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Preparation of 3D Printed Divertor Mock-up Design and Fabrication

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1. Introduction

The divertor for fusion reactor is known to be able to remove the extreme heat flux up to 10 MW/m^2 and the various type of divertors have been developed for enhancing the heat transfer such as hypervapotron, twisted tape insertion, screwed tube, and so on. However, the geometry of these devices is limited due to the fabrication especially with machining. In order to overcome this limitation, 3D printing method is considered to be used in the fusion reactor divertor design in present study.

With the advantages of the 3D printing, the various shapes of the inner divertor cooling tube are investigated to enhance the turbulence of coolant and to reduce the pressure drop. The metallic powder of the fusion reactor candidate mateiral is produced as the preliminary step for using in 3D printer. The material is a reduced activation ferritic-matensitic steel named as ARAA (Advanced Reduced Activation Alloy) which have been independently developed in Korea. Gas atomization method was used to make the spherical particles with average diameter of 100 μm. Several candidates were presented to achieve the excellent heat removal capacity and the low pressure drop.

Thermal-hydraulic analysis was performed to confirm the effects of the inner cooling tube geometry with a conventional CFD code, ANSYS-CFX v14.5. The 3 types of channel which are a simple straight tube, a tube with a twisted tape and an unique tube with a rail-type geometry were selected to compare the cooling performance and the pressure drop, in which a rail-type cooling tube is invented in the present study. The size of screw tab and pitch was determined by the optimization process. From the preliminary analysis, it is confirmed that a tube with a rail-type geometry has the same heat transfer performance of a twisted taped tube with a reduced pressure drop.

2. Preliminary study and candidate design selection

As shown in Fig.1, in ITER, the divertor, located at the bottom of the machine, is based on a single null poloidal geometry with active pumping, and provides for power and particle exhaust. It is designed to facilitate large radiation losses and to control the location of the radiating region by confining the recycling of neutral impurities and hydrogen to the divertor chamber. The reference design employs a socalled 'vertical target' concept which has the advantage that the plasma provides a tight seal for the neutrals while the 'wetted' area is maximised due to the inclination of the divertor plates. The vertical target must be designed to the most demanding divertor heat load requirements, namely for transients of up to 20 MW/m^2 over about 10 s.

For remove the extreme heat in the divertor, different PFC coolant channel configurations were considered to provide an acceptable CHF margin for the given coolant conditions, including swirl tapes, hypervapotrons, screw tubes and channels with porous coating. Other discerning factors included the impact on the cooling system design and cost such as the overall required flow rate and the in-vessel pressure drop, the performance and lifetime of the PFC configuration and the breadth of the data base.

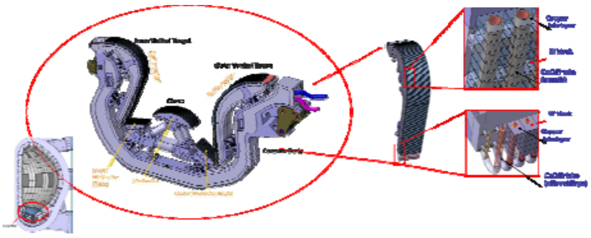
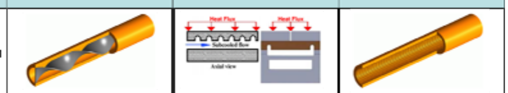


Fig. 1. ITER divertor and its cooling tubes

Table I: Candidate divertor design and their characteristics



	Swirl tube	Hypervapotron	Screw tube
Concept design			
Advantage	Swirl flow(turbulence↑) Centripetal force (CHF↑)	Cavity, side slot (CHF↑) Curve surface (O) Low pressure drop	Heat transfer area↑ Simple manufacturing Low pressure drop
disadvantage	High pressure drop Curve surface (X)	Welding (thermal fatigue)	Curve surface (X)
application	ITER divertor concept	ITER divertor concept	

