A Model for Velocity Profile in Turbulent Boundary Layer with Drag Reducing Surfactants

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Received: 26.08.04, Final version: 22.04.05

Abstract:
A new model for mean velocity profile of turbulent water flow with added drag-reducing surfactants is presented in this paper. The general problem of drag due to frictional resistance is reviewed and drag reduction by the addition of polymers or surfactants is introduced. The model bases on modified Prandtl's mixing length hypothesis and includes three parameters, which depend on additives and can be evaluated by numerical simulation from experimental datasets. The advantage of the model in comparison with previously reported models is that it gives uniform curve for whole pipe section and can be determined for a new surfactant with less necessary measurements. The use of the model is demonstrated for surfactant Habon-G as an example.

Zusammenfassung:
Ein neues Modell für das mittlere Geschwindigkeitsprofil einer turbulenten Wasserströmung mit hinzugefügten widerstandsreduzierenden grenzflächenaktiven Substanzen wird in diesem Artikel präsentiert. Die allgemeine Fragestellung des Widerstandes aufgrund von Reibungswiderstand wird zusammengefasst, und Widerstandsverminderung durch die Zugabe von Polymeren oder grenzflächenaktiven Substanzen wird eingeführt. Das Modell basiert auf einer modifizierten Hypothese der Mischungslänge von Prandtl und beinhaltet drei Parameter, die von den Additiven abhängen und durch numerische Simulation von experimentellen Datensätzen bestimmt werden können. Der Vorteil dieses Modells im Vergleich mit früher beschriebenen Modellen liegt darin, dass es eine einheitliche Kurve für den gesamten Rohrabschnitt liefert und für neue grenzflächenaktive Substanzen mit weniger Messungen bestimmt werden kann. Der Nutzen von diesem Modell wird exemplarisch für die grenzflächenaktive Substanz Habon-G gezeigt.

Résumé:
Un nouveau modèle pour le profil de vélocité moyenne dans un écoulement turbulant d'eau additionnée de surfactants est présenté dans cette contribution. Le problème général de la force d'entrainement due à la friction est revue, et sa réduction à l'aide de l'addition de polymères ou de surfactants est introduite. Le modèle repose sur une modification de l'hypothèse de Prandtl pour la longueur de mélange, et inclus trois paramètres qui dépendent des additifs et qui peuvent être évalués par une simulation numérique des données expérimentales. L'avantage du modèle, en comparaison avec les modèles précédents, est qu'il donne une courbe uniforme pour toute la section de la conduite et qui peut être déterminée pour un nouveau surfactant avec moins de mesures. L'utilité de ce modèle est démontrée avec le surfactant Habon-G.

1 INTRODUCTION

In the case of fluid motion through ducts, i.e. tubes, the drag force is induced due to frictional and form resistance. In straight round pipes, relationship for pressure drop [1] is:

$$\Delta p = \lambda \frac{\rho v^2}{2} \frac{L}{D} \quad (1)$$

where L is the length of the pipe, D the inner diameter of the pipe, ρ the density of the fluid, λ the friction factor, and υ the cross-section mean velocity of the flow. Measuring the pressure drop and the flow velocity, λ can be evaluated by Eq. 1. For the friction factor in laminar flow the analytically derived and experimentally confirmed expression, known as Poiseulle's relationship, is given for $Re < 2100$ by

$$\lambda = \frac{64}{\mathrm{Re}} \quad (2)$$

where Re is the Reynolds number. For turbulent flow, the expression for the friction factor can be obtained only by experiments. One of these empirical equations $\lambda = 0.316\ Re^{-0.25}$ was established by Blausius for hydraulically smooth pipes ($4000 < Re < 105$). To maintain necessary water flow through the pipelines, these pressure losses need to be compensated by additional power of pumps. Therefore, there are strong economical motivations to reduce such losses.

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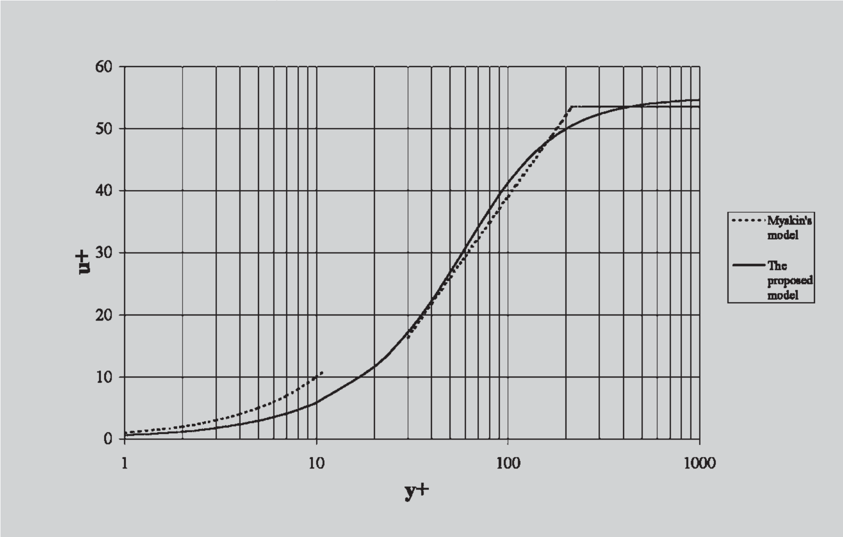

Figure 10: The comparison of the proposed model to Myskin's model for Habon-G.

ence with higher friction factors in laminar flows observed by Ohlendorf et al. [8]. Velocity gradients in the turbulent core are small. Thus calculated mean velocity profiles are nearly flat and are approaching asymptotically to the value of velocity at the pipe axis. In Fig. 10 the results are compared to Myskin's model made also for Habon-G [28]. The advantage of our model is that, while the equations for viscous, elastic layer and turbulent core are not adequate with experimental results in transitional zones of layers our model gives smooth and correct curve for whole region.

6 CONCLUSION

Polymer and surfactants additives cause considerable drag reductions offering many benefits in practical applications, e.g. higher flow velocities, energy savings, reduction of operating and capital costs. They are effective in water transport systems with turbulent flow regimes, which are common for industrial pipe networks and distant heating pipelines.

Because polymers tends to degrade permanently when passing through a region of high shear stresses, surfactants have the advantage that micelle structures, which cause drag reduction, decompose in such regions only temporary and repair themselves very soon. LDA measurements for velocity profiles are expensive and have to be carried out for every new surfactant. The proposed method demands less experimental points and gives uniform function for whole pipe section. At using drag-reducing additives, a special intention has to be given to heat exchangers, where these additives could affect the effectiveness of heat exchange. Namely, the elastic sublayer, formed by additives, has much lower heat transfer factor. Therefore, in such systems the use of surfactants instead of polymers is recommended with a net installed in inlet pipe to decompose micelles temporary.

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