



Short Communication

Drag increase at the very start of drag reducing flows in a rotating cylindrical double gap device



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ABSTRACT

In this note we present some results concerning the time required for turbulent structures to achieve their steady state, called here the *developing time*. Notably, there is a drag increase at the very start of the test. Such a drag increase is strongly dependent on the concentration, molecular weight, temperature, Reynolds number, and molecule conformation before the test start-up. The analysis conducted here improves the understanding of the way drag reduction evolves over time, which was considered in Pereira et al. (2013).

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1. Introduction

Drag reduction (DR) by polymers has been much analysed over the years after Forrest and Grierson [4], Toms [14], Mysels [6], who were the first to recognize it. Many relevant papers were highlighted in the review carried out by Virk [15], in which a number of practical aspects of the problem were noted, such as the effect of the Reynolds number, concentration, molecular weight, solvent quality, and different polymers on the efficiency of the drag reduction. Despite some recent significant works, such as Dubief et al. [3] and Benzi [1], it is clear that the theory of drag reduction is not yet closed. Most attempts to explain the mechanism of DR are still based on the main ideas introduced independently by Lumley [5], Seyer and Metzner [9] (concerned with viscous effects) and Tabor and de Gennes [10] (concerned with elastic effects). A good review of the recent progress on polymer drag reduction is White and Mungal [16], which presents an overview of the state of the numerical and experimental techniques and their relevance to understanding the phenomenon of polymer drag reduction. With such a review, it is even easier to perceive that the phenomenon is not completely understood and many aspects of the problem remain unclear.

Any attempt to completely understand polymer DR must consider two important issues: the development of turbulent structures and the mechanical breaking of the polymer molecules. These two phenomena impose a transient behaviour on the polymer efficiency and the drag reduction is clearly divided into three

periods of time (see Fig. 1 in Pereira et al. [7]). Over time, at the very beginning of the phenomenon, when the polymer is injected in a tube or a rotating apparatus is started up, the $DR(t)$ exhibits negative values, before reaching its maximum efficiency at DR_{max} . We presume that the maximum efficiency is reached when a sufficient number of molecules in a coil-stretch cycle are in a state of equilibrium with the turbulent structures. The time to achieve DR_{max} is referred to here as the *developing time*, denoted t_d . The increasing friction factor at the beginning of the process is related to an instantaneous increment of the local extensional viscosity after a high polymer stretching (see Dimitropoulos et al. [2], Tamano et al. [11]). Following t_d , we observe a constant value of DR for a period of time, which is denoted by t_r , the *resistance time*. Finally, after this period, $DR(t)$ begins to fall, reaching a minimum level after a long enough time, when the degradation process has reached its steady state and $DR(t)$ assumes an asymptotic value, DR_{asy} . In other words the polymer scission stops and the molecular weight distribution reaches a steady state. In our previous papers Pereira and Soares [8] and Pereira et al. [7] (also using a rotating cylindrical double gap), we have analysed how DR evolves over time from the very start of the test until reaching its asymptotic value. The negative values of DR were not captured because they occur in the very first few seconds of the test. For the range of Reynolds numbers investigated in those previous papers, the rotor reaches its final angular velocity after more than 3 s. In that period, the time when DR_{min} occurs has already passed. As far as we know, experimental study showing negative values of DR were scarcely reported. Some data with drag increase were presented in Tiederman et al. [13]. The authors visualized the turbulent structures when drag-reducing additives were directly injected in the

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linear sublayer of a turbulent channel flow of water. The negative value of DR was only observed in the immediate vicinity of the injection point, in which, obviously, the solution is not totally mixed. The authors attributed the drag increase to the mixing process. Supposedly, the drag increase could be avoided, or at least decreased, if the mixing velocity was improved. Such an explanation is completely different from that one reported by Dimitropoulos et al. [2], who used direct numerical simulation to compute $DR(t)$ in a turbulent boundary layer flow of a FENE-P fluid.

There have been a number of papers treating polymer drag reduction as a function of time, but as far as we know, few ones show with clarity, experimental data for negative values of DR. In this note we present new results to improve the understanding of the problem reported by Pereira et al. [7], which shows how DR evolves over time. It is highlighted here that the drag increases in the very start of the test, and this drag increase depends on the concentration, molecular weight, Reynolds number and temperature. The same three kinds of polymers employed by Pereira et al. [7] (Poly(ethylene oxide), Polyacrylamide, and Xanthan Gum) are used.

