Importance of the entrance jet shape at the water surface in the Fuel-Coolant Interaction

Woo Hyun Jung [a], Hyun Sun Park [a*], Kiyofumi Moriyama [a], Moo Hwan Kim [a]
[a]*Division of Advanced Nuclear Engineering, Pohang university of science and technology (POSTECH)*
San 31, Hyoja-dong, Pohang, Gyunbuk, Republic of Korea, 37673
[*]*Corresponding author: hejsunny@postech.ac.kr*

1. Introduction

During a severe accident of LWRs, the molten corium can be ejected due to the failure of reactor pressure vessel (RPV) into the coolant causing fuel-coolant interaction (FCI) having the potential probability of the steam explosion. Through the FCI, the molten corium becomes particulate debris and it settles down on the basemat of the reactor cavity in the form of a porous debris bed [1-2]. The coolability of this debris bed is related to the progress of molten core concrete interaction (MCCI) which has relation with the melt jet breakup phenomenon as investigated in the previous studies [3-5].

In the melt jet breakup phenomenon, the jet breakup length is important variable and has large uncertainty in the experimental data and the correlation. In spite of the active experimental research on the jet breakup length from the early 1980s [6-7], the jet breakup length correlation that can represents all the experimental data is not developed until now. Thus, developing the jet breakup length correlation is remaining issue.

However, most of the research have little interest on the entry conditions of the jet (the jet diameter, the jet velocity, or the jet shape etc.) except our previous preliminary study [8]. As a result, the determining method of the jet diameter is investigated as a possible factor inducing the uncertainty on the dimensionless jet breakup length result, in this paper.

2. Experiment

In this section, the MATE facility is introduced with the newly installed nozzle opening system (slide gate system). The data analysis methods will be investigated about the jet diameter in terms of the uncertainty factor.

2.1 MATE facility

The melt jet breakup experimental facility, named MATE (Melt jet breakup Analysis with Thermal Effect) was constructed in POSTECH, Korea in order to investigate the FCI phenomenon. Fig. 1 shows the schematic figure of the MATE facility including the water pool part and the crucible part with the visualization system. The Bi-Sn alloy at the eutectic composition (58:42 wt%, melting temperature: 138) is used as a simulant of corium having similar density and surface tension [9].

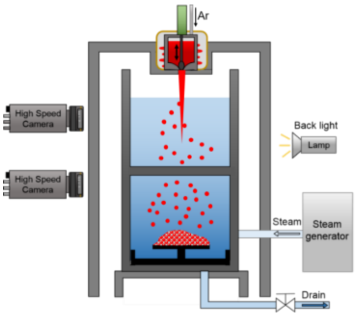

Figure 1. Schematic figure of the MATE facility

2.2 Slide gate system

In our early experiments (MATE00 ~ MATE09), the nozzle opening was operated using the plug only. The jet shape was not clear enough due to the movement of the plug causing disturbance or fluctuating flow. Thus, the slide gate system was additionally added in order to produce clear and stable melt jet reducing the initial arbitrary fluctuating flow. The slide gate system is attached outside under the nozzle (Fig. 2 (b)). After approximately 0.6 seconds from the operation of the plug system, the slide gate opens producing clear and well defined jet. With this well defined jet, six additional experiments are conducted. The influence of the slide gate system on the dimensionless jet breakup length result is discussed in terms of the jet diameter. The experimental conditions are summarized in Table 1 including the nozzle opening system information.

