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First thermal-hydraulic and thermal-mechanical analysis of a CO2-cooled solid breeding blanket for the EU-DEMO

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ABSTRACT : Due to the larger density of CO2, the use of this gas as primary coolant for DEMO can lead to key advantageous features, mitigating most of the issues posed for He-cooling and resulting in a higher net efficiency than that of HCPB, as reported in a previous study. Therefore, a CO2-cooled Pebble Bed (CCPB) has been proposed as an alternative coolant to He for the EU-DEMO. After identifying that CO2 will have a negligible influence on the neutronic performance, making the CCPB's TBR almost equal to the HCPB's one (TBR ≈ 1.15), a full first set of thermo-hydraulic and thermo-mechanical analyses with the commercial code of ANSYS CFX are reported here. The analyses are based on the newly proposed design of breeding zone (BZ) in the enhanced HCPB fuel-pin concept for the EU-DEMO. Such pin-type fuel elements have been already used, for instance, in liquid metal fast reactors since the 1960s. The paper will show that, despite the lower heat transfer capability of CO2 with respect to He, the fuel-pin design breeding zone improves the thermo-hydraulic performance, meeting the materials' temperature requirements. For the thermal-mechanical analysis, the structural behavior under normal operation has been assessed according to the available codes and standards (RCC-MRx). The results show that the CCPB can satisfy the basic thermal and mechanical blanket requirements and that CO2 is a realistic option as primary coolant for gas-cooled fusion reactors.

1. Introduction

The EU Demonstration Fusion Power Plant (DEMO) is considered to be the last step before building a commercial fusion power plant. The main goals of EU DEMO are:

- resolving all remaining physics and technical issues foreseen in the plant and demonstrating the necessary reactor relevant technologies;
- demonstrating production of several 100's MW of electricity power;
- achieving tritium self-sufficiency;
- operating with adequate availability over a reasonable time span;
- minimization of radioactive wastes, with no-long-term storage; (vi) extrapolation to a commercial fusion power plant.

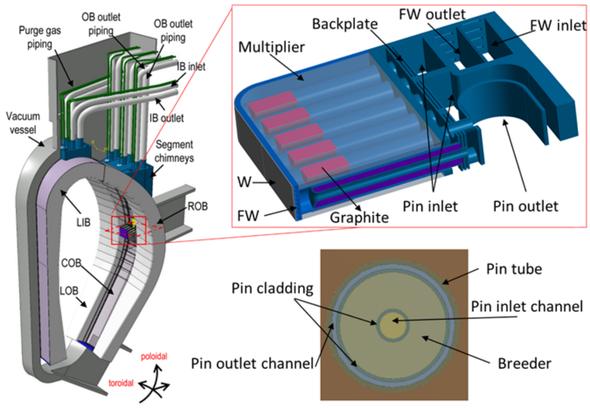


Fig. 1 CCPB integrated in EU DEMO BL2017 sector

2. The CCPB BB design

2.1 Material selection

- Structure material: EUROFER97
- Tritium breeder: Li_4SiO_4
- Neutorn multiplier: $Be_{12}Ti$

2.2 Basic structure

- Combined FW design
- 12 Pins for CCPB BZ
- Pin diameter: 86 mm

2.3 Coolant parameters and gas flow scheme

- CO2 as coolant, inlet/outlet temperature: 300° C / 500° C;
- Coolant pressure: 8 MPa, 0.2 MPa purge gas (He+ 0.1% vol. H_2).

