

STABILIZATION OF JET INTERFACE WITH CHEMICAL REACTION

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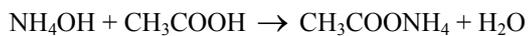
Sodium-water reaction is one of the basis potential accidents in the development of the steam generator of the sodium cooled nuclear reactor. Consider a small water/steam jet assumed to eject into the sodium pool through a micro crack at the steam tube wall. Since the amount of the leakage is small, the accident is not expanded at the initial stage. However the generated sodium oxide may damage the surrounding steam tube, causing tube rupture, i.e., huge explosion of hydrogen. Therefore, the initial small water/steam jet should be detected to prevent the large damage. To evaluate the phenomena, the basic characteristics of the chemically reacting jet should be investigated precisely., utilizing a micro-jet with a chemical reaction.

The interaction between a chemical reaction and turbulence had been studied by many researchers, e.g., Breidenthal (1). The effects of mixing enhancement by the turbulence were discussed. While the turbulence enhances the chemical reaction, the chemical reaction affects the turbulence. The jet mixing phenomena are closely related to the interfacial stability, but there are only a few reports on the effects of chemical reaction on the interfacial stability. In this study, the interfacial stability due to the chemical reaction was experimentally investigated using the LIF (Laser induced fluorescent) technique.

EXPERIMENTAL

The small jet was injected into the channel. Figure 1 shows the schematic view of the test section. The test channel was made of transparent acrylic resin. The cross-section of the channel was 100mm x 100mm square. A horizontal nozzle was installed at the center of the channel. Outer and inner diameters of the nozzle were 2mm and 3mm respectively. The 2mm round jet was injected into the channel. The temperature of the fluid was kept constant (14 degree C), so that the viscosity of the fluid to be similar. To quantitatively visualize the mixing phenomena, LIF (Laser Induced Fluorescent) and PIV (Particle Image Velocimetry) were applied. In the LIF system, small amount of Rhodamine B was dissolved into the jet fluid only. The vertical plane with the jet axis was illuminated by the 2mm laser light sheet generated by the Nd:YAG pulse laser.

A simple irreversible chemical reaction was selected: The mixing of ammonia solution and acetic acid solution that generates ammonia acetic acid solutions.



The reaction factor $k = 10^8 \text{m}^3/(\text{mol s})$, the Schmidt number $Sc = 250$. The generation of the reacting heat is negligible. Table 1 shows the experimental conditions.

Jet Stability Measurement

To quantitatively evaluate the interface stability of the jet with and without chemical reaction, flow field with several jet/ambient fluids pairs were experimentally visualized using LIF technique. Figure 2(a) shows an example of the visualized image. The velocity of the ambient flow and jet flow were fixed at $V_a = 5\text{mm/s}$, $V_j = 500\text{mm/s}$ respectively. The image represents the instantaneous image for case N0, i.e., Water jet into Water flow case. The laser light intensity distribution was not uniform. The relatively dark area just downstream of the nozzle appeared because of an illumination problem at the test equipment. This area is neglected in the following investigation.

To investigate the interface stability, the temporal averaged images were obtained using 100 instantaneous images. The example of the averaged image is shown in Fig. 2(b). The jet mixing and the transition point were clearly visualized in the averaged image. The jet mixing denotes the diffusion of the fluid. The transition point relates to the interface stability, i.e., the stability between the fast jet and

slow ambient fluid.

