical Company), is that it is relatively resistant to mechanical degradation especially in the pumps.

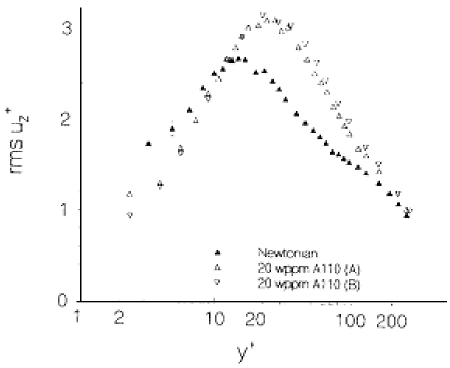

Fig. 1.1 Measured axial rms profile
Re = 9772
rms = root-mean-square

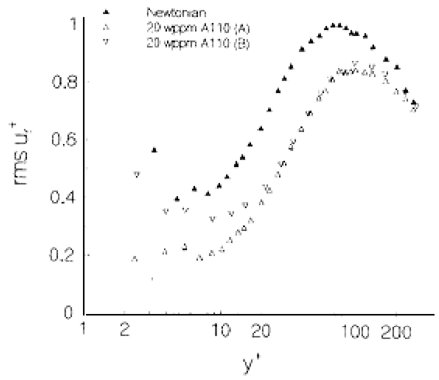

Fig. 1.2 Measured radial rms profile
Re = 9772

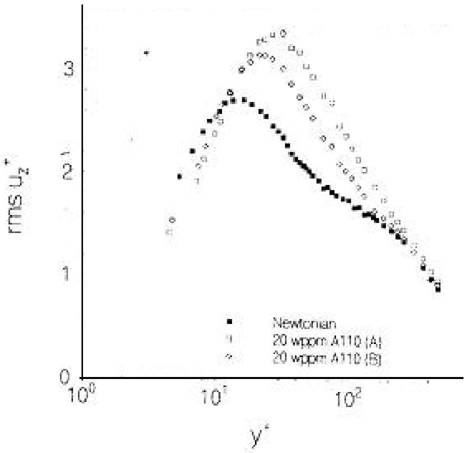

Fig. 1.3 Measured axial rms profile
Re = 17773

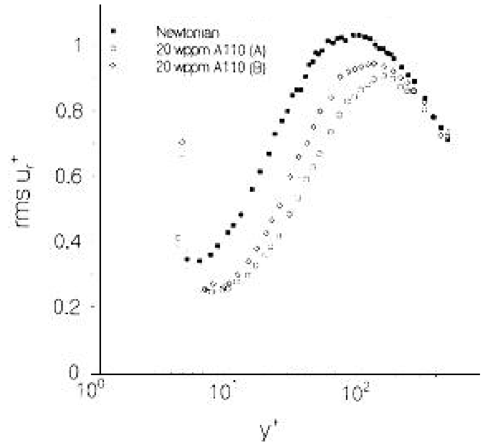

Fig. 1.4 Measured radial rms profile
Re = 17773

2. Turbulence Statistics of the polymer solution

Experimental results show that compared to Newtonian fluids the axial and radial turbulence intensities are lower by 20%-40% for a non-Newtonian fluid. As figs. 2.1,2.2 and 2.3, 2.4 are depicted. We can see that for $0<y^+<30$ turbulence intensities for the polymer solution and the solvent are near the same, but as we go far from the wall for $30<y^+<150$ the axial turbulence fluctuations begin to be higher compare with radial fluctuations for polymer solutions compare with the solvent [2]. For $y^+ >150$ in the central area of the pipes, turbulence intensities are practically the same for the polymer solutions and the solvent .The polymer we used in our experiments is a partially hydrolised romanian polyacrylamide and polyethylene oxide (Solacril RPC, Prestol, Medasol). It is very important for experimental studies to use optimal concentration for the polymer solutions and to use a polymer that is resistant to mechanical degradations.

