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# Preliminary steady state and transient thermal analysis of the new HCPB blanket for EU DEMO reactor

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ABSTRACT

This paper reports the thermal analyses of a new version of the Helium Cooled Pebble Bed (HCPB) blanket developed in Karlsruhe Institute of Technology (KIT) for the updated European fusion DEMO reactor. The blanket thermal behavior under DEMO typical pulse operation has been investigated, which serves as input to the structural analyses. The impact of thermal contact conductance between pebble beds and wall on blanket temperatures has been analyzed. The result shows that the thermal contact conductance has a sensitive influence on the temperature of Be pebble bed while exerts a limited influence on that of lithium orthosilicate pebble bed and EUROFER. The lack of contact may cause a local overheating of the Be pebbles, hindering the tritium extraction capability of the purge gas. The transient thermal analysis of the blanket after ex-vessel loss-of-coolant accidents has been studied, finding the FW will not melt under assumed conditions. The analysis of two soft plasma shutdown schemes after Ex-VV LOCA suggested that non-disruptive plasma shutdown should be as quickly as we can manage to reduce the high temperature reaching on the FW.



## Introduction

Development of a demonstration fusion power plant (called DEMO) is considered in almost all the fusion roadmaps (see e.g. the EU roadmap [1]) as a crucial step beyond ITER leading toward fusion energy. In such a plant two major functions have to be achieved, namely to breed tritium for fuel self-sufficiency and to extract the heat at high coolant temperature to allow an efficient production of electrical energy. The breeding blanket is the key component to ensure these two functions. One of the most studied blanket concepts is the helium cooled solid breeder blanket; it is considered in the design of several ITER Test blankets and DEMO breeding blankets [2–9]; in Europe it is known under the name of Helium Cooled Pebble Bed (HCPB) blanket and is one of the main

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candidates for the EU DEMO reactor [10–12]. This concept uses high pressure (8 MPa) helium gas at the temperature of 300–500 °C as coolant. Lithium orthosilicate ($Li_4SiO_4$) pebble bed acts as tritium breeder, beryllium (Be) pebble bed as neutron multiplier and the Reduced Activation Ferritic/Martensitic (RAFM) steel EUROFER as the structural material. The blanket currently has a "sandwich" layout of flat Cooling Plates (CPs) and alternating $Li_4SiO_4$ and Be pebble beds (see Fig. 1a) [10]. Two identical independent loops have been adopted for the flow scheme, which offers a redundancy feature in the cooling system. Coolant from two loops flows in the CPs and FW in a counter-flow manner to get a uniform temperature field in the blanket. The coolant flows in series, firstly through FW and thereafter into the CP. More details of this blanket are presented in Ref. [10].

This paper presents a thermal study done in support of the design activity of the KIT HCPB Team: scope of this activity was to investigate several aspects of a newly proposed blanket configuration in order to transfer later the most promising results in the current HCPB design. For this scope a particular ANSYS model was developed that reproduces a thin toroidal-radial section of the blanket module, the so call 3D slice model (see Fig. 1b). This model exploits the typical toroidal-radial cooling scheme adopted in this blanket concept to provide a simple model able to reproduce with good approximation the thermal behavior of the blanket box. The model (see Fig. 1b) includes half of a $Li_4SiO_4$ bed, half of a Be bed, a complete 5 mm thick cooling plate separating ceramic and Be; The model includes also one and half channels of first wall and the back supporting structure at the back of blanket. To investigate the most critical case, typical thermal load of the equatorial zone of the outboard blanket have been applied to reproduce the region in which the highest temperatures are expected.