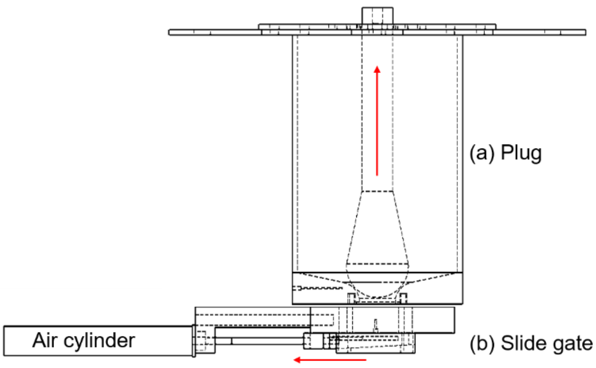

Figure 2. Nozzle opening system;
(a) plug system, (b) slide gate system

Table 1. Experimental conditions of MATE

Case	**Nozzle diameter [mm]**	**Melt temperature [˚C]**	**Pool temperature [˚C]**	**Nozzle opening system**	**Free fall height [m]**
MATE00	14	306	95	Plug	0.81
MATE01	35	300	99	Plug	0.56
MATE02	35	300	99	Plug	0.56
MATE03	35	200	57	Plug	0.56
MATE04	35	300	99	Plug	0.78
MATE05	35	300	99	Plug	0.78
MATE06	22	300	99	Plug	0.56
MATE07	28	302	99	Plug	0.56
MATE08	14	250	60	Plug	0.56
MATE09	22	250	60	Plug	0.56
MATE10	14	300	99	Plug & Slide gate	0.56
MATE11	14	250	60	Plug & Slide gate	0.56
MATE12	35	248	61	Plug & Slide gate	0.56
MATE13	35	300	99	Plug & Slide gate	0.56
MATE14	22	250	60	Plug & Slide gate	0.88

2.3 Data analysis method – jet diameter

The jet diameter at the water surface is an important variable in the dimensionless jet breakup length because the dimensionless jet breakup length is the jet breakup length divided by the jet diameter at the water surface (L/D). Thus, measuring precise jet diameter at water surface is important process in order to study the jet breakup length.

In our study, the high speed camera focusing a small area near the water surface is utilized for measuring the jet diameter at water surface. The data analysis process was conducted as follows.

1. The images are binarized through several image processing methods.
2. The diameter of the jet above the water surface (~10 cm) is measured in each frame because of the splashed water.
3. The average jet diameter is calculated that has same cylindrical volume with the sum of descrete cylindrical volume based on each frame's diameter.
4. The free fall height to the water surface from the measured height (~10 cm) is compensated based on the measured velocity at the water surface and the measured height.

Through this methodology, the average jet diameter of each case can be measured. Not only the measured jet diameter directly from the high speed camera, also the calculated jet diameter is obtained based on the Bernoulli's equation with the information of free fall height and the melt height inside the crucible.

Figure 3 shows visualized melt jet shape before entering the water surface. The jet shapes without the slide gate (Fig. 3. left) is more irregular compared to that with the slide gate (Fig. 3. right).

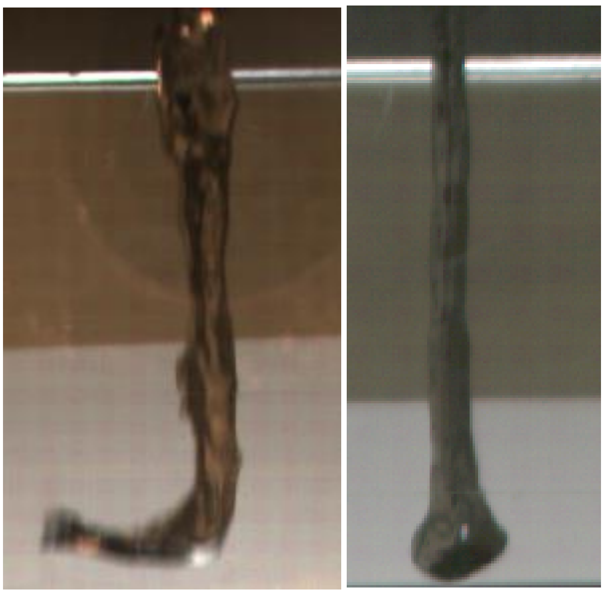

Figure 3. Melt jet shape before entering the water surface with same nozzle diameter; (left) MATE09 (without slide gate), (right) MATE14 (with slide gate)

