Flow Visualization of Natural Circulation Flow inside a Pool Using PIV/PLIF Technique

Seok Kim [a*], Dong Eok Kim [a], Young-Jung Youn [a], Dong-Jin Euh [a]
[a] *Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, 305-600, KOREA*
[*] *Corresponding author: seokim@kaeri.re.kr*

1. Introduction

The large pools at near atmospheric pressure provide a heat sink for heat removal from the reactor or steam generator, and the containment by natural circulation as well as a source of water for core cooling. For examples, the PAFS (passive auxiliary feedwater system) is one of the advanced safety features adopted in the APR+ (Advanced Power Reactor Plus), which is intended to completely replace the conventional active auxiliary feedwater system. The PAFS cools down the steam generator secondary side and eventually removes the decay heat from the reactor core by adopting a natural convection mechanism. In a pool, the heat transfer from the PCHX (passive condensation heat exchanger) contributed to increase the pool temperature up to the saturation condition and induce the natural circulation flow of the PCCT (passive condensate cooling tank) pool water. When a heat rod is placed horizontally in a pool of water, the fluid adjacent to the heat rod gets heated up. In the process, its density reduces and by virtue of the buoyancy force, the fluid in this region moves up. After reaching the top free surface, the heated water moves towards the other side wall of the pool along the free surface. Since this heated water is cooling, it goes downward along the wall at the other side wall. Above heater rod, a natural circulation flow is formed. However, there is no flow below heater rod until pool water temperature increases to saturation temperature.

In order to understand the flow phenomena inside a pool, it is reasonable that non-invasive technique is adopted to measure the flow velocity field and temperature field. In this study, the PIV (particle image velocimetry) and PLIF (planar laser induced fluorescence) measurement technique is adopted to get velocity vector field and temperature distribution of a natural circulation flow and thermal stratification in a pool.

2. Experimental Condition and Measurement Technique

Figure 1 shows the schematic diagram of experimental setup for PIV/PLIF velocity and temperature field measurements. It consists of 150 mJ Nd:YAG laser with an injection seeder, 2K×2K CCD camera and a pulse generator. The laser light sheet illuminated the flow through the right side poly-carbonate plate side gap as shown in figure 1. Working fluid used for flow visualization was de-ionized water. Fluorescent beads of about 10 μm in mean diameter were used as tracer particles. A long pass filter (λ > 550 nm) is used to eliminate scattered light except fluorescence light and installed in front of digital recording device.

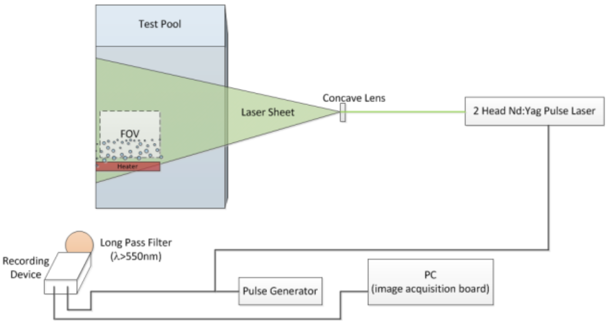


Fig. 1. Schematic Diagram of PIV/PLIF measurement.

A small pool with a single heater rod simulates the PAFS prototype and the volumetric scaling ratio of the facility is 1/910 as shown Table I. The volume of pool was also reduced to 1/910 of the prototype. The length and the width of the pool are 300 mm and 60 mm, respectively. And the height of the pool is 400 mm. The test rig consists of a water pool with a single heater rod, a constant temperature bath. The test section is made by transparent windows and 3/4" diameter of a heater rod is installed at h=90 mm vertical position. The thermal capacity of a heater rod is about 2 kW.

Table I: Geometry and scaling parameters

Parameter	APR+ PAFS	Model	Scale ratio
h (m)	8.9	0.4	22:1
l (m)	6.7	0.3	22:1
d (m)	0.112	0.06	1.87:1
h_1 (m)	2	0.09	h/h_1, 1:1
Power (kW)	540	0.6	910:1

An advantage of LIF against liquid crystals is the better accuracy relative to the temperature range which is typically 1.5 C for a 40 C temperature range. LIF is based on natural fluorescence of molecules and atoms which is induced by absorption of a photon (energy). This absorption causes a transition from the ground

