An Experimental and Numerical Investigation of the Terminal Velocity of Sinking Objects

Karl Travis [C, S], Adam Squires, David Burley and Fergus Gibb
Department of Materials Science and Engineering, University of Sheffield, Sheffield, South Yorkshire, United Kingdom
k.travis@sheffield.ac.uk

Deep Borehole Disposal (DBD) is an alternative disposal route to mined repositories for managing the high-activity, moderate-volume components of radioactive waste inventories. It entails emplacement of waste packages in the lower portions of large diameter (up to 0.66 m) vertical holes drilled 4 to 5 km into the crystalline basement of the continental crust. An important quantity of interest from an engineering safety case perspective is the terminal speed attained by a waste container which may (though highly unlikely), break free from the emplacement mechanism, and enter into free-fall. A useful engineering model should be capable of predicting the terminal speed as a function of the diameter of the waste package (relative to the internal diameter of the borehole), its length and density. Dimensional analysis, coupled with experimental measurements using small-scale physical models provides guidance in constructing such a model. In principle, solution of the Navier-Stokes equations could be used to improve upon this by providing expressions for the drag force acting on the surface of the sinking object. In practice, useful analytical solutions can only be found for highly idealized cases such as creeping (low Reynolds number) flow past a sphere in an infinite Newtonian fluid. Numerical simulation using particles provides an alternative and promising route to increasing knowledge of the complex flow patterns (and hence the frictional forces) which can develop in cases where the Reynolds numbers are large, the surface of the sinking object is close to the physical boundaries, or the object is non-spherical. In this presentation, we present the results of an experimental study in which a series of steel cylinders and ball bearings of various physical dimensions and weight are allowed to sink through a long vertical column of water and their terminal speed accurately determined. We also present the results of related numerical simulations of the sinking of disks (2D) and spheres in a gravitational field via both non-equilibrium molecular dynamics (NEMD) and smooth particle applied mechanics (SPAM), as well as the flow of fluids past stationary disks and spheres. We discuss the latter results in terms of the local velocity, density, temperature, and stress fields using smooth particle averaging.