Experimental Study of Thermodynamic Effect of Tip Vortex Cavitation in Hot Water

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Long Abstract

1. Introduction

A number of cavitation studies have been conducted for cavitation in water of room temperature. However, when the working fluid is replaced to cryogenic fluid, the behavior of cavitation is different from that of cavitation in room temperature water. Latent heat is needed for evaporation, then local temperature around cavity decreases. As a result, saturated vapor pressure locally decreases and the growth of cavity is suppressed. The thermal suppression effect on cavity growth is called thermodynamic effect of cavitation. Thus, the cavitation performance of inducer of liquid propellant rocket turbopump with liquid hydrogen and oxygen is improved by the thermodynamic effect.

It is known that the intensity of thermodynamic effect increases with increasing temperature of working fluid. Also, the intensity is large when fluids are used on a condition near critical temperature. Then, the thermodynamics effect in room temperature water is negligibly small, on the other hand, that in the cryogenic fluids or hot water or refrigerant cannot be neglected.

Cervone et al. [1] reported inverse behavior of cavitation in hot water at 70 ^{o}C, in which the cavitation develops thicker and longer compared with that in room temperature water at 25 ^{o}C. The result indicates that the intensity of thermodynamic effect is still unclear, and that is considered to depend not only on thermosphysical property of the fluid but also on cavitation pattern or the unsteadiness.

The authors have conducted experimental studies about thermodynamic effect on cavitation around single hydrofoils in hot water [2], where sheet cavity and sheet/cloud cavity occurs. However, cavitation in inducer is not sheet cavity which is separation type but tip leakage cavity which is vortex type. Therefore, in the present study, experiment is conducted about tip vortex cavitation in order to clarify the intensity of thermodynamic effect on vortex type cavitation.

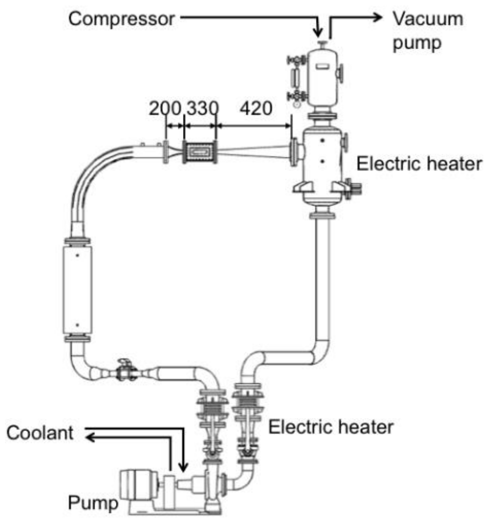


Figure 1. Overview of high temperature and high pressure water tunnel in Institute of Fluid Science of Tohoku University.

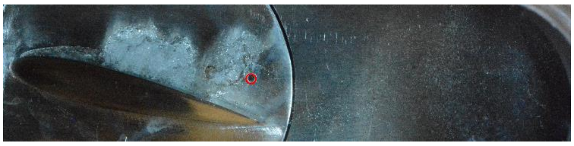
2. Experimental Set up

High temperature and high pressure water cavitation tunnel in Institute of Fluid Science Tohoku University is used to the present experiment. The overview of this tunnel is shown in Figure 1. This tunnel is made of stainless steel. The geometry of flow channel is 30 mm × 20 mm in cross section and length is 330 mm. The window of glass enables end-view visualization of cavitation appearance. This tunnel can vary the temperature of water up to 140 °C and raise the pressure up to 0.5 MPa. The present experiment is conducted room temperature to 80 °C. Temperature of water was increased and controlled by using electric heater with accuracy of 0.1 °C. The pressure of free stream is measured at upstream and downstream of test body with pressure transducer. The flow velocity and its distribution were measured with LDA (FlowLite 2D, Dantec Dynamics). The thickness of boundary layer was about few millimeters. Uniform velocity distribution was confirmed around the center of the test section.

To measure temperature inside a tip vortex cavity, thermistor probe (Nikkiso-Thermo Co., Ltd.) is inserted from side wall of test section into the flow field. The thermistor is covered by stainless steel pipe of diameter 2 mm and thickness 0.5 mm. The thermosensible part of thermistor is placed mid span of flow channel. All thermistors are calibrated before conducting experiment with quartz thermo meter. Thermistor shows large change of electric resistance depending on slight change of temperature. The resistance of thermistor is measured with digital multi meter, and the uncertainty of temperature measurement was less than 0.02 K. In order to check the influence of heat conduction from tunnel wall, steady-state heat conduction analysis was conducted [2]. Then, estimated difference between actual temperature and measured temperature was less than 0.01% of freestream temperature and less than 4 % of temperature drop inside a cavity. Also, estimated time constant of the temperature probe was less than 5.42 s. The temperature inside a cavity is obtained by averaging 20 s in the present experiment.

3. Results and Discussion

Figure 2 shown the aspect of cavitation around NACA0015 hydrofoil in hot water at $T_\infty = 80\,^{\circ}C$, (a) shows unsteady sheet/cloud cavitation and (b) shows supercavitation. The red circle indicates the position of the temperature probe inserted from side wall. On the condition of supercavitation, temperature probe is fully immersed into cavity. And on the condition of unsteady cavitation, it is confirmed that the probe does not disturb the cavity and does not cause extra cavity. In these sheet type cavities, the difference of aspect of cavity surface between room temperature and hot water did not be observed. Now, visualization of tip vortex cavity is being conducted in hot water and the temperature drop inside the tip vortex cavity is being measured.



(a) $\sigma = 2.0$

(b) $\sigma = 1.6$

Figure 2. Aspects of cavitation around NACA0015 in hot water at $T_\infty = 80\,^{\circ}C$.

Reference

[1] Cervone, A., Bramanti, C., Rapposelli, E. and d'Agostino, L., "Thermal Cavitation Experiments on a NACA 0015 Hydrofoil," J. Fluids Eng., Vol. 128 (2006), pp. 326-331.

[2] Yamaguchi, Y., and Iga, Y., "Thermodynamic Effect on Cavitation in High Temperature Water," Proc. FEDSM2014, Chicago (2014), FEDSM2014-21433.