Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2017,29(5):871-878
DOI: 10.1016/S1001-6058(16)60799-0
ELSEVIER
www.sciencedirect.com/
science/journal/l0016058

Effect of polymer and fiber additives on pressure drop in a rectangular channel *

Amir Eshghinejadfard, Kashyapa Sharma, Dominique Thévenin
Laboratory of Fluid Dynamics and Technical Flows, University of Magdeburg "Otto von Guericke", Universitätsplatz 2, 39106 Magdeburg, Germany, E-mail: amir.eshghinejadfard@ovgu.de

(Received March 16, 2017, Revised April 10, 2017)

Abstract: The influence of minute amounts of additives on pressure drop is an interesting fundamental phenomenon, potentially with important practical applications. Change of the pressure drop in a quasi-two-dimensional channel flow using various additives is experimentally investigated. Tests were conducted for a wide range of concentrations (100 ppm-500 ppm) and Reynolds numbers (16 000-36 000) with two polymers and four rigid fibers used as additive. Maximum drag reduction of 22% was observed for xanthan gum. However, xanthan gum loses its drag-reducing property rapidly. It was also seen that drag reduction percentage of xanthan gum remains almost constant for different Reynolds numbers. Guar flour demonstrated good drag reduction property at high Reynolds numbers. Drag reduction of 17.5% at $Re = 33\,200$ using 300 ppm solution was observed. However, at low Reynolds numbers guar flour will cause an increase in pressure drop. Fiber fillers (aspect ratio=21) have been tested as well. In contrast to polymers, they increased the drag for the range of examined concentrations and Reynolds numbers. Polyacrylonitrile fiber with three different aspect ratios (106, 200, 400) was also used, which showed an increase in pressure drop at low aspect ratios. Polyacrylonitrile fibers of larger lengths (6 mm) demonstrated minor drag-reducing effects (up to 3%).

Key words: Pressure drop, polymer, fiber, channel flow

Introduction

Effect of suspended particles and additives on flow properties is always an important topic for both experimental and numerical studies. In this regard, some types of additives lead to lower pressure drop in the flow[1-3] while some others increase it[4,5]. Particle and fluid type in addition to flow regime and geometry play the main roles in this regard. Therefore, recognizing the conditions that can result in reduction or enhancement of pressure drop is of great importance.

Reduction of pressure drop and consequently pumping cost is an interesting topic for many liquid transportation systems. This can be achieved by addition of small amounts of drag-reducing agents (DRA)[6]. The concept of drag reduction (DR) can be traced back to the work of Toms[7]. He discovered that introduction of a few parts per million (ppm) of long-chain polymers can result in reduction of wall friction. DR leads to an increase of pipeline flow rate for the same pressure head. Most studies focus on polymers as drag reduction agent[8-11]. In this regard, long-chain and flexible polymers such as polyacrylamide and polyethylene oxide (PEO) are recognized as DRA. Onset of DR occurs when polymers are unraveled from the coiled to an extended conformation. Therefore, DR due to polymer solutions is expected to happen beyond a certain Reynolds number for a unique concentration. Below this Reynolds number usually no DR is observed.

Two types of explanation have been given for the onset of DR when polymers are utilized. Some researchers[12-14] attribute DR to viscous effects. They reason that stretching of polymers in the regions of strong deformations of flow field leads to a higher effective viscosity in this turbulent region and consequently the thickness of buffer region is increased and velocity gradient is reduced. On the other hand, the elastic theory of Tabor and De Gennes[15] postulates that DR occurs when the elastic energy of polymers is large enough to terminate the Kolmogorov-type energy cascade. A major practical problem associated with flexible polymers is their fast thermal, biological, chemical, or mechanical degradation. This would limit their application to one-pass

---

* **Biography:** Amir Eshghinejadfard (1983-), Male, Ph. D. Candidate

systems. Nowadays, rigid polymers[16], surfactants[17], bubbles[18], nanoparticles[19] and fibers[20,21] have been proven as possible alternatives for flexible polymers.

