Scaling Analysis of the APR+ ECC Bypass

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1. Introduction

The direct ECC bypass and sweep out behavior are strongly dependent on the Wallis parameter[1]. Because the downcomer gap is reduced by installation of the ECC duct of the DVI+, the Wallis parameters for the prototype plant APR+ and APR1400 under condition of with/without duct (DVI+)[2] are compared to evaluate the ECC bypass fraction. The geometrical conditions such as downcomer height, pipe diameter of hot let and cold leg, the break size are not changed except the core power increase by 7% in the APR+. In this scaling parameter comparison, the dimensionless circumferential velocity $j^*_{g,ent}$ and $j^*_{l,ent}$ are compared.

2. Flooding Limit

Flooding limit for the flow reversal mechanism by Wallis gives following relationship [3,4]

$$j_g^* + m\, j_l^* = C \qquad (1)$$

Wallis parameter is defined as following,

$$j_k^* = \frac{\dot{M}_k}{\rho_k \cdot A_{DC}} \left[\frac{\rho_k}{(\rho_f - \rho_g)\cdot g \cdot C_{DC}} \right]^{1/2} \qquad (2)$$

where,

$\dot{M}_k$: gas or liquid mass flow rate

A_{DC} : D/C annuls vertical area

C_{DC} : D/C circumferential length

Flooding limit for the entrain mechanism by Kutateladze gives following relationship [3,4]

$$K_g^* + mK_l^* = C \qquad (3)$$

The Kutateladze number defined,

$$K_k^* = \frac{\dot{M}_k}{\rho_k \cdot A_{DC}} \left[\frac{\rho^2{}_k}{(\rho_f - \rho_g)\cdot g \cdot \sigma} \right]^{1/4} \qquad (4)$$

From the full scale UPTF test results, the flooding limit suggests by Glaser [3]

$$K_g^{1/2}\left(v_g^{2/3}/(g^{1/3}l)\right)^{1/2} + 0.011K_l^{1/2} = 0.0245 \qquad (5)$$

where,

$$l = 0.65\pi\, d_{outer}\, \sin^2(0.5\theta_{ECC-BCL})$$

d_{outer} : D/C annulus outer diameter

θ : C/L-to-DVI angle

From the UPTF TEST 21D, the top void gap (void height) relationship is as following;

$$H_{v,top} = 0.35(j_{g,eff}^* / j_{l,ent}^*{}^{1/4})^2 \qquad (6)$$

where ,

$H_{v,\,top}$: top void gap (void height)

The dimensionless circumferential velocity $j^*_{g,eff}$ and $j^*_{l,ent}$ are defined as

$$j_{g,eff}^* = \frac{\dot{M}_{g,eff}}{\rho_g \cdot A_{Flow}} \left[\frac{\rho_g}{(\rho_f - \rho_g)\cdot g \cdot L_{DC}} \right]^{1/2} \qquad (7)$$

$$j_{l,ent}^* = \frac{\dot{M}_{g,eff}}{\rho_l \cdot A_{Flow}} \left[\frac{\rho_l}{(\rho_f - \rho_g)\cdot g \cdot L_{DC}} \right]^{1/2} \qquad (8)$$

where ,

$\dot{M}_{g,eff}$: gas mass flow rate

L_{DC} : CL bot.-to-D/C top height (or Cold leg Diameter, D_{CL})

A_{Flow} : $L_{DC} \times (D/C)_{Gap}$ (gap area)

3. Scaling Comparison

3.1 Downcomer Annulus Without Duct

The Wallis parameter for the prototype plant APR+ and APR1400 under condition of without duct (DVI+) is compared. The geometrical conditions of the APR+ and the APR1400 are not changed except the core power increase by 7%. The dimensionless circumferential velocity, $j^*_{g,eff}$, ranges at 4.92~5.9 for the cold leg velocity of 50~60m/s[5]. If the steam condensation rate of 50% is assumed, the $j^*_{g,eff}$ ranges 2.46~2.95. The downcomer gap and its height, diameter of cold leg, the break size are not changed. These conditions give the following ratios of the dimensionless circumferential velocity $j^*_{g,eff}$ and $j^*_{l,ent}$

$$\left(j_{g,eff}^*\right)_R = \frac{\left(\frac{\dot{M}_{g,eff}}{\rho_g \cdot A_{Flow}} \left[\frac{\rho_g}{(\rho_f - \rho_g)\cdot g \cdot L_{DC}} \right]^{1/2} \right)_{APR+}}{\left(\frac{\dot{M}_{g,eff}}{\rho_g \cdot A_{Flow}} \left[\frac{\rho_g}{(\rho_f - \rho_g)\cdot g \cdot L_{DC}} \right]^{1/2} \right)_{APR1400}} = \left(\dot{M}_{g,eff}\right)_R = 1.07 \qquad (9)$$

