First results of W7-X - relevant conditioning procedures on the upgraded TOMAS device

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Introduction

Proper wall-conditioning is an important element allowing to achieve the highest possible performance of magnetically confined plasmas. It improves discharge reproducibility, minimizes the release of impurities from the exposed plasma surface and controls the recycling hydrogenic fluxes [1]. Requirements to control the surface state of the plasma facing components (PFC) of the present day fusion devices pushes forward studies of the effectiveness of different wall-conditioning techniques, the effects of its relevant substitution and their combination. The foreseen wall conditioning procedures in the upcoming W7-X operations phase OP1.2a are baking, Glow Discharge Conditioning (GDC) and Electron Cyclotron Wall Conditioning (ECWC) [2].

The recently upgraded TOroidal MAgnetized System (TOMAS) operated at FZ-Juelich (Germany) is made available for systematic investigations of wall conditioning techniques in toroidal geometry [3]. Its wide experimental flexibility allows to pre-study GDC and ECWC in W7-X – like conditions.

Experimental setup

TOMAS, with the major radius of 0.78 m and minor radius of 0.26 m (Fig.1), has an inner surface area of 8.5 m^2 while the volume of the vacuum vessel is 1.1 m^3. The device has metallic plasma-facing components (PFC) and 16 magnetic field coils for a variable toroidal magnetic field. The magnetic field on axis can reach up to 120 mT which corresponds to 2.2 kA of coil current. One pumping unit with the effective pumping speed of 140 l/s delivers typical base pressure of $2*10^{-7}$ mbar. The gas injection system provides controllable injection of up to 3 gases simultaneously with a maximum gas flow of 500 sccm for each gas. Hydrogen and helium are used as the main working gases. The pressure is measured by Baratron and Penning gauge. The differentially pumped quadrupole mass spectrometer, Pfeiffer Prismaplus with Faraday detector, (QMS) is used for residual gas analysis during the wall conditioning experiments.

The vacuum vessel of the TOMAS device is equipped with a baking system consisting of 16x750 W heating tapes. Maximum average temperature of the vessel reaches 70 ^{0}C within approximately 1 hour. Recently installed W7-X prototype calotte – shaped graphite anode with a diameter of about 0.15 m is used as a basis of the GDC system [4]. The power supply with the maximum output of 1.5 kV and 15 A but limited to 9kW provides sufficient GD parameters for the pressure operational range down to $2*10^{-3}$ mbar. A magnetron with the fixed ECR frequency of 2.45 GHz and the maximum output power of 6 kW CW is available for ECWC at the pressure range from $5*10^{-5}$ mbar to $8*10^{-4}$ mbar [3,5]. In order to achieve

reproducible initial conditions for the wall conditioning experiments the device was vented with air prior to the experiments for 10 minutes at atmospheric pressure.

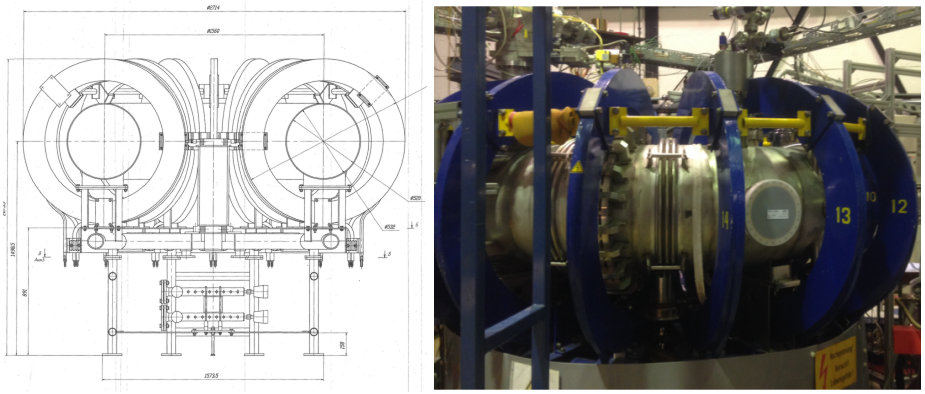

Fig. 1 The schematic view of the TOMAS device (left), the photo of the TOMAS device (right).

Results and discussion

Baking

Baking of the TOMAS vacuum vessel was done during 10 hours. In mass spectrometry signal it is clearly seen that the H_2O is the dominating impurity and its signal repeats the shape of the pressure curve (Fig.2(left)).

