# Development of a measurement technique for droplet behaviors during reflood

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## 1. Introduction

It is generally known that the spacer grid can enhance the heat transfer by single-phase forced convective enhancement due to the thermal boundary layer separation and reattachment, early rewetting of spacer grids, breakup of the entrained droplets into smaller fragment, and direct radiation from the fuel rods.

A great quantity of droplets is entrained from a continuous liquid at advancing quench front during the reflood process of a postulated loss of coolant accident in nuclear reactors. According to Stosic (1999), it has been reported that the temperature of rod bundles is decreased considerably through not only heat transfer between superheated steam and droplets but also by the direct contact of droplet to the rod bundles. Hence, it is of vital importance to analyze the droplet behaviors during the reflood process.

In the meantime, it is well known that the spacer grids play a key role in the reflood heat transfer process because the droplet behavior is greatly affected by the spacer grids. For this reason, advanced designs such as mixing vane have been proposed by many researchers (Stosic 1999).

However, the droplet size and velocity are not fully quantified yet. Moreover, despite the importance of the spacer grids, most system codes do not consider the effect of the spacer grids on the droplet behavior. If any, the spacer grid types seem to be out of date. The existing codes have a tendency to predict the peak-cladding temperature higher than experimental value. Accordingly, it is needed to quantify the droplet behaviors depending on current types of spacer grids.

The major difficulty for measurement arises from fast droplet speed. According to Cho et al. (2009) and Cho et al. (2010) experiments, the droplet speed is estimated to be up to 15 m/s. Such a fast speed makes experiment very difficult, with general equipment. To overcome this, the present study is dedicated to develop an experimental technique being free from the droplet speed.

## 2. Experimental setup

### 2.1 2×2 Sub-channel

A test apparatus equipped with a 2×2 rod array was fabricated, which has a transparent window for droplet visualization and four electrically-heating rods inside a square channel. A schematic of the apparatus is illustrated in Fig. 1. The diameter of the heating rods is 20 mm and the pitch between rods is 27 mm. Such enlarged dimensions were intended to be advantageous for visualization. The heating rods with a height of 1.8 m have a uniform axial and radial power distribution.

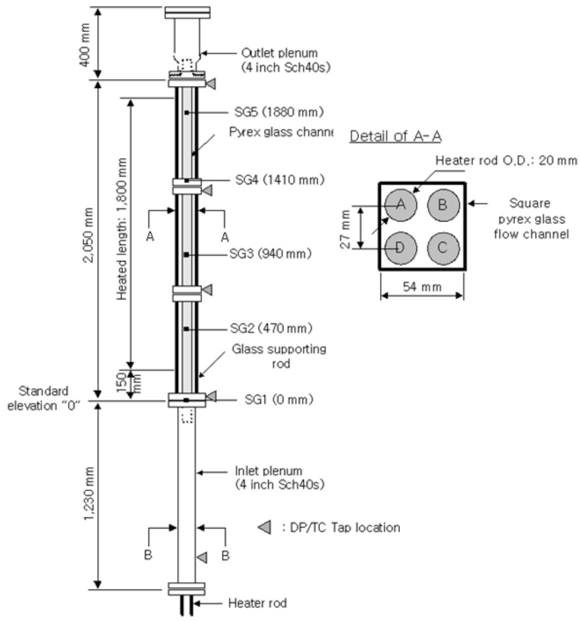


Fig. 1. Schematic of sub-channel with a 2×2 rod array

### 2.2 Image-capturing system

As mentioned earlier, it is anticipated that the speed could be up to about 15 m/s. Such a high speed requires a high-end camera. As a solution to this, we decided to make use of particle image velocimetry. This technique is used to obtain 2D or 3D velocity vector fields of single-phase flow (Raffel et al. 2007). In general, it uses a pulse laser system to illuminate the region of interest. The advantage of this technique is to be capable of capturing droplet images even in Mach speed, due to about 4ns illumination time. Accordingly, this technique is suitable for droplet measurement during reflood.

