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Preliminary Thermal Analysis of the K-MSR

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1. Introduction

Carbon dioxide emissions from ships will be limited as part of global climate warming measure. For this reason, the MSR (Molted Salt Reactor) which is especially safe in accidents situations among numerous advantages has been spotlighted as the alternative of ship operations.

The project to apply the MSR to the marine ship started recently, that is named as K-MSR (Korea-Molten Salt Reactor), and the conceptual design has been in progress. To operate the K-MSR, it is essential to keep the salt fuel molten. Before injecting the molted salt fuel into the loop, all the components must be heated to the sufficient temperature. This paper contains the transient thermal analysis on the reactor at the initial stage of operation of the K-MSR.

2. Methods and Results

2.1 Reactor Description

As shown in Fig.1, the inlet of the salted fuel is located at the bottom of the cylinder-shaped reactor and it is discharged to the top of the cylinder-shaped reactor by operating the pump. The inside of the reactor has the perforate plate in order to distribution of the molten salt fuel flow uniformly, and the nuclear fission reaction occurs above the perforate plate.

At the initial stage, the inside of the reactor is vacant, and the reactor has to be heated sufficiently to prevent the molten salt fuel from solidifying before injecting it into the reactor. The target temperature on the surface contacting the molten salt fuel is selected as 590 ℃ within one day, and the reactor is heated through the heaters located outside the reactor.

Because the component including reactor arrives at very high temperature, the acceptable materials is inevitably limited [1]. The chosen material of the reactor vessel is 316 H after careful consideration, and the reflector of which the material is BeO is in annular space of the inside of the reactor. Meanwhile, the cladding on the surfaces contacting the molten salt is necessary due to corrosion and the cladding material is candidated as the Inconel 625.

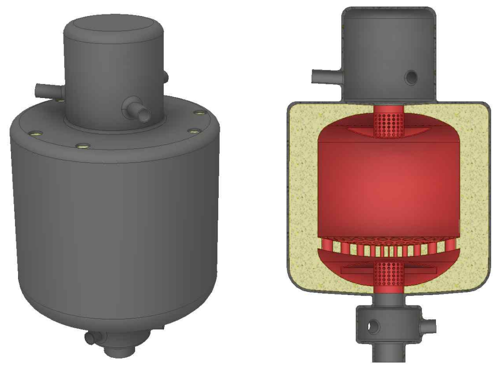

Fig. 1. Reactor Configuration

2.2 Equivalent Analysis Model

To carry the effective analysis out, the axisymmetric finite element model is constructed, and the reliable results can be obtained by replacing with the equivalent perforate plate. The inside of the perforate plate is occupied by BeO, and it contributes dominantly to thermal conduction and capacity.

The full 3D model of BeO in the perforate plate is as shown in Fig.2. It is assumed that the density and the thermal conductivity of BeO are 2930 kg/m^3 and 270 $W/m\cdot K$ [2]. The outer surface is applied to 600 W heat flow, and the hole surface located in the center is applied to 20 ℃ temperature. Other surfaces correspond to thermal insulation.

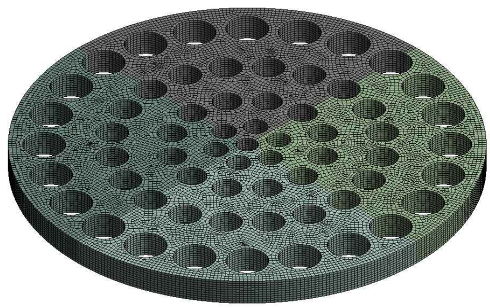

Fig. 2. Full 3D model of the BeO part in the perforate plate

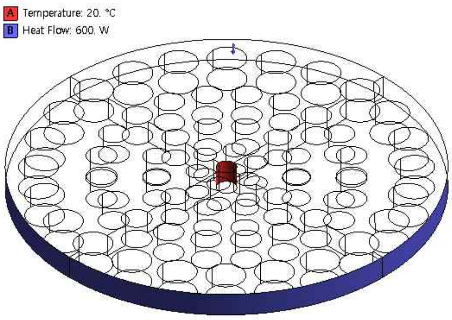

Fig. 3. Thermal Conditions

To construction the equivalent model, the nine parts are separated as shown in Fig. 4. The equivalent thermal conductivity on each part is calculated by using the following equation in cylindrical coordinates [3], and it is assumed that the thermal capacity is proportional to the volume fraction in corresponding part.

$$k_i = \frac{Q}{2\pi L\left(T_{i\_in} - T_{i\_out}\right)} \ln\left(\frac{R_{i\_out}}{R_{i\_in}}\right) \quad (1)$$

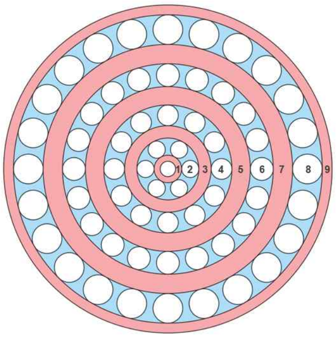

Fig. 4. 9 separated parts

The obtained equivalent thermal properties that are listed in Table I are substituted into 2D dimensional model as shown in Fig. 5, and the same thermal conditions are applied to the 2D axisymmetric equivalent model as shown in Fig. 6.

