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Heat Transfer of Submerged Ar Arc Plasma to Water for the Decommissioning of Degraded Nuclear Power Plant

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Arc discharge plasma is expected as a basic technology for decommissioning of nuclear reactors, even after severe-accident like Fukushima Daiichi Nuclear Power Plant. Laser technology is considered to be difficult due to color center formation by γ-ray. Hence, arc-cutting technology is one of the promising methods, together with submerged arc discharge plasma. However, the water flow and the heat transfer from the arc plasma to water, submerged structural materials and nuclear fuel debris is not yet understood well. The main objective of the present study is to investigate the water flow characteristics, particularly, to examine the velocity of the bubbles and the heat transfer to the ambient water.

Figure 1 schematically shows the plasma generator and other equipment. Concerning the arc-discharge generator, the anode was made of copper and the cathode of 2%-thoriated tungsten. Further details are given elsewhere [1]. We measured flow velocity distribution in the vicinity of the arc plume ejected into the water. The bubbles formed in the water enable us to trace the water flow by Particle Image Velocimetry (PIV). Figure 2 shows the observed flow velocity, which shows that the flow velocity ranges about 20 – 80 cm/sec, increasing with the increasing arc discharge current, together with the position dependence. Meanwhile, we measured electron temperature T_e and density with spectroscopic measurement of continuum spectrum. Since the argon arc plasma in the present study is generated under atmospheric pressure with large DC current more than 100 A, it is justifiably considered to be in a state of thermodynamic equilibrium. Details had been reported elsewhere [1, 2]. It was found that T_e ranges about 0.6 – 2.2 eV, where it becomes lower as it flows to the downstream direction.

We also examined heat flux by measuring the water temperature with thermocouples at various positions in the water. Figure 3 shows the observed heat flux in terms of Nusselt number plotted against the electron temperature. It should be noted that the Nusselt number

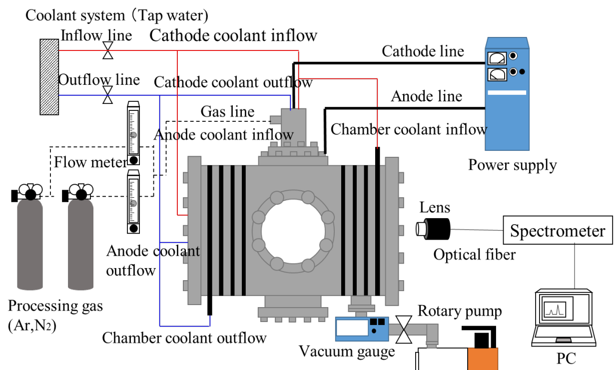

Fig. 1 Experimental set up.

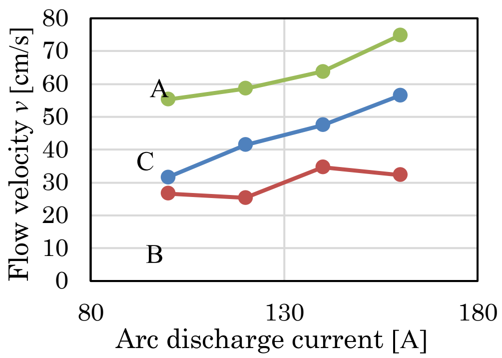

Fig. 2. 3-D Flow velocity measured with PIV method. A, C and C denote the observed position: A - just near the anode nozzle, B - deepst in the bubbles, and C - rising bubbles.

Nu is defined as follows:

$$Nu = \frac{h^* C_p De}{\lambda_c},$$

where h^* is the heat transfer coefficient for the plasma, C_p is the constant pressure specific heat, D_e is the representative length, taken as plasma column diameter, and λc is the thermal conductivity averaged over plasma temperature from the axis to the plasma-wall interface. We found a peak of Nu for $T_e \sim 8000$ K, which can be attributed to the dominant recombination of Ar^+ ion on the interface. It is considered that this temperature range could give us an optimized operation condition in terms of thermal efficiency in the decommission processes of degraded reactors.

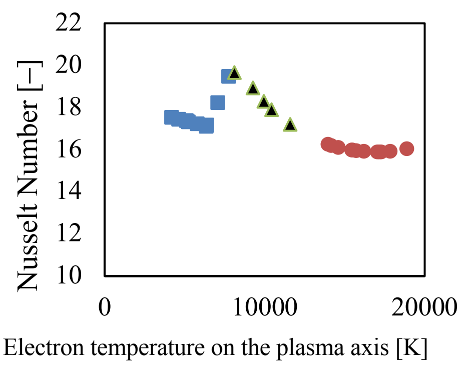

Fig. 3 Nusselt number plotted against the electron temperature on the plasma axis.

References

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