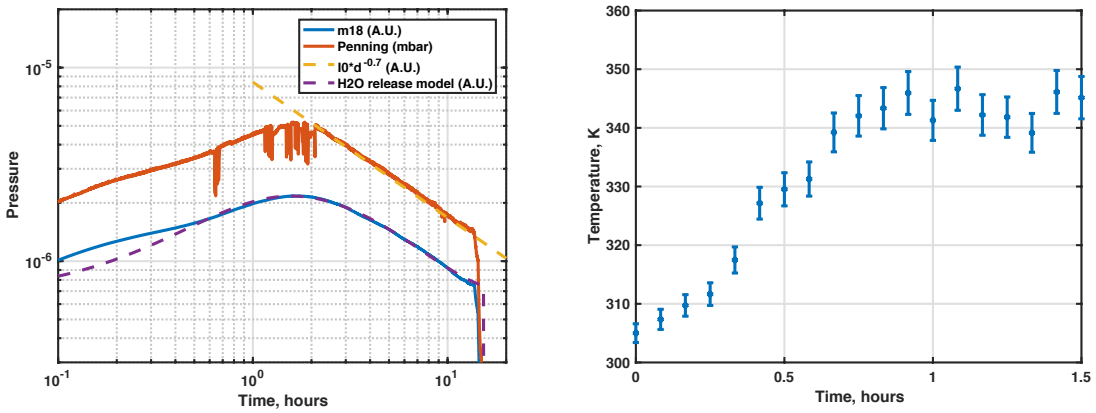

Fig.2 The temporal evolution of pressure and water release during baking (left). Average temperature of TOMAS vacuum vessel as a function of baking time(right).

To describe the release of water during the baking, the approach described in [6] is adopted. The change of total H_2O content in the device, in neutral gas and wall, is given by $\frac{\partial C}{\partial t} = -K_p\beta_0 e^{-E/kT}C + S$, where K_p is the pumping rate coefficient, $\beta_0 e^{-E/kT}$ gives the balance between thermal desorption from the wall and reabsorption, S is an additional source of impurities that allows to describe the steady initial H_2O partial pressure at the measurements and E (26 kJ mol^{-1}) is the desorption activation energy for water on stainless steel [7]. The fitting of the H_2O signal gives $K_p\beta_0 = 1.8*10^3$, maximum average heating temperature T_{max} = 347 K. The last fitting parameter (T_{max}) is in a good agreement with temperature measurements shown on the Fig.2(right). The H_2O partial pressure as well as total pressure, increases until the average wall temperature reaches its maximum, whereafter the outgassing rate tends to follow the typical $\sim t^{-0.7}$ dependence.

GDC

First GDC results have been obtained with the newly installed W7-X prototype GDC anode on TOMAS. The DC breakdown could be reliably obtained with the maximum possible

anode voltage of 1,5 kV for pressures $2*10^{-2} – 4*10^{-2}$ mbar for H_2 and $7*10^{-3} – 9*10^{-3}$ mbar for He. Decreasing the working gas pressure down to ~ $2*10^{-4}$ mbar for H_2 and ~ $4*10^{-4}$ mbar for He, which are at the limits for sustaining the GD at the maximum injected power of 9 kW, improves the discharge homogeneity which is found beneficial for the impurities release efficiency [8]. Fig.3(left) shows the typical anode voltage characteristics obtained in He and H_2 at a glow current of 3 A. The operation window is limited towards low pressures by strongly increasing anode voltage, and by sustainability and homogeneity of GD towards higher pressures.

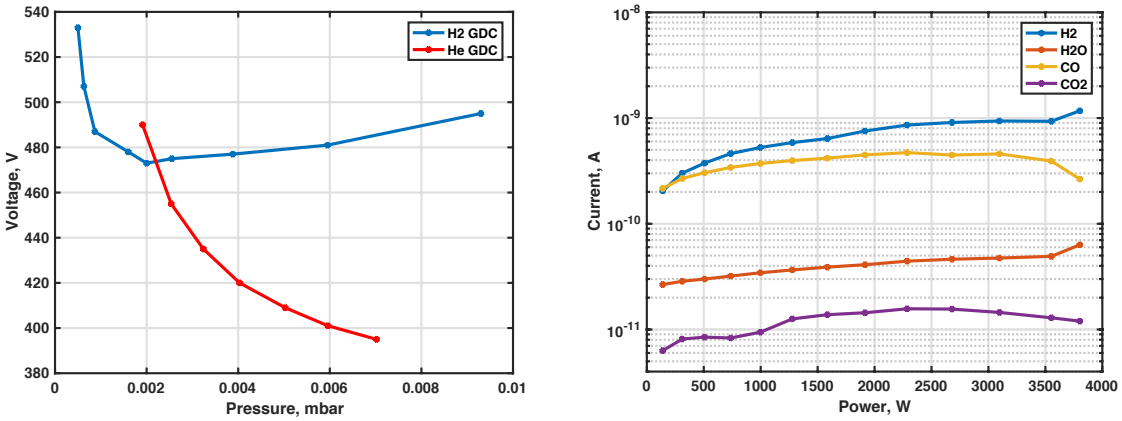

Fig. 3 Operation voltages as a function of pressure during H_2 and He GDC at current of 3 A (left). Mass spectrometry intensities as a function of injected power during He GDC (right).

The impurity removal dependency on injected power was studied for He-GDC. While the outgassing of H_2 and H_2O keeps constantly growing upon increasing the power, the partial pressures of CO and CO_2 decrease again after a certain level of injected power is reached (2.4 – 2.7 kW at He pressure of ~ $2.7*10^{-3}$ mbar). The latter is due to re-ionisation/dissociation of released impurities.

