Experiences from the operation tests with the ITER model pump

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Within the development work for ITER (International Thermonuclear Experimental Reactor), the test bed TIMO (**T**est facility for the **I**TER **mo**del pump) was built at Forschungszentrum Karlsruhe. The aim of this test facility is to check the suitability of the 1:2 ITER torus model cryopump under all aspects of operation. This model pump is the result of extensive preliminary examinations focusing on different aspects of cryosorption vacuum pump operation in the ITER fuel cycle. To pump out the required plasma exhaust gas flow of 120 $(Pa \cdot m^3)/s$, which essentially consists of all mix hydrogen isotopes as well as helium and various impurities, the pump surfaces cooled to 5 K were coated with activated charcoal embedded in an inorganic cement. Apart from all the gases which are condensed at the operation temperature of 5 K, helium a hydrogen isotopes are fixed on the activated charcoal-coated pump area of 4 m^2 by means of sorption.

TIMO TEST BED FOR TESTING THE ITER MODEL PUMP

TIMO provides all the necessary tools to examine all operation modes foreseen for the ITER vacuum pumps [1].

Process gas supply in TIMO is realised with seven supply lines between a gas storage and the metering system. For the different tests with the model pump, pure gases, such as protium, deuterium, helium, neon, argon, nitrogen, and an ITER-relevant gas mixture, are available. The necessary gas throughputs are controlled with four flow meters in the range between $1.7\ 10^{-2}$ and 169 $(mbar \cdot l/s)$

For standard operation, coolant supply of the two cooling circuits in the model pump, the 80 K shielding and sorption panels, gaseous helium at 80 K, and supercritical helium at 4.5 K are required. The coolant flows are controlled in a valve box which is installed between the model pump, a 4.5 K control cryostat, and a 80 K facility.

The 4.5 K helium flow at a max. pressure of 6 bar is supplied to a control cryostat by the 2 kW LINDE refrigerator [2]. From this control cryostat which consists of a 3500 l liquid helium tank, the 5 K panel circuit of the model pump is provided with a Joule Thomson flow of 60 g/s as well as with a helium mass flow of 250 g/s by a centrifugal pump. The 80 K circuits of the model pump are supplied by the 80 K facility. This 80 K facility includes a 600 l liquid nitrogen tank, a heat exchanger, and a centrifugal pump to transfer the maximal mass flow of 200 g/s at 15 bar.

For the regeneration and reactivation process after a pump test performed with the sorption panel, a helium mass flow of max. 50 g/s is available at a temperature level of 300 K as well as 450 K.

To simulate the ITER duct conditions during pumping, the TIMO test vessel can be warmed up to a maximal temperature of 480 K.

With the process control system (Simatic S5 135U), an ITER-relevant cycle operation can be simulated with the model pump.

To analyse the actual gas compositions during the steps of the pump test, an analytical device of the type of quadrupole gas mass spectrometer “Balzers GAM 400” was installed in the TIMO test vessel. With this mass spectrometer, a standard mass range between 1-128 AMU can be measured. In addition to this normal analysis mode, high-resolution operation is possible over the mass range of 1-22 AMU. In this high-resolution operation, the separation of helium (4.0026 AMU) and deuterium (4.0282 AMU) can be achieved.

OPERATIONAL TESTS

To check the operational behaviour of a cryosorption pump, TIMO was built at the Forschungszentrum Karlsruhe. During several test campaigns with the ITER model pump, a lot of data were collected, which improved the understanding of the mechanism of cryosorption pumps on the prototype scale [3,4,5]. Within a new test campaign at TIMO, further tests were performed to check the feasibility of ITER neutral beam heating and current drive (H&CD) system requirements and to study the behaviour of this type of cryopump in view of heat losses as well as in safety aspects.

NBI simulation tests

The ITER Neutral Beam Injectors (NBI) consists of two operational and one diagnostic injector line, including different pump sections [6]. One NBI produces a deuterium beam of 16.7 MW at 1 MeV during maximal operation pulses of up to 3600 s. The aim of the simulation tests in the TIMO test bed was to check with the ITER model pump the required operation conditions of the NBI cryopumps. A very essential point of these tests was to study the behaviour of the charcoal-coated cryopanels under typical conditions of the NBI pumps. To fix comparable parameters for the simulation tests, the size of the pump areas in the different NBI pump sections, the required gas loads, the operation pressures, and the type of panel coating were taken into account.

