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ADDITIVES SHEAR-THINNING AND TURBULENCE DAMPING INFLUENCE ON THE FITTING LOSS COEFFICIENT OF BENDS

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INTRODUCTION

A large part of the auxiliary energy for cooling and heating systems in buildings is needed for the pumps that distribute the heat transfer medium in the thermal distribution network. Roughly half of the pressure losses in such systems are due to straight pipes and roughly 10 % are due to bends and T-pieces. Drag reducing additives have not so far been widely used for domestic thermal distribution networks. The BioNet-project at the Hermann-Rietschel-Institute in Berlin aims at adopting promising solutions for this specific application and evaluating potential energy savings. The specific typical technical conditions for this application, such as Reynolds numbers and pipe diameters are considered. In addition to measurements, numerical simulations (CFD) are used to adopt and evaluate the approaches to heating and cooling nets as well as to explain the physical principles of the developments.

The flow of a drag-reducing surfactant solution in a bend with a curvature radius R_k/D of 1.5 is considered, where D=20 mm is the pipe inside diameter. It is known that the pressure drop of straight pipes can be reduced considerably with additives such as surfactants due to the damping of turbulent structures. Measurements were performed on two test setups to assess the influence of additives on the pressure drop in straight pipes as well as for a circuit containing ten bends. The experiments are further described in [1] and [5]. In the measurements of the circuit, a drag reduction of 40 % was found as compared to 60 % for the straight pipes.

The investigations could so far not clearly explain why this was the case. Is it that the pressure drop of fittings may actually increase under specific circumstances if additives are used? The question already motivated other experimental studies, e.g. Gasljevic and Matthys[2]. This would mean that additives are then disadvantageous in thermohydraulic nets that contain many fittings such as bends. The physical properties of surfactant solutions depend on the actual chemical and physical system conditions such as water quality and the materials used for the pipes. In addition to the turbulence damping by the micelle structures which leads to a reduction of pressure losses, a non-Newtonian viscosity with a shear thinning behaviour is introduced that may actually increase the pressure losses. That is why a simple and straightforward model was needed to explain the basic influence of the shear-thinning behaviour and the turbulence damping in bends.

METHOD

In this study two simple computational fluid dynamic models are used to assess the effect of the turbulence damping and the shear-thinning behaviour separately and combined. The models are available in the commercial computational fluid dynamics software package STAR-CCM+ version 11.06.010. The intermittency model is used for the turbulence damping. The intermittency is a parameter that is used in the k-ω-SST turbulence model to reduce the turbulent production and therefore obtain lower turbulence levels.

The shear-thinning behaviour is considered by a generalised Newtonian fluid model that allows for a dependence of the dynamic viscosity on the shear rate. In this case, the Carreau-Yasuda curve is used (see figure 1). The coefficients of the Carreau-Yassuda curve are fitted to an approximation given in [4] and evaluated for a temperature of 22 °C, corresponding to the experimental conditions. Further conditions such as medium degradation or chemical influences on the successful micelle formation were not considered. Measured viscosities from two different sources are also shown as a reference. The measured shear viscosities are of a turbulent drag-reducing cationic surfactant solution CTAC with counter ion NaSal at a concentration C_m of 200 ppm. Data is only available for shear rates below 150 s^{-1}, but data for much higher shear rates was needed for this investigation. It was therefore assumed that for very high shear rates, an asymptotic value $\mu_\infty = \mu_{\text{Water}}$ of the dynamic viscosity of pure water is approached. An asymptotic value μ_0 at low shear rates is not clearly visible in the experiments, probably due to experimental uncertainties. Therefore, an approximation for μ_0 given in [4] was used and evaluated for a temperature of 22 °C.

The Reynolds number Re was varied between 2000 and 140 000 (16 steps) and the intermittency I between 0.1 and 1.0 (10 steps), resulting in 160 simulated cases for the straight pipe and for the bend, respectively. A two-dimensional mesh with a resolution of 200 points in the radial direction was used for the straight pipe. Periodic boundary conditions were used to obtain a fully developed flow. For the bends, a three-dimensional mesh of approximately 1×10^6 cells was used. The dimensionless wall distance y^+ of the computational meshes was always below 0.7 in all investigated cases.