In most cases from dilute to dense regimes, however, pressure drop increases after addition of rigid particles[22-27]. This effect is highly dependent on particle shape, Stokes number (St) and solid phase volume fraction (φ). There are many practical cases, in which, fibers or polymers are transported by the piping system. It would be thus important to recognize the conditions that can lead to each of above mentioned pathways and to understand the effect of different additives on decrease or increase of pressure drop.

The current work aims at experimentally investigating the influence of different additives on pressure drop in a straight rectangular channel. The experimental set-up includes a long channel of rectangular cross section to mimic a quasi-two-dimensional flow. Pressure drop measurements are performed and results are compared with those of pure water to calculate the pressure drop change. The first part of the results deals with behavior of semi-rigid polymers (xanthan gum, guar flour) and investigates their effect for different flow rates. Since less attention has been paid to rigid particles so far, the second part considers the effect of rigid particle shape, concentration and size on pressure drop in semi-dilute regime. In the end, we aim to arrive at a final method on the selection of rigid fibers to lower the pressure drop in particle-laden systems.

1. Turbulent channel flow characteristics

For theoretical calculations, a fully developed turbulent flow through a channel is assumed in this study. Pressure drop and flow characteristics are thus related through

$$\Delta p = \rho f_D \frac{L}{D_h}\frac{U_b^2}{2} = 2\rho f_F \frac{L}{D_h} U_b^2 \tag{1}$$

where ρ is the fluid density, f_D is Darcy friction factor, f_F is Fanning friction factor, L is distance, D_h is the hydraulic diameter and U_b is the mean (bulk) velocity. Due to large width to height ratio of the channel, D_h is considered to be equal to $4H$ with H being the half-channel height. Consequently, the friction velocity (u_τ) is given by

$$u_\tau = \sqrt{\frac{\tau_w}{\rho}} = \sqrt{\frac{H\Delta p}{\rho L}} \tag{2}$$

with τ_w being the mean shear stress at the wall and Δp a constant pressure gradient. The Reynolds number based on the friction velocity reads

$$Re_\tau = \frac{u_\tau H}{\nu} \tag{3}$$

where ν is the fluid kinematic viscosity. The bulk Reynolds number is given based on the channel height by

$$Re_\tau = \frac{U_b 2H}{\nu} \tag{4}$$

The Fanning friction factor for turbulent fluid flow in smooth pipes is usually described by the Prandtl-von Karman (PK) expression[28]

$$f_F^{-0.5} = 4.0\lg(Ref_F^{-0.5}) - 0.4 \tag{5}$$

In the case of water as carrier fluid, the Blasius approximation can be used as well

$$f_F^{-0.5} = 0.079 Ref_F^{-0.25} \tag{6}$$

Based on the Virk's maximum drag reduction (MDR) asymptote[29], the lowest friction factor that can be attained in a turbulent flow is defined by

$$f_F^{-0.5} = 19.0\lg(Ref_F^{-0.5}) - 32.4 \tag{7}$$

Therefore, the friction factor of a drag-reducing system must fall between the PK law and Virk's MDR asymptote for a given Reynolds number. In multiphase flows, DR percent is defined as the ratio of reduction in the pressure drop to the pressure drop without DRA

$$\mathrm{DR}\% = \frac{\Delta p_0 - \Delta p_{\mathrm{DR}}}{\Delta p_0} \times 100 \tag{8}$$

Here, subscripts 0 and DR denote the states in the absence and presence of DRA, respectively. Both pressure drops are measured at the same Reynolds number based on water properties.

Another important parameter in particle-laden turbulent flows (mainly for rigid particles) is the particle Stokes number. It is defined as the ratio of the particle response time (τ_p) to the characteristic time scale of the turbulent flow. A particle with low Stokes number responds quickly to the flow. Characteristic time scale of the fluid flow can be either the Kolmogorov $(\tau_K = \sqrt{\nu/\varepsilon})$ or the near-wall scale $(\tau_V = \nu/u_\tau^2)$. The Stokes number based on the former one is denoted by St_K and the latter one by St^+.