Preliminary Comparison Analysis on Spreading Distance of Spill Molten Salt with Corium using Simple Analytical Model

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1. Introduction

As a part of small reactor developments for the GEN-IV (Generation IV) reactors, a MSR (Molten Salt Reactor) is selected for reactor technology and safety aspects worldwide. In the MSRs, the molten liquid salt is at the same time the fuel and the cooling liquid. The first MSR was developed in the USA at 1,960 and 1,970 years, which was thermal-neutron-spectrum graphite moderated concepts [1]. Since 2005, European research and development interest has focused on fast neutron MSR (MSFR) as a long term alternative to solid-fueled fast neutrons reactors [2]. The general characteristics of MSR is molten fluorides or chloride salt as fuel fluid and low-pressure, high boiling-point coolant.

In a severe safety of the MSR, the most important thing is a loss of the molten fuel salt with the coolant in the primary system. For this reason, the spreading and cooling process of the spill molten fuel salt is very important for MSR safety. Fig. 1 shows spreading and cooling concept of the spill molten salt in an environment condition.

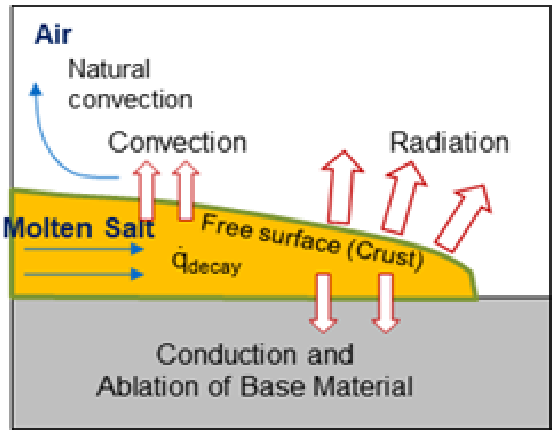

Fig. 1 Spreading and cooling concept of the spill molten salt.

The corium spreading and cooling in PWR (Pressurized Water Reactor) was widely studied for severe accident mitigation [3]. The developed methodology for corium spreading may be used for spreading of the molten salt in MSR. This is focused on preliminary comparison analysis on spreading distance of the spill molten salt in MSR with corium in PWR using a simple analytical model. Table I shows a comparison on the general material properties of the molten salt for the MSR with the corium for the PWR.

Table I: Comparison of the molten salt with corium on material properties.

Material Property	Molten Salt ($NaCl$-$MgCl_2$-UCl_3)	Corium (UO_2, ZrO_2, and so on)
Density (kg/m^3)	2,606~2,795	8,191
Thermal Conductivity (W/m.k)	0.435~0.727	5.3
Kinematic Viscosity (m^2/s)	1.6-3.6x10^{-6}	5.7x10^{-7}
Specific Heat (J/kg. K)	690.0	533.2
Thermal Expansion Coefficient (1/K)	9.9x10^{-5} (450~550°C)	1.1x10^{-4}

2. Simple Analytical Model on Melt Spreading

In a hydrodynamic aspect, the spreading of molten salt or corium depends on the gravitational, inertial, and viscous forces. In general, fluid spreading is divided into gravity and viscous regimes. In gravity-inertia regime, fluid spreading is not dependent on the viscosity. In the assumption of no heat generation without heat transfer, spreading height of h shows the following governing equation by a lubrication theory in the one dimensional surface of x direction.

$$\frac{\partial h}{\partial t} - \frac{1}{3}\frac{g}{\nu}\frac{\partial}{\partial x}\left(h^3\frac{\partial h}{\partial x}\right) = 0 \qquad (1)$$

In the above equation, g is gravitational acceleration and ν is viscosity of the fluid. For the molten salt or corium of the constant temperature with constant volume spill rate of $\dot{V}$, boundary and initial conditions are as follows:

$$-\frac{1}{3}\frac{g}{\nu}\frac{\partial}{\partial x}\left(h^3\frac{\partial h}{\partial x}\right)_{x=0+} = \frac{\dot{V}}{w} \qquad (2)$$

$$h(x,0) = 0 \qquad (3)$$

In the above equation, w means the width of the spreading fluid. The inertia-driven and viscous-driven solution for a spreading distance (x_f) may be solved using an asymptotic method. Boundary condition of equation (2) and initial condition of equation (3) were applied in a solution process.