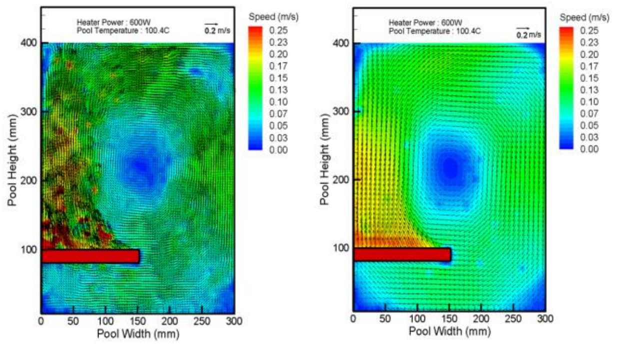
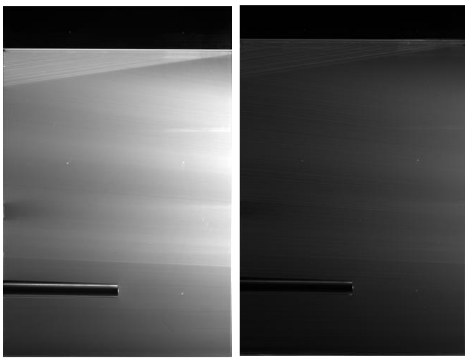


Fig. 2. Instantaneous and mean velocity vector field (Pool temperature is 100.4 °C).



T=52 °C T=99 °C

Fig. 3. LIF calibration image with different pool temperature

state to an excited state. Part of the absorbed energy is re-emitted during spontaneous transition from the excited state to the ground state (fluorescence). In case of PLIF measurement, the fluorescent dye rhodamine B (MW=379.02) is dissolved in demineralized water with a concentration of 6 mg per liter. In order to measure temperatures, a calibration curve between temperature and fluorescence intensity is necessary. To obtain calibration curve, the temperature dependence of the fluorescence intensity is measured by heating the test fluid to uniform temperatures. The uniform temperatures are achieved by constant temperature bath. The temperature dependence is measured in the middle of the test section in 6 measurement points.

3. Experimental Results

The 600 W of thermal power was supplied at heater rod as a rated power. The temperature above the heater rod was increased by the larger heat flux. The heat transfer from the heater rod contributed to increase the pool temperature up to the saturation condition and induce the natural circulation flow of the pool.

Break-up of thermal stratification started when the pool temperature was saturation temperature as shown in Fig. 2. Figure 2 showed instantaneous and mean velocity vector filed at pool water level 400 mm. After pool boiling occurred, pool water level was decreased

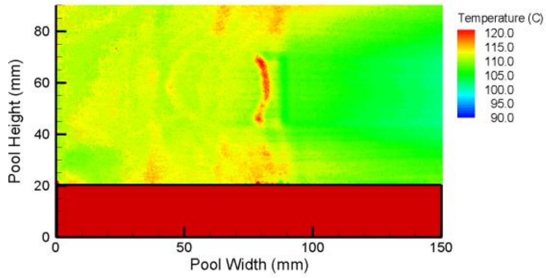


Fig. 4. Instantaneous temperature distribution at pool temperature 97 °C.

continuously. A natural circulation flow speed above/ below a heater rod was increased continuously.

LIF calibration images were shown in Fig. 3. During LIF calibration experiment, LIF intensity was decreased continuously with increasing pool temperature. From Fig. 4, a hot plume visualized was rising from the electrical heater rod.

4. Conclusion

Experimental results show a large natural circulation flow above a heater rod and thermal stratification below a heater rod. Thermal stratification and no flow region start to break up when pool temperature is saturation temperature.

In this study, two-dimensional temperature distribution and velocity vector fields during the decrease of water level was experimentally investigated in a pool which has a horizontal heater rod. Experimental results show a large natural circulation flow above a heater rod and thermal stratification below a heater rod. Thermal stratification and no flow region start to break up when pool temperature is saturation temperature. The CFD-grade experimental results will contribute to provide the benchmark data for validating the calculation of thermal hydraulic phenomena inside a pool with a heat source.

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012M2A8A4004176).

REFERENCES

[1] C.H. Song et al., Thermal-hydraulic R&Ds for the APR+ Developments in Korea, Proceedings of the 18th International Conference on Nuclear Engineering, May 17-21, 2010, Xi'an, China.

[2] J. Cheon et al., The Development of a Passive Auxiliary Feedwater System in APR+ Track 1: Water-Cooled Reactor Programs & Issues, Proceedings of ICAPP'10, June 13-17, 2010, San Diego, CA, USA.

[3] B.J. Yun et al., Construction Report of Separate Effect Test Facility for PAFS, KAERI/TR-4085/2010.

[4] A.N. Nahavandi et al., Scaling laws for modeling nuclear reactor systems, Nucl. Sci. & Eng., Vol. 72, p. 75, 1979.