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Experimental study of DEMO helium cooled divertor target mock-ups to estimate their thermal and pumping efficiencies

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Abstract

The helium cooled divertor for the DEMO fusion reactor is designed for removal of surface high-heat-flux up to 15 MW/m^2 during normal operation. To reduce thermal stresses in divertor plates finger-like array structure was chosen, where each tungsten finger is cooled by helium at inlet parameters of 10 MPa, 634 °C. The gas puffing facility (GPF) was developed for measurement of mock-ups performance at the reversed high heat flux, when the plasma-facing surface of finger-like mock-up was intensively cooled by water. The goals of these experiments are: (1) to compare heat removal performance for different design mock-ups and (2) to adjust computational fluids dynamics (CFD) codes for accurate simulations. Long helium pulses (∼100 s duration) and sufficient capability (1–2 kg of He per pulse) facilitate attainment of the steady-state regime in experiments, when 5–15 g/s mass flow rate of helium was scanned. Results of last experimental campaign carried on in December 2004 revealed that all helium distributing cartridge options demonstrate optimistic performance (as compared to CFD simulations) and capability to transfer 10–25 MW/m^2 in the helium mass flow rate (MFR) range of 5–15 g/s.

Keywords: DEMO divertor; Helium cooling; High heat flux experiments

1. Introduction

The next-generation fusion reactors to be developed after ITER, such as DEMO, are now under investigation. Such reactors should be capable of electric power generation, reliable in operation, have long lifetime. Helium, as a cooling and heat-transfer agent, is considered an attractive candidate and has been proposed as a coolant for the DEMO tungsten divertor [1,2]. High pressure is necessary to achieve acceptable heat removal capacity; high inlet temperature should be provided for operation above the ductile–brittle transition temperature (DBTT) of tungsten. The chosen design

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of the divertor target plate is based on a modular type with finger arrays to reduce thermal stresses under both normal operation and abnormal events. The helium inlet parameters as 10 MPa and 634 °C were chosen for the thermohydraulic investigation of the finger unit.

The computational fluids dynamics (CFD) codes are now powerful and accurate tool for the numerical thermohydraulic simulations, but the specific conditions of the helium-cooled divertor require experimental tests to be carried out. The experiments under real DEMO conditions with an applied surface heat flux of ~10 MW/m^2 and a tungsten tile surface temperature of ~2000 °C are planned for the nearest future, which require an appropriate heat source (such as a powerful e-beam) associated with high costs. It is also necessary to undertake R&D prior to such experiments to find or to create new tungsten grades, joint technique, machining technique, etc. Relatively, simple facilities were proposed for experiments in order to obtain preliminary data on the DEMO divertor.

The first gas puffing facility (GPF1) was intended to measure pressure drops in different mock-ups at nominal helium inlet parameters started to operate at the end of 2002.

2. Description of GPF2

The next facility (GPF2) was designed to measure the heat transfer in order to estimate the cooling efficiency of variously designed mock-ups. For this purpose the reversed heat flux concept was proposed, whereby the helium input parameters (temperature, pressure and mass flow rate) remain constant and the contact mock-up surface is intensively cooled by water. With such an approach there is no more need in a large-sized vacuum system and e-beam driver. Besides, mock-ups can be made of conventional materials with the possibility to simulate the thermal conductivity of tungsten. The aims of the experiment are: (1) to compare the heat removal efficiency of variously designed mock-ups and (2) to adjust the CFD codes for accurate prediction of the experiment results. The second aim is of particular importance, because accurate simulation of the experiment with helium flux close to the nominal DEMO conditions will make possible reliable prediction of mock-up behavior under the DEMO conditions.

To attain the steady-state regime of heat transfer in mock-ups helium the pulse should be much longer than in GPF1. The GPF2 facility is equipped with two sets of helium source and receiving balloons (Fig. 1).

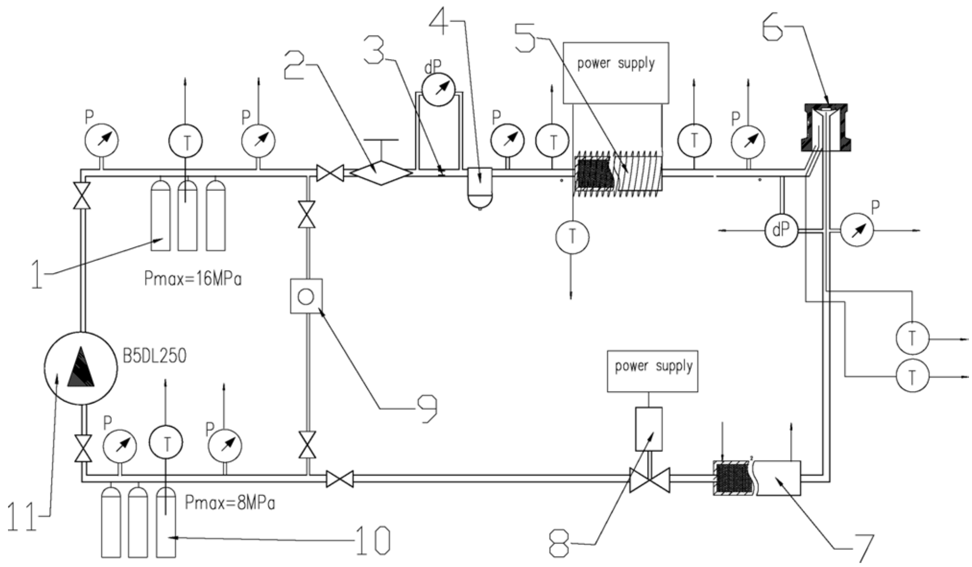

Fig. 1. Helium subsystem GPF2 scheme: (1) source balloon set; (2) pressure reducer; (3) helium flowmeter orifice; (4) filter; (5) ball filled heater; (6) tested mock-up; (7) ball filled cooler; (8) helium flow rate scanner; (9) vacuum pump; (10) receiver balloon set; and (11) membrane compressor.