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A study on cooling performance of out-core reflectors for a research reactor

Minkyu Jung [a*], Kijung Park [a], Kyoungwoo Seo [a], and Seonghoon Kim [a]
[a]*Korea Atomic Energy Research Institute, Daejeon 34057, Korea*
[*]*Corresponding author: minkyujung@kaeri.re.kr*

1. Introduction

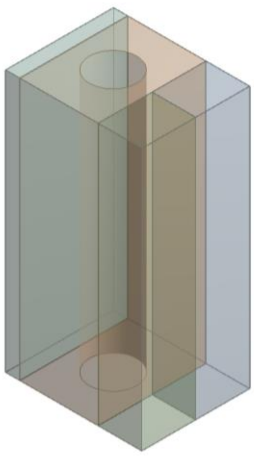
The reactor core is surrounded by a reflector. Main function of the reflector is to scatter neutron that leak from the core. Beryllium, graphite, or aluminum is mainly used for the material of reflectors. There are two reflector types, such as in-core and out-core reflectors. This reflector is particularly important in research reactors, since it is the region in which much of the experimental apparatus is located. The out-core reflectors provide site for NTD (Neutron Transmutation Doping) and PTS (Pneumatic Transfer System) [1].

In accordance with reactor operation, large heat is generated at the out-core reflector block. Thus, cooling shall be performed to reflector to maintain the structural integrity. To cool the out-core reflector, sufficient coolant and flow path are required. Therefore, in the present study, the simulation of the cooling characteristics for the out-core reflectors was performed in consideration of generated heat on reflectors.

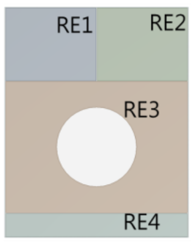
2. Methods and Results

2.1 Out-core reflector configuration

The configuration of out-core reflector block is represented in Fig. 1. The out-core reflector block consists of four reflectors with one NTD hole. To cool the reflector, the coolant shall pass the very small gap (<< 1cm) among the reflectors. The flow inlet is located at the bottom of the reflector block, and the coolant travels to the reflector gap through the horizontal flow path. The generated heat is high in order RE1, RE2, RE3, RE4.



(a) Perspective view



(b) Top view

Fig. 1. Configurations of the out-core reflector

2.2 Design requirements

For the cooling performance evaluation of the out-core reflector, two main design requirements are defined. The first requirement is that boiling should not be happened to retain the structural safety of the reflector. The second one is that the reflector should not be floated. As the reflector has no specific fixtures, the reflector could be floated by excessive upward flow. Therefore, the evaluation of the vertical forces, such as weight force, buoyancy force, and pressure force, should be performed.

2.3 Numerical methods

A commercial CFD (Computational Fluid Dynamics) software, ANSYS FLUENT is used for the cooling performance test of out-core reflectors [2]. Hexahedral meshes are mainly introduced to minimize the dispersion error by the mesh quality except for very complex region. Total 17M meshes are used for the flow simulation. The fluid motion is modeled by incompressible Reynolds-averaged Navier-Stokes equations. The numerical domain is discretized using cell-centered finite volume method. To check the cooling characteristic, energy equations also adopted.

2.4 Flow path design

The designed flow path is shown in Fig. 2. There are three inlet holes, which has the mass flow rate of 0.25kg/s for each inlet hole. The flow rate is determined by a precedent study [3]. The horizontal flow path is also presented that helps the coolant flow travels to the reflector gap.