ECWC

ECWC experiments were carried out with hydrogen and helium at a pressure of $1.2*10^{-4}$ and $2.3*10^{-4}$ mbar respectively with an injected power of ~ 2.2 kW and coil current of 1800 A which corresponds to 102.6 mT of toroidal field on axis. The length of each discharge is 5 s with the duty cycle of 10%. Both experiments had a duration of approximately two hours each. Fig.4 shows the comparison of the H_2O concentration as dominating impurity species during H_2 and He ECWC experiments.

The temporal evolution of the outgassing rate is typically described by function $\phi = At^{-d} + C$ [8]. Analysis shows that He ECWC removes less water than H_2 RF discharges and moreover the partial pressures decay faster. These observations are valid as well for other impurities. Such behaviour results from the different dominating processes in He and H2 conditioning, although it may also be partly explained as effect of the difference between pressures of the working gases.

The release of H_2O species results from a few processes during H_2 ECWC. This fact is shown by two different types of peaks on the curve related to H_2O signal for H_2 ECWC (Fig.4). The highest peaks (yellow line), existent during the discharge only, corresponds to the direct outgassing of water from the vessel wall stimulated by hydrogen bombardment. The second and slower outgassing process (purple line) corresponds to recombination or the chemical

reaction between elements of the working gas (H, H_2) and oxygen removed from the inner elements of the TOMAS vacuum vessel. Both types of water release occur at almost identical rates (d_1 = 0.8355 and d_2 = 0.8324). The average distance between two peaks is around 12 s at the given discharge conditions. The position and the amplitude of the peak corresponding to hydrogen-oxygen chemical reaction, as well as the reaction rate and removed amount of outgassed oxygen, depend on gas pressure and injected power.

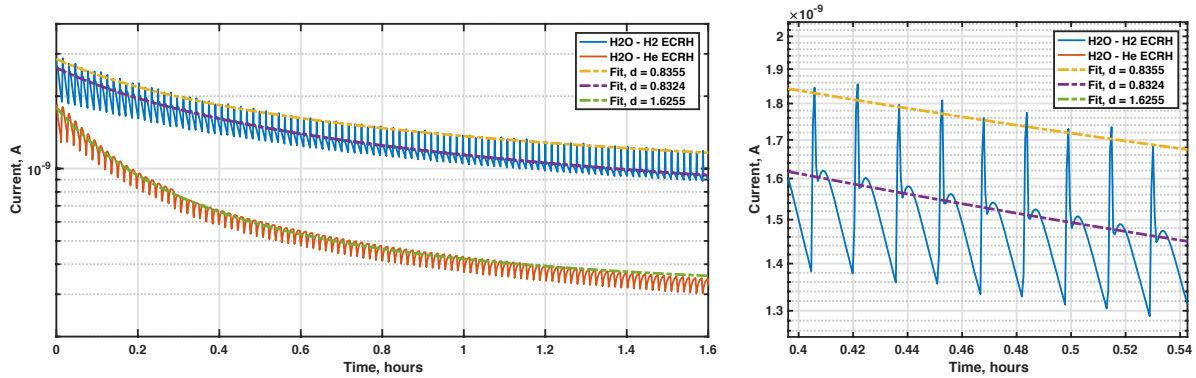

Fig.4 Comparison of H_2O QMS spectra. Blue and red oscillating lines represent the level of H_2O impurities during H_2 and He ECWC, respectively (left). The part of H_2O spectrum during H_2 ECWC (right). Dashed curves show the fitted outgassing rate functions.

Conclusion

The upgraded TOMAS device is well-suited to study W7-X relevant wall conditioning methods. First results of three main wall conditioning techniques have been demonstrated. The outgassing rates of the dominating species during the baking procedure can be described by adopting known models. The operational range and main GD parameters for W7-X – prototype anode have been defined. The behaviour of impurities release during the GDC is briefly described but, nevertheless, it needs more detailed analysis. In case of ECWC, the difference between H2 and He conditionings was analysed and the presence of different water release processes with H2 as working gas has been shown. The origin of this type of impurities source will be studied in future.

Acknowledgement

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References

[1] J. Winter, Plasma Phys. Control. Fusion 38 (1996) 1503.
[2] T. Wauters et al., 43rd EPS Conference on Plasma Physics (2016).
[3] H.B. Stork et al., Fusion Technology 39 (2001) 54.
[4] A. Spring et al., Fusion Engineering and Design 66 – 68 (2002) 371.
[5] J. Ihde et al., Journal of Nuclear Materials 290 – 293 (2001) 1180.
[6] P. Andrew et al., Journal of Nuclear Materials 220 – 222 (1995) 601.
[7] J.P. Joly et al., Vacuum 59 (2000) 854
[8] D. Kogut., PhD thesis, IRFM CEA (2014).
[9] V. Phillips and J. Ehrenberg., J. Vac. Sci. Tech. A 11 (1993) 437.