

Thermohydraulic Behavior of Spilled Molten Salt on a Horizontal Open Channel

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1. Introduction

The salt spill accident is regarded as the maximum credible accident in MSRs (molten salt reactors) [1]. MOSTA (MOLten Salt Thermohydraulic behavior and Aerosol generation test) facility was constructed to investigate the thermohydraulic behavior of spilled molten salt and estimate the amount of fission product release during the accident. The shakedown test of salt melting and delivery using NaCl-KCl simulant salt was performed successfully and introduced in the previous paper [2]. In this study, we investigated the effects of salt temperature (or degree of superheat) and discharge mass on the spreading behavior accompanied by salt phase change (cooling and solidification). The test data will be utilized for the validation of the lumped parameter code ‘MSRMELT’ currently under development [3].

2. Experimental Methods

2.1 Experimental Setup

The MOSTA facility can load up to 5 kg of salt powder in a crucible to produce molten salt at temperatures up to 900°C. The overall facility design features and specifications with instrumentations are described in the previous paper [2], and the facility was updated recently to control the molten salt delivery as shown in Fig. 1. A funnel and pneumatic slide gate system were added prior to the spreading channel (Fig. 2) to control the salt discharging rate and mass. The spreading channel is rectangular horizontal channel open at the top with dimensions of L 976 mm × W 176 mm × H 88 mm. Once all amount of molten salt from the crucible is poured into the funnel by rotating the furnace, the slide gate is lifted up immediately by a pneumatic valve to keep the discharge hole (10 mm in diameter) open and release the molten salt from the funnel through the hole. After the designated time of a few seconds, the gate is pushed down automatically to block the hole and stop the salt release.

The furnace, crucible and spreading channel are equipped with several K-type thermocouples (Fig. 3) to monitor the heater temperature (HTT-01), salt temperatures inside the crucible (TF-01~TF-04) and at the delivery mouth (TF-05), ambient temperatures above the spreading channel (TG-01, TG-02) and the channel temperatures (TS-01~TS-20). Also, one additional K-type thermocouple was installed at the center of the

discharge hole to measure the salt discharge temperature (TF-06). A long wave infrared (LWIR) camera is installed above the spreading channel to observe the salt spreading behavior and three camcorders to monitor the whole test procedure.

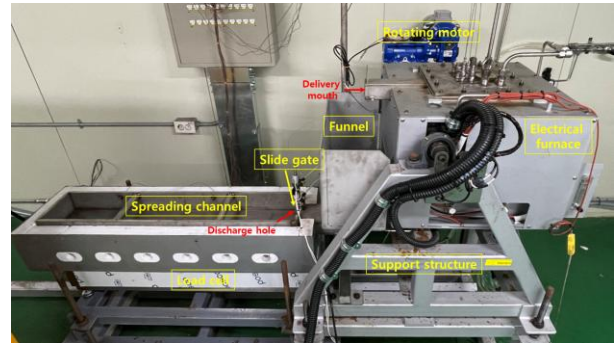
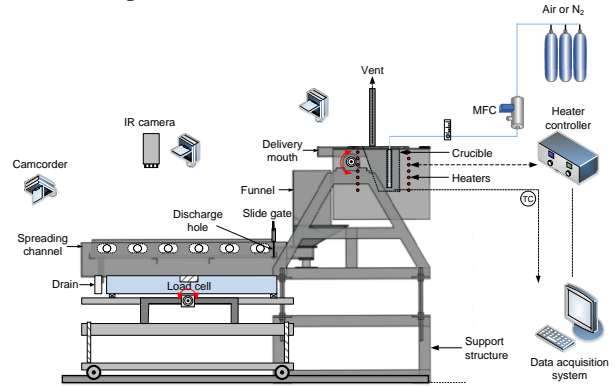


Fig. 1. MOSTA test facility

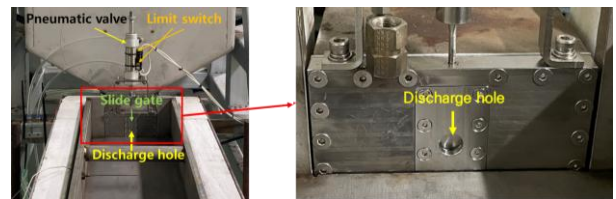


Fig. 2. Molten salt discharge control system

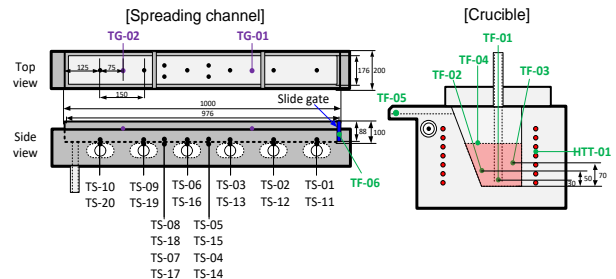


Fig. 3. Thermocouple locations

2.2 Experimental Conditions

NaCl-KCl (50:50 mol %) was used as the simulant of fuel salt NaCl-KCl-UCl₃. Test matrix was determined as shown in Table I, where the test variables are salt temperature (or degree of superheat) and discharge mass on the spreading channel according to the salt generation and delivery mass into the funnel, and discharge hole opening duration (salt discharge time).

