# Magnetic suppression of gas entrainment for sodium-cooled fast reactor

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## 1. Introduction

A vortex core phenomenon, such as a bathtub vortex, is mainly observed on the free surface when water is drained through the lower outlet of a cylindrical tank [1,2]. This vortex core phenomenon is also found in the free surface around the suction of the sump pump station for water intake [3] and the free surface in a mold of continuous casting widely used in the production of steel [4]. Since the vortex core phenomenon is closely related to engineering problems such as vibration, noise, damage to pump blades, reduction of pump efficiency, and slag entrainment, many studies have been conducted in the industrial fields described above [3,4].

On the other hand, the vortex core phenomenon is also found in the sodium-cooled fast reactor (SFR) [5,6], which is attracting attention as the most commercially possible reactor among the 4$^{th}$ generation reactors. The SFR has advantages such as high thermal efficiency, reduction in radioactive waste, increase in uranium utilization, and reduction of high-level waste storage space. Instead of water used in conventional light water reactors, liquid metal (molten sodium) is used as a working fluid to cool down the core of a large heat source. The upper part of the reactor is filled with inert argon gas, and argon gas entrainment has been reported due to the vortex core phenomenon during liquid metal circulation [5]. When argon gas passes through the core part, which is one of the important parts, it can affect the reactivity and cause serious safety problems [5]. Therefore, the vortex core phenomenon must be solved for the stable operation of the sodium cooling furnace. Although a mechanical method of adding a plate to a specific location to suppress the vortex core in the SFR was proposed, this method couldn't eliminate the vortex core phenomenon [6].

In this study, focusing on the fact that the working fluid of the SFR is a liquid metal, experimental and numerical studies were conducted to suppress the gas entrainment using a magnetic method. A counterflow model using water and liquid metal was designed, and it was confirmed that the vortex core phenomenon can be fundamentally blocked by applying a magnetic method.

## 2. Methods and Results

In this section, the explanations for the counterflow model used to investigate the gas entrainment and test the magnetohydrodynamics suppression effect are described.

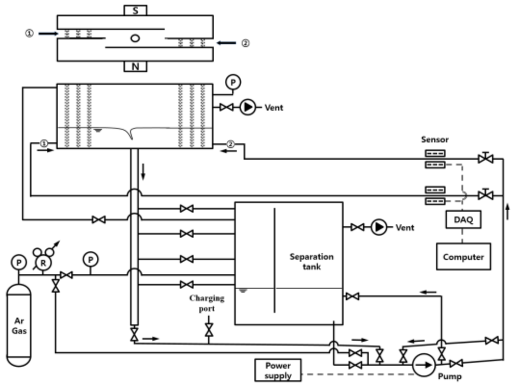

Fig. 1. Schematic of experimental apparatus for testing gas entrainment in counterflow model.

### *2.1 Experimental apparatus*

Fig. 1 is a schematic of experimental apparatus for testing gas entrainment in counterflow model. The water and liquid metal were used for working fluids; Ga-In-Sn eutectic alloy is proper for the magnetic-case studies because of its safety for human body and similar order of properties with sodium in density, viscosity, and electrical conductivity. The working fluid moves through the pump to the upper counterflow test section, and the flow rate is measure through an ultrasonic sensor in the pipe, and the measured data is saved in the computer. The working fluid, flowing into the misaligned inlets in the counterflow model, is discharged to the separation tank through the bottom nozzle. The separation tank aids to separate liquid and gas when the gas is entrained by the vortex core. As the separated liquid flows back into the pump, the working fluid circulate through the entire experimental apparatus. In the counterflow model, the lateral flow is controlled by a pump, and downward flow is controlled by valves connected with various heights, using the static water pressure of hydraulic height. The gas entrainment was observed depending on the various test conditions. For magnetic conditions, the permanent magnets were installed in normal direction of inlet flow at the vicinity of the free surface.

