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Numerical modelling of cavitation-induced water hammer in cryogenic fluid management systems with finite volume method

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A water hammer is a pressure surge that occurs when a liquid in motion within a pipe is suddenly stopped, often due to a rapid closing of the valve or shutting down of the pump. This abrupt change in momentum creates a powerful pressure wave that can cause severe damage to pipes, pumps, and other components and also leads to reduce the efficiency of the components. Whenever the amplitude of the pressure wave reaches below its vapour pressure, it can lead to the rupture of fluid, and a vapour cavity will form and collapse when localized pressure becomes high due to the dynamic nature of the pressure wave. This is known as cavitation during water hammer. Because of the cavitation, an additional pressure is added to the generated wave.

In cryogenic fluids, however, water-hammer becomes even more complex due to its unique and peculiar thermophysical properties at low temperatures. Here, the phenomenon differs due to the 'thermal suppression effect'. This effect occurs because of the reduction in localized vapour pressure during the formation of a vapour bubble that makes cavitation harder. This alters the way the pressure wave behaves compared to water hammer in non-cryogenic fluids. Hence, understanding and predicting the dynamics of the cavitation-induced fluid hammer in cryogenic fluids becomes crucial for optimizing the design and operation of various engineering applications. Numerical modelling is employed to predict and understand this intricate behaviour. The investigation utilizes a Finite Volume Method (FVM) approach to analyze the water hammer phenomenon. Initially, the model is developed for water, leveraging its well-defined properties and the abundance of existing experimental data. This serves as a baseline for understanding and validating the model. The water model is then adapted to accommodate the unique thermophysical properties of cryogenic fluids, allowing the exploration of the complex behaviour of cavitation-induced water hammer for cryogenic fluids. Finally, the modified model has been validated against available experimental data specific to cryogenic fluids to ensure its accuracy.

Keywords: Cryogenics, Cavitation, Numerical modelling, Water Hammer, Thermal suppression.

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