# Effects of Hydrodynamic Cavitation of a Restriction Orifice on Crud-like Deposits

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## 1. Introduction

Axial Offset Anomaly (AOA) referring to an unexpected neutron flux depression is also known as Crud Induced Power Shift (CIPS). Fuel assemblies removed from an AOA core has shown a thick porous deposition layer of crud on fuel clad surface [1]. The deposition layer was induced by precipitation reactions of both boron species and crud during sub-cooled nucleate boiling. Therefore, to resolve the AOA issues, a fuel cleaning technology using ultrasonic cavitation has been developed by EPRI and applied to the domestic NPPs by KNF. However, the performance of crud removal during maintenance of NPPs is known to be not enough.

Hydrodynamic cavitation is the process of vaporization, bubble generation and bubble implosion which occurs in a flowing liquid as a result of decrease and subsequent increase in pressure. Hydrodynamic cavitation generates shock pressure of a few tens MPa due to bubble collapse like the cavitation generated by Ultrasonics [2]. It is well known that the cavitation can erode the metal surface. The idea of the current study is that such energetic cavitation bubble collapses could help to remove the crud from the fuel assembly. Therefore, the current study first investigates effects of hydrodynamic cavitation occurred from a single hole orifice fundamentally.

## 2. Experiment

### *2.1 Experimental facility*

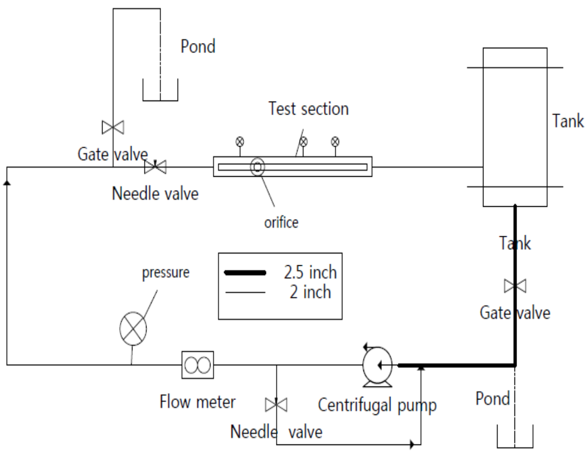



Fig. 1. A schematic diagram of the cavitation test facility

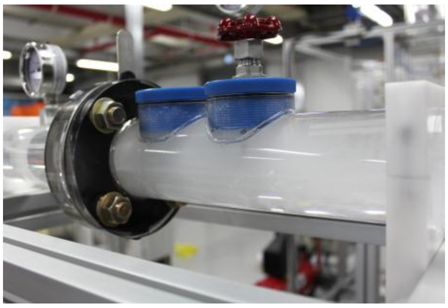


Fig. 2. Test section with a single hole orifice and two crud sample holders.

Experiments are carried out using 2 inch looped water piping system. Figure 1 shows the experimental facility. Test section is 50mm in inside diameter and is made of the transparent acrylic pipe to observe the effects of the cavitation flow. The water which is pumped up by a centrifugal pump ($35m^3/h$ x 1.1MPa), flows through the 2 inch piping, goes to the test section via a flow meter, and returns into a reservoir tank.

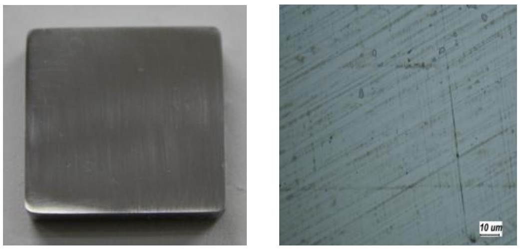
### *2.2 Experimental method and Conditions*

The shock pressure is produced by the collapse of bubbles in downstream of a single hole orifice with 17 mm diameter used to restrict the flow or generate cavitation bubbles[3][4]. Therefore, the spatial distribution of cavitation shock pressure inside the pipe at the downstream of the restriction orifice is examined through observing the bubbles using a high speed camera and the crud-like sample holders are installed inside the pipe at 1D and 2.5D distances from the orifice in order to investigate the cleaning effects by collapse of bubbles. The cavitation effects on crud-like coating surface for the 2.5 D holder were investigated at the flow rate of 140 lpm, the inlet pressure of 2.2 bar and the outlet pressure of 0.84 bar. The water has a room temperature of 26 $^{o}$C and its vapor pressure is ~0.034 bar.