The increased ECC flow rate is assumed about 7%.

$$\left(j^*_{l,ent}\right)_R = \frac{\left(\frac{\dot{M}_{l,ent}}{\rho_l \cdot A_{Flow}}\left[\frac{\rho_l}{(\rho_f-\rho_g)\cdot g\cdot L_{DC}}\right]^{1/2}\right)_{APR+}}{\left(\frac{\dot{M}_{l,ent}}{\rho_l \cdot A_{Flow}}\left[\frac{\rho_l}{(\rho_f-\rho_g)\cdot g\cdot L_{DC}}\right]^{1/2}\right)_{APR1400}} \quad (10)$$

$$= \left(\dot{M}_{l,eff}\right)_R = 1.07$$

where,

$$\left(\dot{M}_{g,eff}\right)_R = \frac{(CoreSteamFlow)_{APR+}}{(CoreSteamFlow)_{APR1400}} = 1.07$$

$$\left(L_{DC}\right)_R = \frac{(D_{CL})_{APR+}}{(D_{CL})_{APR1400}} = 1$$

$$\left(A_{Flow}\right)_R = \frac{(L_{D/C} * Gap_{D/C})_{APR+}}{(L_{D/C} * Gap_{D/C})_{APR1400}} = 1$$

$$\left(\rho_g\right)_R = \frac{(\rho_g)_{APR+}}{(\rho_g)_{APR1400}} = 1$$

$$\left(\frac{\rho_g}{(\rho_f-\rho_g)}\right)_R = 1$$

3.1 Downcomer Annulus with Duct (DVI+)

The downcomer gap will be reduced in the APR+ because of the duct height of DVI+. The Wallis parameter is compared for the APR+ ducted downcomer and APR1400 simple annulus. The duct height affects the dimensionless circumferential velocity $j^*_{g,ent}$ and $j^*_{l,ent}$ as following;

$$\left(j^*_{g,eff}\right)_R = \frac{\left(\frac{\dot{M}_{g,eff}}{\rho_g \cdot A_{Flow}}\left[\frac{\rho_g}{(\rho_f-\rho_g)\cdot g\cdot L_{DC}}\right]^{1/2}\right)_{APR+}}{\left(\frac{\dot{M}_{g,eff}}{\rho_g \cdot A_{Flow}}\left[\frac{\rho_g}{(\rho_f-\rho_g)\cdot g\cdot L_{DC}}\right]^{1/2}\right)_{APR1400}}$$

$$= \left(\dot{M}_{g,eff}\right)_R * \frac{1}{(Gap_{D/C})_R} = 1.07 * \left(\frac{1}{0.8}\right)$$

$$= 1.3375$$

The dimensionless circumferential velocity, $j^*_{g,eff}$ of the APR+ is increased by 33.75% when compared to that of the APR1400 because the APR+ core power is increased about 7%, and the downcomer gap is reduced about 20% by DVI+ duct.

$$\left(j^*_{l,ent}\right)_R = \left(\frac{\dot{M}_{l,ent}}{\rho_l \cdot A_{Flow}}\left[\frac{\rho_l}{(\rho_f-\rho_g)\cdot g\cdot L_{DC}}\right]^{1/2}\right)_R$$

$$= \left(\dot{M}_{l,ent}\right)_R * \frac{1}{(A_{Flow})_R} = 1.07 * \left(\frac{1}{0.8}\right)$$

$$= 1.3375$$

where,

$$\left(\dot{M}_{g,ent}\right)_R = 1.07$$

$$\left(A_{Flow}\right)_R = \frac{(L_{D/C} * Gap_{D/C})_{APR+}}{(L_{D/C} * Gap_{D/C})_{APR1400}} = \frac{(Gap_{D/C})_{APR+}}{(Gap_{D/C})_{APR1400}} = \frac{20}{25} = 0.8$$

4. Conclusions

In order to evaluate the ECC bypass fraction, the dimensionless circumferential velocity $j^*_{g,ent}$ and $j^*_{l,ent}$ are compared between the APR+ and the APR1400.

Acknowledgement

This research has been performed as a part of the nuclear R&D program supported by the Ministry of Knowledge Economy of the Korean government.

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