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Spillage of ECC Water Jet by Cross Flow

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1. Introduction

The ECC spillage fraction of HPSI water injected into the ECBD which is attached on a core barrel is strongly dependent on a cross flow during a LBLOCA late reflood phase (Kwon et al, 2012). The momentum, gravitational force, and the cross flow drag force are major components to deflect the ECC water column in the downcomer annulus with a cross flow. The force ratio between cross flow drag and injection moment is governing the ECC intake fraction in the ECBD duct system. To quantify the ECC bypass fraction with spillage, a CFD model of 1/1-scale downcomer annulus with DVI+ ECBD is considered. In this numerical study, the applicability and feasibility of a commercial CFD code for the simulation of the ECC water column are tested.

2. Numerical Simulation

The 1/1-scale APR+ downcomer annulus numerical model was established for CFX code analysis. The major downcomer components of 4-Cold leg, 2-hot leg and 4-DVI nozzle with ECBD ducts are modeled in the numerical model. The flow is modeled with air and water. The CFX version 14 is applied. The total number of node of this model is about 12.2 million. The heat transfer and phase change are not considered in the numerical model.

The calculation conditions for a steady-state flow are as follows:

- CL-1,-2,-3 air velocity : 50~70 m/sec
- Outlet : Broken C/L
- DVI ECC injection : Water
- Turbulence intensity : 5%
- Turbulence model : *k-ε*

Fig. 1 shows the major components of downcomer used in the modeling. The main objective of this test is to investigate the displacement of the ECC water jet by a cross flow for the DVI+ ECBD system. The velocity of the cross flow at the upper downcomer is assumed to be 30% of an injection velocity of cold legs. The drag force of this cross flow component forces to shift the ECC water to the outside of the ECBD intake hole.

Fig. 2(a) shows the flow distribution of the downcomer annulus at given conditions. Fig 2(b) shows the shifted ECC water jet by the cross flow. The ECC water jet does not flow to the outside of the ECBD though the disturbance take places due to the cross flow. Figs. 3(a) and 3(b) show the ECC water shapes in the experiment and numerical calculation, respectively. Fig. 3(a) shows the test results for the condition of a stagnant air flow(zero velocity). Fig. 3(b) shows the CFD results for the high air cross flow condition and the shape of the ECC water jet in the downcomer is the same as that in the stagnant condition.

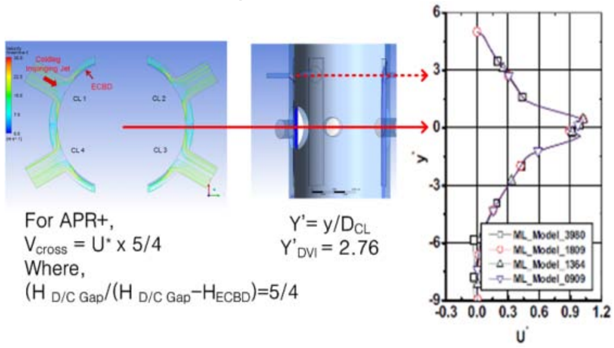
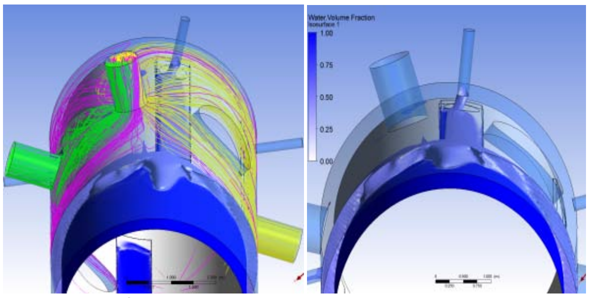
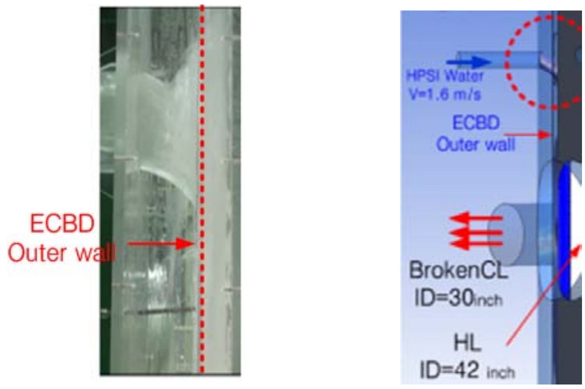


Fig. 1 Cross flow velocity in the downcomer



(a) flow distribution (b) ECC water shape

Fig. 2 Shifted ECC water jet by cross flow



(a) Experiment (b) CFD

Fig. 3 ECC water jet

3. Analogy

The external forces applying on the ECC water jet are the gravitation force, drag of cross flow, drag of axial flow, etc. The drag by the axial flow is negligible because the jet velocity of the ECC water is very low compared to that of the cross flow of downcomer.

