Jet Breakup of a Simulant Melt in Water With and Without Free Fall in Air

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1. Introduction

The potential risk of explosive molten fuel coolant interactions (FCI, steam explosion) has drawn substantial attention in the safety analysis of reactor severe accidents. An ex-vessel steam explosion may occur when the core melt is released from the failed reactor vessel lower head into the water-filled reactor cavity. The water level in the cavity, if it exists, can be either below or above the reactor vessel lower head depending on the severe accident management strategy. The former, a partially-filled cavity with free-fall space for the melt jet, has been the major condition for the steam explosion studies in the past. An In-Vessel Retention by External Vessel Cooling (IVR-ERVC), however, requires the water level in the cavity be above the reactor vessel lower head so that the vessel can be completely submerged in coolant water. In this case, the melt jet falls in liquid water without free fall. The jet breakup behavior in these two conditions can be different in many respects [1].

In this work, jet breakup with and without free fall in air has been experimentally investigated using stimulant melt of Woods metal. The initial melt temperature was set below the boiling point of water so that only the hydrodynamic mechanism of jet breakup can be identified. High-speed videos were taken to visualize the jet breakup behavior and the post-test debris were collected and sieved to obtain debris size distributions.

2. Experiment

The experimental apparatus consisted mainly of melt generator, intermediate melt catcher with quick-opening slide valve, and water pool tank. The schematic of the experimental apparatus with and without free fall in air are shown in Fig. 1. The melt generator has a stainless steel crucible placed inside a cylindrical radiant heater of 2.7 kW rating.

To deliver melt jet directly into the water pool without passing in air space, an intermediate melt catcher was designed and coupled with the melt generator. It has a pneumatically-operated quick-opening slide valve with circular hole of 50 mm at the bottom. This valve pack was submerged in water pool. The set of melt generator and intermediate melt catcher can be pressurized with air in case of increasing the initial velocity of melt jet. For the tests with free fall in air, this melt delivery unit was raised by 1 m from the water tank.

The water tank was an open-topped rectangular box, made of transparent glass wall for the visualization purpose. The tank dimension is 0.6 m in each side, 1.0 m of water pool depth.

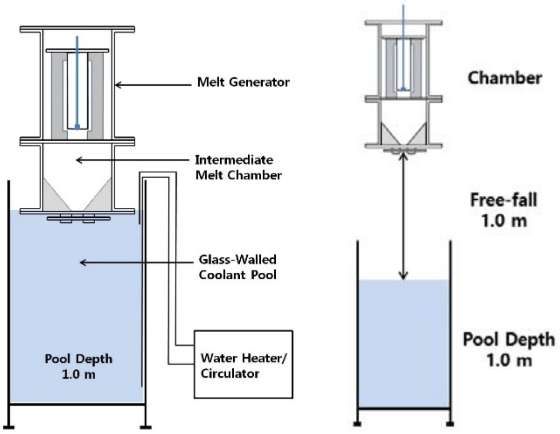

Fig. 1. Experimental apparatus with (right) and without (left) free fall in air

3. Results and Discussion

The jet breakup experiments were conducted using 50 mm-diameter Woods metal jet. The density of Woods metal is 9380 kg/m^3. The melt mass was 15 kg and the melt temperature was 85ºC to prevent water from boiling. The water temperature was set at 40ºC.

The breakup of Woods metal liquid jet in water pool was visualized using a high-speed video camera. The overall shapes of jet breakup with and without free fall in air are compared in Fig. 2. The jet velocity at entering water was ~4 m/s in both cases. In the case of free fall in air, it was observed that considerable air was entrained into water with the melt. This air can affect the jet breakup caused by the Kelvin-Helmholtz instability.

2.1 Jet Breakup Length

The amount of corium jet breakup in a pre-flooded reactor cavity is affected by the depth of water pool, so-called shallow or deep pool. The distance of jet traveling to a point of complete breakup is called 'jet breakup length' and there have been a few studies on building a semi-empirical relation of the jet breakup length such as Saito[2] and Epstein & Fauske[3]. In order to assess these correlations, the major experimental data were collected and compared as shown in Fig. 3. It is concluded that the Epstein & Fauske correlation with Eo=0.1 is more suitable for the high-temperature corium jet breakup. It is noted that the Epstein & Fauske correlation is independent of jet velocity.

$$\frac{L_{brk}}{D_j} = \frac{1}{2E_o}\left(\frac{\rho_j}{\rho_l}\right)^{1/2} \quad (1)$$

