Use of Quadratic Model for Modelling of Fly Ash-Water Mixture

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Abstract:
Novel approach to rheological modelling of a fly ash-water mixture is proposed. The model is first tested against the available experimental data for a corn starch-water, a glass beads-water and a fly ash-water mixture and then used taking the advantage of available CFD code for a calculation of major and minor losses. Numerical results for Quadratic model are compared with results for Power law.

Zusammenfassung:
In diesem Manuskript wird ein Ansatz für die rheologische Modellierung von Flugasche-Wasser Suspensionen diskutiert. Zunächst wird das Modell mit verfügbaren experimentellen Daten einer Maisstärke, einer Glaskugel und einer Flugasche Suspension abgeglichen und dann dazu benutzt die Rheologie der Flugasche Suspension mit einem kommerziell verfügbaren CFD Code zu berechnen. Die numerische Ergebnisse für das quadratische Modell werden im Abschluss mit Ergebnissen für das Potenzgesetz verglichen.

Résumé:
Une nouvelle approche pour la modélisation rhéologique d'un mélange eau-cendre est proposée. Le modèle est premièrement testé avec les données expérimentales existantes pour des mélanges eau-pulpe de maïs, eau-billes de verre et eau-cendre. Il est ensuite utilisé en prenant avantage des codes CFD disponibles pour le calcul des pertes majeures et mineures. Les résultats numériques pour un modèle quadratique sont comparés avec les résultats obtenus pour une loi de puissance.

Key words: non-Newtonian flow, rheological modelling, numerical analysis

1 INTRODUCTION

Most CFD codes offering treatment of non-Newtonian fluids use the well-established Power law rheological model. User of a CFD code should supply the code with both parameters (consistency K and flow index n) valid for an actual fluid being modelled. These parameters are obtained from measurements, e.g. with a capillary viscometer. However, the results are not always presented as a relation of a shear stress vs. a shear rate but rather as a wall shear stress vs. an apparent wall shear rate.

The regression analysis used to arrive at Power law parameters (e.g. the least squares method) is no longer in a form:

$$\tau_W = K\dot{\gamma}_W^n \qquad (1)$$

but rather:

$$\tau_W = K\left(\frac{3n+1}{4n}\right)^n\left(\frac{8\bar{v}}{D}\right)^n \qquad (2)$$

where τ_W stands for a wall shear stress, $\dot{\gamma}_W$ for a wall shear rate, K for a consistency, n for a flow index and $8\,\bar{v}/D$ for an apparent wall shear rate. Similar, but more cumbersome approach can be used with a three-parameter Sisko model.

In the past, we have performed both types of analysis for a fly ash-water mixture, and were (in general) not satisfied with accuracy (Fig. 1). Rather then insisting on these two rheological models we have tried a simple polynomial (i.e. parabolic) data fit which was much more accurate than the classical Power law or Sisko model. The remaining question then was if such a data fit can be transformed into a relationship

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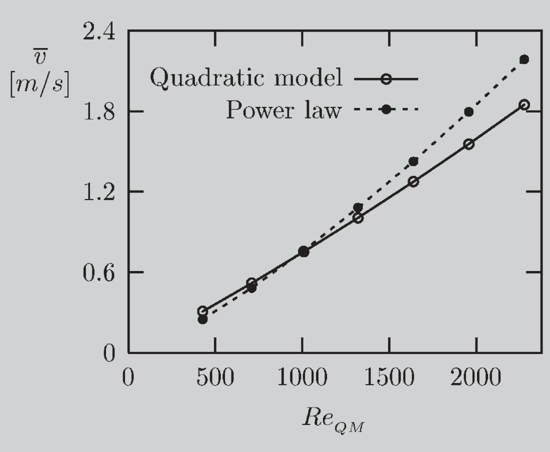


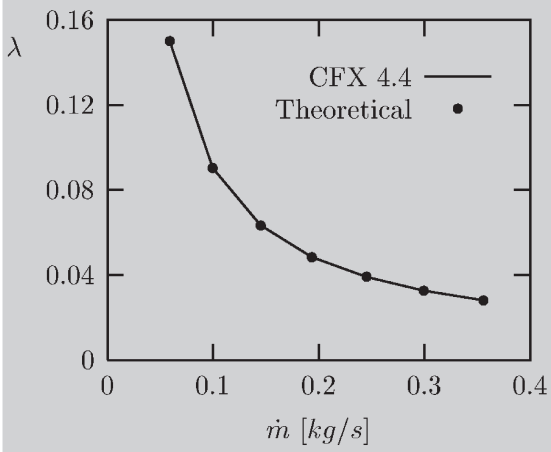
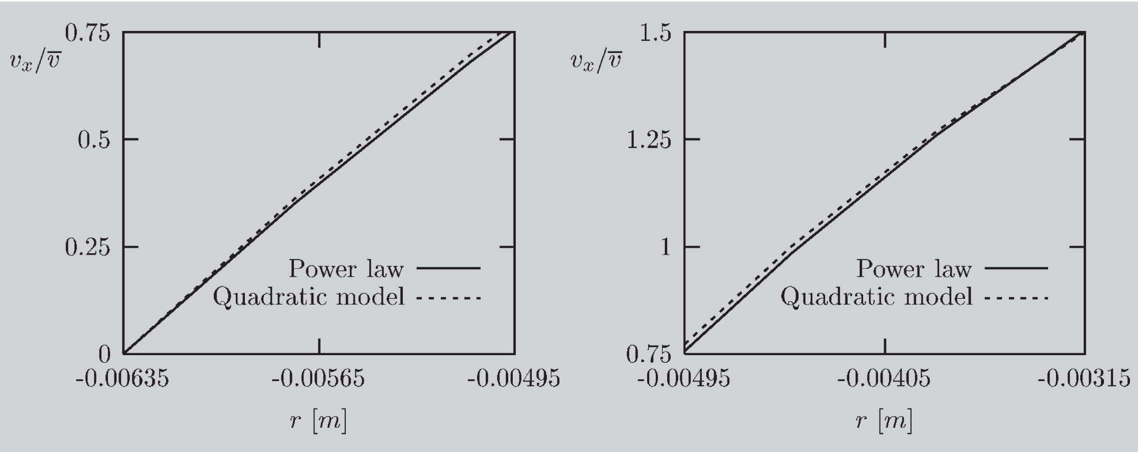