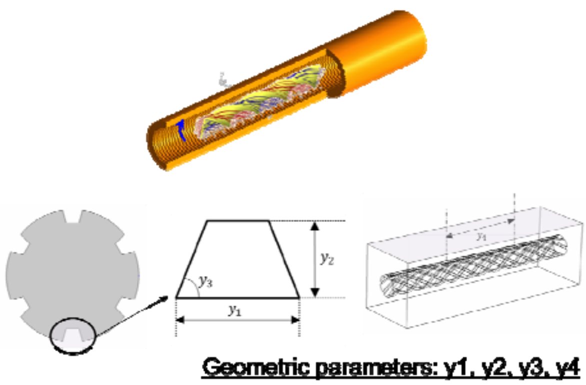


Fig. 2. Invented rail-type cooling concept

The main characteristics of both swirl tube and hypervapotron are summarized in Table I including the other concept of screw tube. It is known that these concept can remove the heat flux up to 5 ~ 10 MW/m^2 but the applied area is very limited due to the fabrication by machining. If there is no limitation to make the cooling tube, the various geometries can be applied in the divertor design and we started with the draft design of the rail-type cooling tube, as shown in Fig. 2. The key assumption is to use the 3D printing method and therefore, the possibility that the candidate material for fusion reactor structure was investigated in the next section.

3. Fabrication of metallic powder with ARAA

Gas atomization method was used to make the spherical particle with the diameter of under 100 μm. And also the Korean fusion structural material, ARAA (Advanced Reduced Activation Alloy) was used. Figure 3 shows the gas amoization method and the successfully fabricated ARAA powder.

Fig. 3. Fabrication method and resulted powder with ARAA

4. Preliminary analysis

For invented rail-type cooling tube design, the nominal tube and swirl tube were compared through the analysis in terms of heat transfer enhancement and pressure drop reduction. The proposed design especially for the diameters and lengths are shown in Fig. 4; inner diameter is 6 mm and the tube wall thickness is 2 mm. The heat absorbed area was considered with monoblock type divertor for testing in the KoHLT-EB at KAERI.

Total numbers of elements is 3 to 5 Millions as shown in Fig. 5. And also, In the analysis, only the surface heat flux was considered, and the water condition was reflected by considering the KoHLT-EB water supply system (0.3 MPa, 25°C). To determine the proper test time and to avoid the W evaporation temperature, the heat fluxes were assumed to be a 0.75 MW/m^2.

From the analysis, the maximum temperatuers are 441 °C for nomal tube, 430 °C for twisted tape tube, and 431 °C for rail-type tube, respectively. It is the case of heat flux with 0.75 MW/m^2 but the temperature differences are enlarged according to the increased heat flux up to 10 MW/m^2. For the pressure drop aspect, 0.012 MPa for normal tube, 0.066 MPa for twisted tape tube, and 0.042 MPa for rail-type tube, respectively. Conclusively, the rail type twisted tube showed similar performance on heat transfer and reduced pressure drop in comparison with the conventional twisted tube.

