

## Development of a post accident analysis model for KALIMER

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### 1. Introduction

An ultimate safety measure of the KALIMER depends on the inherent safety, which have the core maintain a negative reactivity during any accident periods. In order to secure the integrity of a fuel rod, the void reactivity feedback under sodium boiling must be analyzed. Even though the KALIMER design might not allow boiling at any circumstance, sodium boiling would be possible under HCDA (Hypothetical Core Disruptive Accident) initiating events which are represented by UTOP (Unprotected Transient Over Power), ULOF (Unprotected Loss Of Flow), ULOHS (Unprotected Loss Of Heat Sink), or sudden flow channel blockage, due to power excursion caused by the reactivity feedback.

The slug and annular flow regimes tend to prevail for the boiling of a liquid-metal coolant such as sodium near the atmospheric pressure. In contrast, the bubbly flow is typical under a high pressure in light water reactors.[1,2] This phenomenon difference brings to develop the present model, especially, at the onset of boiling.

A few models had been developed for the sodium boiling analysis. The models such as those in the HOMSEP-2 and SAS series [2,3] are classified into relatively detailed models. Both models are usually called a multiple-bubble slug ejection model. Some simpler models [4,5] are also introduced to evade either parameter sensitivities or a mathematical complexity associated with those rigorous models.

The present model based on the multiple-bubble slug ejection model. It allows a finite number (N) of bubbles, separated by liquid slugs, in a channel as illustrated in Fig.1. Boiling occurs at a user specified superheat, and a generated vapor is modeled to fill the whole cross section of the coolant channel except for a static liquid film left on the cladding or/and structure surfaces. The model also assumes a vapor with one uniform pressure. The present analysis is focused on the behavior of early sodium boiling after ULOHS.

### 2. Model description

The description of the momentum conservation equation for a liquid slug flow between two vapors is similar to that used in SAS2A [2], except expressing it with flow rate instead of mass flux. A liquid slug is approximated as an incompressible fluid. Thus, the liquid slug momentum equation is given by

$$\frac{1}{A_c} \frac{\partial W}{\partial t} + \frac{\partial P}{\partial z} + \frac{1}{A_c} \frac{\partial(WV)}{\partial z} = - \left( \frac{\partial P}{\partial z} \right)_{jf} - \left( \frac{\partial P}{\partial z} \right)_K - P_c g \quad (1)$$

The momentum equation is applied to each liquid slug which is represented in Fig. 1. Since the interface moves along the axis, both Eulerian or Lagrangian schemes are used for temperature calculation in the liquid slug. The Eulerian scheme is usually applied before the incipient boiling, while the Lagrangian scheme is used for all liquid slugs other than the inlet liquid slug after boiling. The Lagrangian scheme, however, is also used for the inlet liquid slug with a low flow rate (~ 10 % of the initial flow rate). The Lagrangian total time derivative,  $dT_c/dt$ , as seen by an observer moving with the coolant velocity, is involved in the calculation and axial heat conduction through the interfaces is ignored.

The total energy added to a vapor bubble consists of  $Q_{es}$  and  $Q_i$ , i.e.

$$Q_i = \int_t^{t+\Delta t} [Q_{es}(\tau) + Q_i(\tau)] d\tau \quad (2)$$

where,  $Q_{es}$  is the heat flow from the heat structures, and  $Q_i$  denotes total heat flow through the liquid-vapor interfaces which are composed of an upper interface term  $I_{iu}$  and a lower interface term  $I_{il}$ . Figure 2 demonstrates the heat flow contribution to the temperature rise of an already existing vapor.

The energy balance between the energy transferred to a vapor control volume and the energy change within the volume, determines the change of the vapor energy. In general, if a series of N vapors with uniform pressures extends from the bottom

