Consideration on horizontally stratified condensation phenomena at water surface of IRWST in APR1400

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1. Introduction

The In-Containment Refueling Water Storage Tank (IRWST) of APR1400 is installed at the bottom of containment building to promote the plant safety functions during an accident. This design feature brings about uncertainty factors which may necessitate conventional prediction of temperature and pressure of containment building improved or revised when an accident occurs. The hot steam which is released from RCS break enters the IRWST through four Pressure Relief Dampers (PRDs). It is expected to be condensed with water stored in IRWST, in which water is colder than incoming steam.

Basically, the purpose of this study is to assess the correlations which are previously used for the analysis of IRWST's condensation in the code system.

2. Application conditions

2.1 Structures

The APR1400 containment building is a pre-stressed cylindrical structure of concrete which has net free volume of 3.3×10^6 ft^3. IRWST is connected to other containment compartments by four PRDs, and has nominal free volume of 117,416 ft^3. The heights of lower and upper floor are 81 ft and 97 ft, respectively.

The PRDs are located at the lowest floor of annular containment compartment and have a configuration of separation of approximately 90° between one and another. The designed net flow area for each PRD is 36 ft^2.

In containment, it is assumed that the temperature is 50 ˚F, the pressure is 14.7 psia, and the humidity is 90 %, being consistent with other modelings. In IRWST, cooling water level is 11.5 ft.

2.2 Database for condensation heat transfer rate

When the accident occurs hot steam is released from RCS and then enters into IRWST. Its maximum pressure is 290 kPa, maximum temperature is 170 ˚F. Because the atmosphere of IRWST is initially filled with air(non condensable gas), the mass fraction of steam is less than 10 %, that is, air mass fraction is more than 90 %(Fig. 1), even the hot steam enters into IRWST with high pressure and temperature.

Fig. 2 and Fig. 3 show steam and water velocity, respectively. Since the operation of CSS pump starts at 27 seconds later, the water velocity increases dramatically at that time.

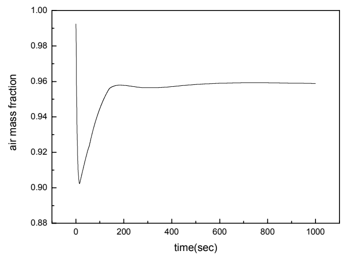

Figure 1. Air mass fraction

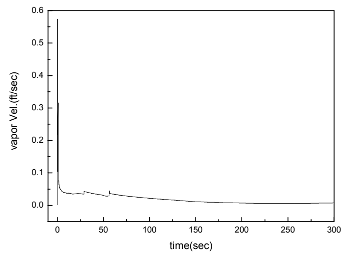

Figure 2. Steam velocity

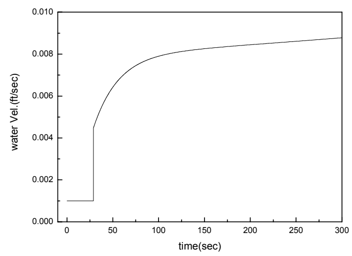

Figure 3. Liquid velocity

3. Horizontally stratified condensation phenomena

3.1 Direct-contact condensation model

Many experimental studies for the direct-contact heat transfer in stratified steam water flows, cocurrent or countercurrent, have been performed (Segev et al., 1981; Lim et al., 1981; Kim and Bankoff, 1983; Kim et al., 1985). Among those, the modified Kim's correlation is suitable for the conditions of the present study. The effect of non-condensable gas is also considered by referencing the UCB multiplier in

RELAP5/MOD3.2, which is respectively described below;

$$\cdot\ \mathrm{Nu} = \frac{h_i \delta}{k_f} = 0.996\times10^{-3}(\mathrm{Re}_f^{0.98}\,\mathrm{Fr}^{0.8}\,\mathrm{Pr}_f^{0.95}\,\mathrm{f}) \qquad (1)$$

where, f = 1-$X^{0.22}$ for $X > 0.65$

(X is air mass fraction)

3.2 Condensation model of GOTHIC code

In order to analyze the present phenomenon, GOTHIC code which has used condensation model was selected. The correlation combines three correlations, consisting of vapor, liquid corresponding and mass transfer for both side.

For the vapor side, the heat transfer rate is calculated from the maximum value of heat transfer coefficients for turbulent natural convection which based on comparisons with experimental data for superheated pools and forced convection based on the Reynold's analogy applied to a flat plate. For the liquid side, it is also calculated from the maximum value of turbulent natural convection, the default interfacial area which is the pool surface, defined as volume/height. These correlations are described below;

$$\mathrm{Nu}_{vl}(D_h) = \mathrm{Max}\begin{pmatrix} 0.036\,\mathrm{Re}_\upsilon^{4/5}\,\mathrm{Pr}_\upsilon^{1/3} \\ 0.21\left(\mathrm{Gr}_\upsilon\,\mathrm{Pr}_\upsilon\right)^{1/3} \end{pmatrix} \qquad (2)$$

$$\mathrm{Nu}_{ll}(D_h) = \mathrm{Max}\begin{pmatrix} \dfrac{2D_h}{\mathrm{PoolDepth}} \\ 0.13\left(\mathrm{Gr}_l\,\mathrm{Pr}_l\right)^{1/3} \end{pmatrix} \qquad (3)$$

$$\mathrm{Nu}_{ml}(D_h) = \mathrm{Max}\begin{pmatrix} 0.036\,\mathrm{Re}_\upsilon^{4/5}\,\mathrm{Pr}_\upsilon^{1/3} \\ 0.21\left(\mathrm{Gr}_\upsilon \mathrm{Sc}_\upsilon\right)^{1/3} \end{pmatrix} \qquad (4)$$

4. The result

Fig. 4 shows the prediction from modified Kim's correlation which is also compared with that of GOTHIC source code. According to Fig. 4, the value of the GOTHIC's correlation is always higher than that of Kim's in a range of interest.

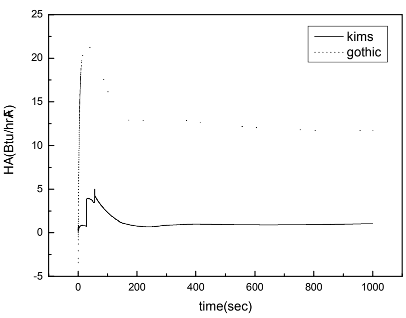

Figure 4. Comparison of correlation value

5. Conclusion

The APR1400 design feature brings about uncertainty factors which may necessitate conventional prediction of temperature and pressure of containment building improved or revised when an accident occurs. In this study, heat transfer rate between hot steam and cold water, as one of uncertain factors is assessed under stratified steam-water interfacial condensation. According to the result, the prediction of GOTHIC is lager than Kim's one. In other words the calculation of GOTHIC code is more conservative than that of the direct-contact condensation in assessing the IRWST thermal hydraulics.

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