## Transient thermal analyses

In this section, the blanket thermal behavior under DEMO typical pulse operation has been investigated. A pulsed heat flux of 0.5 MW/m$^2$ during a period of 9000 s (2.5 h) with a plasma ramp-up of 30 s and a ramp-down of 60 s has been used (see Fig. 2) [11]. Optimized mass flow rate in each channel

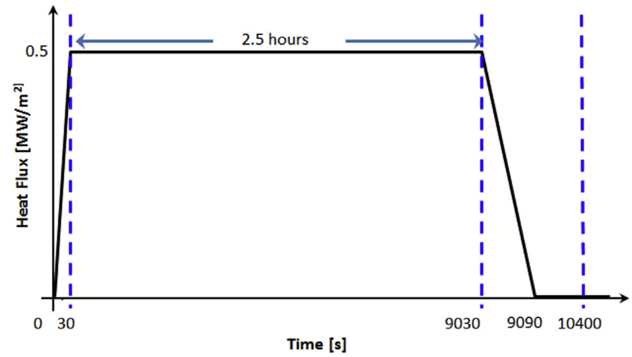


**Fig. 2 – A typical pulse operation of DEMO.**

of each CP is shown in Fig. 3; this distribution is derived from several runs in which the mass flow of each channel has been adjusted in order to ensure a consistent temperature field for the materials and the fluid. Coolant helium flowing into each FW cooling channel is 0.08777 kg/s; again this is the results of parametrical studies on the model. Heat exchange between coolant and CPs in this work is simulated in ANSYS Workbench 16.0 by FLUID116 element, which is a 3-D element with the ability to conduct heat and transmit fluid between its two primary nodes (ANSYS 16.0 Release Documentation). The FW cooling channel has a round-edged rectangular cross-section of 13.5 × 13.5 mm$^2$, the CP cooling channel is 5 × 3 mm$^2$ with round-edged cross-section. The temperature and pressure dependent helium properties are taken from Ref. [13].

The resulting evolution of maximum temperature of different sub-components (e.g. FW, breeding beds, cooling plates) are shown in Fig. 4. These results are used as inputs for the structural analyses that are reported in a second paper submitted to this volume of this journal [14]. At about 909 s, the blanket achieved the asymptotic state as the temperature of all sub-components did not change after that time point. At the end of the DEMO plasma pulse, the blanket returned to initial temperature. It is interesting to observe the different time constants for different part of the blanket. Shorter time constant are observed for the FW that is thin and in direct contact to the plasma, longer for the materials in the breeding zone. The presence of this differential behavior is source of

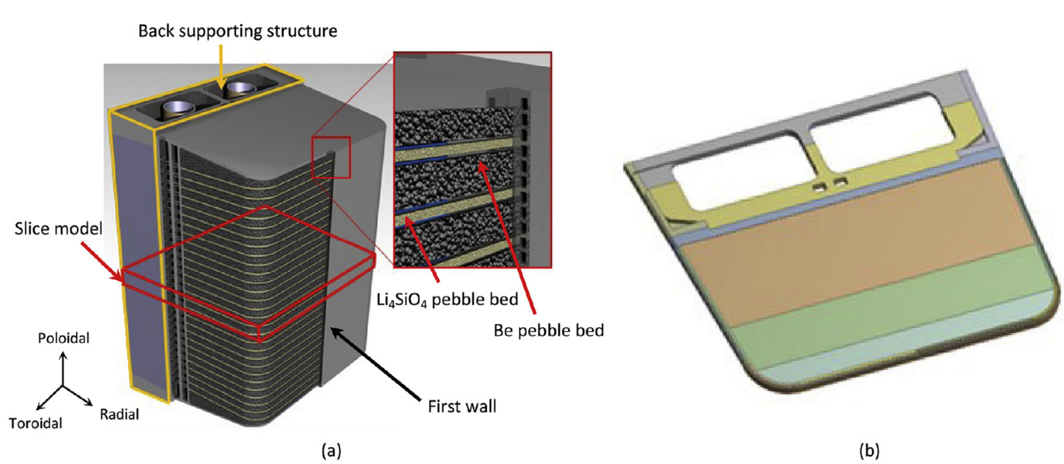


**Fig. 1 – (a) Isometric view of the equatorial outboard blanket module; (b) 3D slice model.**