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Thermodynamic scaling analysis of cavitation-induced fluid transients in a cryogenic environment

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Fluid transients resulting from rapid flow acceleration or deceleration can pose a significant risk to the structural strength of fluid handling networks, such as those in cryogenic rocket propulsion systems, LNG transport systems, powerplant flow systems, household water systems and many others. Additionally, due to its oscillating behaviour, fluid transients can lead to the formation and subsequent collapse of vapour cavities in the high-pressure regions, leading to cavitation that may potentially damage equipment if not adequately addressed. The complexity of cavitation-induced fluid transient is heightened in cryogenic fluids due to significant variations in thermophysical properties and the presence of a thermal delay effect, an outstanding phenomenon for cryogenic fluids resulting in cavitation suppression through a reduction in the localized vapour pressure.

Cryogenic liquids, operating at extremely low temperatures, require increased maintenance and additional safety precautions. Also, the cryogenic fluids operate near the critical temperature, making them prone to cavitation. In such a situation, experiments using cryogenic fluid become challenging and expensive. Therefore, non-dimensional thermodynamic scaling analysis emerges as a valuable tool, facilitating the substitution of cryogenic fluid with a preferred alternative while maintaining comparable fluid dynamics and thermodynamic characteristics, accounting for the thermal delay effect.

This article presents a scaling analysis of the cavitation-induced fluid transient within a fluid network consisting of a fast-closing valve at the downstream end. The study employs cryogenic fluid and hot water at a temperature corresponding to the same thermodynamic parameter, using various scaling models. A comprehensive comparative assessment of the cavitation-induced fluid transient behaviour in cryogenic fluid and hot water is conducted to ascertain the similarity in flow conditions. The similarity approach based on this thermodynamic scaling will be used for a proposed scaled-down experimental setup to study the cryogenic fluid transients at IIT Kharagpur.

Keywords: Cryogenic, Cavitation, Fluid transients, Thermodynamic scaling, Thermal delay effect

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