RESULTS

Figure 2 shows the predicted pressure loss coefficient for a straight pipe. The results at the lowest two Reynolds numbers 2000 and 5000 should only be interpreted qualitatively because the used turbulence model is in principle not applicable for such low Reynolds numbers. The curve by Gersten[3] is the reference curve for a smooth pipe and water. The curve by Zakin[6] is the expected maximum drag reduction that can be achieved by using surfactants as additives. The black lines show the calculated pressure loss coefficients for different values of the intermittency I between 0.1 and 1. The pressure loss coefficient decreases with decreasing intermittency. I=0.1 is the smallest value used for the intermittency in this study; the calculated pressure drop is still above the curve by Zakin when this value is implemented. The turbulence in the simulation could, therefore, be even further reduced. The red (top) lines show the pressure losses for the shear-thinning fluid. The corresponding curves for the pressure loss coefficient of the single bend are depicted in figure 3. For low Reynolds numbers below 30 000, the pressure loss coefficients λ and ζ increase because of the additional viscosity at low shear rates.

Compared to straight pipes, the influence of turbulence damping on the drag reduction is lower for bends. It is known that the transition from laminar to turbulent flows occurs much later for curved pipes than for straight pipes. This can be seen in figure 4. Depicted is the effective viscosity that results from the water viscosity, the additional viscosity due to the additive and the turbulent eddy viscosity. Especially for low Reynolds numbers, the turbulent eddy viscosity is already relatively low in the bend, therefore further damping does not lead to the same larger reduction of the pressure loss coefficient that is observed for straight pipes. Furthermore, the additional viscosity at low shear rates becomes important at low Reynolds numbers below 30 000.

FIGURES

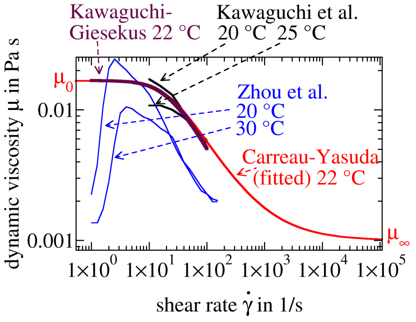

Figure 1: Used model of shear-thinning behaviour and experimental data of Kawaguchi et al.[4] and Zhou et al.[7]

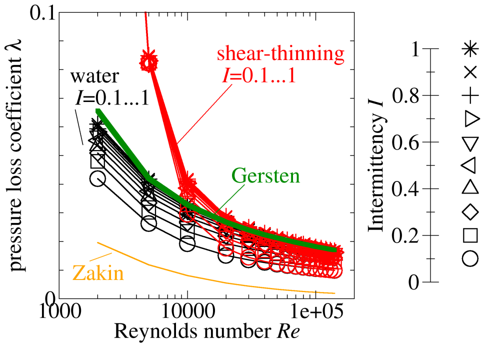

Figure 2: Influence of intermittency and rheologic properties on the pressure loss of a straight pipe

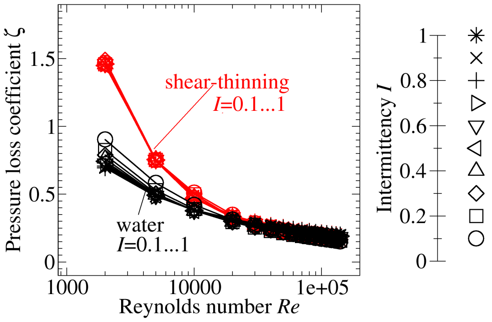

Figure 3: Influence of intermittency and rheologic properties on the pressure loss of a bend

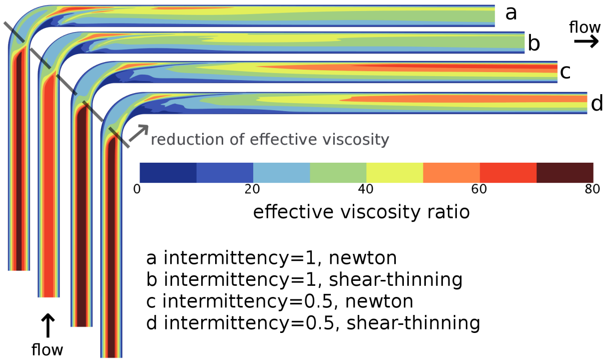

Figure 4: Influence of intermittency and rheologic properties on the effective viscosity in a bend,Re=20 000

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