2. Experimental apparatus and procedure

Our tests were carried out with the aid of a rotational rheometer holding a cylindrical double gap device, Fig. 1. The details about the geometry, procedure, and the kind of polymers used were sufficiently discussed in Pereira and Soares [8] and Pereira et al. [7]. It is worth noting here the definition of our important parameters Re, f and DR . The Reynolds number, Re , and the friction factor, f , are defined by Eqs. (1) and (2), respectively,

$$Re = \frac{\rho \bar{h} u}{\eta} = \frac{\rho(\bar{h})(\omega \bar{R})}{\eta}, \tag{1}$$

$$f = \frac{2\tau}{\rho u^2} = \frac{2\tau}{\rho(\omega \bar{R})^2}, \tag{2}$$

where η is the solution's viscosity, $\omega \bar{R}$ is a characteristic velocity, $\bar{R} = (R_2 + R_3)/2$ is the mean radius and \bar{h} is the average gap given

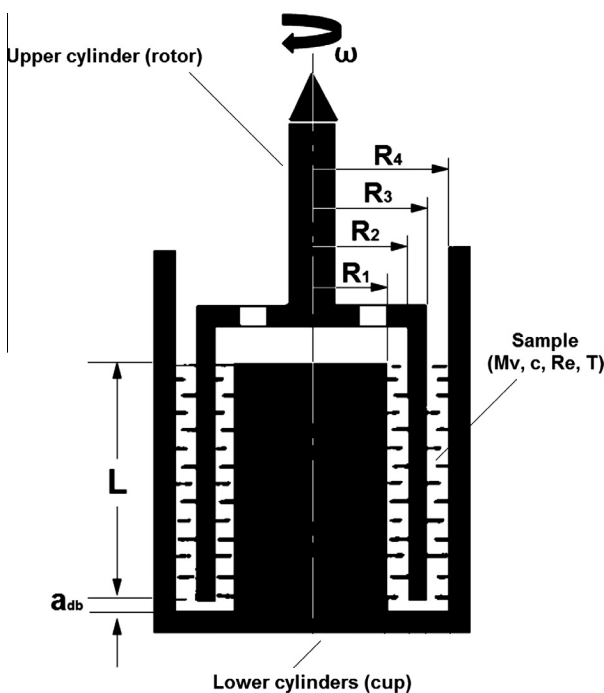


Fig. 1. Schematic illustration of the axial symmetric double gap geometry.

by $((R_2 - R_1) + (R_4 - R_3))/2$ (see Fig. 1 in Pereira and Soares [8]). Since our solutions of PEO and PAM are Newtonian, η is directly measured at low rotor speed of rotation, in which the flow is laminar. For the Xanthan Gum solutions, which are shear-thinning even for low concentrations, η is the Newtonian plateau at high shear-rate (η_{∞}). It is worth noticing that our tests were carried out at fixed Reynolds number. Hence, the values of η used to determine Re are that for the same temperature of the test. Finally, the DR is calculated by Eq. (3),

$$DR = 1 - f_p/f_0, \tag{3}$$

where f_p and f_0 are the friction factor of the polymeric solution and solvent, respectively.

3. Results and discussion

Since we are interested in the values of the friction factor in the very first seconds after the test startup, we conducted a sequence of tests to take into account the time the rotor requires to achieve its steady state when a rotational speed is imposed. Thus, only after this time does the test evolve at a fixed Reynolds number. These preliminary tests were carried out with deionized water and are displayed in Fig. 2, in which the shear stress is plotted over time for different values of rotational speed, n , and temperature, T . Since in the rotor steady state regime the value of the shear stress must be constant, it is easy to see that the rotor achieves its final velocity in 0.5 s when n is smaller than 1500 rpm, despite the value of the viscosity. Here, the level of viscosity was controlled by increasing or decreasing the temperature, falling from 8.84×10^{-3} Pa s, at 25 °C to 6.59×10^{-3} Pa s, at 45 °C. The rotor reaches its steady state in 3 s when the rotational speed is larger than 1500 rpm. Again, this time is independent of the level of viscosity.

Our main experiments were conducted using a rotational speed below 1500 rpm and data below 0.5 s were excluded. The maximum value of the Reynolds number was 854. We choose to analyse all the data in terms of Reynolds number, instead of Weissenberg numbers. The main reason is the difficult to take a reliable measurement of the relaxation time of very diluted solutions (in the case here, $25 \leq c \leq 100$ ppm).

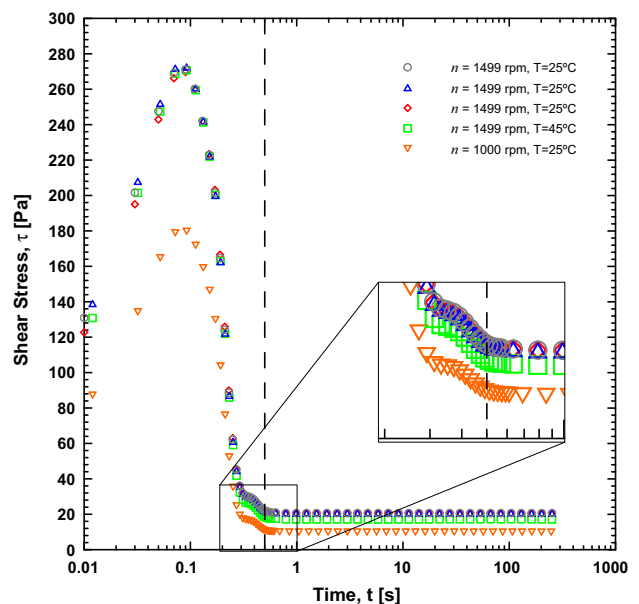


Fig. 2. Shear stress, τ , as a function of time.

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