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Numerical Analysis on Heat Flux Distribution through the Steel Liner of the Ex-vessel Core Catcher

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1. Introduction

The ex-vessel core catcher is installed to retain the corium in the reactor cavity. When the reactor vessel fails, the reactor cavity is flooded by the gravity driven flow from the IRWST after the molten corium spreads on the core catcher body during a severe accident. In order to prevent material failure of steel container of the core catcher system due to high temperatures, heat flux through the steel liner wall must be kept below the critical heat flux (CHF), and vapor dry-out of the cooling channel must be avoided.

In this study, CFD methodology has been developed to simulate the heat flux distribution in the core catcher system, involving following physical phenomena: natural convection in the corium pool, boiling heat transfer and solidification/melting of the corium. Thereafter, numerical analysis has been carried out to estimate the heat flux through the steel liner of the core catcher.

2. Core Catcher System

Fig.1 shows the conceptual design of an ex-vessel core catcher system. The core catcher system is composed of steel container and cooling channel. Sacrificial material is located in the steel container to reduce the decay heat of the corium. Coolant flow in the cooling channel is driven by a natural convection and bubbles inside the cooling channel.

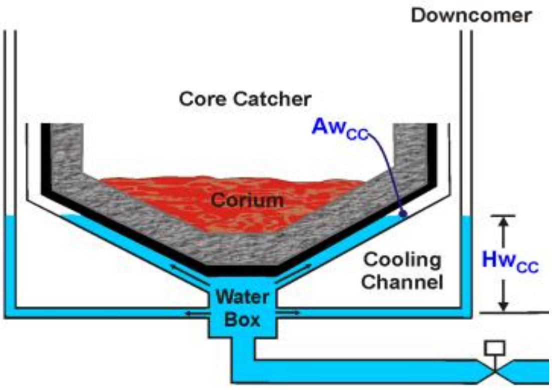

Fig.1 Conceptual design of a core catcher system

3. Physical Phenomena in the Core Catcher System

The major physical phenomena that must be considered in the design quality evaluation for the core catcher is as follows: natural convection in the corium pool, boiling heat transfer and solidification/melting of the corium.

Typical boiling curve is shown in Fig.2. In the boiling curve, the following regimes and points of interest can be identified:

- **Nucleate boiling regime**: Individual bubbles grow and are released from the wall. Stirring of the liquid and latent heat consumed in producing vapor bubbles cause a large increase in the heat transfer.
- **Critical heat flux:** Bubbles coalesce and interact with each other in such a way that they inhibit the efficient removal of heat from the heated wall. A maximum heat transfer exist at this point.
- **Transition regime:** Vapor patches start forming and heat transfer is further inhibited as temperature increases.
- **Minimum film boiling heat flux:** The minimum value of the heat flux that can sustain a hydrodynamically stable vapor layer over the wall.
- **Film boiling:** After the MFBHF point, a continuous vapor layer separating the wall from the liquid becomes hydrodynamically stable, acting as an insulator and inhibiting the heat transfer from the wall. Radiation heat flux becomes more important as the temperature of the wall increases.

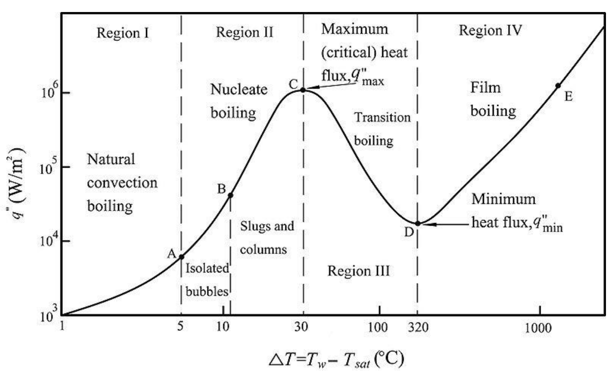

Fig.2 Typical boiling curve and regimes of boiling

4. Numerical Analysis Method

The calculation domain consists of two main parts: corium pool and steel liner(Fig.3). Surrounding coolant region is not considered in the CFD calculation. Therefore, boiling heat transfer correlations is used as an external heat flux boundary conditions. To avoid the thermal expansion problem in the closed domain(corium pool), boussinesq approximation is used to simulate natural convection in the corium pool. Solidification and melting phenomena of the corium also considered in the analysis method. Solidus temperature of corium is 1,658K. 2D unsteady CFD analysis has been conducted. To calculate the natural convection flow, continuity equations and momentum equation have been used. And laminar model is adopted, because the Rayleigh number in the corium pool is sufficiently small. About 23,000 grids are used in the entire calculation domain(Fig.4).

