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ABSTRACT.
A cryosorption panel test arrangement will be installed in the cryogenic forevacuum system of the Active Gas Handling System (AGHS) at JET. The panel is of ITER relevant design in terms of geometry and dimension, coating and sorbent material. The central objective of this task is to study, for the first time in such an in-depth and parametric way, the interaction of tritium and tritiated gas mixtures with the panel, with respect to pumping performance, desorption characteristics and structural influences. This paper describes the motivation for this task and outlines the experimental aims and how they are planned to be achieved. It presents the actual status and gives a description of the test arrangement design. The paper demonstrates how the AGHS is used as a benchmark test bed for an ITER component to qualify ITER tritium technology.

1. INTRODUCTION

The reference design of the ITER high vacuum system is based on a number of cryosorption pumps located inside the vacuum vessel in the divertor ducts [1]. To pump helium, which cannot be condensed at the available 5 K cooling conditions, and to help pumping hydrogens, the cryopanels are on both sides coated with activated charcoal granules [2]. The primary pumping system is not only designed to pump the exhaust gases from the plasma, but is also needed during fine leak-testing of the torus, for wall conditioning and bake-out and to provide ultimate vacuum in the torus. This means that a broad spectrum of gases, such as all the six isotopic hydrogen species, noble gases and low- and high- molecular impurities (air-likes, water, hydrocarbons) will have to be pumped. To investigate experimentally the pump characteristics in all aspects of operation, a near ITER scale model pump has been manufactured and is currently being tested in the TIMO test bed (Test Facility for ITER Model Pump) at Forschungszentrum Karlsruhe (FZK) [3, 4]. The panel design is being validated in all aspects of operation except the performance under tritium, which is not possible to do in TIMO. Thus, a test campaign of a dedicated test installation is under preparation to be performed within the Active Gas Handling System (AGHS) of the JET tokamak, as an essential complement to the parallel assessment of the pump performance in TIMO.

2. MOTIVATION OF THE TASK

The qualification programme of the ITER cryosorption pump at the TIMO test facility involved a series of different ITER-relevant exhaust gas compositions. However, in all cases, the tritium fractions have been replaced by deuterium, which worked as a model gas. Thus, the pumping and regeneration behaviour for H_2- and D_2-based mixtures could be very well demonstrated [5], but the tritium performance still remains to be investigated although pumping of tritiated exhaust gases is one of the main duties of the cryopumps. Therefore, as first approximation, the own protium and deuterium data scaled up to the other isotopes using the molecular weight as parameter, were used for the advanced 2002 vacuum pump design [6]. However, this approach is only valid if cryosorption is assumed as underlying pumping mechanism.

2.1 PUMPING MECHANISM

All gases which cannot be condensed at the 80 K baffle structure, and the hydrogen isotopes belong to these species, will be pumped by the 5 K charcoal coated panel. The saturation pressure curve of the gas being pumped decides, if it is pumped at the pressure and temperature conditions there by condensation on the sorbent or by cryosorption. It is also possible that both mechanisms are involved at the same time.

Practical experience shows that one needs to have a certain safety margin in the saturation pressure being about 2 orders of magnitude lower than the operation pressure when judging if condensation pumping is technically applicable. Only in this case, the condensation pumping speed becomes close to the normal value with condensation coefficients higher than 0.9. The non equilibrium conditions for the gas-surface interaction is a necessary dynamic factor to generate efficient pumping. For example, it has been shown that deuterium under liquid helium (LHe) cooling conditions in the usual 10^{-2} to 10^{-3} Pa range inside the pump is pumped by a combination of sorption and condensation, whereas protium is practically pumped by sorption only, although, according to the sublimation pressure curves shown in Figure 1, both gases should theoretically be pumped by condensation [7]. The pumping process is also influenced from energetic effects, such as the sorption enthalpy and the enthalpy impact of the incoming particles from 80 K. The decay heat of tritium may therefore become a dominant influence, although, from the order of the saturation pressure curves (Figure 1), one would expect that DT and T_2 will be immobilised predominantly by condensation.