The tests were performed at the temperature levels of 15 K, 20 K, and 25 K. During the tests at these temperature levels, the operation was simulated for the two types of neutralisers, the standard NBI line and the diagnostic NBI line as well as for the NBI calorimeter. For each of these NBI pump sections, the different panel configurations, coated on one side and coated on both sides, were studied. To specify the necessary gas load for the two different cases, the distribution of the incoming gas between the panel

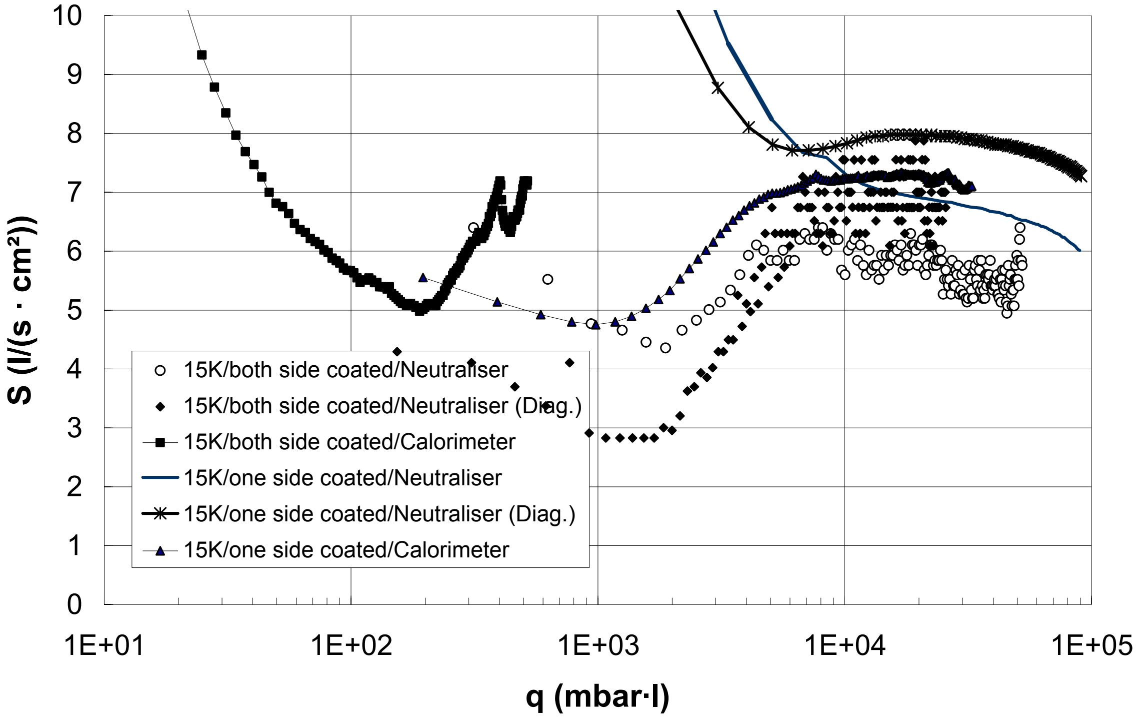

Figure 1: Results of the NBI simulation tests at a temperature level of 15 K.

sides was checked using a Monte Carlo code. As a result of the preparatory work, it was found that for the one-side-coated panel tests, the simulated metering rate must be higher by a factor 6.

The test results demonstrate that using a charcoal-coated panel, the required pumping speed of the NBI cryopumps (~1 l/s•cm²) can be fulfilled. Concerning the high gas loads in the long pulse, NBI pump operation could not be examined due to the limited deuterium inventory allowed for TIMO. Further tests in a future NBI test bed are necessary to clarify open questions regarding the feasible capacities of the charcoal-coated pump surface during long-pulse operations.

Heat load tests

To check the heat loads of a cryopump of ITER-comparable design, tests were performed in TIMO with the model pump. The data collected served to support the working group responsible for the design of the ITER cryoplants.

During these tests, both cooling circuits of the ITER model pump were operated in a steady-state mode at constant temperature. This means that after adjusting the cooling flows in the 80 K shields and 5 K panels to a constant value, helium was metered into the volume of the model pump. The heat loads of both cooling circuits were measured at pressure levels between 10^{-4} mbar and 10 mbar.

The measured values show that depending on the pressure inside the model pump and the coolant flows, the heat loads in the 80 K circuit of the ITER model pump rise up to max. values of 4500 W. In the 5 K panel circuit of the model pump at 10^{-1} mbar, a heat load of ~480 W was measured. At higher pressures of up to 10 mbar, the results rose up to 950 W. Nevertheless, such high heat loads are only expected during unusual disturbances of the regular pump process.