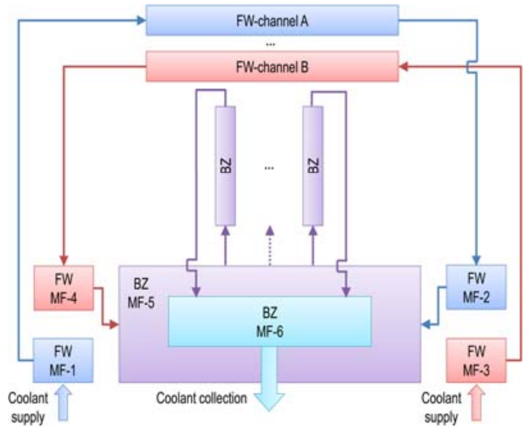
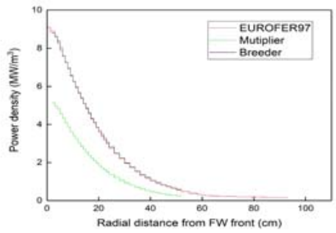


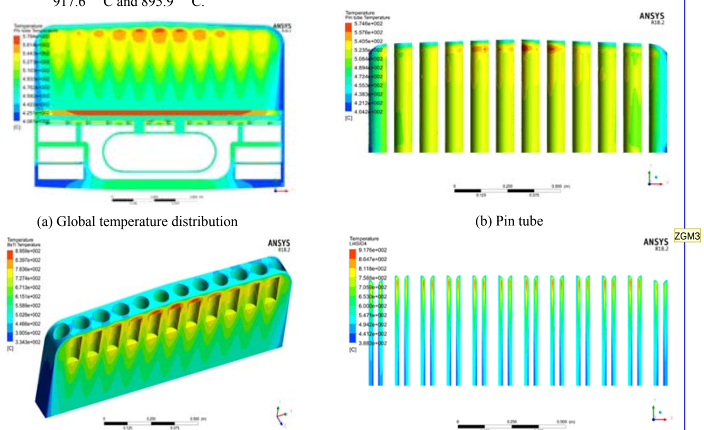
Fig. 2 Schematic flow scheme

4. Thermal-hydraulic analysis

- Combined FW design;
- 12 Pins for CCPB BZ;
- Pin diameter: 86 mm;
- Thermal power for BB: 2248.9 MW;
- A total mass flow of BB: 10199.5 kg/s;
- The mass flow for one cooling channel of FW is 0.12 kg/s ;
- The inlet mass flow for one pin of BZ is 0.08 kg/s.



- Heat flux of 0.37 MW/m², including the radiation heat flux of 0.31 MW/m² and the particle heat flux of 0.06 MW/m² ;
- The maximum temperature of the structural material, the Li_4SiO_4 and the $Be_{12}Ti$ are 574.6 ° C, 917.6 ° C and 895.9 ° C.



(a) Global temperature distribution (b) Pin tube

(c) $Be_{12}Ti$ (d) Li_4SiO_4

Fig. 4 Temperature distribution of typical CCPB unit slice

5. Thermal-mechanical analysis

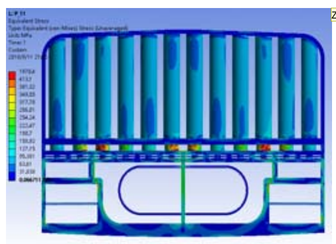


Fig. 5 Primary stress of typical CCPB slice

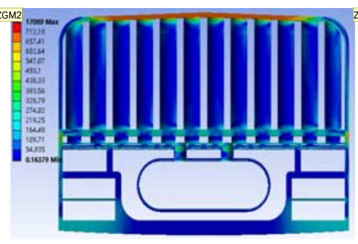


Fig. 6 P+Q of typical CCPB slice

- A well global structural performance at FW and BSS
- Improvement needed for connecting regions of BZ and BSS

6. Conclusion

✓ A EU DEMO CCPB BB has been firstly presented in this paper. CO2 is selected as coolant for the blanket;

✓ The basic structure, preliminary thermal hydraulic and thermal mechanical analysis have been described;

✓ Results show that the current CCPB BB meets the basic thermal requirements and the mechanical performance should be improved.

Reference:

[1] F. Hernández, et al. "A new HCPB breeding blanket for the EU DEMO: Evolution, rationale and preliminary performances." Fusion Engineering and Design 124 (2017): 882-886.

Folie 1

ZGM1 Zhou, Guangming; 12.09.2018

ZGM2 Figure should be changed.
Zhou, Guangming; 12.09.2018

ZGM3 Fig.4 Figures should be changed.
Zhou, Guangming; 12.09.2018