The operation characteristics of a cryovacuum pump differ completely according to the underlying pump mechanism. Condensation pumping is accompanied with high sticking coefficients; the capacity of the pump to accumulate gases is practically unlimited, assuming sufficient cooling power. Sorption pumping is characterised by sticking coefficients smaller than unity (experimental values found are between 0.6 for H_2 and 0.9 for D_2 [9]) and a clear saturation capacity limit. Moreover, it requires regeneration temperatures considerably higher than the corresponding sublimation temperatures. Thus, the pumping mechanism directly determines the potential gas inventory accumulated in the pump and is therefore very important for safety aspects of the operation with tritiated gases.

However, if regenerated, even cond ensed species will evaporate and may re-adsorb on the charcoal, as the temperatures sufficient to sublimate the cryodeposits are still sufficient to provide for sorption at the charcoal. By this mechanism, all gas species, no matter where pumped at first, will have a principal impact on the sorption panels and, sooner or later, the physisorption data for all species present must be considered in a good design of the regeneration step.

An even more complex issue is the concurrent pumping of mixtures containing species which may condense and species which cannot condense (like He) at the operating conditions, as it is the case for fusion exhaust gas mixtures [10]. This is because for sorption a good access to the charcoal pore structure is required, whereas for condensation only the projected cold surface is relevant. The build- up of a condensate layer may significantly diminish the pumping speed for helium by blocking and clogging of the pores [11].

2.2 LEVEL OF KNOWLEDGE

A first hint at tritium cryosorption pumping in fusion may be derived from the experiences gained at JET, which is the only existing tokamak that was operated with tritium. However, the JET cryovacuum system for neutral beams and torus exhaust involves cryotransfer pumps with pure cryocondensation of the hydrogen isotopes at 3.2 to 3.4 K. The JET pumped divertor configuration was equipped with an in- vessel Ar frost pump. The only charcoal coated pump (the same charcoal as proposed for ITER) at JET is installed at the LHCD antenna, but was ne ver parametrically investigated and is of very limited geometrical comparability. Thus, the JET vacuum pumping results are not applicable to ITER.

Up to now, only two small scale panel dedicated test programmes were performed, both of them initiated by FZK. The first one was done at TSTA at Los Alamos in the early 90s, which only focussed on the mechanical integrity of a coated flat panel structure at LHe conditions under tritium exposure [12]. The second and more recent trial was a small scale phenomenological experiment, which was performed in the Russian Hometeam over the last years, but limited to liquid nitrogen temperatures [13, 14].

For performance prediction and pump design, cryosorption isotherms of tritium and tritiated gases measured at the charcoal sorbent at the relevant temperatures and pressures would also be quite helpful, however, they are very scarce in literature. Only three studies were found, presenting data for H_2, D_2 and T_2, but limited to one isotherm at 77 K. Besides the Russian work mentioned above [14], these are an older study of Jones et al. [15], and a most recent one by Kawamura, Willms and co-workers at Los Alamos [16]. However, there are differences in the adsorbed amounts of up to a factor of two. For correct interpretation of the little available data, one must also keep in mind that there is a considerable scatter due to different experimental techniques and due to the various charcoal types used, ranging from micro- to mesoporous material, and, in this respect, not necessarily representative. Moreover, it has been found that the behaviour of the loose charcoal grains may change when bonded as a monogranular layer to a flat panel to form a cryopanel structure. Apart from that, a potential change in the specific charcoal/binder structure due to long term effects of tritium exposition and radiation must also be addressed. However, in the small scale tests performed so far, no indication of a deteriorating impact of tritium on bonding microstructure was found [13].

Thus, there is no alternative to an investigation of a real panel structure identical to the ones foreseen for ITER. This is why efforts have been made within the EFDA–JET workprogramme to investigate this effect systematically in the Active Gas Handling System (AGHS) of JET under the conditions of an operated tokamak. The planned experiment is a benchmark test which would reveal any showstoppers to the ITER cryopumping concept arising from tritium interaction.

