COMPARATIVE NEUTRONICS ANALYSIS OF THREE STRUCTURES OF HELIUM - COOLED BLANKETS FOR COMPACT FUSION REACTORS

[1] Ziqiang Zhao, [1] Xiaoyong Wang
[1] Southwestern Institute of Physics, Chengdu, China
Email: zhaozq@swip.ac.cn

1. Introduction

Most fusion reactor designs, such as ARIES, CFETR, and DEMO, assume high power (e.g., 1000 MW) and large size (major radius > 6 meters). This leads to high costs and long construction times, posing challenges to nuclear fusion engineering R&D. In contrast, a certain compact Tokamak fusion reactor with a compact layout is more competitive due to its smaller volume, lower cost, and reduced risk.

In fusion reactors, the tritium breeding blanket (TBB) is crucial for tritium self sufficiency, requiring a tritium breeding ratio (TBR) > 1.15. The helium cooled ceramic breeder blanket (HCCB) is a promising candidate for its advantages in heat conduction, chemical stability, and safety. However, the traditional multi module segment (MMS) sandwich structured blanket has difficulties meeting the TBR requirements of compact reactors. Issues like neutron leakage between modules and neutron absorption by side plate materials reduce the TBR. Also, in compact reactors, the large proportion shielding area leaves a relatively small breeding area, making it hard for the MMS blanket to meet design expectations, and its maintenance is inconvenient.

2. Research Aims

This study focuses on three HCCB structures for a compact Tokamak fusion reactor: the multi module sandwich structure, the single module ring arranged dense type structure, and the single module pin shaped sleeve structure. The aims are two fold: 1. Compare the advantages and disadvantages of single module blanket designs. 2. Design a blanket structure considering port situations that meets the tritium self sufficiency requirement (TBR > 1.15).

3. Methodology

A three dimensional neutronics model was established. Neutronics transport calculations were performed using the MCNP program and the FENDL2.1 library. Neutronics burn up calculations were carried out with the help of the FISPACT 2007 and EAF 2007 library. As shown in Fig. 1, it is the outer blanket of the single - module ring - arranged dense - type structure.

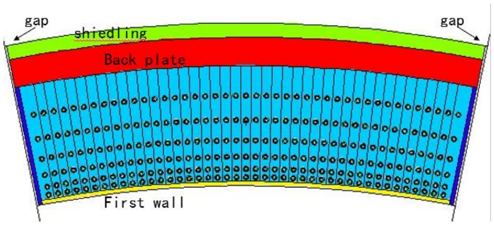

Fig.1 the single module ring arranged dense type structure outer blanket

4. Key Results

4.1 Tritium Breeding Ratio Improvements

Sandwich structured blanket: The initial TBR of the sandwich structured blanket design was 1.07. By increasing the blanket coverage rate, especially in the divertor area, and enhancing neutron reflection, the TBR increased by 11.60% to reach a relatively high level. This optimization improved the blanket's neutron capturing and utilizing efficiency, promoting more neutrons to participate in the tritium breeding reaction. As depicted in Fig. 2, it is the Sandwich - Structured Blanket.

Single module blanket: In the single module blanket design, three optimization measures were taken. Adjusting gaps to increase the coverage rate reduced neutron loss in the gaps, allowing more neutrons to interact with breeding materials. Selecting low neutron absorption cross section structural materials minimized neutron absorption by the structure. Using beryllium materials with a high neutron scattering cross section increased neutron multiplication. These measures increased the TBR by 7.29%, demonstrating the effectiveness of the single module structural design in optimizing neutronics performance. As presented in Fig. 3, it is a distribution map of TBR values for different design cases of the pin - shaped blanket.

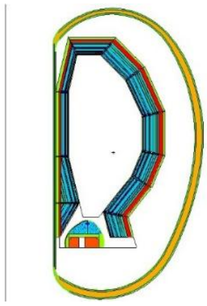

Fig.2 the Sandwich-Structured Blanket

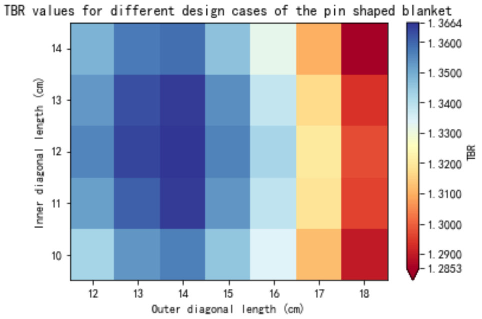

Fig.3 a distribution map of TBR values for different design cases of the pin shaped blanket

4.2 Comparison of Different Structures

Research results show that single module structures (ring arranged dense type and pin shaped sleeve) have a higher TBR than the multi module sandwich structure. However, they also have greater nuclear heat deposition and lithium burn up. The differences in irradiation damage among the three structures are small.

4.3 Impact of port Design

For the single module ring arranged dense type structure with an initial TBR of 1.28, the port design reduced the blanket coverage rate and increased neutron leakage, causing the TBR to decrease by 3.48%. This indicates that blanket coverage rate and neutron leakage significantly impact the TBR.

4.4 Achieving Tritium Self Sufficiency

A blanket structure that meets the tritium self-sufficiency requirement (TBR > 1.15) considering port conditions was designed. This achievement is presented in Fig. 3 (360degree neutronics model considering the port), which lays a solid foundation for further blanket design in terms of optimization, thermo hydraulic design, and structural design.

5. Conclusion

This research successfully compared the performance of different HCCB structures for compact fusion reactors. The single module designs showed higher TBR but higher nuclear heat deposition and lithium burn up. The impact of port design on TBR was also clearly demonstrated. The designed blanket structure meeting the tritium self-sufficiency requirement is a significant step forward.

6. Novelty and Future Work

The analysis of the three specific HCCB structures and their performance comparison is novel. Future work could further optimize the single - module blanket structures to reduce nuclear heat deposition and lithium burn - up while maintaining a high TBR.

ACKNOWLEDGEMENTS

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