3. Uncertainty factors on the dimensionless jet breakup length

3.1 Determination methods of jet diameter

According to the previously mentioned methods in Section 2.3, the jet diameters of each cases are obtained. The difference between the average diameter (measured diameter) and the calculated diameter with the slide gate system is relatively smaller than one without the slide gate system. Especially, MATE07 and MATE09 show very large deviation (~240%) from the calculated diameter, that would be an uncertainty factor. The influence of this deviation of jet diameter was investigated in terms of the dimensionless jet breakup length. Some particular cases show noticeable uncertainty. The noticeable cases are MATE06, 07 and 09 which have large deviation between the measured jet diameter value and the calculated jet diameter value.

4. Conclusions

The effect of the determination methods of the jet diameter was examined for the dimensionless jet breakup length with enhanced melt jet delivering system with the additional slide gate system.

The determination methods of the jet diameter gives large uncertainty on the dimensionless jet breakup length, especially in the cases without the slide gate system. Without the slide gate system, the results have large uncertainty especially due to the jet diameter uncertainty (maximum ~240%). The results with the slide gate system show relatively small uncertainty on the jet diameter and dimensionless jet breakup length. Our results imply that the consideration of the melt jet shape (entry condition) would be the important factor in the melt jet breakup experiments.

ACKNOWLEDMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KOFONS), granted financial resource from the Nuclear Safety and Security Commission(NSSC), Republic of Korea (No. 1305008)

REFERENCES

[1] Kim, E., Jung, W. H., Park, J. H., Park, H. S., & Moriyama, K. (2016). Experiments on sedimentation of particles in a water pool with gas inflow. Nuclear Engineering and Technology, 48(2), 457-469.

[2] Kim, E., Lee, M., Park, H. S., Moriyama, K., & Park, J. H. (2016). Development of an ex-vessel corium debris bed with two-phase natural convection in a flooded cavity. Nuclear Engineering and Design, 298, 240-254.

[3] Jung, W. H., Lee, M., Moriyama, K., Hwang, B., Kim, M. H., Park, H. S. (2017). Experiemental Investigation of the Molten Bi-Sn Alloy Jet Breakup Behvior in Water using MATE Facility. The 8th Korea-China Workshop on Nuclear Reactor Thermo-Hydraulics, WORTH-8

[4] Moriyama, K., Park, H. S., Hwang, B., & Jung, W. H. (2016). Analysis of ex-vessel melt jet breakup and coolability. Part 1: Sensitivity on model parameters and accident conditions. Nuclear Engineering and Design, 302, 107-117.

[5] Moriyama, K., Park, H. S., Hwang, B., & Jung, W. H. (2016). Analysis of ex-vessel melt jet breakup and coolability. Part 2: Uncertainty analysis. Nuclear Engineering and Design, 302, 118-127.

[6] Magallon, D. (2006). Characteristics of corium debris bed generated in large-scale fuel-coolant interaction experiments. Nuclear Engineering and Design, 236(19), 1998-2009.

[7] Spencer, B. W., Wang, K., Blomquist, C. A., McUmber, L. M., & Schneider, J. P. (1994). Fragmentation and quench behavior of corium melt streams in water (No. NUREG/CR--6133; ANL--93/32). Nuclear Regulatory Commission, Washington, DC (United States). Div. of Systems Research; Argonne National Lab., IL (United States).

[8] Jung, W. H., Moriyama, K., & Park, H. S. (2016). Multiple Boundary Layer Stripping Model by Plateau-Rayleigh Instability for Fuel-Coolant Interactions. Transactions of the Korean Nuclear Society, May 12-13

[9] Bang, K. H., Kumar, R., & Kim, H. T. (2014). Modeling corium jet breakup in water pool and application to ex-vessel fuel–coolant interaction analyses. Nuclear Engineering and Design, 276, 153-161.