EXPERIMENTS ON DRAG REDUCTION BY FIBRES IN TURBULENT FLOW

R. Delfos, J. Hoving, J. Westerweel, B.J. Boersma
Process and Energy Technology Department
Delft University of Technology, Leeghwaterstraat 17, 2628 CA Delft, the Netherlands

INTRODUCTION

In turbulent pipe flow of liquids, drag reduction by polymer additives has been studied already for a few decades both experimentally and theoretically/numerically. Theoretical attempts to explain the physical working mechanism point towards the formation of an 'elastic layer' between viscous sublayer and logarithmic layer. Maximum drag reduction (MDR, 'Virk's asymptote') is found when it grows towards the full pipe cross section.

For gases, applications to reduce frictional drag are sought in the addition of small rigid fibres. A complication in the modelling of these fibres is that they have macroscopic dimensions compared to the smallest length scales of turbulence.

Experimental studies with fibres as additives are scarce, and the data found in literature is in general more scattered. In this paper, it is our aim to do a systematic study on friction drag of turbulent flow with monodisperse high-aspect ratio fibres.

EXPERIMENT & RESULTS

To minimise complications caused by particle inertia we performed experiments on frictional drag with water as the carrier fluid in a minimal volume horizontal flow-loop. We used nylon fibres of two diameters, i.e. $d = 10\&20\mu$m and four different fibre lengths, i.e. l, ranging from 0.5 till 4 mm, with this varying fibre aspect ratio $r = l/d$, between 25 and 400. Furthermore, we varied the bulk Reynolds number, $Re = U_B.D/\nu_{carrier}$ between $\approx 5.10^3$ and $\approx 2.10^5$, and the fibre volumetric concentration c, from 0 until values with increased drag. We start with a low fibre concentration c and measure pressure drop, hence drag difference relative to data with water only, over a relevant range of Reynolds numbers. Then we increase the fibre concentration c and so on.

With increasing concentration, we observe three regions. For a specific fibre, (here the 10 μm, $\times$ 1 mm), we find, as shown in figure 1:

- At low concentrations, there is drag reduction DR at the middle range of Re, with maximum reduction a certain Reynolds number Re_{max}. For all Re, DR is roughly linear with fibre concentration c.
- At a certain concentration c_{MDR}, maximum drag reduction MDR is found at a certain Reynolds number $Re_{MDR} \approx Re_{max}$.
- Further increasing c, the change of drag with Re stays similar; however, the DR vs. Re curves now move towards higher Re, without a significant change in magnitude or shape. Further increasing c drag increases and eventually the flow loop gets clogged.

Compiling the data of experiments with seven different fibre lengths and diameters, we obtain the following:

- Re_{max} decreases significantly with increasing fibre length l, but does not depend on fibre diameter d. Best correlation is found with viscous wall units, as at Re_{max}, $l = 75\nu/u^*$.
- MDR decreases with increasing fibre length l. The 0.5 mm gives an MDR of more than 50%, the 4 mm fibres only 25%. The required concentrations c_{MDR} varies strongly: For the 4 mm fibre as little as 0.15% is needed; for the thick 0.5 mm fibre as much as 5%. The transition correlates well with the theoretically inspired $c_{MDR} \times r^2/(\ln(r) - 0.8) = 38 \pm 4$.
- Flow visualation shows that the flow changes dramatically around c_{MDR}. For low c, the flow is turbulent throughout the tube cross section; whereas beyond c_MDR the fibres suppress internal motion: We get a plug flow near the core of the tube. This matches the observation bu Xu (2003), who obtained a flat velocity profile near the pipe centre.

Our experiments have given quantitative data on drag reduction in turbulent pipe flow with fibre additives, and have marked some different flow regimes, with a remarkable transition towards plug flow. Further investigation with more detailed experimentla techniques is required.

Based on these experiments and the derived scaling rules, application of fibres for natural gas transport pipe drag reduction seems unrealistic.