

EXPERIMENTAL RESEARCH ON DRAG REDUCTION BY POLYMER ADDITIVES

Shao Xueming, Lin Jianzhong

Department of Mechanics, State key laboratory of fluid power transmission and control,

Zhejiang University, 310027, Hangzhou, P.R.China

mecsxm@public.zju.edu.cn

ABSTRACT

In this paper, in order to study the mechanism of drag reduction by polymer additives, the turbulent intensities and Reynolds stresses in a mixing layer and pipe flow are measured by LDA respectively. The results show that polymer additives do not simply suppress the turbulent fluctuation as we expected. The turbulence structures are changed rather than suppressed.

INTRODUCTION

It is well known that the addition of a small amount of polymer to a turbulent Newtonian fluid flow can result in a drag reduction, which appears in a number of flow fields, and has received considerable attention since the initial publications of Toms [1](1949) and Mysels[2] (1949). Apart from the obvious practical application on industry, the phenomenon of drag reduction is also interesting from a fundamental point of view. It is closely related to turbulent structures in flow. That means that a study of polymeric drag reduction could help in gaining more insight into turbulence itself.

Although the drag reduction effect of polymer has been known for almost half a century, a generally accepted explanation of the mechanism that causes this drag reduction is still not available. During the past three decades, a vast number papers have appeared on polymeric drag reduction, which can be roughly divided into three categories[3]. The first category includes studies on drag reduction from a molecular perspective. The behaviour of polymer molecules in various model flows (e.g. simple shear, pure strain, etc.) was examined. One of the most thorough literature reviews of the dynamics of polymer molecules in turbulent flows was written by Lumley[4] (1969). He reported a consensus opinion that drag-reducing polymer molecules in turbulent boundary layers are stretched by the flow, resulting in an increase in the total increase in

the local fluid viscosity. A recent theoretical study was conducted by Rabin & Zielinska[5] (1989). They examined the effect of polymer molecules on the vorticity distribution in elongational flows and argued that there will be a shift in the turbulent energy from high down to low wavenumbers.

The second category includes studies on the effects of polymers on the time-averaged turbulence statistics. One of the best examples of this type of research was done by Virk[6] (1967). They measured streamwise velocity in a drag-reducing pipe flow with different molecular weight polymers and different solvents. This work produced the well known 'Virk asymptote' for drag reduction as a function of polymer concentration.

With advances in instrumentation and visualization techniques, the third category arose, in which changes in coherent turbulent structure due to polymers are examined. In this paper, a mixing layer and pipe flow are chosen for the experiments, The coherent structure in a mixing layer is visualized, and the turbulent intensities and Reynolds stresses in both flow fields are measured.

EXPERIMENTAL SET-UP

The experiment is performed in a re-circulatory flow facility which is shown in fig.1(a). The facility consists of a reservoir, screw pump, valves, constant-head reservoir and test section.

For the measurement of mixing layer, the test section is shown in fig.1(b). The flow is divided into two streams and passes through the setting chamber, which contains screens to damp large-scale turbulence, and through a 9:1 contraction to the test section which is 12×8 cm in cross-section and 150cm long. The setting chamber and contraction are divided in half by a separating plate.

For the measurement of pipe flow, the test section is shown in fig.1(c). The fluid passes first through a setting chamber, and then a contraction to the test section which is a cylindrical pipe with length 12m and inner diameter 10cm. Due to the differences in

