Numerical investigation of the thermo-mechanical behavior of ceramic breeder unit of fusion reactor blankets using finite element analysis

Abstract

The breeder units of the fusion reactor are very crucial for generating required tritium fuel for the fusion reaction. The Helium Cooled Ceramic Breeder (HCCB) concept utilizes an edge-on configuration with ceramic pebbles as the breeder material and beryllium as the neutron multiplier, encapsulated in a Reduced Activation Ferritic Martensitic Steel (RAFMS) structure. Previous thermal-hydraulic studies have successfully predicted temperature distributions across the breeder unit (BU) under ITER-relevant operating conditions using constant thermal properties and assuming perfect thermal contact at material interfaces. However, to ensure the structural integrity of the ceramic breeder (CB) under intense thermal gradients of a reactor environment, a more sophisticated thermomechanical assessment is required.

In this project, a comprehensive literature survey will be conducted for the thermomechanical properties of lithium titanate pebble beds. A 2D Finite Element Method (FEM) simulation will then be carried out, focusing specifically on the thermomechanical behavior of the ceramic breeder (CB) zone. This simulation will integrate the experimental data, including the effective thermal conductivity, instantaneous coefficients of thermal expansion along with effective Young’s modulus for the pebble beds. By incorporating the contact resistance and temperature-dependent properties, this simulation will achieve accurate temperature prediction and provides a critical preliminary structural assessment of the HCCB concept. Numerical analysis will be employed to predict the thermal stress distributions and peak stress locations under both steady-state and pulsed operational scenarios. This study fills a critical gap in the development of the HCCB concept, offering specific design improvement suggestions to enhance the mechanical reliability and thermal performance of future breeder unit modules.

Academic Project Requirements:

1) Required No. of student(s) for academic project: 1

2) Name of course with branch/discipline: M.E./M.Tech Mechanical Engineering

3) Academic Project duration:

(a) Total academic project duration: 38 Weeks
(b) Student’s presence at IPR for academic project work: 4 Full working Days per week

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