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Thermal Hydraulic Analysis of K-DEMO Single Blanket Module for Preliminary Accident Analysis using MELCOR

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1. Introduction

To develop the Korean fusion commercial reactor, preliminary design concept for K-DEMO (Korean fusion demonstration reactor) has been announced by NFRI (National Fusion Research Institute). This pre-conceptual study of K-DEMO has been introduced to identify technical details of a fusion power plant for the future commercialization of fusion reactor in Korea. Before this consideration, to build the K-DEMO, accident analysis is essential. Since the Fukushima accident, which is severe accident from unexpected disaster, safety analysis of nuclear power plant has become important. The safety analysis of both fission and fusion reactors is deemed crucial in demonstrating the low radiological effect of these reactors on the environment, during severe accidents. A risk analysis of K-DEMO should be performed, as a prerequisite for the construction of a fusion reactor. To investigate the consequence of severe accidents in the fusion reactor, a number of thermal hydraulics simulation codes are used (ECART, INTRA, ATHENA/RELAP, MELCOR etc.).

The role of blanket module in the vacuum vessel is important in the accident. Blanket has ability of cooling itself and breeding tritium. In the case of K-DEMO, water cooling concept is introduced. This coolant can leak into the vacuum vessel. This accident terminates plasma giving impact on the plasma facing components and lots of hazards can be mobilized in the form of aerosol. Not only this, damaged coolant pipe can be a corridor of mobilized hazards (Tritium in the form of HTO and activated tungsten dust from plasma transient) to the environment which can lead to public evacuation. Activated corrosion products in the first wall coolant can be mobilized in the case of coolant pipe break accident (LOCA : Loss Of Coolant Accident). Penetration accident between confinement building and vacuum vessel which is one kind of LOVA (Loss Of Vacuum Accident) accident which can release the radioactive aerosol into environment. Coolant from first wall cooling loop can increase pressure in the vacuum vessel and boiling accelerates the speed of radioactive material release.

Lee et al. [1] and Kim et al. [2] conducted thermal hydraulic analysis using MARS-KS and multiple module simulation. Using the results of radiation heat load and neutron wall loading on the in-vessel component first wall [3]. The results shows that the capability of MARS-KS to simulate the K-DEMO blanket module.

In this research, thermal-hydraulic analysis of single blanket module of K-DEMO is conducted for preliminary accident analysis for K-DEMO. Further study about effect of flow distributer is conducted. The normal K-DEMO operation condition is applied to the boundary condition and simulated to verify the material temperature limit using MELCOR [4], [5]. MELCOR is fully integrated, relatively fast-running code developed by Sandia National Laboratories. MELCOR had been used for Light Water Reactors and fusion reactor version of MELCOR was developed for ITER accident analysis.

2. Modeling K-DEMO Blanket Module using MELCOR

To simulate the single blanket module in the K-DEMO, whole geometry of blanket is simplified into one unit of coolant channel. Figure 2. Shows the configuration of this simulation. In the top view of the slice of blanket module, a number of coolant channel pass through between first wall and other breeder & multiplier layers. This coolant channel and structure