3. Basic Equations

By adding just few parts per million(ppm) of polymer in the solvent , the fluid deviates from Newtonian profile and become a non-Newtonian fluid . In the present paper we describe a study of shear-thinning non-Newtonian fluids whose rheology is described by the power law, Ostwald-de Waele model which is in fact a generalized Newtonian model.

$$\tau = \kappa \left(\frac{du}{dy} \right)^n \tag{1}$$

where κ is the fluid consistency,n is the flow index, τ is the yield stress, u centerline velocity and y distance from the pipe wall. In this case of the power-law model, n<1 for shear-thinning, n=1 for Newtonian and n>1 for shear-thickening fluids. For a better understanding C.Thirriot model present this equation as-

$$\tau = \frac{m}{t^*}\left(t^* \frac{du}{dy}\right)^n \tag{2}$$

where t^* is a parameter of time and m a rheological parameter.

Metzner and Reed proposed some interesting equations for pressure drop in a pipe for non-Newtonian fluids if we know the flow rate and the pressure values. The first step is to establish an equation with which is possible to calculate the flow. Rabinowitch-Mooney proposed an equation in order to obtain this parameter for this kind of fluids.

$$\left(\frac{du}{dr}\right)_0 = \frac{1}{4}\frac{pd}{4}\frac{d\ln\left(\frac{8u_m}{d}\right)}{d\ln\left(\frac{pd}{4}\right)} + \frac{3}{4}\frac{8u_m}{d} \tag{3}$$

where u_m is the mean velocity in the pipe ,p is the pressure gradient, d is the diameter of the pipe and $\left(\frac{du}{dr}\right)_0$ is mean pipe wall shear rate.

Metzner and Reed present this equation as

$$\left(\frac{du}{dr}\right)_0 = \frac{3n'+1}{4n'}\frac{8u_m}{d} \tag{4}$$

$$\text{where } n' = \frac{d\ln\left(\frac{8u_m}{d}\right)}{d\ln\left(\frac{pd}{4}\right)} \tag{5}$$

so

$$\tau_0 = \frac{pd}{4} = K'\left(\frac{8u_m}{d}\right)^{n'}, \tag{6}$$

τ_0 is the mean pipe wall shear stress.

When the viscosity varies in space and time the appropriate viscosity scale to use in order to define a Reynolds number is not obvious.

The Metzner-Reed , Reynolds number for a power law fluid can be written in closed form as

$$\mathrm{Re}_{MR} = \frac{8\rho u_m^{\;2-n} d^n}{K\left(6+\frac{2}{n}\right)^n} \tag{7}$$

The Metzner-Reed Reynolds number reflects flow behaviour for power law fluids.

The generalized Reynolds number Re_g reflects flow behaviour in the near wall region that play a fundamental role in transition and the development of turbulence and is a suitable basis for study turbulence of these kind of flows.

$$\mathrm{Re}_g = \frac{\rho u_m d}{\eta_w} \tag{8}$$

where η_w is the mean wall viscosity is obvious Re_g is different from Metzner-Reed Reynolds number.

Experimental research studies can determinate the rheological parameters K and n for different values of u_m and d and to investigate the effect of all these.

4. Results

The mean axial velocity for a steel pipe with d=0.15m, l=1200m and Q=0.08m^3 /s is 4.52m/s for water with polymer additive Polyacrilamide SOLACRIL RPC with rheological parameters n=0.7 and K=0.4. These parameters were obtained by experimental measurements. In order to calculate the generalized Reynolds number we used Re_{MR} (7) and has the value 4718. So,it is the turbulence that characterize the flow and we obtained a reduction between 15-20% of friction factor as a function of the Metzner –Reed Reynolds number, compare with simple water flow with the same conditions of flow.

5. Conclusions

In this paper we try to present some results regarding the complex nature of the phenomenon of drag reduction by polymer additives. A large number of measurements of drag reduction flows in pipes and channels and also a lot of theoretical analyses have been published in the literature. Apart from the obvious practical applications and theoretical reflections it cannot be said that the phenomenon is well understood. Experiments show that the rheological properties of drag reduction polymer solution as intrinsec viscosity, anisotropy and elasticity are very important parameters for the dynamics of the flow. The keyword that appears in many attempts of explaining polymeric drag reduction is to study polymers by rheological methods this can open up many possibilities for general studies on liquid dynamics as well as polymer characterization.

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