Analysis of the Nonlinear Density Wave Two-Phase Instability in a Steam Generator of 600MWe Liquid Metal Reactor

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1. Introduction

A 600 MWe demonstration reactor being developed at KAERI employs a once-through helically coiled steam generator. The helically coiled steam generator is compact and is efficient for heat transfer, however, it may suffer from the two-phase instability. It is well known that the density wave instability is the main source of instability among various types of instabilities in a helically coiled S/G in a LMR. In the present study a simple method for analysis of the density wave two-phase instability in a liquid metal reactor S/G is proposed and the method is applied to the analysis of density wave instability in a S/G of 600MWe liquid metal reactor.

2. Analysis

The present method is formulated with control volumes with moving boundaries and the homogeneous equilibrium flow model is used in the two-phase region. The governing equations for the calculation domain shown in Fig.1 are as follows;
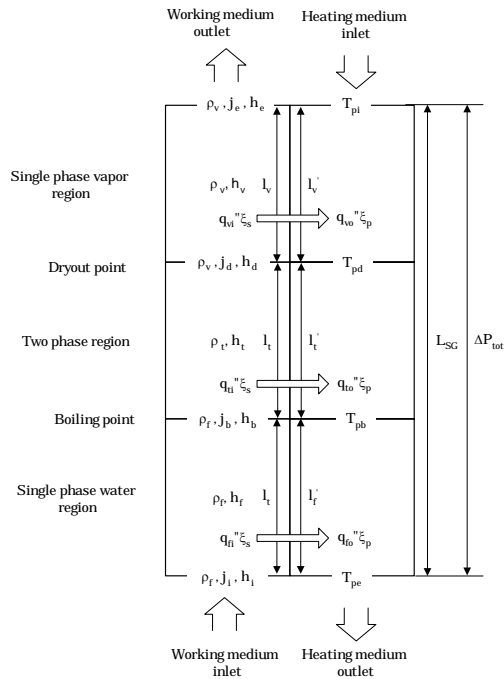

Fig.1 Calculation domain and parameters

2.1 Primary side

$$\dot{m}_p (C_{pi} T_{pi} - C_{pd} T_{pd}) = q_{vo}^{"} \xi_p l_v \tag{1}$$

$$\dot{m}_p (C_{pd} T_{pd} - C_{pb} T_{pb}) = q_{to}^{"} \xi_p l_t \tag{2}$$

$$\dot{m}_p (C_{pb} T_{pb} - C_{pe} T_{pe}) = q_{fo}^{"} \xi_p l_f \tag{3}$$

where

$$q_{fo}^{"} = h_{fo} \frac{(T_{ep} - T_{is}) - (T_{bp} - T_{bs})}{\ln[(T_{ep} - T_{is})/(T_{bp} - T_{bs})]} \tag{4}$$

$$q_{to}^{"} = h_{to} \frac{(T_{bp} - T_{bs}) - (T_{dp} - T_{ds})}{\ln[(T_{bp} - T_{bs})/(T_{dp} - T_{ds})]} \tag{5}$$

$$q_{vo}^{"} = h_{vo} \frac{(T_{ip} - T_{es}) - (T_{dp} - T_{ds})}{\ln[(T_{ip} - T_{es})/(T_{dp} - T_{ds})]} \tag{6}$$

2.2 Secondary side

(1) Sub-cooled region.

$$\rho_f \frac{d}{dt}(l_f) = \rho_i j_i - \rho_b j_b \tag{7}$$

$$\rho_f \frac{d}{dt}(l_f h_f) = \rho_i j_i h_i - \rho_b j_b h_b + \frac{q_f^{"} \xi_s l_f}{A_s} \tag{8}$$

(2) Boiling region.

$$\rho_t \frac{d}{dt}(l_t) = \rho_b j_b - \rho_d j_d \tag{9}$$

$$\rho_t \frac{d}{dt}(l_t h_t) = \rho_b j_b h_b - \rho_d j_d h_d + \frac{q_t^{"} \xi_s l_t}{A_s} \tag{10}$$

(3) Dry out region.

$$\rho_v \frac{d}{dt}(l_v) = \rho_d j_d - \rho_e j_e \tag{11}$$

$$\rho_v \frac{d}{dt}(l_v h_v) = \rho_d j_d h_d - \rho_e j_e h_e + \frac{q_v^{"} \xi_s l_v}{A_s} \tag{12}$$

The momentum equation is given as follows;

$$\Delta P_{ext} = \frac{d(\rho_f j_f)}{dt} l_f + \frac{d(\rho_t j_t)}{dt} l_t + \frac{d(\rho_v j_v)}{dt} l_v + \rho_e j_e^2 - \rho_i j_i^2$$
$$+ g(\rho_f l_f^{'} + \rho_t l_t^{'} + \rho_v l_v^{'}) + \frac{\xi_s}{A_s}(\tau_{wf} l_f + \tau_{wt} l_t + \tau_{wv} l_v) + \frac{1}{2} k_i \rho_i j_i^2 \tag{13}$$

The details of the governing equations are given in Choi [1] and are not reproduced here.

