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2 authors:

Ferhat Hadri
Université de Versailles Saint-Quentin -LISV

Guillou Sylvain
Université de Caen Normandie

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Drag reduction by surfactant in closed turbulent flow

Ferhat HADRI[1*] and Sylvain GUILLOU[1]
[1] *Laboratoire Universitaire des Sciences Appliquées de Cherbourg (EA4253)*
Cherbourg-Octeville, France

Abstract.

Many surfactants and polymers are considered as excellent drag reducing agents. This phenomenon induces a significant head loss reduction compared to the pure solvent. In this study an aqueous solution of CTAC/NaSal (CetylTrimethyl Ammonium Chloride and Sodium Salicylate) is used in turbulent pipe flow system. Drag reduction experiments were carried out for different experimental conditions using pressure drop measurements. At the same time the spatial velocity distribution was measured and analysed using particle image velocimetry (PIV).

Keywords: Pressure drop, drag reduction, turbulent flow, surfactant

1. Introduction

In pipe or channel flows, a great part of the pumping energy is lost by the friction of the fluid on the wall. However, dissolving small amounts of additives such as polymers or surfactants in water can reduce the fanning friction factor by 70% - 80%. In this way for instance the amount of liquid that is transported in a pipe for a given pressure drop can be increased significantly. This implies a wide range of industrial applications. Literature research (Li and al., 2005) resulted that low concentrations of surfactant (>25 ppm) exhibit effective drag-reduction. Therefore, CetylTrimethyl Ammonium Chloride mixed with Sodium Salicylate (CTAC/NaSal) are now being considered as particle drag reduction additives. CTAC/NaSal in solution are less affected by mechanical degradation (Gyr and Bewersdorff., 1995). Numerous researches have been focused on mechanism of drag reduction. The elongational viscosity Lumley (1969) or the elasticity (Tabor and De Gennes, 1986) are usually proposed to explain this effect for polymer's solutions. Indeed, some drag reducing solutions, like surfactant one, are not neither viscoelactic fluid nor present elongational viscosity (Zakin, 1998, Lu et al., 1997, Lin et al., 2001). Gyr and Bewersdorf (1995) suggested that the shear induced structure (SIS) is responsible for drag reduction. Therefore, other hypotheses have been explored such as local shear-thickening (Guillou and Makhloufi, 2007) or wall slip (Drappier et al., 2006, Hadri et al., 2010). Thus, the impact of one or another rheological behaviour is not of clear evidence, and a lot of studies are focused on the investigation of turbulent structures and frictional behaviour, particularly, near the wall of channel or pipe flow. In spite of this effort, the underlying physical mechanisms are ill understood and none of the existing theories match the existing experimental data [Zakin, 1998 and Li et al, 2008]. The key macroscopic property of these solutions that is known to be significantly different from that of the solvent is its turbulence characteristics.

The aim of this work is to study the effect of an aqueous surfactant solution (CTAC/NaSal at 75ppm) on drag reduction and on the flow pattern in the large range of Reynolds number. The measurement set-up used in the pressure drop measurement was developed in our laboratory. A particle image velocimetry (PIV) system is used in order to analysis the internal flow properties.

2. Measurement set-up

The surfactant used in the present study was CetylTrimethyl Ammonium Chloride ($C_{16}H_{33}N(CH_3)_3Cl$) dissolved in tap water which is belonging to the cationic group of surfactants and is less affected by metallic ions in water. Sodium Salicylate (NaSal) was added to provide counter ions with a weight concentration equivalent to that of CTAC (Li and al., 2005). For the present study we use CTAC/NaSal at a concentration of 75 ppm.