Table I: equivalent thermal conductivity on each part

Part	Volume Fraction	Density [kg/m^3]	R_{in} [m]	R_{out} [m]	T_{in} [℃]	T_{out} [℃]	Equivalent k [W/(m·℃)]
1	1	2930	0.043	0.077	20.00	21.46	367.16
2	0.424	1242	0.077	0.173	21.46	31.38	74.90
3	1	2930	0.173	0.242	31.38	31.84	671.44
4	0.42	1230.6	0.242	0.358	31.84	36.46	77.76
5	1	2930	0.358	0.461	36.46	36.92	509.17
6	0.39	1144.1	0.461	0.589	36.92	40.11	70.53
7	1	2930	0.589	0.697	40.11	40.40	534.91
8	0.36	1059.3	0.697	0.863	40.40	43.51	-63.11
9	1	2930	0.863	0.918	43.51	43.63	457.49

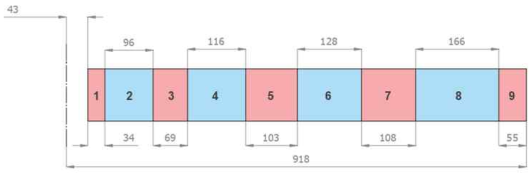

Fig. 5. Equivalent 2D model

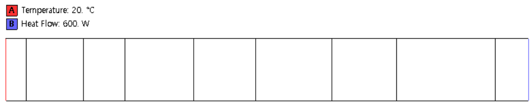

Fig. 6. Thermal conditions on the equivalent axisymmetric model

The temperature profiles along the center line for the full 3D model and equivalent 2D axisymmetric model are plotted in Fig. 7, and it is demonstrated that the equivalent 2D axisymmetric model can capture the thermal characteristic very well.

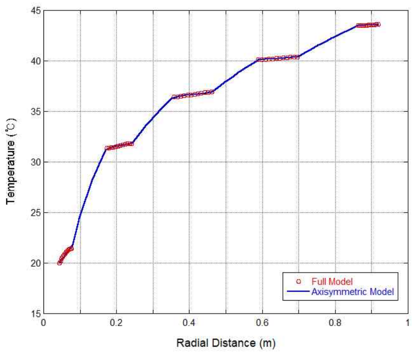

Fig. 7. Temperature profile along the center line for the 3D full model and the equivalent 2D axisymmetric model

2.3 Thermal Analysis of the Reactor

The perforate plate is replaced by the equivalent plate, and the axisymmetric model of the reactor for thermal analysis is shown in Fig.8. The material properties of 316 H are given in ref.[4]. Since the applied temperature on the outer surface of the reactor vessel is not still specified, it is assumed that temperature rises uniformly and is maintained costantly on all the surfaces.

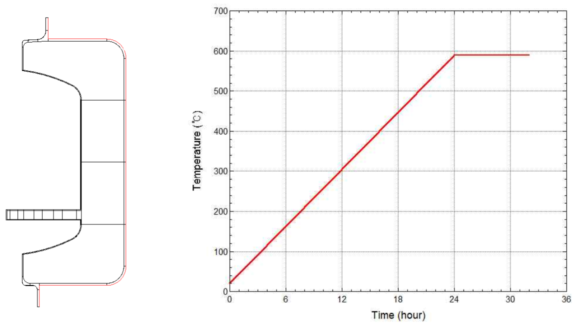

Fig. 8. The axisymmetric model of the reactor (left) and the applied thermal conditions on the red line (right)

The transient results on the reactor vessel and the reflector in the temperature rise section and the temperature maintenance section are plotted in Fig. 9 and Fig. 10, respectively. As shown in the temperature with time, all the part of the reactor reachd at the target temperature 590 ℃.

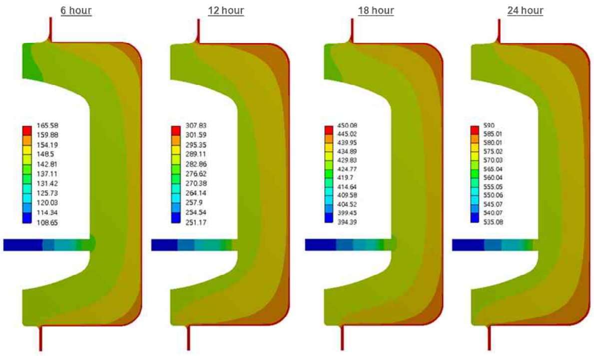

Fig. 9. The temperature results with varying time in the temperature rise section

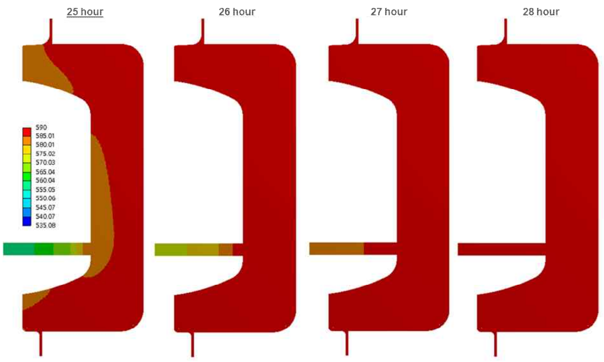

Fig. 10. The temperature results with varying time in the temperature maintenance section

3. Conclusions

This preliminary thermal analysis was carried out to judge the solidification of the molten salt fuel at the initial stage and specify the capacity of the heater approximately. The accurate analysis must be accompanied by the radiation from the heater later.

ACKNOWLEDGMENTS

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