Table I: Test Matrix

Case ID	Set values			Measured values	
	Salt generation mass [kg]	Target salt temperature [°C]	Salt discharge time [s]	Avg. salt discharge temperature (TF-06) [°C] (superheat)	Salt discharge mass [g]
1	3	800	3	723 (66)	273
2	3	760	3	702 (45)	271
3	2.5	800	3	716 (60)	242
4	2.5	760	3	697 (40)	240
5	2.5	800	4.5	722 (62)	396
6	2.5	760	4.5	694 (38)	377

3. Result and Discussions

3.1 Molten Salt Generation

Figure 4 shows the typical NaCl-KCl melting process for Case 1, representing the evolutions of salt temperatures near the bottom of the crucible (TF-01), in the middle (TF-02, TF-03) and near the salt top surface (TF-04) (refer to Fig. 3) with heater temperature (HTT-01) and supply power according to the set value of heater temperature (HT-SV). TF-04 becomes lower than the others (TF-01~TF-03) because it is gradually exposed to the ambient inside the crucible as the salt pool is formed. On the other hands, TF-01~TF-03 values get close to the target temperature (800 °C for Case 1), which means uniform temperature of salt pool is formed in the crucible. HT-SV value was controlled to reach the target salt temperature and maintained for a few minutes for steady state.

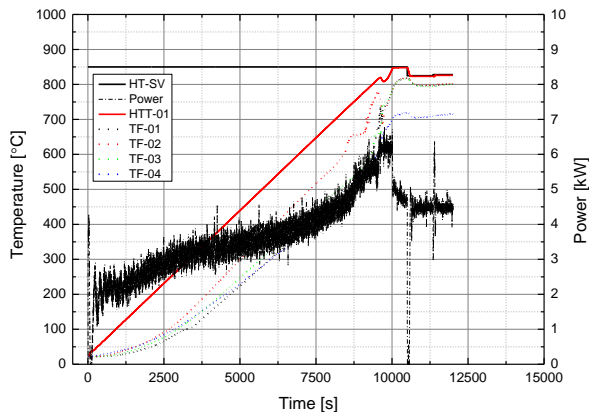


Fig. 4. NaCl-KCl melting process (Case 1)

3.2 Observations of Spreading Behavior

Figure 5 shows salt temperatures at the delivery mouth of the crucible (TF-05), salt discharge temperature at the center of the discharge hole (TF-06) for Case 1. The change of spreading channel weight is also plotted in Fig. 5, which quantifies the salt discharge mass into the channel. The average salt discharge temperature in Table I is calculated using the TF-06 values during the time period of the discharge hole opening (3 seconds for Case 1). As 800°C molten salt being cooled down during the salt pouring into the funnel, about 273 g of 723°C (66°C superheat) salt was discharged into the spreading channel.

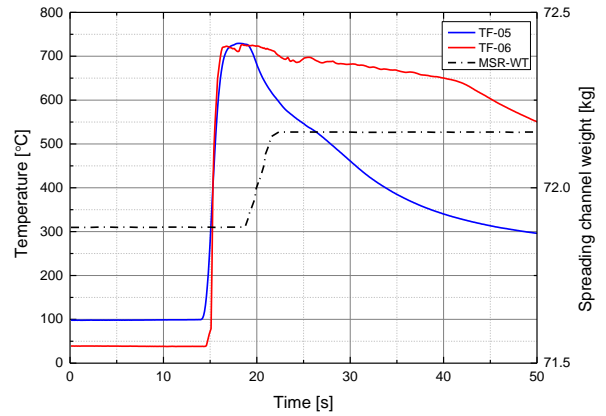


Fig. 5. Molten salt delivery and discharging process (Case 1)

The LWIR still images of spreading shapes with time and camera image at the final state for Case 1 are shown in Table II. LWIR still images at 10 seconds for all the tests are compared in Fig 6. The elongated shapes of spreading were observed in all the tests. As the molten salt spread on the spreading channel at room temperature, it was cooled and solidified very rapidly, and as a result cracked into several large chunks. The channel temperatures exhibited low temperatures below 100°C for all the tests during the whole spreading process as shown in Fig. 7 for Case 1.

