Development of a Mathematical Model for Compressible Liquid Transients and Its Numerical Implementation

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by

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Abstract

This research work report the development and implementation of a mathematical model for the simulation of hydraulic transients in compressible liquids. The work discusses the importance of understanding the hydraulic transients for different theoretical and practical flow situations. The significance of this study is derived from the need for accurate fluid property estimates in liquid transient simulations as there are *unaccounted* liquid compressibility effects and improper pressure damping techniques affecting the reliability of computational models for numerical simulation.

This research work presents a new equation of state (modified NASG) for the compressible modelling of liquid water over wider range of pressures. The proposed compressible model could be applied in theoretical flow modelling and computational flow simulations of the liquid. Theoretical implementation of the model has been demonstrated through the development of an analytical solution to the water shock tube problem. The same problem has been computationally simulated, and the corresponding numerical results are compared and validated against the analytical solution. The research further focuses on improving the simulation accuracy of valve-induced hydraulic surges, a commonly observed liquid transient. Relevant valve-closure experimental cases from the literature are selected for the study. A suitable mathematical model is chosen for simulation of these transients, which is further upgraded with the compressible model. Results from simulation experiments suggested the need for improvement in friction models to achieve better accuracy. In this context, we introduced the concept of adaptive damping by defining 'variable pressure wave damping coefficients' (VPDCs) for unsteady friction formulation. This parameter, VPDC, adds flexibility to the computational solver by providing dissipation to the waves based on prevailing flow conditions. Numerical simulation of hydraulic transients at upstream and downstream locations of closing valves using unsteady friction model with VPDC shows good improvement in the computational accuracy. The mathematical model that accounts the liquid-compressibility effects and equipped with the adaptive damping capability is used to study the transient pressure difference developed across fast-closing valves.

The modified NASG equation of state for water could be used for high accuracy liquid compressibility modelling and for the estimation of wave speed over varied range of applications. The research work presents analytical solution to the water shock tube problem as

a simple yet powerful benchmark solution for testing computational algorithms developed for the simulation of compressible liquid flows. The VPDC definition presented in the work for imparting adaptive damping capability could be applied to improve the accuracy and numerical stability of computational solvers for the simulation of highly transient flows. The research also brings out and explains the variations in surge characteristics based on the location in a system with respective to the closing-valve. Numerical experiments performed as part of the research work also explored the impact of valve closure duration on the pressure difference across closing valves during valve-induced surges.