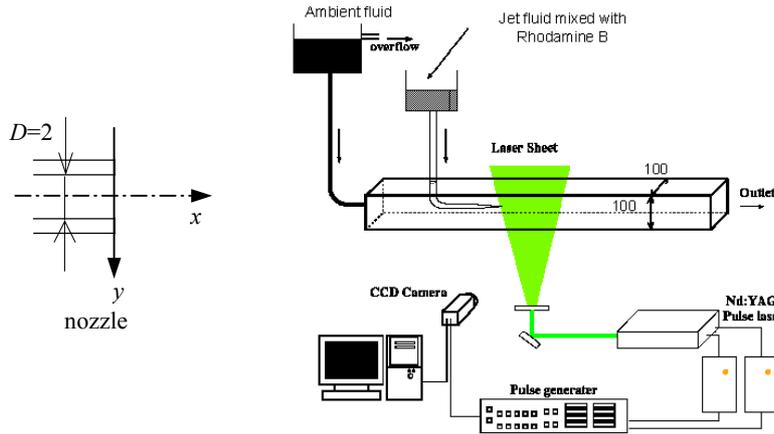


Fig. 1 Experimental Setup

Table 1. Pairs of the jet and ambient fluids

Case	Jet fluid	Ambient fluid
N0	Water	Water
N1	Brine (0.1mol/L)	Water
N3	Ammonia – Acetic Acid Solution (0.1mol/L)	Water
R0	Water (Ammonia Solution 0mol/L)	Acetic Acid Solution (0.1mol/L)
R1*	Ammonia Solution (0.1mol/L)	Acetic Acid Solution (0.1mol/L)
R2*	Ammonia Solution (0.01mol/L)	Acetic Acid Solution (0.1mol/L)
R4*	Ammonia Solution (0.0005mol/L)	Acetic Acid Solution (0.1mol/L)

*: chemical reaction at the interface

Figure 3 shows the averaged images of the cases R0 (0mol/L) and R1 (0.1mol/L), respectively. The image of the non-reacting case R0 is almost similar to the water case N0 (Fig. 2(b)). This means that the difference of the ambient fluid (water and acetic acid solution) had no effects on the diffusion and interface stability.

However, the image of the case R1 is clearly different from those in cases N0 and R0. In case R0, the transition point appears near the nozzle exit. The expansion of the white area, i.e., the turbulent mixing, at the downstream is wide while the transition point moves downstream significantly in case R1. This means that the interface in the reacting condition was more stable than that in the non-reacting condition. Also, the white color area was not wide because the momentum diffusion at the downstream was not so large.

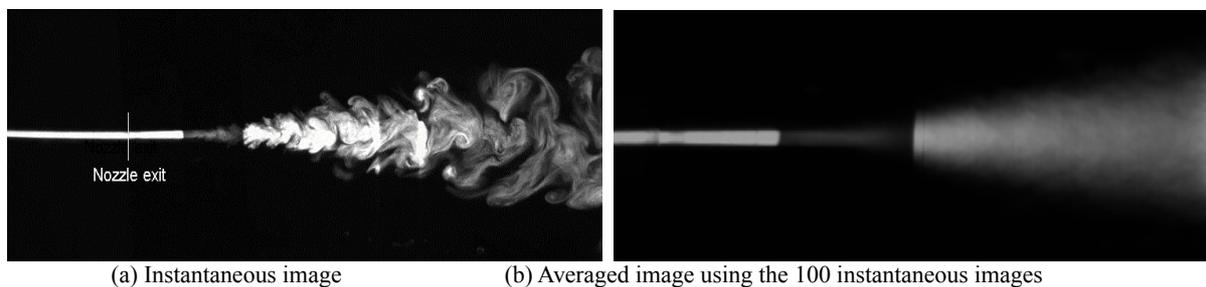


Figure 2 Images of the Water jet into Water flow (case N0)