Table II: LWIR images during the salt spreading (Case 1)

Time [s]	Spreading shape
1	
5	
10	
Final state	

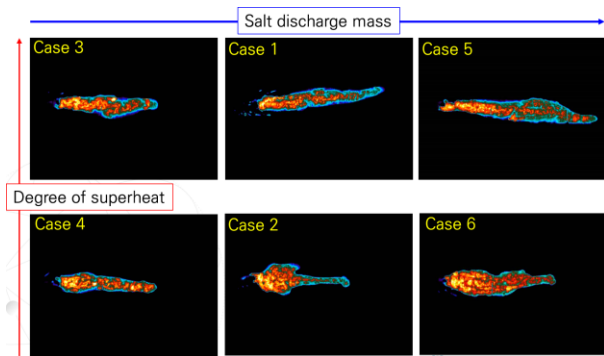


Fig. 6. Comparisons of spreading shape at 10 seconds

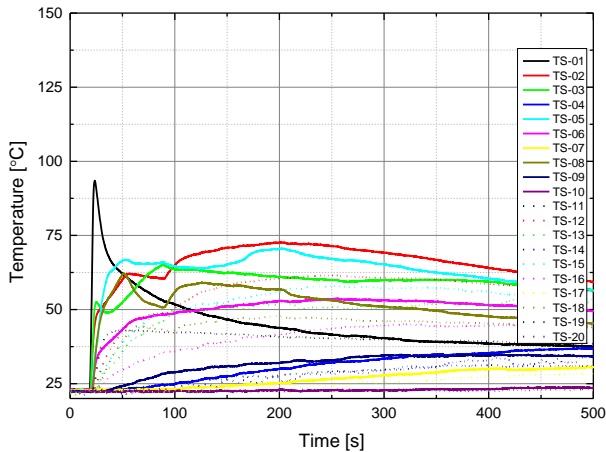


Fig. 7. Spreading channel temperature (Case 1)

3.3 Spreading Distance and Area

The variations of one-dimensional spreading distance and two-dimensional spreading area were quantified by the post processing of LWIR still images and compared in Figs 8 and 9, respectively. The results show a tendency for both the spreading distance and area to increase with higher degree of superheat and larger salt discharge mass into the spreading channel, which can be shown also in Fig. 6. This trend was more pronounced for the spreading area.

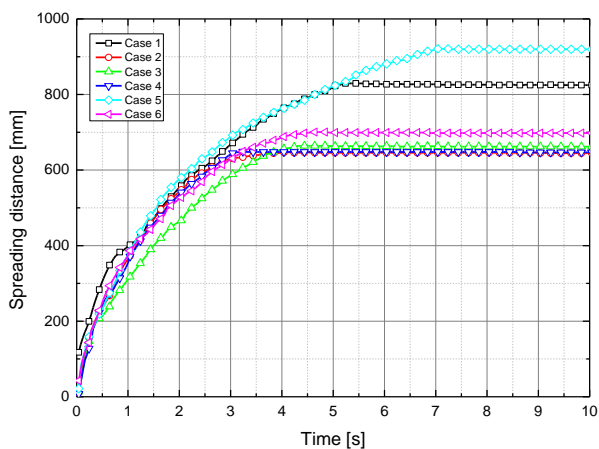


Fig. 8. Spreading distance

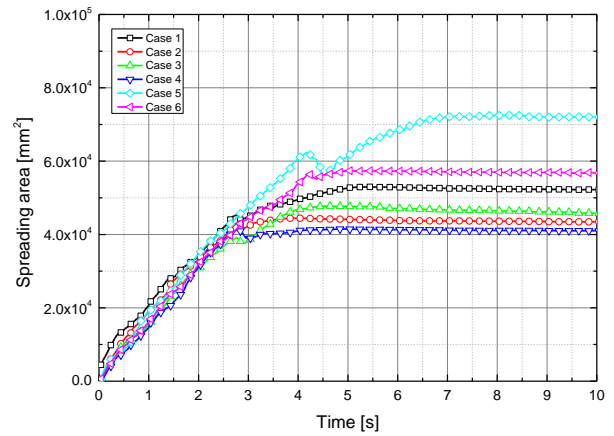


Fig. 9. Spreading area

4. Conclusions

The thermohydraulic behavior of spilled NaCl-KCl molten salt on a horizontal open channel was observed and the effects of salt temperature (or degree of superheat) and discharge mass was investigated experimentally. As expected, the molten salt spread further on the spreading channel with higher superheat and larger mass. However, the salt at the leading edge froze rapidly and formed a barrier to further spreading as the molten salt flowed onto the spreading channel, which was estimated in the previous CFD code analyses [1, 4]. After the spreading, the salt was rapidly cooled and solidified at room temperature.

Even though the salt surface temperature during the spreading is necessary to evaluate the amount of fission product release, the data was not obtained due to high LWIR measurement uncertainty. Instead, it was used only for the observation of spreading shapes in this study. Thus, a proper IR model will be adopted in the near future and the test data will be used for the estimation of fission product release as well as ‘MSRMELT’ code validation.

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