The experiments were performed in a horizontal closed loop circuit (figure 1). The circuit consists of two long linear sections. The first a stainless steel (304L) pipe equipped with a deferential pressure transducer (DRUCK, PDCR 2111) connected at 2 pressure taps 6 m apart. For this section a pipe diameter of 22.5 mm has been investigated. The downstream part of the second section is a 1.2 metres long borosilicate pipe. The fluid flow is driven by a volumetric pump (PCM, MR13I10) and a pressure damper is also installed. Temperature is

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[*] Corresponding author at; LUSAC - BP 78, 50130, Cherbourg.
Tel.: +332 33 01 41 37; fax: +332 33 01 42 01.
E-mail address: ferhat.hadri@unicaen.fr (F. Hadri).

controlled by a shell and tube counter flow heat exchanger and measured by two sensors (ANALOG DEVICES, AD592CN). All data (temperature, pressure gradient, flow rate) are sampled in a computer.

In order to perform the PIV measurement, the test section of the glass tube was enclosed in a rectangular Perspex box filled with water in order to reduce the optical curvature effect. The measurements were carried out at location of about L_b =70 cm, where L_b is the length from the glass pipe inlet to the test section. The flow is seeded with solution particles (hollow glass particles) of 15 µm diameter. Illumination source is a double pulsed Nd-Yag laser. Laser sheet is positioned according to the symmetry plane of the pipe. Flow images are recorded perpendicularly by CCD camera (1024×1280 pixels). Velocity fields are obtained through a particle image velocimetry method using the DaVis software (from La Vision). The double frame are processed using adaptive cross correlation FFT on 32x32 pixels final windows size with an overlap of 50%. Finally, Average velocity fields are calculated from 1000 instantaneous fields.

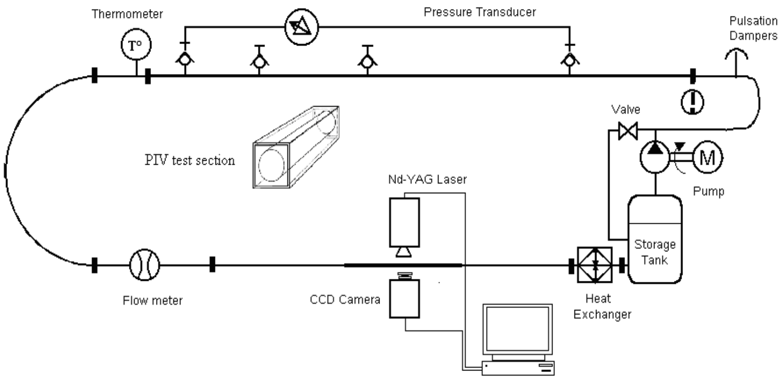

Fig. 1: Schematic diagram of the experimental apparatus

3. Results and discussion

3.1. *Pressure drop and drag reduction*

The fanning friction factor is defined as the ratio of the wall shear stress and of the kinetic energy of the flow (equation 1), where U represents the bulk velocity, ρ is the flow density and the wall shear stress τw is linked to the pressure drop ΔP (which is measured) along the pipe of length L and of diameter D.

Drag reduction occurs if, at the same flow rate, the pressure drop is reduced or if, at the same pressure drop, the flow rate is increased. This implies two kinds of definition of the drag reduction rate. As Zakin et al. (1998), we define the Drag reduction rate at constant flow rates by equation (2), where f_S and f_{DR} represent respectively the friction factor for the solvent alone and for drag reducing solution (respectively). So the friction factor is plotted as a function of the Reynolds number based on the bulk velocity, the diameter of the pipe and the solvent's viscosity.

$$C_f = \frac{2\tau_w}{\rho U^2} = \frac{\Delta P D}{2\rho U^2 L} = \frac{\Delta P \pi^2 D^5}{32\rho L Q^2} \qquad (1)$$

$$DR(\%) = \frac{f_S - f_{DR}}{f_S} \qquad (2)$$

We report on figure 2 the pressure drop for pure water and aqueous surfactant solution versus the bulk velocity. For the water flow, the pressure drop increases with increasing Reynolds number (velocity). At the beginning, the evolution of the pressure drop produced by the adding of the additives is slow compared to the pure solvent. However, around 1 m/s, the difference between the solvent pressure drop and that found for the drag reducing solution exceeds 300%. This pressure approaches 30 mbars for the water and tends to 10 mbars for the drag reducing solution at the same experimental conditions: Reynolds number, concentration and temperature. If the velocity increases even more (> 1.5 m/s), the pressure drop tends to the results found for the pure water. However, if one use the drag reduction rate (figure 2b), it appears that the percentage of drag reduction increases to reach 70% at Re= 10.000 and approach 80% at Re around 40.000. When the Reynolds number is continually increased, it reaches a point where the drag reduction breaks down (we note this state the break-down point). Such behaviour is described by Bewersdorff and Ohlendorf (1988) for higher concentration surfactant solutions (700 ppm). After this critical Reynolds number friction coefficient increases again till it reaches solvent behaviour.

