Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Thermal Analysis on Conceptual K-DEMO Breeding Blanket on parallel flow configuration

Il-Woong Park[a*], Jeong-Hun Lee[a], Geon-Woo Kim[a], Kihak Im[b], Keeman Kim[b], Hyoung Chan Kim[b], Goon-Cherl Park[a], Hyoung-Kyu Cho[a]
[a]*Department of Nuclear Engineering, Seoul National University 1 Gwanak-ro, Gwanak-gu, Seoul 151-744*
[b]*National Fusion Research Institute 169-148 Gwahak-ro, Yuseong-gu, Daejeon 305-806*
[*]*Corresponding author: chohk@snu.ac.kr*

1. Introduction

A preliminary concept for the Korean Fusion DEMOnstration reactor (K-DEMO) has been studied by the National Fusion Research Institute (NFRI) [1] based on the National Fusion Roadmap [2]. The feasibility study consists the design guidelines and requirements for the K-DEMO reactor. It is possible to design flexible and realistic concepts of the demonstration fusion power plant. As a part of the NFRI research, Seoul National University (SNU) is conducting thermal design, evaluation and validation of the breeding blanket for the K-DEMO reactor. Recently, a new breeding blanket concept has been proposed for the K-DEMO reactor, and preliminary feasibility studies are actively ongoing.

2. Design concept of breeding blanket

The breeding blanket concept was proposed by NFRI [3]. In the concept definition, pressurized water is used as a coolant and a reduced activation ferritic/martensitic steel (F82H) [4] is adopted for the structural material. A Li_4SiO_4 pebble bed and beryllium pebble bed [5] are considered as the tritium breeder and neutron multiplier in the breeding blanket. The design requirements are defined by the temperature window of the structural material [6, 7] and temperature limits of the beryllium and Li_4SiO_4 pebble beds [8].

The plate-type blanket geometry consists of stacked parallel components and has purge gas lines penetrating those layers as conceptually illustrated in Fig. 1. In this study, it was assumed that the blanket has a rectangular geometry. The preliminary conceptual design has 1.0 m in poloidal height, 0.1 m in toroidal width and 0.01 m poloidal flow header height.

There are two flow concept for plate-type blanket as shown in Fig. 2. In feasibility test, (a) type of flow configuration which is reference of breeding blanket was used. It has an advantages on simple geometry of flow configuration. However, it has a disadvantages on efficiency of heat transfer. This is because too much pressurized water flows along the far-off side from first wall which has very low heat is generated. To obtain enough outlet temperature and flow rate of near first wall channel, (b) type of flow configuration is proposed. It is expected to have a better efficiency on heat transfer. However, it has drawbacks on neutron penetration. Type of (b) flow configuration could yield neutron penetration along the flow path which is widened compared to reference flow configuration. There are no restriction on flow header size to concern about penetrating neutrons but, it has to be considered to design breeding blanket.

3. Feasibility test on thermal design

For proposed breeding blanket design concept, a feasibility study was performed and thermal limitations was evaluated using CFX-13 [9]. The pressurized water is distributed and collected by flow headers which are located at the lower and upper parts of the breeding blanket. The breeding blanket was cooled by pressurized water at 300℃ inlet temperature and 15 MPa operating pressure in CFD simulation. The inlet temperature was selected based on the temperature window of RAFM steel (300-550℃). To retain a sufficient temperature difference and avoid boiling of the water, the operating pressure considered same as that of pressurized water reactor.

As a turbulence model, the k–ω Shear Stress Transport (SST) model, which is well known to have better accuracy for local heat transfer and flow separation, was used [10]. This was because there are several flow separations in the breeding blanket. Also, it is important to obtain the local temperature to identify satisfactions of thermal limits. The size of the first mesh of fluid domain adjacent to the solid domain was 3.2e-5 m and the number of mesh was approximately 3.6 million. A 10 m/s inlet velocity was used for flow inlet header.

The temperature distributions in the breeding blanket were obtained in CFD calculation. The temperatures of the structural material (F82H), the Li_4SiO_4 pebble bed and beryllium pebble bed did not exceed 550℃, 900℃ and 600℃, as shown in Fig. 3. This shows that thermal limitations, including the temperature window of the structural material and temperature limits of the Li_4SiO_4 and beryllium pebble bed, were satisfied with the conceptual design.

The maximum temperatures on the tungsten and the structural material adjacent to first wall, which are not shown in Fig. 2, were calculated as 570.0℃ and 538.39℃. These values were within the temperature windows of tungsten (1000℃) and F82H (550℃). It could be concluded that the results are allowable for this preliminary breeding blanket thermal limitation, with a few margin for surface heat load. Moreover, the pressure drop and outlet temperature were predicted to 47.57 kPa and 311.4℃.

It is expected that not only higher outlet temperature but also higher pressure drop in analysis for type (b). To consider both outlet temperature and pressure drop in breeding blanket, analysis on flow configurations need to be conducted.

