Condensation Performance Evaluation of Evacuate containment with Xenon, Air and CO2 for Small Modular Reactor

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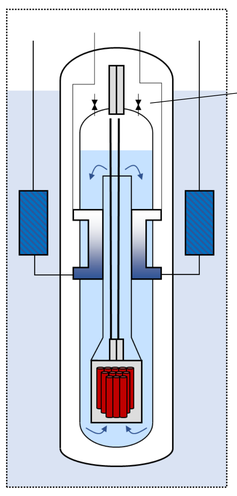
Introduction

● **Evacuated containment of small modular reactors (SMR)**



NuScale
Vacuum

Decrease Maintenance cost

This study
Xe CO_2 Air

During accident, Is it sufficient for condensation?

Evaluation of Condensation performance

✓Condensation performance was evaluated by mathematical model
→ Non-condensable effect was considered

Methodology

● **Calculation flow chart**

✓To calculate the condensation rate, condensation heat transfer coefficient (HTC) was determined by using Dehbi correlation.
✓The condensation rate can be calculated by heat transfer rate of condensation
✓Calculation was proceeded until 3,600 second of simulation time, and condensate level in containment were compared with that of each gases case

Calculation Flow chart

Geometry
V_{gap} A_{cs} A_{cond}

Constant value
T_w M_{AB} m_{nc} ε_{AB}/κ σ_{AB} $P_{sat}(T_w)$

Transient calculation

P T

Steam mass fraction at wall

$$W_{s,w} = \frac{P_{sat}(T_w)\cdot M_s}{(P - P_{sat}(T_w))\cdot M_{nc} + P_{sat}(T_w)\cdot M_s}$$

Mixture Molar mass

$$M = \left(\frac{W_s}{M_s} + \frac{1-W_s}{M_{nc}}\right)^{-1}$$

Diffusion coefficient

$$D = \frac{T^{\frac{3}{2}}\left[3.03 - \frac{0.98}{\sqrt{M_{AB}}}\right]}{P\sqrt{M_{AB}}\sigma_{AB}^2\Omega_D}$$

$$\Omega_D = \frac{\alpha_1}{(T^*)^{\alpha_2}} + \sum_{i=2}^{4}\frac{\alpha_{2i-1}}{e^{\alpha_{2i}T^*}}$$

$$\left\{T^* = \frac{T}{(\varepsilon_{AB}/\kappa)}\right\}$$

Mixture density

$$\rho = \frac{P\cdot M}{R\cdot T}$$

Mixture viscosity

$$\mu = \sum_{i=1}^{2}\frac{X_i\mu_i}{\sum_{j=1}^{2}X_j\theta_{ij}} \qquad \theta_{ij} = \frac{\left[1+(\mu_i/\mu_j)^{0.5}(M_i/M_j)^{0.5}\right]^2}{2\sqrt{2}(M_i/M_j)^{0.5}}$$

Condensation HTC

$$h_{Dehbi} = 0.185D^{\frac{2}{3}}(\rho_w+\rho_\infty)\left(\frac{\rho_w-\rho_\infty}{\mu}\right)^{1/3}\ln\left(\frac{1-W_{s,w}}{1-W_{s,\infty}}\right)\frac{h_{fg}}{(T_\infty - T_w)}$$

Heat required for condensation

$$Q_{cond} = hA_{cond}(T_\infty - T_w)$$

Condensation rate

$$\dot{m}_{cond} = \frac{Q_{cond}}{h_{fg}}$$

Mass of condensate

$$m_{cond}^{t+1} = m_{cond}^{t} + \dot{m}_{cond}^{t}\cdot dt$$

Water level

$$L_c^{t+1} = L_c^t + \frac{m_{cond}^{t+1}}{\rho_l A_{cs}}$$

$\dot{m}_s$

Mass of steam

$$m_s^{t+1} = m_s^t - m_{cond}^t + \dot{m}_s^t\cdot dt$$

Steam mass fraction

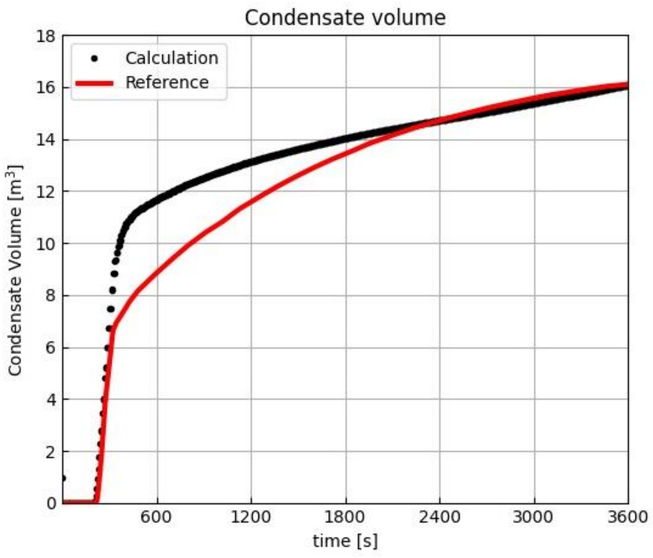
$$W_{s,\infty}^{t+1} = \frac{m_s^{t+1}}{m_s^{t+1} + m_{NCG}}$$

✓Input data for condensation rate calculation was collected from RELAP5 simulation results.
✓Susyadi et al. examined the thermal hydraulics of NuScale's evacuated containment during stuck open of reactor vent valve accident using RELAP5 code.