The solution of equation (1) is as follows:
For gravity inertial driven spreading:

$$x_f \approx 1.2\left(g\,\frac{\dot{V}}{w}\right)^{1/3} t \qquad (4)$$

For gravity viscous driven spreading:

$$x_f \approx \left[\left(\frac{g}{3\nu}\right)\left(\frac{\dot{V}}{w}\right)^3\right]^{1/5} t^{4/5} \qquad (5)$$

The spreading distances of the molten salt for the MSR was estimated using above equations of (4) & (5).

3. Results and Discussion

Preliminary comparison analysis on spreading distance of the spill molten salt in MSR with the corium in PWR [4] was performed using the simple analytical model. Table II shows the input parameters for spreading distance calculation.

Table II: Input parameters for spreading distance calculation.

Material Property	Molten Salt for MSR	Corium for PWR
Density (kg/m^3)	2,650	7,000
Viscosity (kg/m.s)	2.5x10^{-3}	4.1x10^{-3}
Released Mass (kg)	4.0x10^3	2.0x10^5
Released Time (sec)	40	23, 1000
Spreading channel width (m)	0.3	6

Figs 2&3 show spreading distance of the spill molten salt and corium as a function of time, respectively.

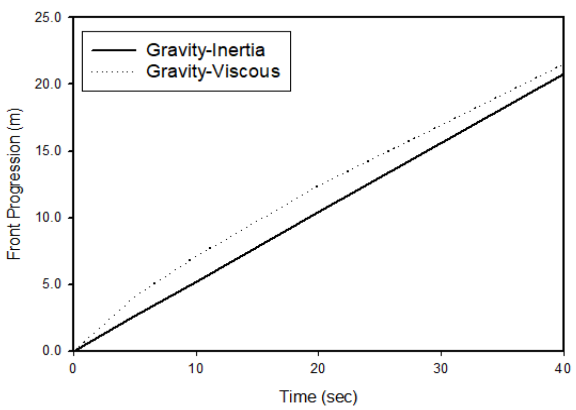

Fig. 2 Spreading distance of the spill molten salt.

As a time increases, the spreading distances show linearly, because the heat transfer from the molten salt or the corium to the environment is not considered. In general, the spreading of the molten salt is not different with the corium spreading, because there is no big difference in material property of viscosity. The spreading is restricted by inertia due to a low viscosity and a high released rate of the spill molten salt or the corium, that is, gravity-inertia spreading regime.

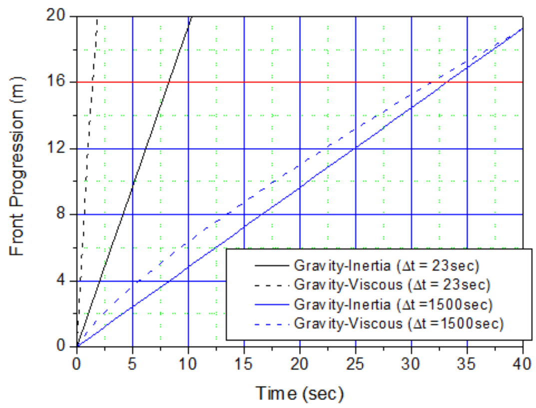

Fig. 3 Spreading distance of the corium.

4. Conclusions

Preliminary comparison analysis on spreading of the spill molten salt for the MSR with the corium for the PWR was performed using the simple analytical model. As a time increases, the spreading distances show linearly. The spreading is restricted by inertia due to low viscosity and high released rate of the molten salt or the corium. More calculations for the spill molten salt are necessary to estimate effect of the main parameters, such as material properties, released mass, released time and spreading channel width. As the next step, more detailed analysis on spreading and cooling of the spilled molten salt including complex heat transfer is necessary, if possible using computer code, to evaluate the severe safety for the MSR.

ACKNOWLEDGEMENT

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