The role of the first wall in the density behaviour in RFX

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Introduction - The RFX Reversed Field Pinch experiment (a=0.46 m,R= 2 m) has been so far operated with plasma currents up to 1.2 MA, electron densities in the range 1- 9 $10^{19}m^{-3}$ and electron temperatures between 200 and 400 eV. The first wall is made of graphite tiles, which cover all over the vessel with a surface of approximately 36 m^2. Average particle confiment time is of the order of few milliseconds and in order to sustain the electron density the fluxes of atomic hydrogen are of the order of 10^{23} s^{-1}. In most of the circumstances the gas flux required to refuel the plasma originates from the recycling processes at the wall. According to the wall conditioning situation the amount of pre-filling gas adequate to allow the breakdown may be in fact enough to drive a whole discharge, that may be longer than 150 ms. In other words, the capability to control the plasma density reflects the capability to control the hydrogen concentration on the tiles facing the plasma. Pellet injection is the only available means to fuel directly the plasma core without resorting to gas recycling. This paper summarizes the way the first wall affects the density behaviour in RFX with particular reference to the different situations of wall conditioning: room temperature wall, hot wall, Glow Discharge Cleaning (GDC) in He, boronisation with GDC in Diborane. It has to be emphasised that in RFX the ohmic input power ranges between 20 and 80 MW, a significant fraction of which is dissipated onto the relatively narrow region (few square meters) where the locking in phase of several MHD modes (m=1, n=6-15) concentrates the interaction with the wall by deforming the plasma column. Such localised interaction implies that locally the surface of the tiles can reach temperatures for which radiation enhanced sublimation and strong hydrogen outgassing are likely to occur. Previous measurements [1] had already shown that the region of enhanced interaction can produce half of the total hydrogen and main impurity influxes(carbon and oxygen).

The study of the wall response presented in this contribution is based on the measurements of the desorbed gas performed by means of absolute pressure gauges and on the ratio between the electron density reached at a certain time during the discharge and the total gas injected up to that time. The latter ratio can be considered as an “effective” recycling coefficient . With this definition the effective recycling is 1 when the plasma density equals the total gas injected. The main difference between the two approaches, pressure gauge measurements and effective recycling , is that the former one includes the effetcs of the processes occurring during the termination of the discharge.

Experimental observations - Fig. 1 shows for several discharges the total desorbed gas and the total gas puffed into the vessel as a function of the shot number. The shot interval includes two experimental sessions each preceded by a He GDC of 40’ (**400** V and **2.4** A). The plasma current was ~ 650 *kA*, the first wall was at room temperature and the effetcs of the last boronisation already negligible. Fig. 2 shows for the same discharges the “effective” recycling coefficient : in approximately 20 shots the coefficient moves from 0.1 to 0.7. At the beginning of the session one has to use relatively large quantities of gas to pre-fill

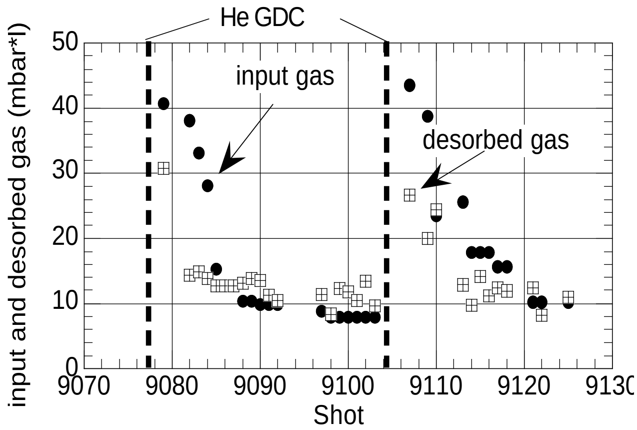

Fig.1 _ Total gas injected and gas extracted after the pulse for two experimental sessions each preceded by 40' of GDC in He

the vessel and only 40 to 60 % of it is desorbed after the pulse. One can estimate the amount of gas trapped into the wall required to reach saturation by summing up the differences between the amount of injected gas and the gas desorbed after the pulse for the various discharges from the GDC till the desorbed fraction overcomes 100%. It turns out that in this case the wall reaches saturation after absorbing approximately 1 10^{20} atoms per m^2 of graphite.

Soon after a boronisation the first wall has a strong pumping capability and larger amounts of gas (~70 *mbar.l*) have to be used to sustain the discharge. For approximately 25 shots only 20% of the injected fuelling gas is desorbed after the discharge as shown in Fig. 3. Correspondingly the effective recycling coefficient may be very low as shown in Fig 4. This ratio slowly increases and stabilises below 100%. He GDC sessions of 40'in this phase can bring the gas desorbed fraction to 20%. The amount of gas that the wall can absorb before it reaches saturation turns out to be of the order 1 10^{21} atoms per m^2, that is ten times higher than in a non-boronised wall conditioned with He GDC (40'). The extended reservoir capacity associated to the boronised wall makes the density control relatively simple: it is for instance possible to perform a complete density scan in both directions during an experimental session while in general, that is in a non-boronized wall, it is very difficult to recover low density regimes. It should be emphasised that soon after boronisation a fairly large amount of He is trapped into the wall. The spectra of the SPRED spectrometer are indeed dominated by He emission and probably the amount of He in the discharges, roughly