### *2.3 Preparation of test specimens with deposits*

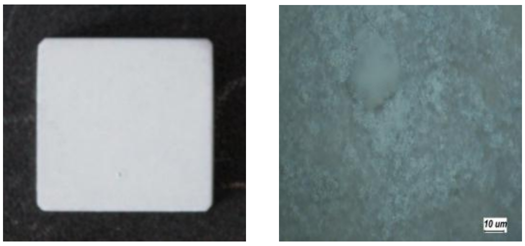
Crud consists primarily of magnetite, nickel ferrite, cobalt ferrite, and so on [5]. For only checking the cavitation effects in this work, however, specimens made of SS316L, alloy of Cr, Ni and Fe are simply deposited by silicon carbide nanoparticles since the nanoparticles deposition layer has a similar structure with the crud porous layer. It shows a crud-like deposition structure.

Fig.3 shows a polished sample sheet. For the experiments, SS316L sheet polished by gauze grit #800 and coated by silicon carbide nanoparticles through boiling of SiC nanofluids with a concentration of 0.1 v%. The sample deposited with SiC nanoparticles is shown in Fig. 4.



(a) (b)

Fig. 3. Bare sample: (a) optical image, (b) microscope image of 1,000x magnification

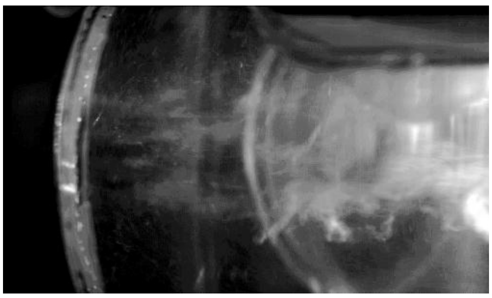


(a) (b)

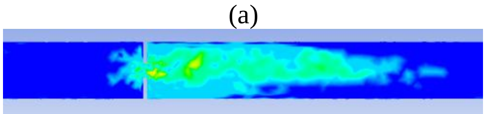
Fig. 4. SiC-coated sample: (a) optical image, (b) microscope image of 1,000x magnification

## 3. Results and Discussion

The cavitation shock pressure depends on a cavitation number. In here, the cavitation number is 0.6. The cavitation phenomena were observed by a high-speed camera as shown in Fig. 5 (a). A prediction by CFD analysis was carried out to determine the distribution of cavitation bubbles or vapors as shown in Fig. 5 (b).



(a)



(b)

Fig. 5. (a) Cavitation phenomena at the downstream of a restriction orifice (a high-speed camera image), (b) Vapor distribution predicted by CFD analysis.

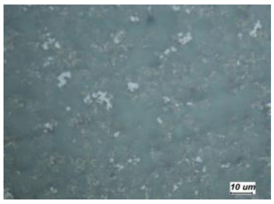


Fig. 6. SiC-coated sample exposed to the cavitation flow

## 3. Conclusion

The results of the experiment for occurrence of hydrodynamic cavitation due to the restriction orifice show that the cavitation can remove the crud-like porous deposits at a certain level more than 30%, at least. Further study will be carried out to more thoroughly quantify the effects of the crud removal performance. And the more effective cavitation-generation geometry will be devised through a parametric study in order to maximize the effects.

## REFERENCES

[1] G. Wang, W. A. Byers, Z. E. Karoutas, L. E. Hochreiter, M. Y. Young, and R. J., Jacko, Single Rod heat Transfer Test to Study the Effects of CRUD Deposition , 14th International Conference on Nuclear Engineering, 2006.

[2] Fortes Patella, R., Reboud, J. L., and Archer, A., Cavitation Damage Measurement by 3D Laser Profilometry, Wear, 246, pp. 59–67, 2009.

[4] Chandan Mishra and Yoav Peles, Flow visualization of cavitating flows through a rectangular slot micro-orifice ingrained in a microchannel, Physics of Fluids, 113602, 2005.

[4] Mishra, C. and Peles, Y, Cavitation in Flow Through a Micro-Orifice Inside a Silicon MicroChannel, Physics of Fluids, 17(1), p. 013601, 2005.

[5] Yang-Hong Jung, Development of CRUD Analytical Techniques using EPMA, KAERI/TR-3808, 2009.