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Velocity Fields Measurement of Natural Circulation Flow inside a Pool Using PIV Technique

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1. Introduction

Thermal stratification is encountered in large pool of water increasingly being used as heat sink in new generation of advanced reactors. These 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 this study, velocity measurement was conducted to reveal a natural circulation flow structure in a small pool using PIV (particle image velocimetry) measurement technique.

2. Experimental Condition

Figure 1 shows the schematic diagram of experimental setup for PIV velocity 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 PIV measurements 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.

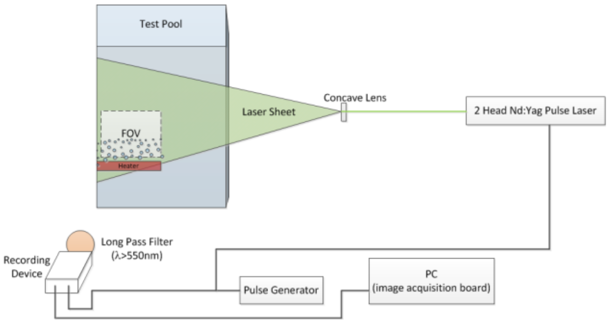

Fig. 1. Schematic Diagram of PIV measurement.

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

Six Watrow class A type of 1/16" thermocouple were installed at back side of pool.

3. Experimental Results

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

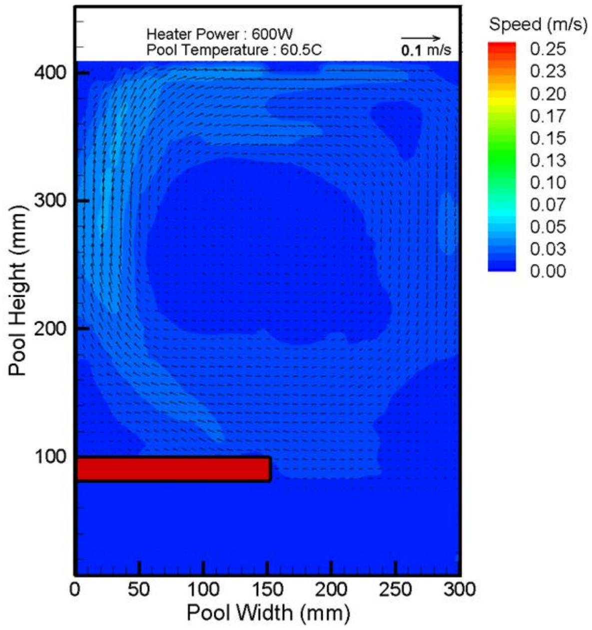

Fig. 2. Velocity vector field at pool temperature 60.5°C.

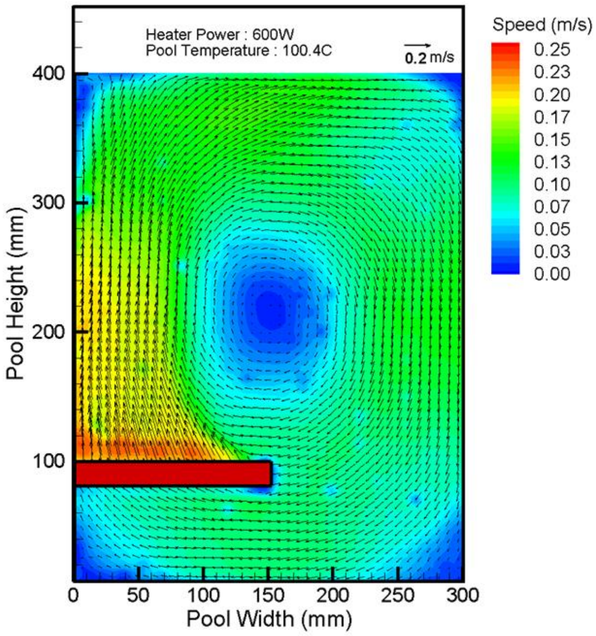

Fig. 3. Velocity vector field at pool temperature 100.4°C.

from the heater rod contributed to increase the pool temperature up to the saturation condition and induce the natural circulation flow of the pool.

Figure 2 showed velocity vector field at pool temperature 60.5°C and pool water level 410 mm. By increasing pool temperature, pool water level was also increased. At this time, a circulation flow was already formed. However, there was no flow below a heater rod. Break-up of thermal stratification started when the pool temperature was saturation temperature as shown figure 3. Figure 4 showed velocity vector filed at pool water level 300 mm. After pool boiling occurred, pool water level was decreased. A natural circulation flow speed above/below a heater rod was increased continuously.

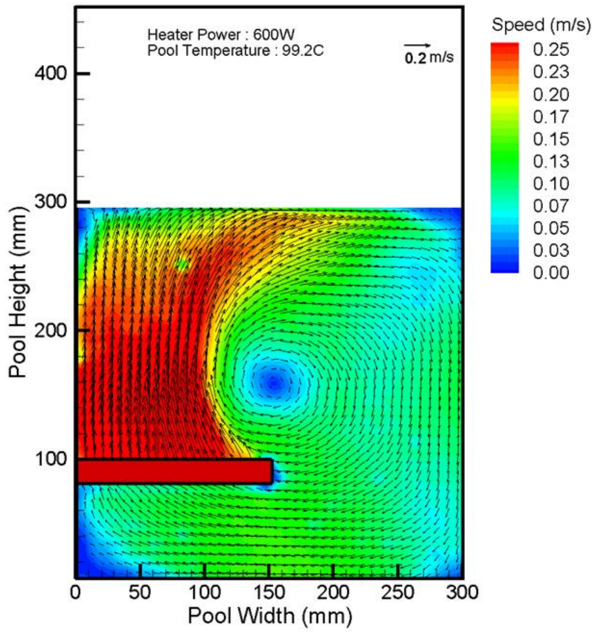

Fig. 4. Velocity vector field at pool water level 300mm.

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. 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

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