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Finite volume modelling of dense granular flow in rotary kilns

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Granular materials are used in several industrial applications. One example of such an industrial application is rotary kilns, often used for drying, pre-heating and the reduction of a moving, high-temperature granular bed. The granular flow in these reactors have an important influence on capacity, product quality, and economic feasibility. Rotary kilns, in the pyrometallurgical industry, often have diameters up to 6m, with lengths in excess of 80m, and operating at temperatures of 1000 to 1400℃. Because of the size of these kilns, modelling the granular flow using the discrete element method (DEM) would result in excessively high computational costs. In this work, we therefore made use of a continuum approach to describe the granular flow.

We adopted the μ(I) dense granular flow model proposed by de Cruz et al. (2005) and later extended by Jop et al. (2006). This model is a rate-dependent, phenomenological description of dense granular materials and can be characterised as an elsto-viscoplastic material description with a frictional yield criteria. The flow model approximates an effective friction coefficient through a relationship between plastic flow strain rates and a confinement time scale to account for the internal, inter-particulate motion.

We implemented the material model into OpenFOAM, an open source, finite volume (FV) based, partial differential equation toolkit. The volume of fluid (VoF) method was used to capture the discrete granular-fluid interface, enabling the simulation of large granular bed deformations. The numerical scheme was stabilised by using pressure and viscosity regularisation, along with a semi-implicit coupling between the internal pressure and velocity fields.

In our project we were faced with serious technical and computational challenges involving combustion, heat transfer, fluid flow, high-temperature chemistry, and the movement of a large granular bed. Our FV approach enabled us to make valuable computational modelling and simulation contributions to the development of a new high-temperature process technology.

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