3. DESCRIPTION OF THE TEST INSTALLATION

In this task, a prototype cryosorption pump (PCP) will be installed in module No. 5 of the AGHS at JET, which currently houses two accumulation-cryotransfer pump series. One accumulation cryopump will be taken out and completely replaced by the new PCP unit, which is shown in Figure 2. It has an overall height of 3.2 m and a diameter in the lower cylindrical tube of 185 mm. The cryosorption panel test arrangement is of ITER relevant design in terms of geometry and dimension, coating, bonding and sorbent material and will also be operated at ITER relevant temperatures. The total panel surface of 0.4 m^2 (both sides counted) is by a factor of 300 larger than for the former small scale experiment [13], and corresponds to one ITER panel (28 of which are installed in each ITER pump). The PCP panel arrangement comprises three sub-panels welded in series. This is to reduce the cutting steps of the then contaminated panel arrangement after the experiment. It is foreseen to ship the panels to tritium labs (TLK Karlsruhe, Germany and CEA Cadarache, France) for further investigations.

The stainless steel cryopanel structure plate is of quilted design. In a special manufacturing step, it is equipped with resistance heating elements, one on each side, to provide for fine temperature control. Details of the panel design are given elsewhere [18]. The cryopanel will be equipped with temperature sensors (Si diodes) on both sides for monitoring and control. Their location pattern is shown in the flow diagram on the right side of Figure 2. The cold ends of the heaters (each 3 m long), and the cryogenic wiring of the temperature sensors are connected to UHV feedthroughs in the upper head of the device. The head also provides connections for a set of pressure gauges and for the gas supply. The LHe is supplied via transfer lines from outside and carried in a simple pipe inside. Both are combined at the level of the upper lid to form a double-walled pipe with LHe inside and exhaust gas in the annular volume. The LHe cooled cryopanel installation will be installed in a stainless steel pipe, which works as primary tritium containment.

The PCP unit is an approved JET component which satisfies the full record of tritium, ultrahigh vacuum and quality assurance. It is current ly under manufacturing at FZK and industry and will be ready for installation at JET until the end of this year.

4. EXPERIMENTAL GOALS

The experimental programme is chosen to reflect the poor data situation described above. First, some of the available data (helium, deuterium) shall be reproduced for the test installation at JET to check for repeatability and representativity. Then, the data base shall effectively be enhanced, particularly in terms of gas composition.

The central test procedure follows an integrated pumping and temperature programmed desorption (TPD) type experiment, which shall provide information on the pumping mechanism and efficiency, on the cryosorption isotherm, and finally, on the regeneration procedure. The feasibility of the proposed test procedure was demonstrated in other facilities before [9, 10]. The cold panel will at first be subjected to a step-wise gas dosage at constant flow rate (using a calibrated dosage valve, see Figure 2) and with equilibration breaks. The measurement of the equilibrium pressure, compared to the saturation pressure at the same temperature, will indicate if the pumping is based on sorption or condensation. The pressure resulting during gas dosage is an indication of the pumping speed.

It must be pointed out clearly that the geometry of the panel arrangement does not allow for determining real pumping speeds, as there is no PNEUROP dome for gas inlet. Nevertheless, the characteristic pressure resulting during gas dosage is a typical fingerprint of the gas-sorbent interaction. By intercomparison of the curves for different gases and gas mixtures at the same throughput, the relative isotopic effect in terms of sticking coefficient and capture probability should be derivable. An integral test device influence for the nonactive gases He, H_2, D_2 can be assessed by comparing the curves measured in the JET arrangement and in the quantitative FZK facilities, like TITAN and TIMO. After the final dosage step, the panel will be warmed up at a defined heating rate. By balancing the pumping speed of the vacuum pump against the pressure evolution curve inside the PCP vessel, the amount of released gas can be estimated for every moment of time, and from that, at every panel temperature. This allows to assess desorption isosteres from the charcoal, in order to see what temperature is needed to achieve complete gas release of a certain gas species.