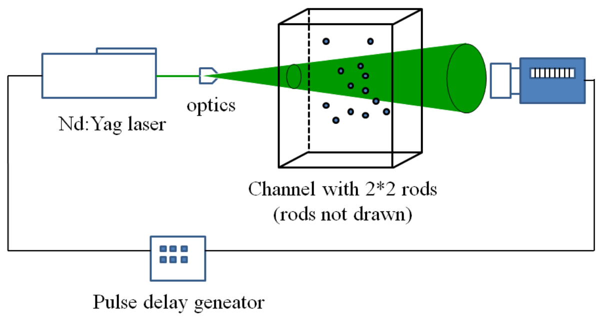

Fig. 2. Schematic of measurement system

Figure 2 depicts the experimental setup. The system consists of a recording camera with 2M×2M pixel$^2$ and a Nd:Yag laser with 200 mJ/pulse. The camera and laser are synchronized by a pulse generator. The laser beam is expanded by using optics to illuminate volumetrically the region of interest. Provided that a pulse laser is fired while the camera shutter is open, we can obtain particle/droplet images. When droplet images are prepared, we can determine the droplet velocity and size through a series of image processing.

### *2.3 Droplet-generating system*

The conceptual design of a droplet-generating system is drawn in Fig. 3. The mass flow rate of liquid is controlled by two valves. One thing to be noticed is that the structure is not fixed perfectly at the stationary wall. Therefore, vibration induced by two shakers is propagated to the nozzle. Vibration with regular frequency helps the nozzle produce droplets with more uniform diameter.

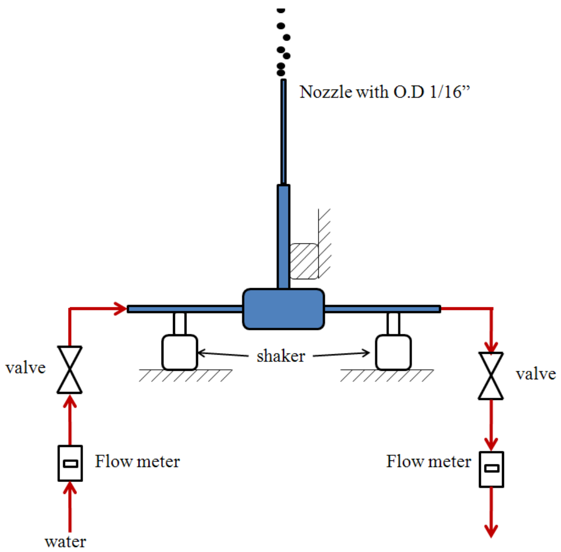


Fig. 3. Droplet-generating system

### *2.4 Results*

To verify the capability of experimental setup, simple tests were made to capture falling liquid droplet with fast speed. A test image is given in Fig. 4. Liquid jet is ejected by high pressure through a nozzle placed above the image. As seen, droplets are clearly captured, which implies that the measurement system has been successfully prepared. Image processing algorithms for extracting the droplet speed and size will be determined by means of the methods implemented in Cho et al. (2010).

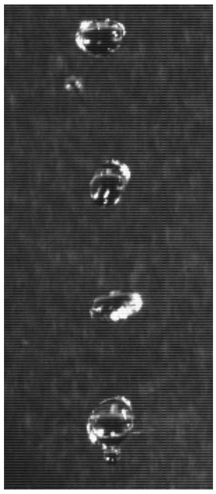

Fig. 4. Captured image of droplet with high speed

## 3. Conclusions

A measurement system has been prepared to capture droplet behaviors with high speed during the reflood process. The system is basically a technique of particle image velocity. With this system, we are going to make a series of experiments to investigate the effects of several spacer grids on the droplet behaviors.

**Acknowledgments**

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