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Magnetohydrodynamic flow in a mock-up of a HCLL blanket

Part II Experiments in a uniform magnetic field

Abstract

Liquid-metal magnetohydrodynamic flows in a scaled mock-up of a helium cooled lead lithium test blanket module for ITER have been investigated experimentally in order to provide a data base as support of the proposed design concept and for validation of numerical tools. The experimental mock-up has been built according to the design developed at CEA as a European candidate for a liquid-metal test blanket module in ITER (Rampal, Li-Puma, Poitevin, Rigal, Szczepanski and Boudot (2005)). In this concept the eutectic liquid-metal alloy PbLi serves as breeder material while the entire thermal power released in the blanket is removed by helium that flows at high pressure and velocity inside small channels embedded in walls and cooling plates. The original geometry is scaled down by a factor of 2 to fit into the large magnet available in the MEKKA laboratory of the Forschungszentrum Karlsruhe, where NaK is used as a model fluid. Measurements of pressure and potential distribution on the surface of the mock-up have been performed for various combinations of magnetic field strengths and flow rates, quantified by the relevant nondimensional groups, the Hartmann number Ha and the Reynolds number Re, respectively.

The experiments confirm previous theoretical predictions that the major part of pressure drop appears in the entrance and exit pipes and in poloidal manifolds. Additional but smaller contributions are present when the flow passes through the narrow gaps in the back plate or at the first wall. The pressure drop in breeder units, where velocities of the order of $1-2\,\mathrm{mm/s}$ are foreseen, is negligible in comparison with the other contributions. The large range of investigated parameters such as $500 \leq Ha \leq 5000$, $200 < Re < 10000$ allows defining a general pressure drop correlation to be used for extrapolations of results to ITER or DEMO conditions.

Results for electric potential measurements on the surface of the module yield information about flow distribution between the cooling plates. For strong magnetic fields and moderate flow rates the agreement with numerical predictions seems quite satisfactory considering the very complicated geometry for which calculations in a central cross section have been performed taking into account the full electromagnetic coupling. A strong coupling results in sufficiently uniform flow distribution in breeder units with increased flow in lateral sub-channels along the so-called grid plates. Inertia effects become more expressed for smaller magnetic fields and higher flow rates. For such conditions at lower Hartmann numbers Ha and larger Reynolds numbers Re the flow distributions in breeder units become non-symmetric and regions with even reversed flow could appear, forming closed recirculation loops in breeder units.