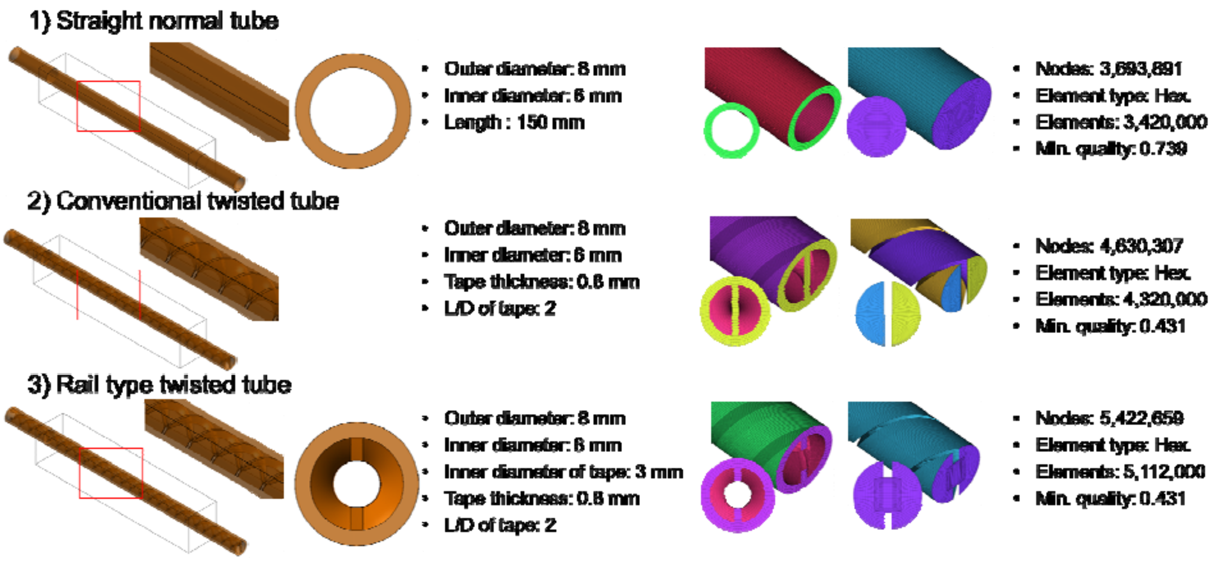


Fig. 4. Geometries and meshes for preliminary analysis

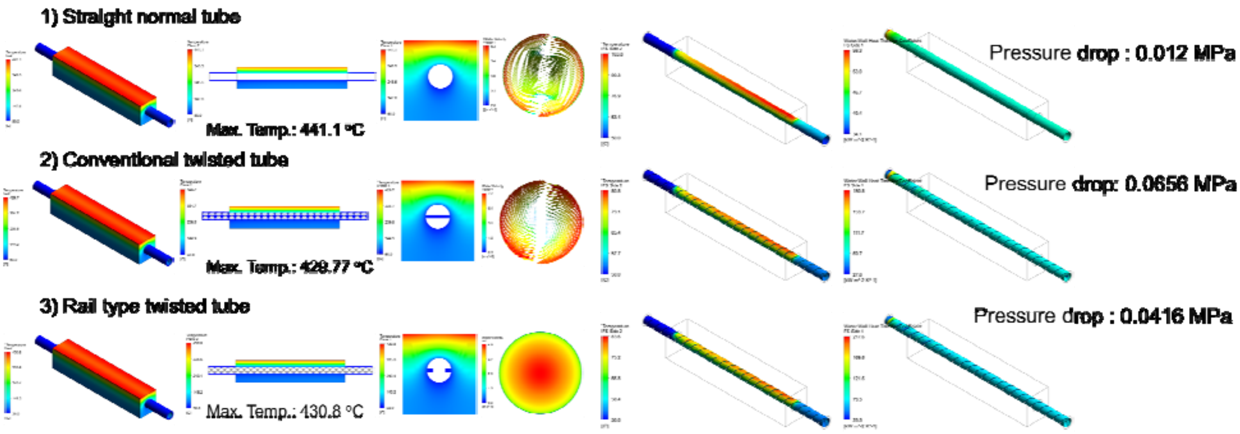


Fig. 5. Temperature and velocity distribution, and pressure drops of preliminary analysis results

3. Conclusions

The modified screw type called as a rail type twisted tube was presented through the optimization process. This complicated tube could be made by 3D printing technology. (metallic powder). Thermal-hydraulic analysis was conducted to compare the 3 type geometric divertor. A rail type twisted tube has good heat transfer performance in comparison with a conventional twisted tube. The pressure drop of a rail type twisted tube was reduced about 36% compared with a conventional twisted tube.

Acknowledgments

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