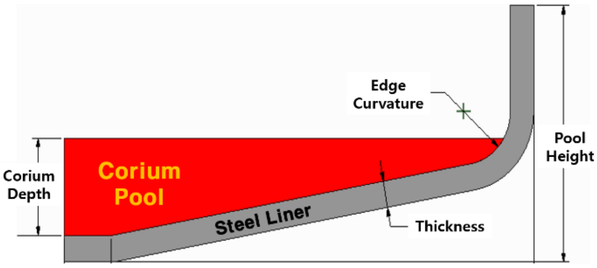

Fig.3 Calculation domain

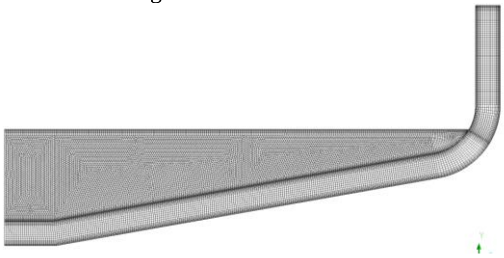

Fig.4 Grid system

5. Analysis Results

Fig.5 shows the temperature distribution in the corium pool and steel liner. Although temperature and velocity distribution in the corium pool changes temporally, overall thermal/hydraulic behavior shows a quasi-steady state characteristics. The corium pool is divided into two regions: region that corium is continuously maintained in the solid state, and region that solidification and melting is repeated intermittently.

Fig.6 shows the heat flux distribution at the external walls of the corium pool and the steel liner. High heat flux values are formed at the free surface of the corium pool. However, the heat flux through the steel liner is maintained below the critical heat flux (CHF).

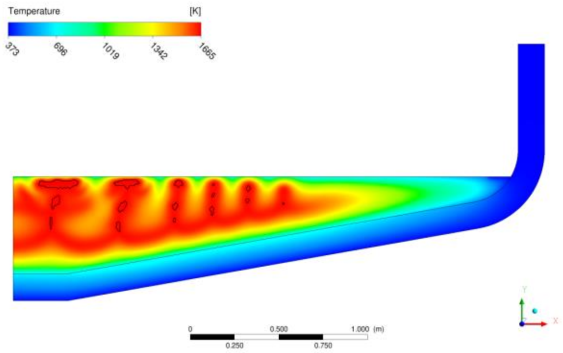

Fig.5 Temperature distribution in the corium pool and liner

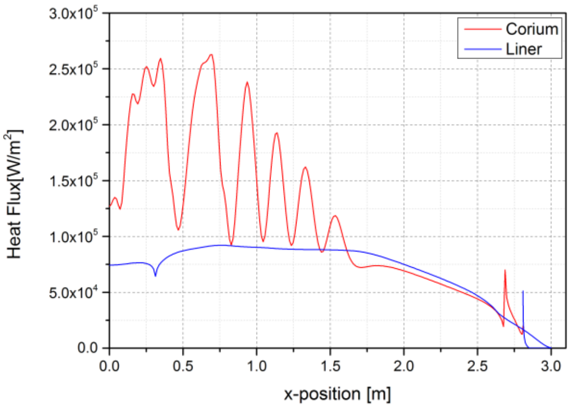

Fig.6 Heat flux profile for the external walls

6. Conclusion

A CFD methodology has been developed to simulate the thermal/hydraulic phenomena in the core catcher system, and a numerical analysis has been carried out to estimate the heat flux through the steel liner of the core catcher. High heat flux values are formed at the free surface of the corium pool. However, the heat flux through the steel liner is maintained below the critical heat flux.

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