3. Results and Discussion

The proposed method is applied to the analysis of density wave instability in a S/G of 600MWe liquid metal reactor. Fig.1 shows six cases of steady solution with experimental data of 50MWt S/G in JAEA . We observe the code is accurate enough to be used in the engineering purpose. Fig.3 shows the size of three regions according to the mass flow rate. Fig.4 shows the pressure drop according to mass flow rate. They follow the general shape given in the literature.
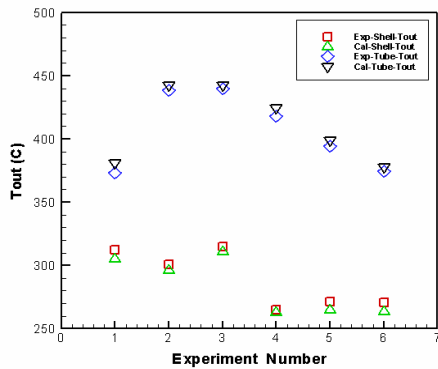
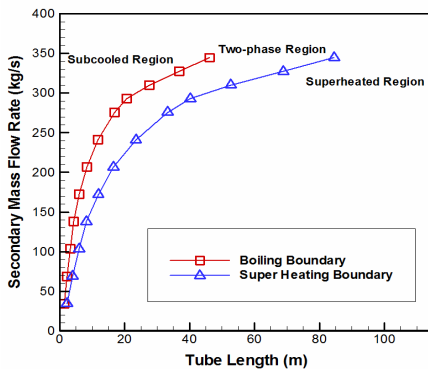

Fig.2 Validation of code

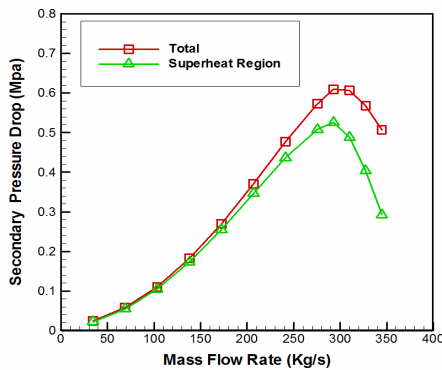Fig.3 Sizes of regions

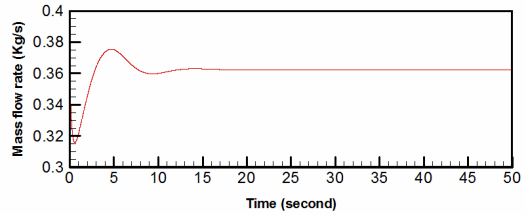Fig.4 Secondary pressure drop

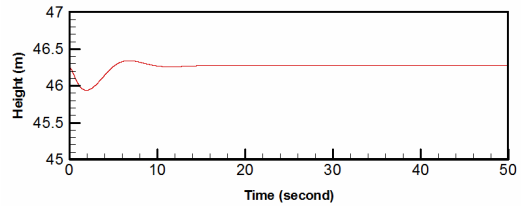Fig.5 Temporal variation of inlet flow rate

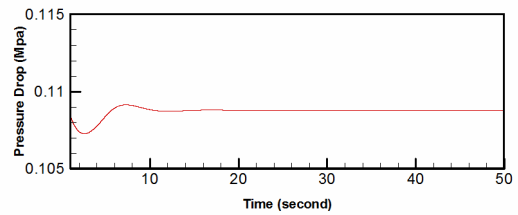Fig.6 Temporal variation of boiling boundary

Fig.7 Temporal variation of pressure drop in a two-phase region

Figs.5-7 show the temporal variations of the inlet flow rate, the boiling boundary and the pressure drop in a two-phase region. These figures clearly show that the variables reach a steady state after some initial variation. This indicates that density wave two-phase instability does not occur in a S/G of 600MWe liquid metal reactor.

4. Conclusions

A simple method for analysis of the density wave two-phase instability in a liquid metal reactor S/G is proposed and the method is applied to the analysis of density wave instability in a S/G of 600MWe liquid metal reactor. The results show that the density wave two-phase instability does not occur in a S/G of 600MWe liquid metal reactor.

REFERENCES

[1] S. K. Choi, "Analysis of the Nonlinear Density Wave Two-Phase Instability in a 600MWe Liquid Metal Reactor Steam Generator", KAERI Internal Report, 2010.