A variation of this basic experiment with the panel being pre- loaded with an impurity gas is the poisoning experiment. The poisoning effect, i.e. the decrease of pumping efficiency on a pre-loaded panel compared to the freshly reactivated panel, can be derived directly by comparison of the poisoning test with the corresponding standard TPD test. This information is needed to define the regeneration scheme for cryopumps, i.e. the maximum allowable accumulated gas amounts to still meet a minimum required pumping speed. When this limit has been reached, a complete regeneration has to be performed. It is also important to quantitatively assess the residual tritium inventories within the vacuum pumping system for different regeneration temperatures [19].

In the first parametric test stage of experiments, the gas will be provided in quite a defined way via an external loop with pre-determined composition. In the second stage, the pump will be operated directly at the JET, connected on- line to the torus matrix line, see Figure 2.

4. STATUS AND OUTLOOK

The PCP unit is currently under manufacturing, for some components at an industrial company, for others at FZK. It is expected to be ready for installation at JET until end of this year. Within this year's shutdown, module 5 was physically separated, so that the tests with the external gas supply loop can be performed independently from the JET torus operation programme. These tests are going to be performed in the first half of 2003. Then, when the performance parameters will be established, the pumping module will be reconnected and the PCP will be operated within the trace tritium campaign. After the performance tests the PCP will be dismantled and the panels will be cut to samples. In a follow-up task, the panels will be subjected to structural investigations and the residual tritium inventories will be determined to assess methods for end of life detritiation.

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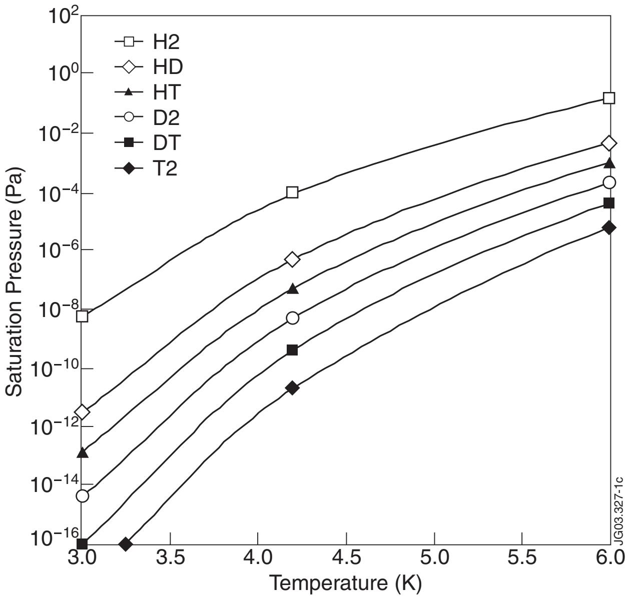

Figure 1: Sublimation pressure curves of the six hydrogen isotopes in the relevant temperature range [8].

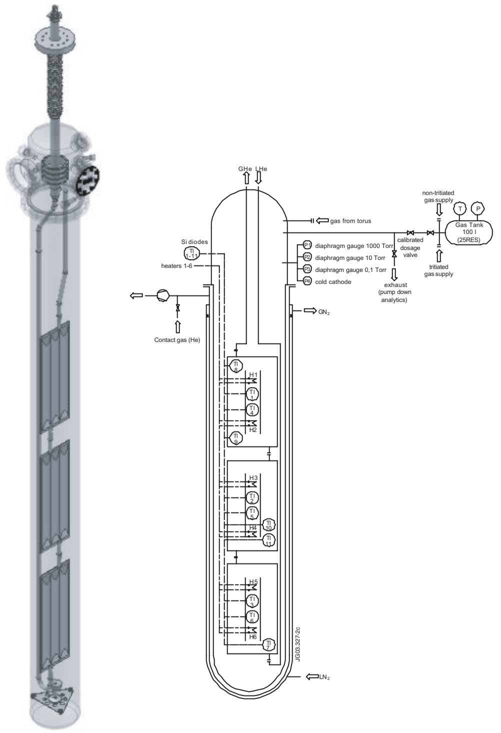

Figure 2: 3D view and flow scheme of the prototype cryosorption pump.