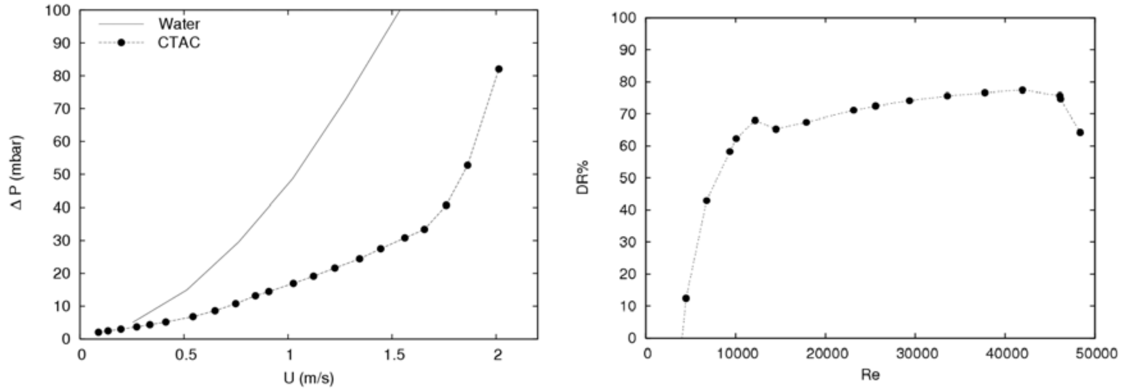

Fig. 2: Pressure drop versus bulk velocity for water and for aqueous surfactant solution dosed at 75 ppm (left); drag reduction rate versus Reynolds number for aqueous surfactant solution dosed at 75 ppm (right): D=22.5 mm, T°=20°C.

3.2. *Instantaneous velocity and turbulence*

Figure 3 shows the distribution of the instantaneous velocity in the surfactant solutions and the water flow with the same Reynolds number (Re≈25.000). We observe a weak acceleration of the core region for the surfactant solution. The contour in the surfactant solution is approximately parallel to the mean flow in the near wall region. That comes from a reduction of the velocity gradient near the wall. For drag reducing flow, it was found that the mean velocity gradient near the wall for the surfactant solution is lower than the one for the solvent, but near the centre of the pipe we observe the opposite situation. It appears that this profile reveals some characteristics of drag reducing solutions described in literature (Zakin et al., 1998, Gyr and Bewersdorff, 1995).

Reynolds shear stress for the CTAC/NaSal solution is nearly zero in comparison to the ones obtained for the Newtonian flow by PIV (figure 4). This is an interesting result which corroborates those reported by some authors as Li et al. (2008). Figure 5 shows turbulent kinetic energy for the water and aqueous surfactant solution. Near the wall, the kinetic energy dissipated is lower compared than the ones found for the water at the same experimental conditions. This observation can explain a part of the drag reduction phenomenon not elucidated now. But the different parts contribution (turbulence, wall slip, elasticity …) is not easy to demonstrate experimentally.

PIV system was also employed to investigate the Re-dependence of turbulence structures in a drag reducing surfactant solution (Li et al, 2005). The drag reduction phenomenon in certain Re number range and concentration of surfactant can be related by the presence of micellar structures. The disappearance of the drag reduction effect can be explained by the destruction of those structures.