### *2.2 Numerical methodology*

Ansys Fluent 12, which is a commercial CFD program based on the finite volume method, is used to solve the mass and momentum equations for counterflow model. Volume of fluid (VOF) method is adopted for modeling the multiphase flow. The geo-

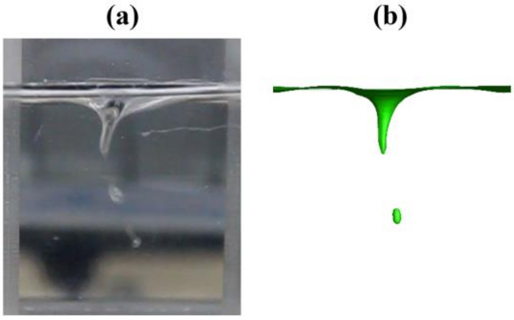


Fig. 2. Gas entrainment in (a) experiment and (b) numerical simulation.

reconstruct method is also used to reconstruct the volume fraction. The working fluid in the counterflow model is initially stagnant. A uniform and constant velocity were applied at inlets and outlet. The no-slip condition is applied for all of the wall boundaries.

*2.3 Gas entrainment and its suppression*

Rotation and downward flows, which can be achieved by the misaligned inlets and suction nozzle in counterflow model, are very important for generation of the vortex core. The gas is entrained into the working fluid under these vortexing flow condition. The numerical simulation showed good agreement with the experiment in terms of the reproduction of the vortex core and bubble detachment, as shown in Fig. 2. As mentioned, these gas entrainment can cause the serious safety problem in reactors of the SFR when a large amount of the entrained gas passes through the reactor core. Therefore, the gas entrainment should be resolved for the safe operation of the SFR. Installation of the plate in the vicinity of the free surface was generally applied for the preventive measure. However, this method could not eliminate the gas entrainment. In this study, we applied a magnetic field near the free surface where the vortex core occurs. The liquid metal is used for investigating the magnetic field effect. Fig. 3 shows the free surface at a magnetic field of 0, 0.01, and 0.10 T (Tesla) obtained from experimental and numerical

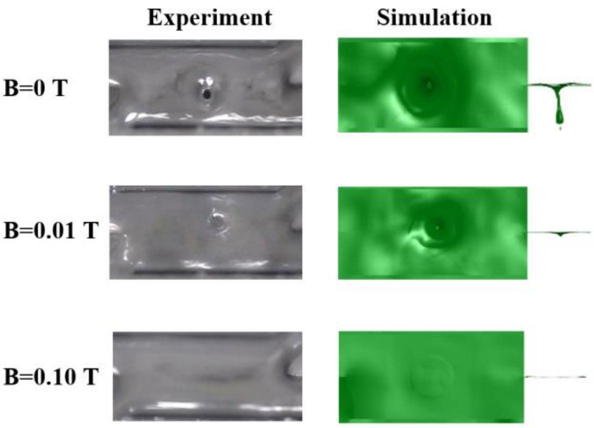


**Fig. 3.** Gas entrainment suppression in (a) experiment and (b) numerical simulation at magnetic field intensity of 0, 0.01, and 0.10 T.

results. At no magnetic field, the strong intensity of entraining the gas was observed in the rotating center of the vortex core in both experimental and numerical results. As the magnetic field increases, the rotation in the vortex core was significantly suppressed owing to the magnetic suppression effect. The gas was never entrained under these non-rotational flow condition. The weak vortex dimple exists at weak magnetic field of 0.01 T.

## 3. Conclusions

In this study, the magnetic suppression was devised to suppress the gas entrainment. In counterflow model, the gas entrainment was successfully reproduced in cases of the working fluids of water and liquid metal. In addition, the gas entrainment could be completely suppressed by applying the magnetic field in the vicinity of the vortex core at free surface.

## Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) funded by Korea Government (Ministry of Science, ICT, and Future Planning – Grant No. NRF-2017M2B2A9A02039561, NRF-2017M2A8A4017283 and NRF-2019R1A2C3003890).

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