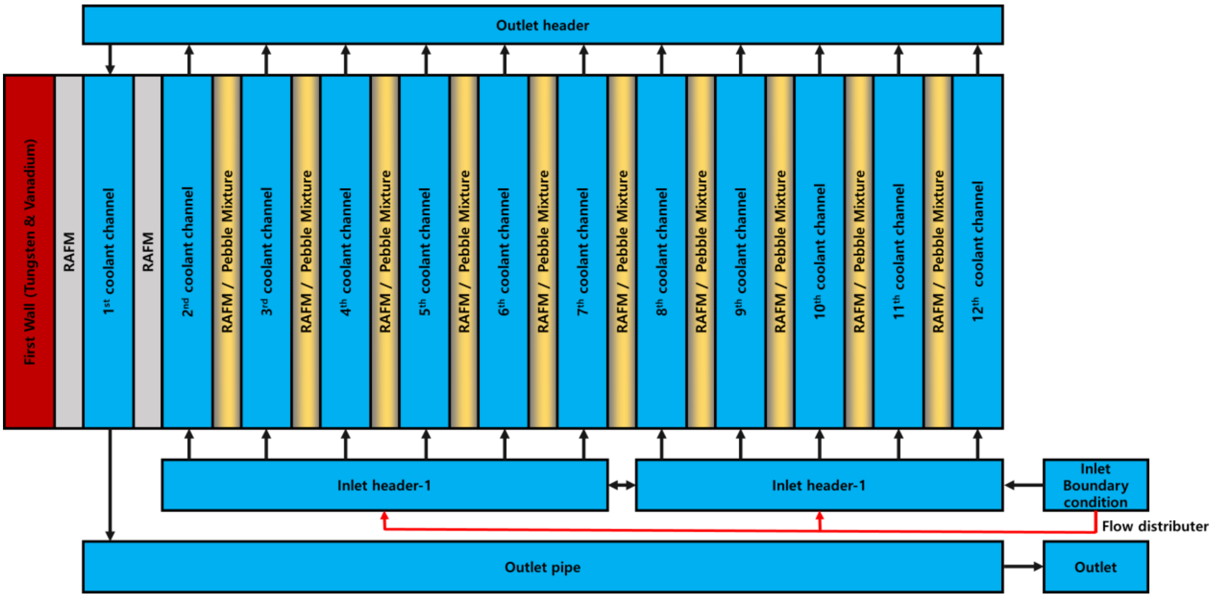

Figure 1. MELCOR Nodalization of K-DEMO single blanket module

geometry is modelled by MELCOR control volume input. For simple simulation, single unit of coolant channel is modelled like figure 3. From 2nd coolant channel to 12th coolant channel from inlet header flows upward and gather in the outlet header. This collected coolant flows into 1st coolant channel and this channel goes to the outlet pipe. Figure 1. shows the nodalization of MELCOR single blanket module. To model the flow distributer of inlet header, inlet header is divided into 2 control volumes and connected with free flow path. Material property of RAFM (Reduced activation ferritic/martensitic) and pebble bed (Li_4SiO_4+$Be_{12}Ti$) in the blanket is assumed as constant function. Pebble bed is assumed to consist of only just Li_4SiO_4. And this effective thermal conductivity of the bed equation is used [6].

$$k_e = 0.768 + 0.496 \cdot 10^{-3} \cdot T_m \qquad (1)$$

Where T_m is average temperature of the bed.

Simulation parameters in this research are indicated in table 1.

Table I. Simulation parameters for MELCOR Single module modeling.

Property and boundary conditions	
Inlet Pressure	15 MPa
T_{in}	290 °C
Flow rate	5.05 kg/s
Single unit width	9 mm
First wall heat flux	455 kW/m^2
Density of pebble	2400 kg/m^3
Specific heat of pebble bed	3.0 J/(kgK) [7]

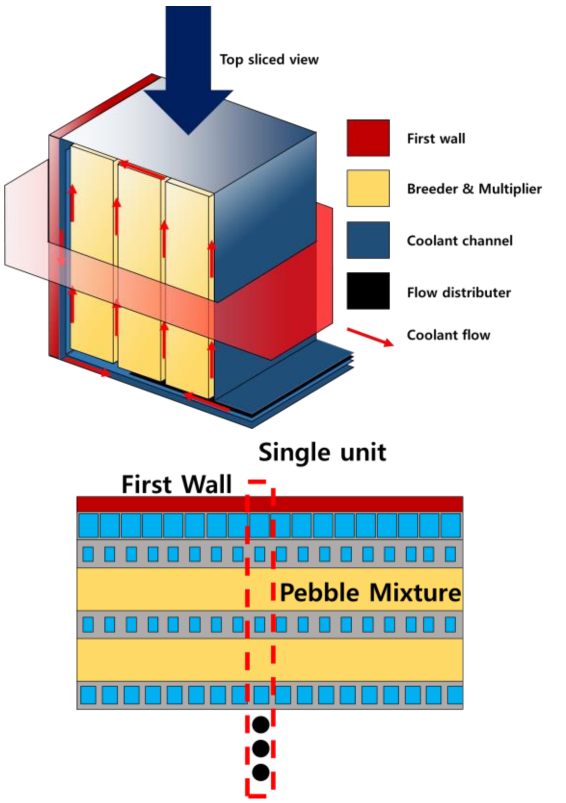

Figure 2. Configuration of K-DEMO single blanket module: overall view and top sliced view

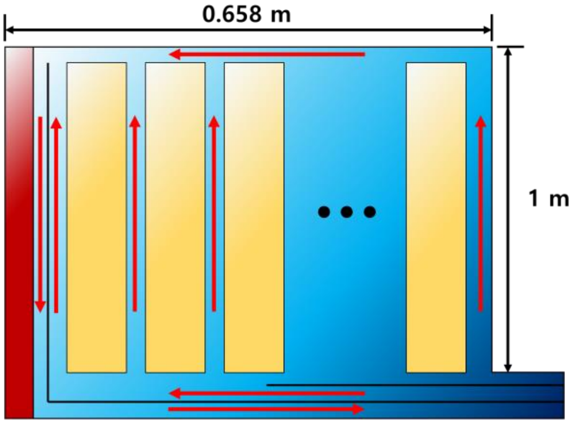

Figure 3. Simplified K-DEMO blanket module : Single unit configuration.