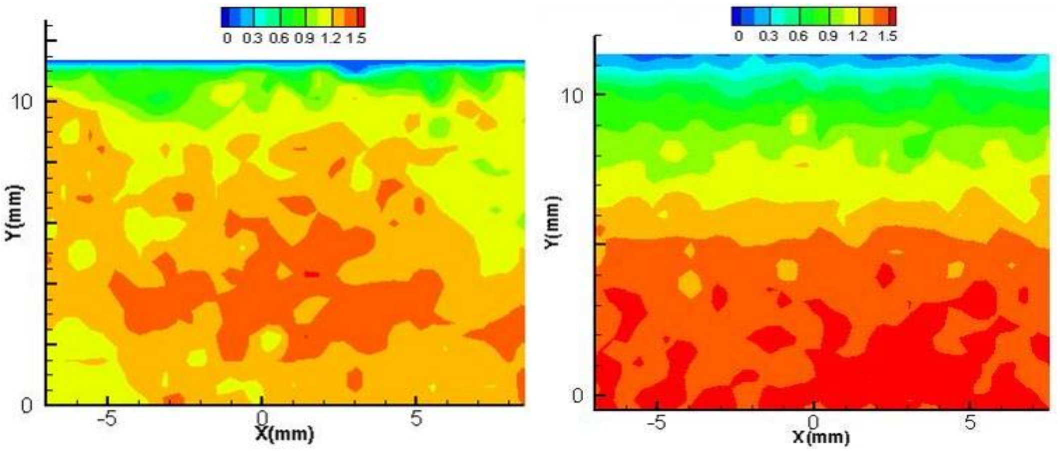

Fig. 3: Instantaneous velocity field at Re≈25.000(D=22.5 mm, T°=20°C): for water (left) and aqueous surfactant solution dosed at 75 ppm (right).

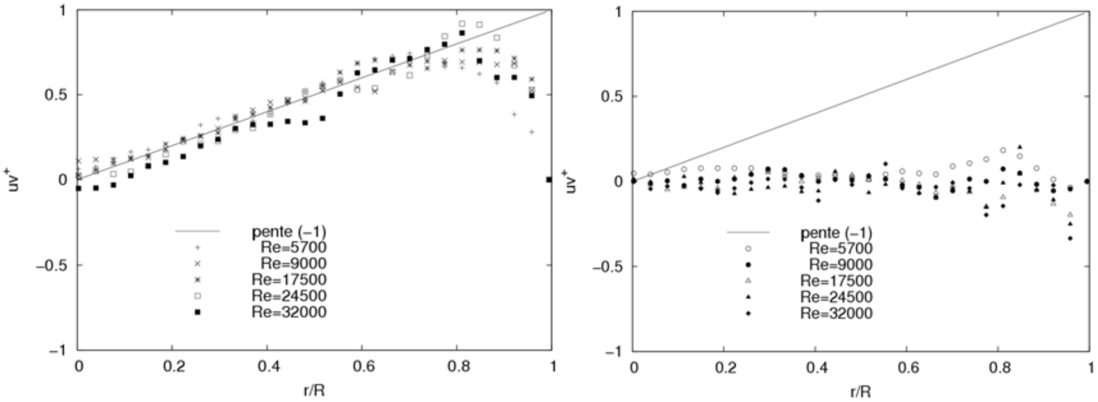

Fig. 4: Reynolds stress in 22.5 mm pipe flow at 20°C: for water (left); for aqueous surfactant solution dosed at 75 ppm (right).