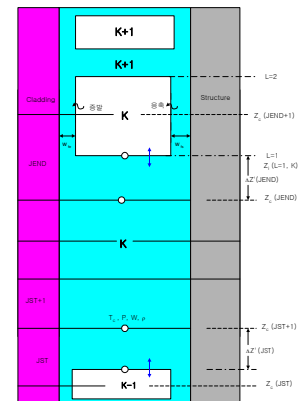


Fig. 1 Nodalizations for numerics

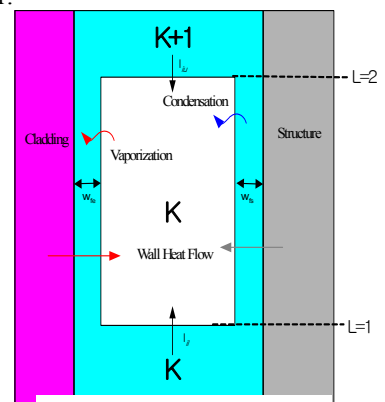


Fig. 2 Vapor energy balance

of the channel, the temperature changes in the N vapors are then calculated by solving a set of linear equations written in terms of N unknown vapor temperatures. Once the vapor temperatures are known, the vapor pressures are obtained from the saturation conditions.

### 3. Analysis results

For the model application to a ULOHS event, the transient core inlet temperature is set to increase 0.5 °K/sec in the present analysis, while the inlet/outlet channel pressures keep the initial values all the time as the boundary conditions. As a local liquid temperature reaches the user specified superheat, a new vapor is generated with the saturation pressure corresponding to the user specified superheat temperature, and thus the vapor pressure should be higher than the liquid pressure at the onset of boiling by amount of the superheat. Consequently, a pressure jump is anticipated at the boiling point.

Figure 3 presents the growth of the firstly generated vapor. The vapor size increases within a short time. The first vapor forms at a point in the fuel region. Both the upper and lower interfaces grow upward and downward, respectively. The second vapor is formed at near 8.015 sec, but the calculation result show unphysical behavior since after. It is noted that when the vapor size exceeds a certain value (~ 8 cm), the secondly generated vapor above the first larger vapor has a negative size which means that its lower interface develops upward much faster than the upper interface. Even though the model reduced the time step by half until a positive vapor size were obtained, the calculation logic would not give a stable solution.

A probable explanation is found in the model itself. The model calculates the liquid slug flow between two vapors depending on their pressure difference. If the upper vapor pressure gets larger than that of the lower vapor, a negative liquid flow will be obtained. Because the interface movements are closely coupled with the liquid slug flows above and below a vapor, the liquid slug above its upper interface can move even downward while the upper interface still rises in the positive direction. As a result, the model allows the lower interface to go over the upper interface. This discrepancy spreads over various other terms in the calculation logics, and it may leads to the unphysical outputs. To resolve the problem, the vapor energy balance is under investigation. The explanation is backed by the negative liquid slug flow observed above the vapor after the second vapor forms.

When the gap size between two vapors reduces to be smaller than a specified length, two vapors are to coalesce and merge into one. Subsequently, the size of the emerged vapor jumps. It is also found that the wall heat

flow does not contribute to the vapor pressure until it grows larger than a certain value.

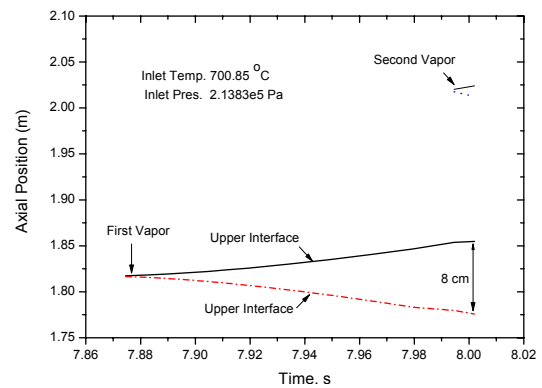


Fig. 3 Vapor progression

### 4. Discussions

Generally, the behavior for the vapor formation and initial vapor growth shows a physical agreement with the assumption made in the model. However, the model should also feature a model which takes account of the pressure drop across the vapor for a large vapor in order to be a complete model. The initial vapor growth is similar to the results shown in CABRI analyses, where the sudden enlargement of the vapor was observed within a short time, ~ ms. [3] Inlet flow reversal was predicted at the onset of boiling in the study, but it has not happened in the present analysis. Therefore, the model should be further elaborated and be applied to transients other than the ULOHS, i.e. UTOP or ULOF with different conditions for its reliability. An additional model which can accommodate such a large vapor is also required for more realistic analyses.

### References

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