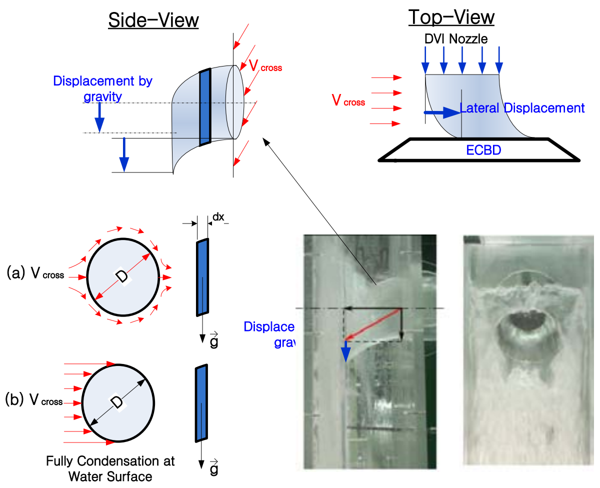


Fig. 4 External forces on ECC water jet

The drag of cross flow per axial unit length is,

$$\oint_S P_B dS = \int_0^{2\pi}\left(P_O + \frac{1}{2}\rho_C\left(2V_C \sin\theta\right)^2\right)\frac{D}{2}\cos\theta d\theta$$
$$= C_D \frac{1}{2}\rho_C V_C^2 D \qquad (1)$$

And the gravitational force per axial unit length is

$$\vec{g}\rho_{Water}\frac{\pi}{4}D^2$$

Therefore, the force ratio per axial unit length is

$$\frac{\text{Drag}}{\text{Gravity}} = \frac{C_D \frac{1}{2}\rho_C V_C^2 D}{\vec{g}\rho_{Water}\frac{\pi}{4}D^2} = \frac{2C_D}{\vec{g}\pi}\frac{\rho_{Steam}}{\rho_{Water}}\frac{V_C^2}{D_{DVI}}$$
$$\approx \frac{2*0.3}{\vec{g}\pi} * \frac{0.9745}{983} * \frac{30^2}{0.2159}$$
$$\approx 0.08 \qquad (2)$$

The drag force of the cross flow is about 8% of the gravitational force. The impact force of cross steam flow with cross flow velocity of 30 m/sec is

$$\oint_S P_B dS = \int_{\frac{1}{2}\pi}^{\frac{3}{2}\pi}\left(\frac{1}{2}\rho_C V_C^2\right)\frac{D}{2}\cos\theta d\theta$$
$$= \frac{1}{2}\rho_C V_C^2 D \qquad (3)$$

For a full impact case, the lateral displacement is

$$\frac{\text{Impact force}}{\text{Gravity}} = \frac{\frac{1}{2}\rho_C V_C^2 D}{\vec{g}\rho_{Water}\frac{\pi}{4}D^2} = \frac{2}{\vec{g}\pi D}\frac{\rho_{Steam}}{\rho_{Water}}V_C^2$$
$$\approx \frac{2}{0.2159\vec{g}\pi} * \frac{0.9745}{983} * 30^2$$
$$\approx 0.269 \qquad (4)$$

Therefore, the maximum lateral displacement by cross flow impact is about 26.9%.

The estimated elapsed time of ECC water jet to cross the downcomer from the exit of DVI nozzle to the intake hole of the ECBD is given as follow;

$$t = \frac{Gap_{DC} - H_{ECBD}}{V_{DVI}} = \frac{0.25m - 0.05m}{1.6m/s} = 0.125sec$$

Then, the displacement (H) of ECC water jet by gravitational force is

$$H_{ECC\_Jet} = \frac{1}{2}\vec{g}t^2 = 0.0766m$$

The steam condensate after hitting the ECC water makes the maximum lateral displacement by the steam cross flow. The maximum displacement of ECC water jet is about 0.077m to the lateral direction from the edge of DVI nozzle. This means the maximum lateral displacement of the ECC water jet by the cross flow is within the vertical displacement by the gravitational force. Thus the spillage of the ECC water jet is not increased by the cross flow in the DVI+ system.

4. Conclusions

The spillage of ECC water jet in the DVI+ ECBD system is estimated by CFD calculation and analogy. The CFD results show that the ECC water jet is bounded in the intake hole of the ECBD. The ECC water jet does not shift to the outside of the intake hole of the ECBD at the given condition. The analogy also shows the similar results.

From the present study, it can be concluded that the displacement of the ECC water jet is bounded on the maximum displacement due to the gravitational force (buoyancy force).

Acknowledgement

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