Simulating unsteady conduit flows with smoothed particle hydrodynamics

Pipelines are widely used for transport and cooling in industries such as oil and gas, chemical, water supply and sewerage, and hydro, fossil-fuel and nuclear power plants. Unsteady pipe flows with large pressure variations may cause a range of problems such as pipe movement and vibration, support failure and pipe rupture. The pressure transient is generally caused by a rapid change of flow velocity due to valve closure or pump stoppage. Water hammer is the best known and extensively studied phenomenon in this respect. Another scenario is that of slug flow, which arguably is the most dangerous form of two-phase pipe flow. Heavy liquid slugs travelling at high speed behave like cannonballs. Damage is likely to happen when these slugs impact on barriers such as bends, orifices and partially closed valves. Moreover, liquid slugs of variable length always occur when filling or draining pipelines. This industrial process should therefore be carried out with greatest care.

The aim of the present investigation is to numerically simulate a travelling isolated liquid slug in a void line with a bend and the process of filling and draining a pipeline. In traditional 1D models, the front of a travelling slug is considered to be planar and the pressure on the bend is calculated according to convective or acoustic transfer of momentum. The plane-front assumption leads to conservative estimates of impact forces caused by slugs hitting pipe bends. Therefore, 2D models are developed and tested, and finally extended to a quasi-3D model. The latter is valid for situations with negligible horizontal flow normal to the pipe axis. Combinations of convective (slug propagation) and acoustic (slug impact) problems are studied. The slugs at the bend are inertia-driven so that viscosity and turbulence can be ignored.

The numerical solution of the 1D, 2D and quasi-3D mathematical models is accomplished with Smoothed Particle Hydrodynamics (SPH). This meshless method has been chosen because it is versatile and robust, and suitable for problems encompassing free surfaces, impact events and fluid-structure interactions. Applying certain approximation rules to the governing equations, the discrete SPH continuity and momentum equations are derived. Artificial viscosity and artificial compressibility are introduced and discussed with the emphasis on how to choose properly SPH parameters. Artificial compressibility may cause numerical problems that are addressed. Conservative properties of the SPH equations are verified. The SPH approximation errors in both the integral and summation forms are investigated. Particular problems are encountered at the system boundaries. Therefore, the enforcement of several types of boundary conditions is described and modifications to the standard SPH approximations are investigated.

The developed 2D models and corresponding SPH solutions are tested for a range of standard flow problems that are closely related to slug flow. These are water-hammer, dam-break, impinging jet, jet under gravity and flow separation at a bend. Then the SPH results for the isolated slug travelling in a void line and rapid pipe filling/emptying with a bend are compared with experimental data from literature and with new large-scale test results that are described in detail. Comparing with the solutions by other models and numerical methods, general better agreement with experimental data are observed for the present SPH solutions.