Temperature Estimation of a Plate Type Target Cooled by Natural Convection in the Air

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1. Introduction

Fission Mo (Molybdenium) is the parent material of Tc-99m for medical diagnosis. Because it is widely used in the cancer diagnosis, the demand is expected to be increased more and more. It can be produced by the fission of Uranium-235 in the high neutron flux environment. Most fission Mo is produced by some research reactors over the world, which can generate a high neutron flux.

After being irradiated in the core for several days, the fission Mo target is withdrawn from the core, and stayed in the reactor pool to remove the decay heat for several dozens of hours. And then the fission Mo target is transported to the hot cell for next process to extract the Molybdenium-99. When the fission Mo target is transported from the reactor pool to the hot cell, it is exposed to the air. If the fission Mo target is not decayed to low level enough to be cooled by the natural convection of air, the temperature of fission Mo target would rise rapidly, moreover, the integrity of fission Mo target could not be ensured.

In the present, a numerical study using a CFD (Computational Fluid Dynamics) code is carried out to estimate the temperature of the fission Mo target cooled by natural convection in the air. There are three different cases. The first is the simplest model considering only single channel and target plate. The second is a full model including all parts of the fission Mo target holder. Finally single channel model considering the target plates separated from the target holder.

2. Modeling and Computation

A fission Mo target holder is designed to accommodate eight target plates. The target plates are in-lined with the uniform interval of 2.58 mm as shown in Fig. 1. The target holder is loaded in the specified irradiation hole of the reactor core. It is forcedly cooled by primary cooling water. After finishing irradiation process, the target holder is withdrawn from the irradiation hole, and wait until the decay power reduces as low as it can be cooled by air natural convection during transporting to hot cell. In order to estimate the temperature rise of the fission Mo target during the transporting to hot cell, three models representing different conditions are considered as follows.

2.1 Side-closed single channel

Because the fission Mo target plates are in-lined with an equal gap, it can be said that every single channel has same geometry and boundary conditions, except both outer channels. Therefore, single channel is available to estimate the temperature rise of the fission Mo target. The red dotted line box in the Fig. 2 indicates the boundary of simple channel model. This single channel model includes one coolant channel and facing target plates. For symmetric condition, the target plates are considered only a half part. The both sides of the channel and the target plates are treated as an adiabatic wall for conservatism. Fig. 3 shows a mesh model for CFD analysis.

2.2 Target holder model

The previous single channel model does not consider the target holder. However, the target holder is expected to act as a heat sink of the target plates. The full model of target holder is employed to determine the effect of heat transfer from the target plates to the holder. Fig. 4 shows the mesh model of targets and holder. The model includes some surrounding space in the vicinity of the holder to consider the condition that the target holder hangs in the air. Considering the symmetry condition of geometry, half model is employed for CFD analysis.

2.3 Side-open single channel

This model considers the condition that target plates are separated from the holder and hangs in the air at which more efficient cooling of target plates is expected owing

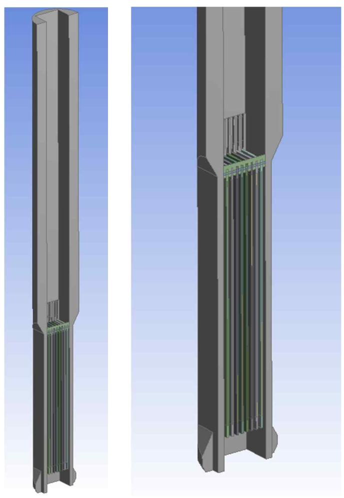

Fig. 1 Geometry of target holder

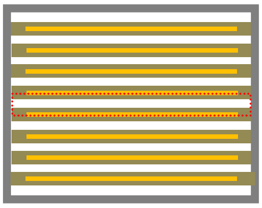

Fig. 2 Cross-section view of target holder

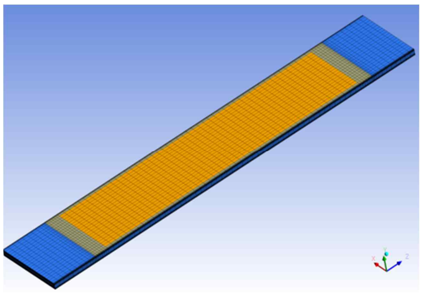

Fig. 3 Mesh model of single channel with both-side wall

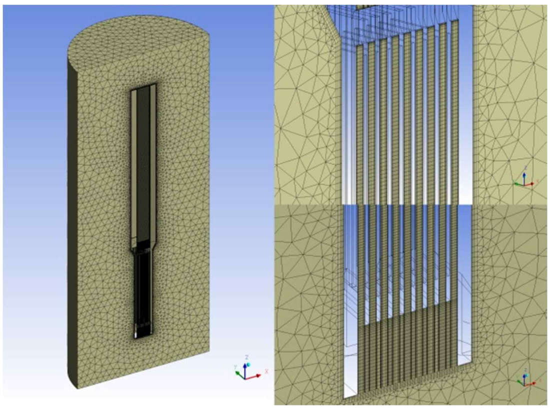

Fig. 4 Mesh model of target and holder

to the smooth flow of air from the open side. In order to determine the effect of air inflow coming from the both open side, this model extends the boundary of CFD analysis to the outer space of target plate as shown in Fig. 5.

