Numerical prediction of critical deposition velocity for turbulent liquid-solid slurry flow through a horizontal pipe

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Abstract

Understanding the dynamics of turbulent two-phase flows is important for a wide range of applications from pneumatic conveying to sediment transport. Of particular interest in this work is the transport of oil sand through pipelines. In a near-horizontal pipeline, depending on the liquid flow rate, the slurry flow can exhibit four main regimes. At low liquid flow rates, the sand will drop out of the carrier liquid and forms a stable, stationary bed. When the liquid flow rate increases above a specific value, sand starts getting transported in a thin layer above the bed. As the flow rate increases further, sand bed breaks into a series of slow-moving dunes which eventually form a moving bed along the bottom of the pipe. At even higher flow rates, the sand particles get fully suspended in the carrier liquid.

The velocity at the onset of a stationary bed formation is referred to as the critical deposition velocity. Formation of stationary sand bed can pose several risks such as increased frictional losses, possibility of microbially-induced corrosion under the sand bed, and equipment failure due to sand. So, it is important to design the pipeline system such that the sand keeps moving. This requires accurate prediction of the critical deposition velocity.

We use a novel, high-fidelity Euler-Lagrange large eddy simulation methodology to investigate the detailed dynamics of liquid-solid slurry flow through a horizontal pipe. A dynamic Smagorinsky model based on Lagrangian averaging is employed to account for the sub-grid scale turbulence in the liquid phase. A fully conservative immersed boundary method is used to account for the pipe geometry on a uniform cartesian grid. The liquid and solid phases are coupled through volume fraction and the momentum exchange terms. Particle-particle and particle-wall collisions are modeled using a soft-sphere approach. A series of simulations have been performed by varying the superficial liquid velocity to be consistent the available experimental data by Danielson (2007). From our numerical simulations, the velocity at which the sand bed starts forming is predicted and compared with the experiments. This is the first time

such a detailed study is presented using a high-fidelity Euler-Lagrange methodology.