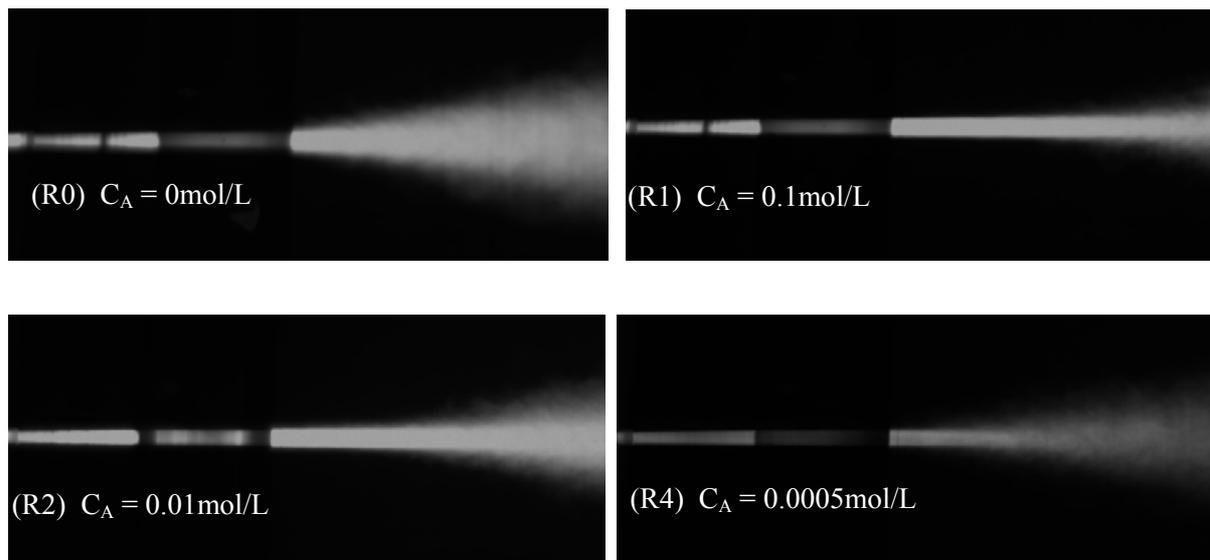


Figure 3. Averaged images for reacting jet (cases R0–R4)

To evaluate the chemical reaction effects, the concentration (C_A) of the Ammonia in the jet fluid varied from 0.1 mol/L (R1) to 0.0005 mol/L (R4). The averaged images are shown in Fig. 3. The white color area (jet) in these images was different from that of the case R0. Even for the small amount of the Ammonia in case R4, the suppression was observed. The small amount of the chemical reaction caused the diffusion suppression and interface stabilization.

Velocity Measurement

To confirm the diffusion suppression and interfacial stabilization by chemical reaction, the velocity distribution was measured using the PIV system. Figure 4 shows the averaged axial velocity for cases N0 and R1, i.e. without chemical reaction, and with reaction (0.1 mol/L ammonia solution jet into 0.1 mol/L acetic acid solution), respectively. The jet average velocity was fixed at 450 mm/s, which was different from the LIF experiment. To reduce the noise, more than 150 velocity distributions were averaged. The velocity distributions clearly show the differences between these two cases. The water jet expanded wider than the ammonia jet. Since the LIF image captures the intensity distribution, the image did not correspond to the velocity distribution. Therefore, the measured location for the PIV was downstream. However, the tendency is almost similar. The PIV results supports the LIF measurement results, i.e., the diffusion suppression and interface stabilization.

CONCLUSIONS

The stabilization phenomenon at the two-fluid interface was observed under the chemically reacting jet. The transition point from laminar to turbulent was found to relate to the chemical reaction at the interface. The transition points went downstream remarkably with a chemically reacting jet, i.e., stabilization of the jet interface. The phenomenon only observed under the reacting jet case under very small amount of the reaction. The chemical reaction affects on the interface stability.

REFERENCES

1. Bennani, A., et al., "The Influence of a Grid-Generated Turbulence in the Development of Chemical Reactions" *AIChE J.*, Vol. 31, (1985), 1157-1166.

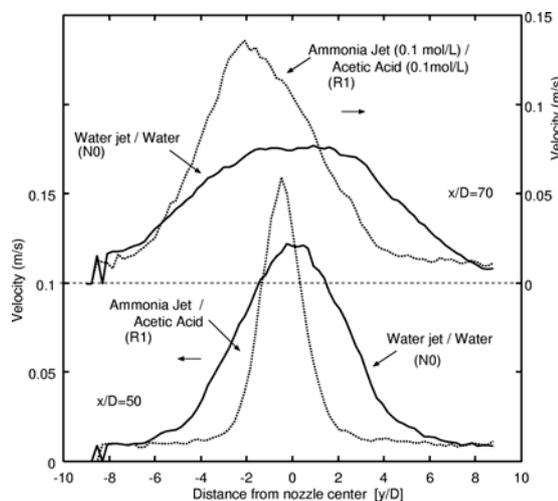


Figure 4. Averaged axial velocity distribution for cases N0 and R1