2.4 Modeling set-up for calculation

For buoyancy of air flow, a full buoyancy modeling method was adopted to all calculation models, which treats the density of air as a function of temperature and pressure. The air is assumed to be ideal gas. The target plate is made of U_3Si_2 meat and aluminum alloy cladding. The target holder is also made of aluminum alloy. The thermal conductivities of them are 54 W/m K and 120 W/m K, respectively.
The k-ω based SST (Shear Stress Transport) model is used to simulate the turbulence effect, which is well known for a good prediction in various practical applications [1]. For treatment of boundary layer flow near wall region, automatic near wall treatment method is applied, which automatically adopts a wall function or a low Reynolds near wall formulation as the mesh is refined.
The iterative calculation keeps up until normalized

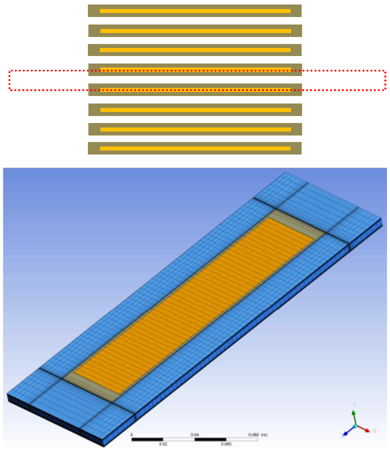

Fig. 5 Geometry and mesh model of target holder

RMS residual values of mass conservation equation and momentum equations reach the convergence criteria, below 1×10^{-4}. The convergence check of calculation is duplicated by means of monitoring dominant physical values such as pressure drop, velocity and temperature at several points. The monitoring values become very stable when the calculation sufficiently converges.

3. Results and Discussions

3.1 Side-closed single channel

Considering the melting point of aluminum alloy cladding, the temperature of target plate should be maintained below 600 °C, which is satisfied under the condition of 6.4 W. But the decay heat generation rate of a the target plate is estimated to be about 32 W after 24 hours from a point of withdrawn time. According to this calculation results as summarized in the table 1, it is impossible to cool down the target plate by the air natural convection. If the channel gap becomes wider to be 5 mm, the target plate could be maintained below 500 °C even at the condition of 32 W, which seems to be owing to more air flow of wide channel.

3.2 Target holder model

Because the both ends of target plates contact to the target holder, it is expected that the target plates transfer their decay heat to the target holder by conduction through the contact area, which means that the target holder may act as a heat sink of target plates. But the target plates do not contact to the target holder perfectly, there exists a contact resistance of heat transfer between them, called as contact thermal resistance. At first, the calculation assuming that the target plates are embedded

Table 1 Results of side-closed single channel

Channel width (mm)	*Total heat Gen. (W)*	*Max. Temp. of surface(℃)*	*Outlet temp. of air (℃)*	*Flow rate of air (kg/s)*
2.58	3.2	270	269	1.41×10^{-5}
	6.4	510	509	1.38×10^{-5}
	9.6	907	906	1.12×10^{-5}
5.0	16.0	260	250	7.47×10^{-5}
	32.0	467	447	7.80×10^{-5}

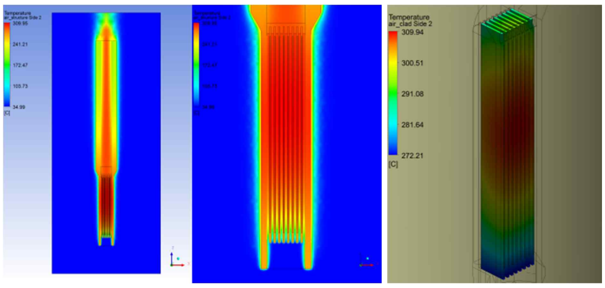

Fig. 6 Temperature distribution of target plates and holder assuming a perfect contact