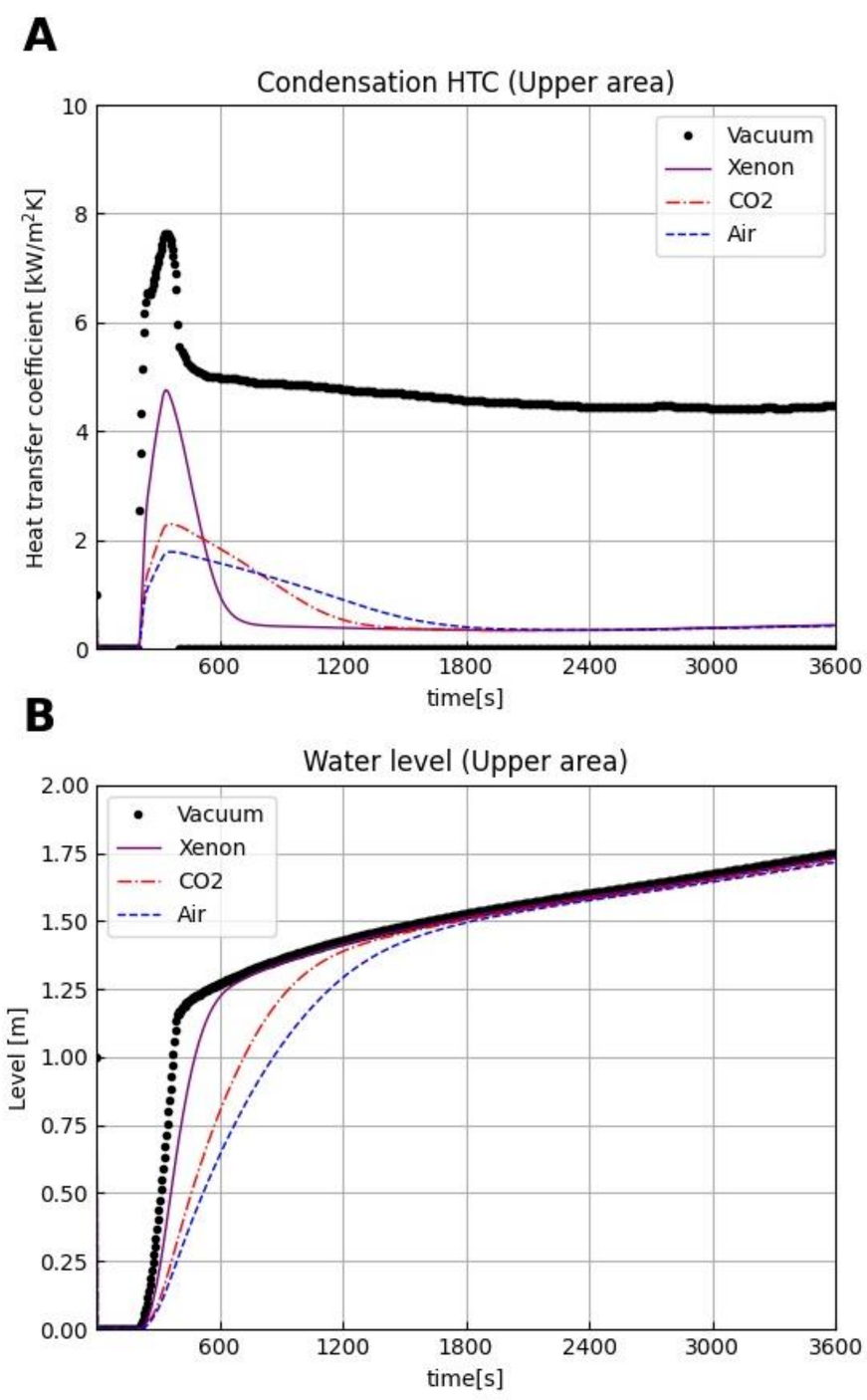
Results

● **Validation of the calculation with RELAP5 results**

✓Condensate volume was compared with the reference RELAP5 results
✓At the early period of calculation, there is a little discrepancy between the reference and calculation
✓Dehbi correlation is only valid for steam mass fractions up to 0.95, and it could be a reason that overestimate



● **Effect of the non-condensable gases**



✓The condensation area was decided as **10% of containment wall area.**
✓Xenon had the largest HTC, followed by CO_2 and air.
✓This is because density difference between the non-condensable gas and steam caused mixing behavior which makes condensation efficient.
✓Therefore, the Xenon had the largest HTC between the non-condensable gases

Conclusion

✓This study evaluated the condensation performance of evacuate containment when non-condensable gases fill up the containment using mathematical method. The condensation HTC of the non-condensable gases were lower than that of the vacuum, but it had not significant effect on the condensation rate. Between the gases, the xenon had the highest condensation performance because of their high-density-difference with steam. The results show the feasibility of the gas filled containment, and it could be a cost-effective on SMR design.

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