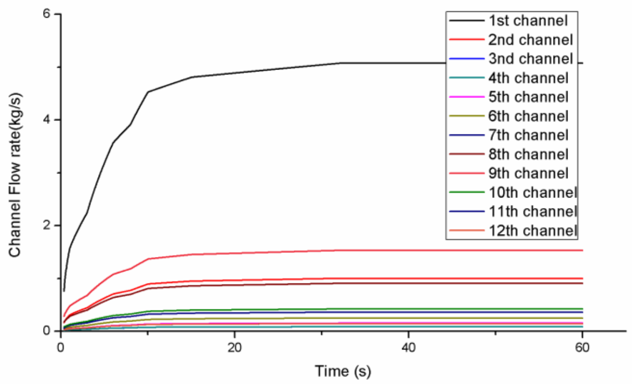

Figure 4. MELCOR result of mass flow rate for each coolant channel

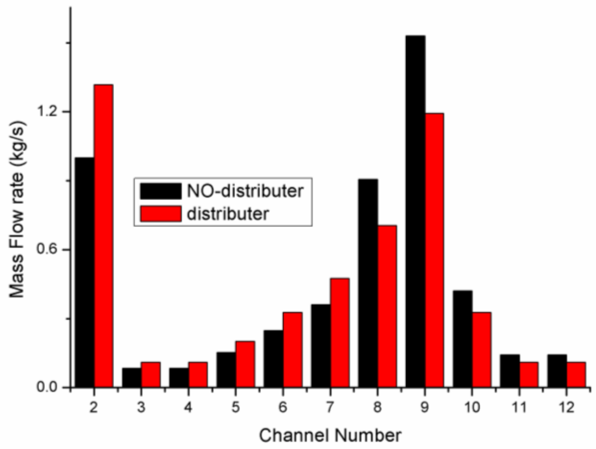

Figure 5. Mass flow rate for each coolant channel with/without Flow distributer

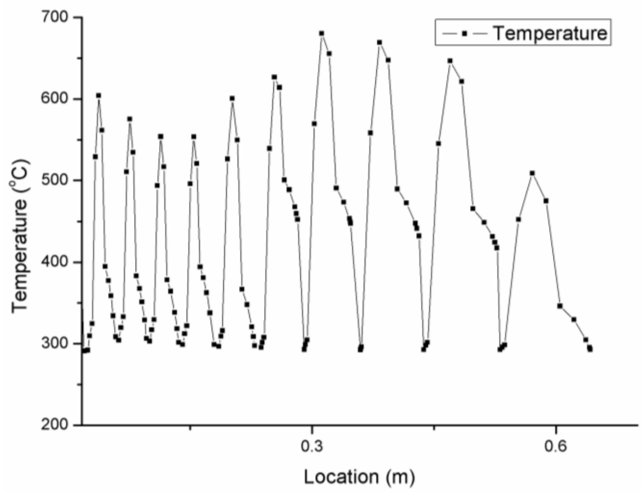

Figure 6. MELCOR result of Temperature distribution of single blanket module

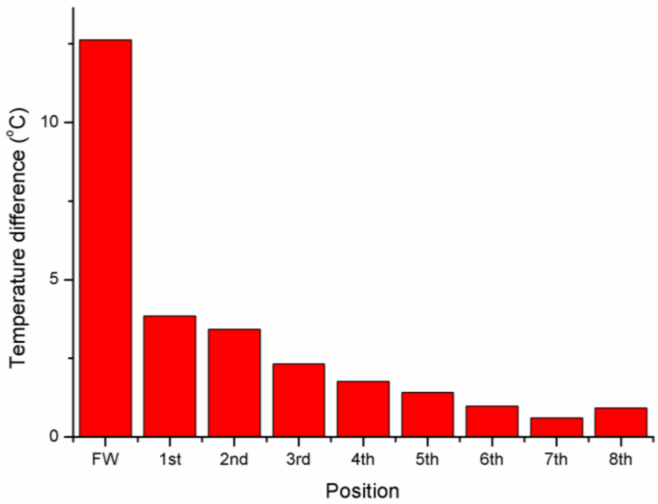

Figure 7. Temperature difference of heat structure between non-distributer and distributer

3. Results and Discussion

Figure 4, 5 and figure 6. Shows main result of MELCOR single blanket module simulation. As the boundary condition, liquid mass flow rate for 1st coolant channel is 5.05 kg/s. Figure 4. shows the results without flow distributer. Figure 5. shows comparison between mass flow rate with/without flow distributer. With flow distributer, mass flow rate for channel number 8, 9, 10, 11 and 12 decreased and this flow goes into channel 3, 4, 5, 6 and 7. This result shows the ability of flow distributer to broadening the temperature gradient which can enhance the safety of blanket module. One important thing is drastic increase of mass flow rate in channel 2 which is closer to first wall where the highest heat flux can be seen in the plasma transient. If proper flow distributer is used, accident tolerance of blanket module against plasma transient accident can be enhanced. In the figure 6, the result of temperature of heat structure is below the temperature limit of blanket module materials. And also the results are similar to the result of [1] and [2]. But some part of graph is different and this should be enhanced with nodalizing in detail with MELCOR. Figure 7 shows the heat structure difference between the results of with/without flow distributer. With Flow distributer, about 13 degree Celsius temperature difference is made.

4. Conclusions and Further Work

This study shows the result of thermal-hydraulic simulation of single blanket module with MELCOR which is severe accident code for nuclear fusion safety analysis. The difference of mass flow rate for each coolant channel with or without flow distributer is presented. With flow distributer, advantage of broadening temperature gradient in the K-DEMO blanket module and increase mass flow toward first wall is obtained. This can enhance the safety of K-DEMO blanket module. Most 13 ºC temperature difference in blanket module is obtained.

For further work, accurate correlation of material property and detailed nodalization of MELCOR should be conducted. CFD should be used for validation this results.

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