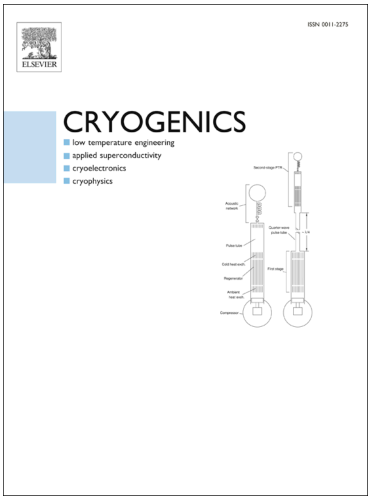

Research paper

Numerical simulation of cryogenic cavitating flow by an extended transport-based cavitation model with thermal effects

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ABSTRACTS

Thermodynamic effects on cryogenic cavitating flow is important to the accuracy of numerical simulations mainly because cryogenic fluids are thermo-sensitive, and the vapour saturation pressure is strongly dependent on the local temperature. The present study analyses the thermal cavitating flows in liquid nitrogen around a 2D hydrofoil. Thermal effects were considered using the RNG k-ε turbulence model with a modified turbulent eddy viscosity and the mass transfer homogenous cavitation model coupled with energy equation. During the cavitation model process, the saturated vapour pressure is modified based on the Clausius-Clapron equation. The convection heat transfer approach is also considered to extend the Zwart-Gerber-Belamri model. The predicted pressure and temperature inside the cavity under cryogenic conditions show that the modified Zwart-Gerber-Belamri model is in agreement with the experimental data of Hord et al. in NASA, especially in the thermal field. The thermal effect significantly affects the cavitation dynamics during phase-change process, which could delay or suppress the occurrence and development of cavitation behaviour. Based on the modified Zwart-Gerber-Belamri model proposed in this paper, better prediction of the cryogenic cavitation is attainable.

1 Introduction

Cavitation is a dynamic phase-change phenomenon characterized by the formation of vapour bubbles in a liquid[1]. The cavitation effect on the hydraulic performance of pumps has been extensively investigated; such effect can cause significant changes in the deviation angle as the flow leaves the impeller and results in an evident change in pump performance[2-4]. Commonly, prediction of the cavitating flow is based on the isothermal thermodynamic hypothesis, and the energy equation is not considered. However, the said method is no longer valid when cryogenic fluids (also known as thermo-sensible fluids) are involved. In cryogenic cavitating flow, the physical and thermal properties of the cryogenic fluid are expected to significantly affect the nature of cavitation[5-7]. It is particularly important for space applications, because cryogens often serve as fuels for space launch vehicles. Cavitation is one of the most difficult problems to overcome in the development of turbo pump for liquid-fueled rocket engine[8].

The thermal cavitating flows generate strong variations in the thermal-sensible material properties, such as saturation vapour pressure, latent heat of vaporization and specific heat capacity, which change the cavities characteristics in turn[9]. When the temperature drops, the saturation vapour pressure declines in time. Due to the effect of evaporation endothermic, the temperature of the cryogenic fluid decreases, cavitating region becomes mushy in accordance with weakening cavitation intensity[10, 11]. The void fraction is smaller than that in isothermal liquid[9, 12-15]. Details of differences between isothermal cavitation and cryogenic cavitation have already been reported by Sarosdy and Acosta[10]. They found that the cavity in water was clear, and the cavitation strength was more intense.