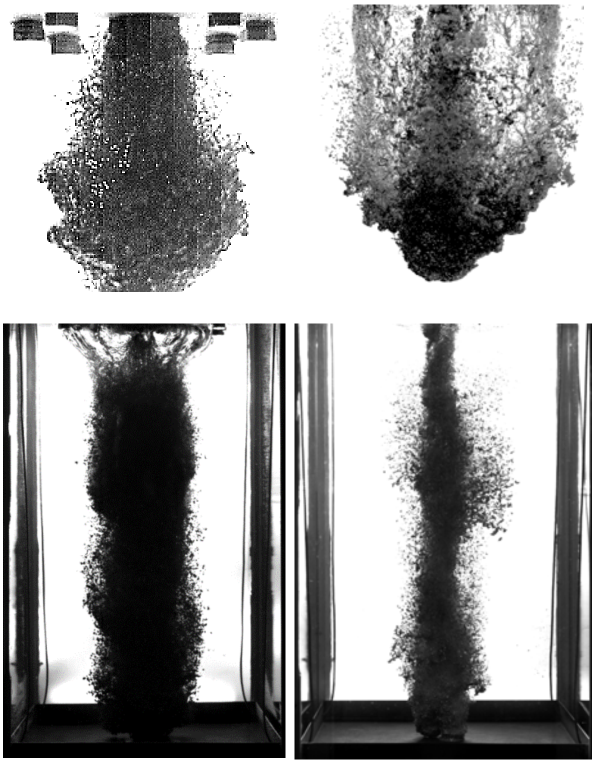

Fig. 2. High-speed video images of initial (top) and final (bottom) stages of jet breakup for with (right) and without (left) free fall in air (V_{jet} =~4.5 m/s, D_{jet}=50 mm)

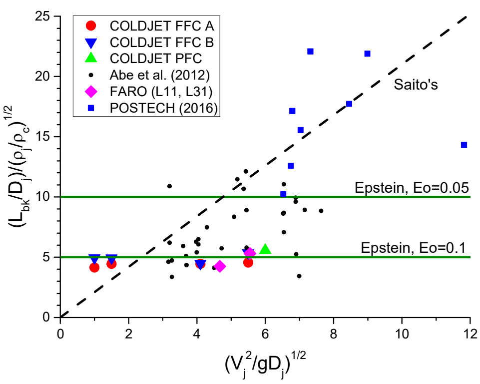

Fig. 3. Comparison of various model predictions and experimental data of jet breakup length

Applying the Epstein & Fauske correlation (Eq. 1), the minimum water pool depth in which the corium jet breaks up completely can be estimated. For a jet diameter of 30 cm, for example, the pool depth higher than about 4 m results in a complete breakup of corium jet.

2.2 Debris Size Distribution

The debris of jet breakup were collected, dried, and sieved. The six levels of sieve size were 0.5, 1.0, 2.8, 4.75, 9.5, and 15.9 mm. Figure 4 shows a comparison of debris size distributions from the jet breakup with and without free fall in air. It is seen that the debris size in the case

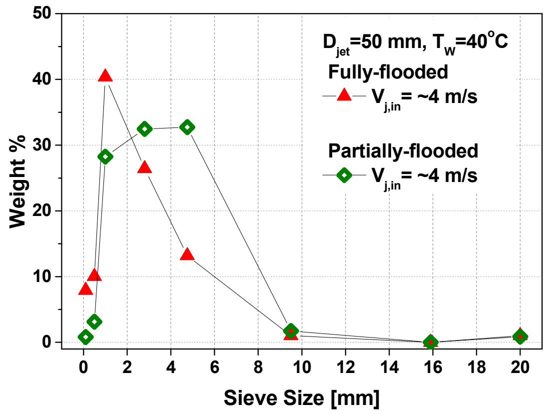

Fig. 4. Comparison of debris size distribution

without free fall was much finer than that of free fall in air case as seen in Fig. 4. This is because in the case of free fall the entrained thin air layer may act just like a vapor layer in boiling condition. Bang et al.[4] proposed a correlation of the fastest growing wave number in KHI of melt-gas-liquid system and thus such a correlation can be used to predict debris size from jet breakup if the entrained air thickness or vapor film thickness is readily known.

4. Conclusion

Non-boiling liquid jet breakup experiment was conducted using 50 mm-diameter Woods metal jet entering water with and without free fall in air. The jet breakup length was compared with available experimental data and correlations and found that the Epstein & Fauske correlation is good for corium case. The post-test debris showed that the debris in the case without free fall was much finer than that of free fall in air case probably by the effect of entrained thin air layer.

Acknowledgements

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