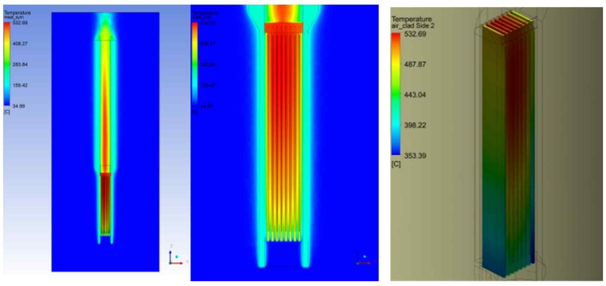

Fig. 7 Effect of contact thermal resistance between the target plates and holder

Table 2 Summary of target holder model

Contact thermal resistance (K℃/W)	*Total heat Gen. (W)*	*Max. Temp. of surface(℃)*	*Outlet temp. of air (℃)*	*Flow rate of air (kg/s)*
0	256	310	246	1.85×10^{-4}
2.75×10^{-4}	256	624	345	1.68×10^{-4}
2.75×10^{-4}	226	533	300	1.72×10^{-4}

into the target holder like one body is carried out. And another calculation considering the contact thermal resistance is conducted.

Comparing to the previous case considering only target plates, target holder model shows much lower temperature at the same decay heat condition as shown in Fig. 6, which means the target holder may act as a heat sink of target plates and enhances the cooling capacity. The heat transfer from the target plates to the holder strongly depends on the contact thermal resistance between them. Fig. 7 shows the effect of contact thermal resistance. By applying merely the contact thermal resistance between the target plates and holder, the temperature of target plates greatly rise high as shown in Fig. 8. Because the target plates are inserted very loosely into the grooves of the holder, the contact thermal resistance would be much larger than the simple contact condition, therefore it is very difficult to estimate the contact thermal resistance for this condition. The value used in this calculation is assumed by referring to a text book [2].

3.3 Side-open single channel

If the target plates are separated from the holder, it could be cooled more efficiently because of air flow increase owing to expanding an inlet flow area. Fig. 9 shows the calculation results on the temperature of target plate hanging in the air without the holder. In the figure the maximum temperature of target is about 413

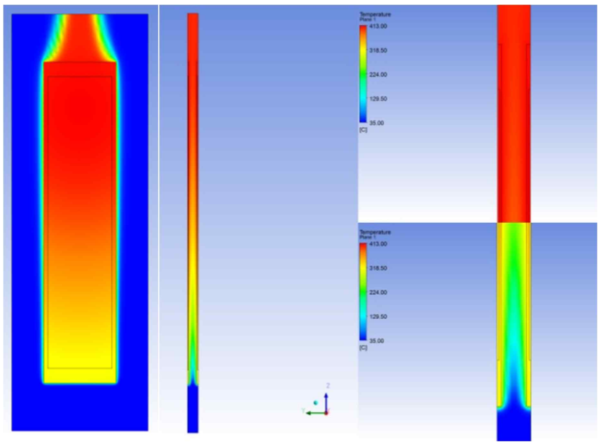

Fig. 9 Temperature distribution of side-open channel

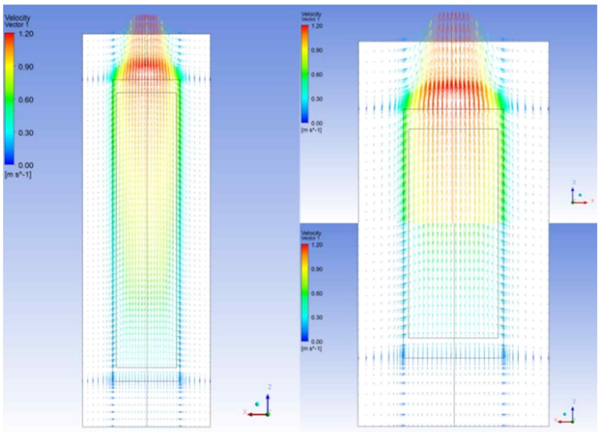

Fig. 10 Velocity vectors in the side-open channel

°C even at the decay heat of 32 W, which is much lower than the aluminum alloy melting point. According to Fig. 10 showing velocity vectors in the side-open channel, the air flow comes from the bottom of channel as well as the both open sides. This attributes smooth air flow to cooling of target plate.

4. Conclusions

A numerical study using a CFD code is carried out to estimate the temperature of the fission Mo target cooled by natural convection in the air. When the target plates are in the holder, the temperature rises up as high as the melting point of aluminum cladding because of the lack of air flow. When the target plates are separated from the holder, they can be cooled more efficiently and maintain the temperature low enough to keep the integrity of target plates.

REFERENCES

[1] ANSYS CFX-Solver modeling guide, 2011, ANSYS Inc.
[2] J. P. Holman, Heat Transfer, 7th Ed. 1990.