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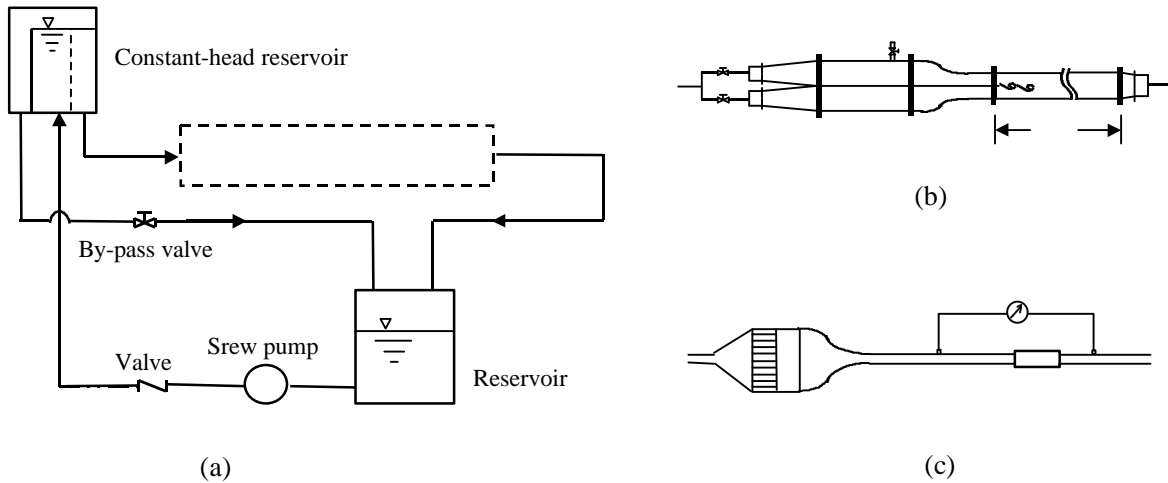


Fig. 1 The experimental facility

refractive index of the test fluid (water with $n = 1.33$) and the material of the pipe (Perspex with $n = 1.49$), the test section is specially designed.

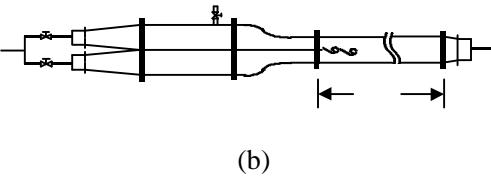
The measurements were performed with a 2-D LDA system of Dantec, which consists of a Ar^+ laser, a three-dimensional traversing system, transmitterbox, two photo-multiplier tubes, two counters and a PC. This system uses two orthogonal pairs of laser beams with pairwise light of a different wavelength to measure the fluid velocity in two directions, so it is so-called 'non-contact measure'. This technique is necessary especially in this experiment.

Polyacrylamide(PAM) is used as polymer additive in this experiment. The advantage of this polymer over other types of polymers is that it is relatively resistant to mechanical degradation. This is an important point, since we use a re-circulatory experimental set-up in which the polymers are continuously subjected to deformations, especially in the pump, which might cause the scission of the polymers. Severe mechanical degradation will lead to unacceptable changes in the measurement conditions during an LDA measurement. The use of screw pump in our experiment minimizes this problem.

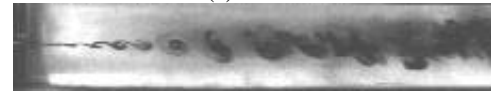
EXPERIMENTAL RESULTS

(1) Visualization of mixing layer

The structure of the mixing layer is visualized by the color injected at the inlet of test section. From the pictures in fig.2, a large effect of polymer additives on the coherent structure can be found. Due to the addition of polymer, the amount of small scale vortices is diminished, large scale vortices and the roll and pairing process can be clearly seen, the growth of mixing layer is decreased.



(a) Water



(b) polymer

Fig. 2 structure in a mixing layer

(2) Measurements of mixing layer

Table 1 lists the experimental conditions of the measurements of mixing layer

Table 1 Experimental conditions

The measurements for water and 50ppm polymer

U_1	U_2	$U = (U_1 + U_2) / 2$	$R_{eq} = Uq/n$
31 cm/s	14 cm/s	17 cm/s	60 1250

solution are compared at (almost) equal Reynolds number.