Figure 10 (left above): Average velocity as a function of the Reynolds number.

Figure 11 (below): Velocity profile near pipe wall ($\overline{v}$ = 0.307 m/s).

Figure 12 (right above): Major loss.



file, and this may also be the reason for the difference between Power law, and Quadratic model results in Fig. 8. For Power law, the profiles remain the same regardless of the Reynolds number. Figure 10 shows the relation between the average velocity and the values of the Reynolds number for both cases.

According to Figure 11 the velocity for Quadratic model is larger in a near wall region than for Power law, and this is true also for shear rate. Away from the wall, the velocity gradient is smaller than for Power law case, see right hand side of Fig. 11.

5.3 MAJOR LOSSES

Using numerically obtained results for the pressure drop in a pipe flow, Δp_{CFX}, the major losses (Darcy-Weisbach friction factor) were determined as

$$\lambda = \Delta p_{CFX} \frac{D}{L} \frac{2}{\rho \overline{v}^2} \tag{45}$$

and compared with theoretical value λ = 64/Re. Comparison of calculated major losses is shown in Fig. 12. It can be seen that the major losses calculated using Eq. 45 agree well theoretical values. Further, one can conclude, that the suggested form of the equivalent Reynolds number (Eq. 29) is an appropriate. Results for Δp as well as for λ show that Quadratic model predicts smaller friction loss than Power law as shown in Fig. 13. For smaller values of a mass flow rate the corresponding pressure drop is smaller for Power law. As mass flow rate increases the pressure drop increases with significantly higher values for Power law.

6 CONCLUSIONS

Quadratic model, describing shear thickening viscous behaviour of non-Newtonian fluids, is proposed. Equations for velocity profile, shear stress and shear rate were derived using the fundamental relationship between the wall shear stress and the apparent wall shear rate of a model proposed. For an actual experimental set up with a capillary viscometer the results for the wall shear stress and the apparent wall shear rate were used to determine the parameters for Quadratic model as well as for Power law. Comparison of determination coefficients of both rheological models, describing non-Newtonian rheological behaviour of an electrostatic ash and water mixture favour Quadratic model over Power law. In addition, Quadratic model was compared to other experimental data available in the open literature showing better results than

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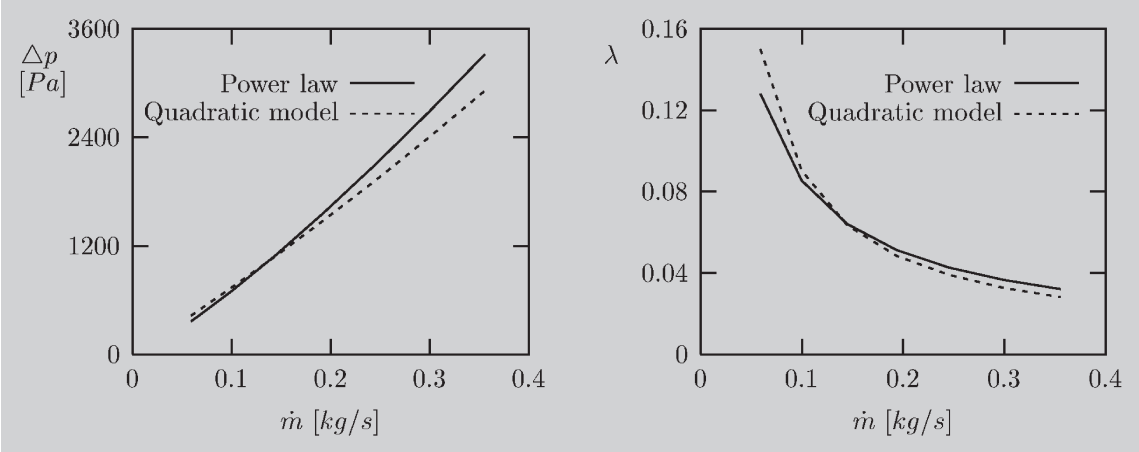

Figure 13: Comparison of results (left: pressure drop, right: major loss).

the customarily used Power law. Using the CFX 4.4 numerical code the fully developed laminar flow of an electrostatic ash and water mixture in straight pipe was modelled. Comparison of numerically obtained and theoretical results for the velocity profile show good agreement as well as validate the Quadratic model as presented.

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