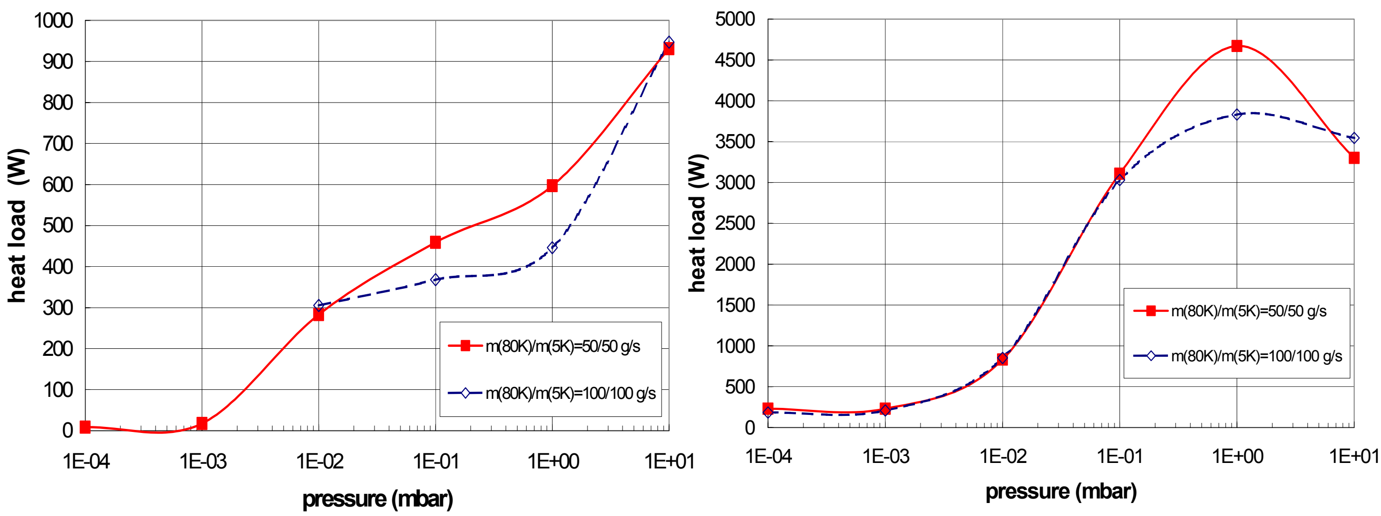

Figure 2: Measured heat loads of the 5 K panel circuit and the 80 K shielding, respectively.

Safety tests

While preparing the design of the different ITER components, also safety studies concerning the risk associated with the high hydrogen inventory were executed parallel to the development activities. As a result of these studies, assumptions were defined for an air inbreak accident into the ITER vacuum vessel. So far, the pressure increase has been assumed to be ~2.7 mbar/s.

To support the modelling work for the safety scenarios, safety tests were carried out with the ITER model pump. These safety tests in TIMO were aimed at collecting experimental data for a fast release of the pumped gas inventory inside the cryopump, followed by high transfer inside the pump volume. To simulate an air inbreak accident with pressure increase rates of 0.5 to 20 mbar/s, a new metering line was integrated in the TIMO test bed. For reasons of safety, nitrogen was used for these tests. During the tests, the different pressure gradients were examined. In addition, the behaviour of the cryopump was studied for operation with and without active cooling, respectively.

The first test results demonstrate that the hydrogen released will be fixed on the pumping surfaces of the connected cryopumps. In further studies, the operation sequences of the different cryopumps of the

ITER vacuum system will have to be taken into account to better assess the real risk potential of the hydrogen inventory inside the fusion reactor.

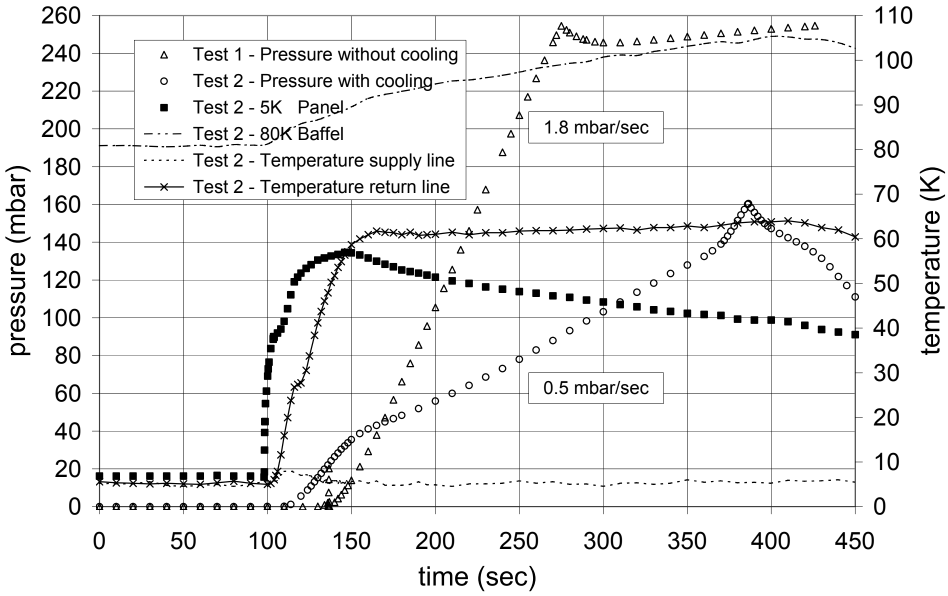

Figure 3: Pressure and temperature measured during the safety tests performed.

CONCLUSIONS AND OUTLOOK

The results of the NBI simulation tests demonstrate that the panel coating technology developed by Forschungszentrum Karlsruhe can also be used for the ITER NBI pumps. The results of the heat load tests and the safety tests supported the further development steps of the ITER cryopump system.

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