Fig.3 shows the distributions of the longitudinal (U_{RMS}) and the transverse (V_{RMS}) fluctuation intensities and the shear stress $\overline{u'v'}$ on different longitudinal position in a polymer added mixing layer. The peaks of these quantities are first lower at the origin of the mixing zone and all grow with longitudinal position x till further downstream they become higher than their counterparts in a Newtonian mixing layer (fig.4). Whereas the water peaks are first higher and remain nearly constant in the developed mixing layer. This result agree well with R. Scharf[7].

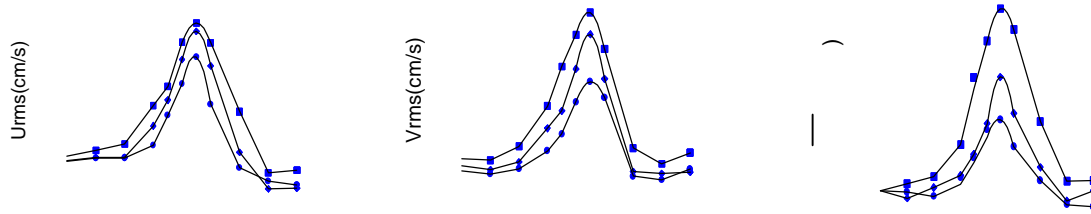


Fig. 3 the distributions U_{RMS} and V_{RMS} on different longitudinal position in a polymer added mixing layer

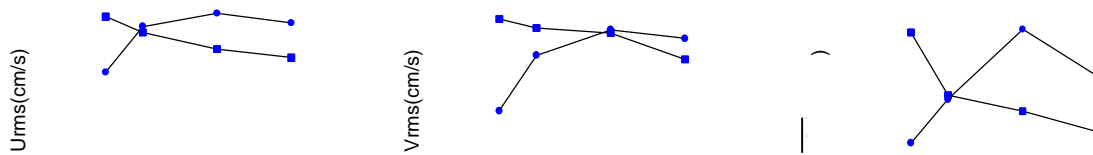


Fig. 4 the peaks of U_{RMS} , V_{RMS} and $\overline{u'v'}$ on different longitudinal position

water polymer

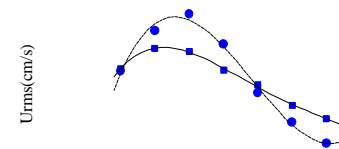
We propose that this is possibly caused by the orientation of the long chain molecules at the inlet of the test section.

(3) Measurements of pipe flow

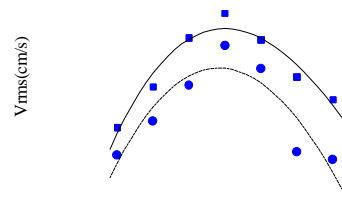
The measurements were conducted on the same flow conditions. The Reynolds number is defined with the average velocity, i.e. $Re = UD/\nu$. For the pipe flow of water and 20ppm polymer solution the Reynolds number are 32710 and 34494 respectively. The amount of drag reduction is 14%.

The axial and radial velocity fluctuations of water and polymer solution are shown in fig.5. The center of the pipe lies at $y = 45$. The effect on the axial rms profile is given in fig.5(a), the peak of polymer solution is higher than their counterparts in a pipe flow of water and is shifted away from the wall to center of the pipe. This behavior is very different with what we thought of before.

In radial direction the turbulent fluctuation intensity is suppressed as expected due to the addition of polymer. As can be seen in fig.5(b), the radial rms of polymer solution is lower than their counterparts in a pipe flow of water.



(a)



(b)

Fig. 5 The axial and radial velocity fluctuations in a pipe flow **water polymer**

RESULTS AND DISCUSSIONS

The visualization of mixing layer shows that the addition of polymer will enhance coherent structure. The measurements of the turbulent intensities and Reynolds stresses by LDA show that polymer additives do not simply suppress the turbulent fluctuation as we expected. On the contrary, the peaks of these quantities in polymer solution are higher than their counterparts in Newtonian fluid at the downstream of mixing layer. In pipe flow the axial turbulence intensity is increased while the radial turbulence intensity is decreased. This means that the turbulence structures are changed rather than suppressed.

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