4. Conclusions

Design concept of parallel plate-type blanket of K-DEMO and thermal limits on components was identified, in this study. It was concluded that an acceptable thermal design was achieved in the proposed breeding blanket design. However, some design improvements in the geometry of the breeding blanket are ongoing. In aspect of pressure drop and outlet temperature, some analysis need to be conducted.

Stage of study on the K-DEMO reactor is in the preliminary concept definition. Thus, the conceptual study of the thermal analysis of the K-DEMO reactor will be performed continuously. Based on this study further conceptual design study of the K-DEMO reactor will be performed.

Acknowledgement

This work was supported by National R&D Program through the National Research Foundation of Korea(NRF) grant funded by MSIP; Ministry of Science ICT & Future Planning (No. 0602-20130023).

REFERENCES

[1] Keeman Kim. et al 2012 Fusion Eng. Des. 88 488
[2] M. Kwon. et al 2012 Fusion Eng. Des. 83 833
[3] Y. S. Lee et al, In Fusion Engineering (SOFE), 2013 IEEE 25th Symposium on IEEE 1.
[4] S Jitsukawa. et al 2002 Journal of Nuclear Materials 307 179
[5] S.J Zinkle, N.M Ghoniem. 2000 Fusion Eng. Des. 51 55
[6] M. Dalle Donne. et al 2000 Fusion Eng. Des. 49 521
[7] X. Jia., Y. Dai, M. Victoria. 2002 Fusion Eng. Des.3053 1
[8] M. Enoeda. et al 2003 Nuclear Fusion. 43 1837
[9] ANSYS 2010 CFX-Solver Theory Guide (Canonosburg: ANSYS Inc)
[10] F. R. Menter, 2003 Turbulence, heat and mass transfer. 4 625
[11] M.K Bassiouny. 1984 Chemical Engineering Science. 39 693
[12] S. Maharudrayya. et al 2005 Journal of Power Sources. 144 94
[13] J. Wang. 2008 International Journal of Hydrogen Energy. 33 6339

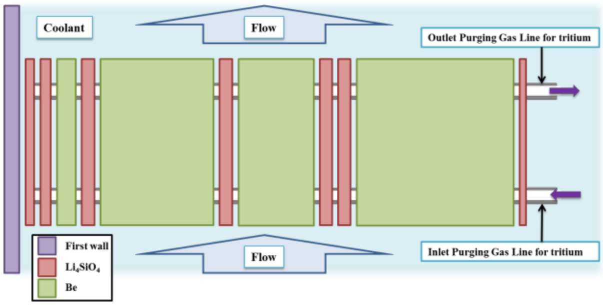

Fig. 1. Plate-type breeding blanket concept K-DEMO

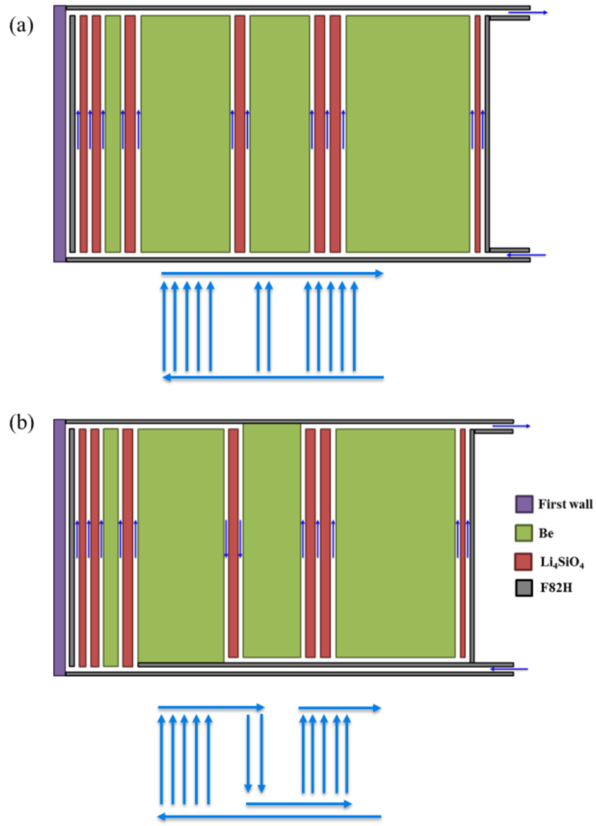

Fig. 2. Two flow line concept for breeding blanket

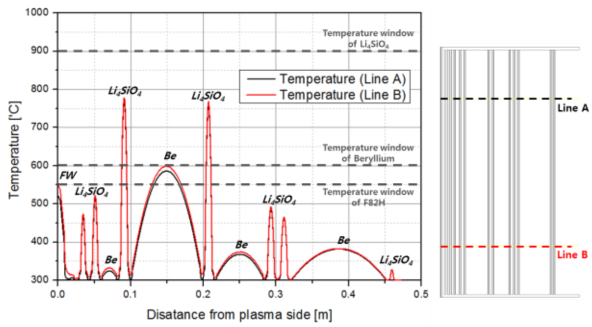

Fig. 3. Temperature distribution in breeding blanket