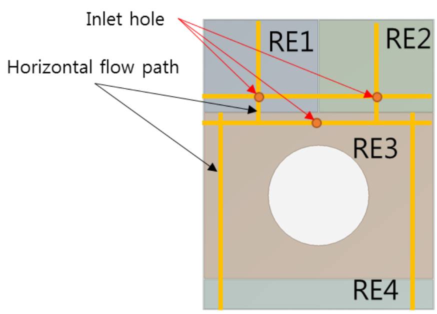


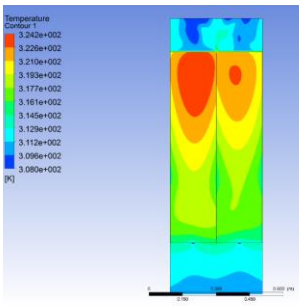
Fig. 2. Flow path for cooling the out-core reflector

3. Results

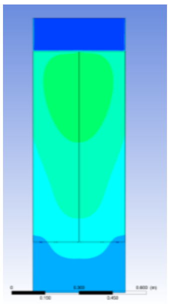
Two main design requirements are maximum temperature of out-core reflector or coolant and reflectors' floating possibility. Thus, numerical results are verified by the viewpoint of two design requirements, respectively.

3.1 Temperature distributions

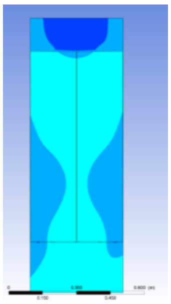
The temperature of inlet coolant is defined as 308 K. Temperature contours of the each reflector cross-section are shown in Fig. 3. It is shown that the maximum temperature is 324 K at the upper section of the RE1, which has highest heat value. It is also shown that the maximum temperature of each reflector is observed at the block center because the coolant flow is propagated along the both sides. Otherwise, only 5 temperature degree increment is shown at the RE4 contained lowest heat value.



(a) Center plane of RE1-2



(b) Center plane of RE3

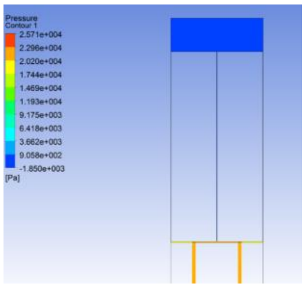


(c) Center plane of RE4

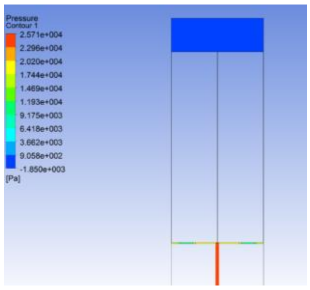
Fig. 3. Temperature contours for reflectors

3.2 Pressure distributions

To check the floating possibility, pressure forces are computed for each reflector. Figure 4 shows the pressure contours for reflectors at the center plane of inlet holes. It is shown that the pressure difference from the inlet hole to reflector top is about 25 kPa and 21 kPa for RE3 and RE1-2, respectively. It is caused that coolant from RE3 inlet travels longer distance to escape the reflector block.



(a) Center plane of RE1-2



(b) Center plane of RE3

Fig. 4. Pressure contours for reflectors

The result of maximum temperature and vertical forces are summarized in Table 1. Pressure forces are induced by the fluid dynamics around the reflector. And, Total forces acting on the reflector are evaluated by the difference between weight and buoyancy, pressure forces. It is presented that weight is higher than sum of buoyancy and pressure forces. From the result, it can be concluded that the designed coolant mass flow rate and flow path design are properly performed to cool the out-core reflector block.

Table 1. Temperature and vertical forces on out-core reflector block

Mass flow rate	0.25kg/s per hole	
Maximum Temperature	324.2K	
Block	Pressure force	Total force
RE1	71.5N	167.6N
RE2	71.5N	167.6N
RE3	127.5N	736.5N
RE4	10.6N	300.9N

4. Conclusions

In the present study, cooling performances are analyzed for the out-core reflector block. The reflector cooling is performed by coolant of 0.25kg/s mass flow rate per each inlet hole. It is shown that cooling of reflector block is suitably performed by the force convection. And, it is also presented that vertical force balance is maintained to ensure the structural integrity. This study could be utilized to design the flow path for various types of out-core reflector blocks.

ACKNOWLEDGEMENT

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[1] https://www.britannica.com/technology/nuclear-reactor/
[2] ANSYS FLUENT theory guide, ANSYS Inc., 2017.
[3] M. K. Jung, K. J. Park, S. H. Kim, CFD analysis for cooling characteristics of out-core reflectors of a research reactor, KSCFE Autumn Meeting, 2015.