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Analytical pore-scale modelling of the effect of particle surface roughness on the pressure drop and/or friction factor of granular porous media

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Surface roughness plays a critical role in modelling fluid flow parameters through granular porous media, with applications in, for instance, hydrology, thermal storage and biofiltration. Accurate flow prediction models are necessary for optimizing production and reducing capital costs. Over the years, the inclusion of surface roughness, defined as the microscopic irregularities on the surfaces of particles, have become apparent in many pressure drop model predictions. The importance of accounting for the effect of particle surface roughness on the pressure drop and/or friction factor of granular porous media has been highlighted by a few authors in the literature (e.g. Allen et al. (2013), Nemec and Levec (2005) and Crawford and Plumb (1986)). The two most common approaches include the use of fractal analysis or empirical modelling. In the case of the fractal modelling, it is often not as straightforward to quantify the fractal parameters. The empirical models, on the other hand, include curve fitting parameters which make these models data specific and not generally applicable, since for every other data set, new empirical coefficients need to be determined. In this study, an analytical pore-scale model is proposed for granular media involving the rectangular Representative Unit Cell (RUC) model (Du Plessis and Woudberg (2008)), which has served well in the literature. This granular RUC model is adapted geometrically to include particle surface roughness and the analytical modelling procedure for the derivation of the pressure gradient adapted accordingly. The resulting predictive equation includes a roughness factor, defined in terms of the average roughness height, amount of roughness elements and particle diameter. In fractal analysis models, the surface roughness is often represented as microscopic conical elements on the surface of granular media, where-as in this study it is represented as cubes, to comply with the rectangular geometry adopted by the RUC model. The proposed model is validated against experimental data from the literature involving flow of gas and/or water through smooth and rough granules. The well known Ergun equation (Ergun (1952)) for smooth particles is also included for comparison (and reference), as well as the empirical model of Allen et al. (2013) for smooth particles. The effect of roughness is, in addition, included into the latter model to, once again, illustrate the significant improvement in the model prediction with the inclusion of surface roughness. Results will furthermore be shown in which the RUC model has been applied to predict the pressure drop over a biofilter by taking particle surface roughness, sphericity and biofilm development into account. The findings of this study have the potential to improve the optimization of applications, such as biofiltration systems, and contribute to a deeper understanding of surface roughness characterization.

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