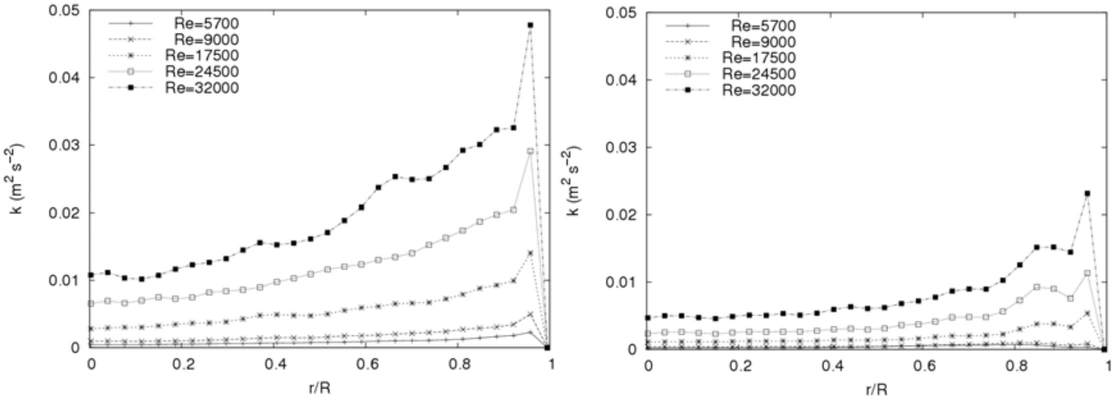

Fig. 5: Turbulent kinetic energy in 22.5 mm pipe flow at 20°C: for water (left); for aqueous surfactant solution dosed at 75 ppm (right).

4. Conclusion

In this communication drag reduction by addition of very small amount of CTAC NaSal (75ppm) was studied by measurements of the pressure drop and by using a PIV system. Drag reduction and turbulence characteristics were investigated. In general, this system presents drag reduction rates of about 75 %.

First, it appears that the pressure drop in drag reducing turbulent flow depends on the velocity (Reynolds numbers). Secondly, one observes on PIV's results that the turbulence characteristics for the very low concentrated surfactant solution are strongly affected, whereas, the flow is fully turbulent, the turbulent kinetic energy for the surfactant solution is lower and the Reynolds stress is negligible.

References

[1] Li. F.C, Kawaguchi. Y, Segawa. T. and Hishida. K.: Reynolds number dependence of turbulence structures in a drag-reduction surfactant solution channel flow investigated by particle image velocimetry, Physics of Fluids, 2005.

[2] Gyr A., Bewersdorff H.W., Drag Reduction of Turbulent Flows by Additives, The Netherlands Kluwer Academic Publishers (1995).

[3] Lumley J.L., Drag reduction by additives, Annual Review of Fluid Mechanics, 1, 1969, pp. 367-384.

[4] Tabor M. and De Gennes P.G., A cascade theory of drag reduction, Europhysics Letters., 2, 1986, pp. 519-524.

[5] Zakin. J.L, Lu. B and Bewersdorff . H.V.: Surfactant Drag Reduction, an invited review article for Reviews in Chemical Engineering, 14, 255-320, 1998.

[6] Lu B., Li X., Zakin J.L. and Talmon Y., A non-viscoelastic drag reduction cationic surfactant system, Journal of Non-Newtonian Fluid Mechanics., 71, 1997, pp. 59-72.

[7] Lin Z., Zakin J.L., Zheng Y., Talmon Y., Zheng Y., Davis H.T. and Scriven L.E., Influence of Surfactant Concentration and Counterion to Surfactant Ratio on Rheology of Wormlike Micelles, Journal of Colloid and Interface Science., 239(2), 2001, pp 543-554.

[8] Guillou S. and Makhloufi R., Effect of a shear-thickening rheological behaviour on the friction coefficient in a plane channel flow: a study by direct numerical simulation, International Journal for Non-Newtonian Fluid Mechanics., 144, 2007, pp. 73-86.

[9] Drappier J., Divoux T., Amarouchene Y., Bertrand F., Rodts S., Cadot O., Meunier J. and Bonn D., Turbulent drag reduction by surfactants, Europhysics Letters., 74 (2), 2006, pp. 362-368.

[10] Hadri F. and Guillou S., La réduction de la traînée en écoulement turbulent, Editions Universitaires européennes (Broché), ISBN10: 6131522405 (2010).

[11] Li. F. C., Kawaguchi Y., Yu. B., Wei. J. J. and Hashida. K., Experimental study of drag-reduction mechanism for dilute surfactant solution flow, International Journal of Heat and Mass Transfer., 51, 2008, pp. 835-843.

[12] Bewersdorff H.W. and Ohlendorf D, The behaviour of drag-reducing cationic surfactant solutions, Colloid Poly. Sci., 266, 941-953, 1988.