Superposition of drag reduction due to riblets on drag reduction due to polymers

C. Christodoulou, K. N. Liu, D. D. Joseph
Department of Aerospace Engineering and Mechanics
University of Minnesota, Minneapolis, MN

Abstract

In the present paper, experiments are reported establishing a superposition of drag reduction due to riblets on drag reduction due to polymers, in fully developed turbulent flow of dilute aqueous solutions of polymers (2–50 ppm) through 25.4mm (1 inch) diameter pipes, lined with a film of grooved equilateral triangles of base S=0.11mm. The range of S^+ (which is the base and height of the riblets expressed in wall units) where drag reduction is superimposed changes with polymer concentration. The higher the concentration, the lower the value of S^+.

Contents

This is our second paper on drag reduction using riblets. In the first paper (Liu et al [1]) we reported drag reduction due to riblets in fully developed turbulent flows of water through one and two inch diameter pipes. Drag reduction occurred in a range of $3<S^+<23$ where S^+ is the riblet spacing expressed in wall units, with a maximum drag reduction of 5–7% occurring at $11<S^+<16$. There are many studies of drag reduction with riblets. References to some of these can be found in an extensive review paper by Walsh [2]. Less is known about the combination of riblets with drag reducing polymers.

Rohr, Anderson and Reidy [3] find no change in drag reduction of dilute polymer solutions flowing through pipes lined with riblets. However, their experiments cover a range of Reynolds numbers of up to around 20,000, which is at the lower end of our experiments. Beauchamp and Philips [4] carried out experiments on a combination of riblets and polymers measuring drag coefficients on an axisymmetric model falling in a drop tank. Although they at first found additional drag reduction caused by riblets in polymer solutions, newer experiments gave no superimposed drag reduction.

For a description of our experimental apparatus, the reader is referred to Liu et al [1]. The polymer was mixed in the gravity feed tank to obtain the dilute solutions the day before each experiment. Since polymers degrade in high shear, the solution was not recirculated but used only once and then disposed of. The size of the tank was such as to allow 25 minutes for each experiment. Although a variety of polymers were tried, only Polyox 301 and polyacrylamide with high molecular weights were found to produce drag reduction.

We shall designate the Darcy friction factor by

$$f = \frac{\Delta P}{\rho g} \frac{2g}{U^2} \frac{d}{L} \ . \tag{1}$$

where ΔP is the pressure drop over the length L of pipe, g is gravity, d is the pipe diameter and U is the average flow velocity. An effective riblets diameter was defined by

$$d_r = \sqrt{\frac{4A}{\pi}} \tag{2}$$

where A is the cross-sectional area of the pipe lined with riblets.

The measured values of the friction factor for the smooth unlined pipes and the pipes lined with smooth film were compared with the values given by

$$f = \left[1.8 \log_{10} \left(\frac{Re}{6.9} \right) \right]^{-2} \tag{3}$$

where the Reynolds number $Re = dU/\nu$, which is an excellent approximation of Prandtl's formula for the range of our experiments. The above formula gave values which agreed quite well with our earlier experiments with tap water. Therefore these values were used as a basis for determining drag reductions due to polymers.

Although the repeatability of the combination experiments is not as good as the repeatability of our earlier experiments, there is definitely a superimposed drag reduction due to riblets.

Figure 1 shows the results of a typical experiment. In this case the solution was 10 ppm of Polyox 301. Plotted are friction factors in smooth and riblet pipes compared with formula (2). The onset of drag reduction due to the polymer is clearly shown and the superimposed drag reduction due to riblets is obvious.

Figures 2 and 3 show the superimposed drag reduction due to riblets for various concentrations of Polyox 301 and polyacrylamide respectively. This drag reduction is defined by

$$\Delta f/f = \frac{f_r - f_p}{f_p} \infty 100\% \tag{4}$$

where f_r is the fraction factor for the riblet pipe and f_p is the fraction factor for the smooth pipe, both in solution flow.

These two figures show a superimposed drag reduction of up to around 4%. In the case of polyacrylamide, the amount of drag reduction seems to decrease with polymer concentration (Figure 3), while this is not true for polyox. However, for both polymers the range were drag reduction occurs is shifted to the right. As is seen in Figure 4, the riblet size (expressed in wall units) at which maximum drag reduction occurs drops with concentration.

The maximum drag reduction due to riblets reported in reference [1] is 5–7%, while the present experiment gave a superimposed drag reduction of up to 4%. We believe that this is due to contamination and degradation of the riblets. The apparatus was not used for one year and although it was cleaned before we used it again, runs with tap water also gave a drag reduction of up to 4%. Other investigators have also reported deterioration of riblet performance (see Walsh [2]).

Conclusion

These experiments have demonstrated that there is a superimposed drag reduction due to riblets in the flow of drag reducing polymers. The amount of this drag reduction depends on the type of the polymer as well as the concentration. Finally the range of S^+ within which drag reduction occurs decreases with concentration.

Acknowledgements

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Figure Captions

Figure 1: Comparison of the measured values of the friction factor in the section with the smooth film with the 25.4mm diameter pipe lined with riblets.

Riblet film

Smooth pipe

Figure 2: Percent drag reduction due to riblets:

Line 1:

25.4mm pipe lined with smooth film

Line 2:

50.8mm pipe lined with smooth film

Line 3:

25.4mm smooth unlined pipe

Line 4:

50.8mm smooth unlined pipe