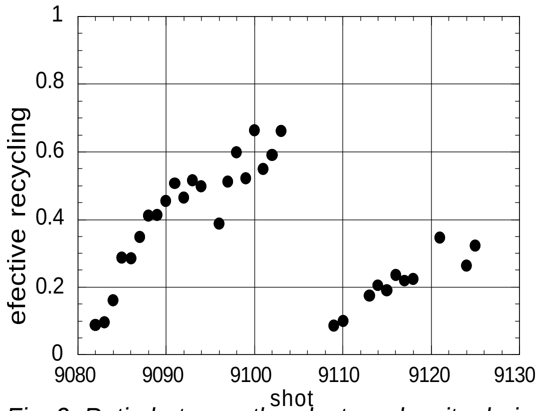

Fig. 2: Ratio between the electron density during the discharge and the total injected gas ratio for the same shots as in Fig.1

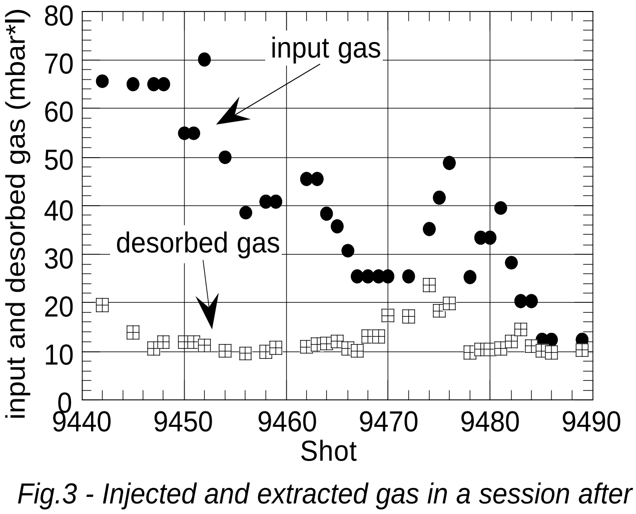

Fig.3 - Injected and extracted gas in a session after boronisation withDiborane

estimated to be around 10% of the electron density, affects the overall recycling, reducing the effective hydrogen pumping capability of the wall. Too an empty surface soon after a wall conditioning procedure may result in an irreproducible start up for a number of discharges as well as in an excessive variation of the density value during the discharge. One efficient way to control the density in such conditions is to add to the standard GDC in He few minutes of GDC in H in order to provide an adequate gas reservoir to enhance recycling and thus sustain the discharge.

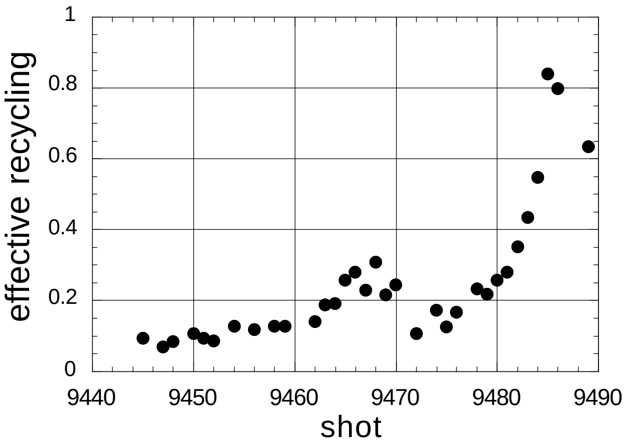

Fig.4 : The effective coefficient for the same sessions as for Fig. 3

When baked up to 280°C the wall behaviour is by far less homogeneous and the fraction of desorbed gas after the shot is always greater than 50%, with an average value close to 100%. A very large amount of prefilling gas is to be injected into the vessel to sustain the plasma current ramp up phase, in order to compensate for the very low recycling immediately after the breakdown. However, especially at plasma currents approaching 1*MA*, typically characterised by large ohmic input power, the density often increases rapidly during the discharge. An excess of density may cool the plasma and lead to a premature quench of the plasma current. In such circumstances the ”effective ” recycling varies during the discharge and from relatively low values may reach and even exceed one. A possible explanation is that the strong power loading (of the order 100 MW/m^2) associated to the locking of the modes leads to a local overheating of the tiles, at temperatures that imply in particular strong hydrogen outgassing. CCD images and external thermocouples confirm that temperature exceeding 1000 °C can easily be reached. Such events accompanied by strong density increase may make the density control in the subsequent discharges very difficult, unless a new He GDC is performed. Operations with a hot wall but soon after boronisation however are immune from such events for at least a few tens of shots (30-60). The data of Fig. 5 refer to this condition and clearly show that plasma operations require very large amounts of fuelling gas (170 *mbar l*) because of the very low effective recycling values.

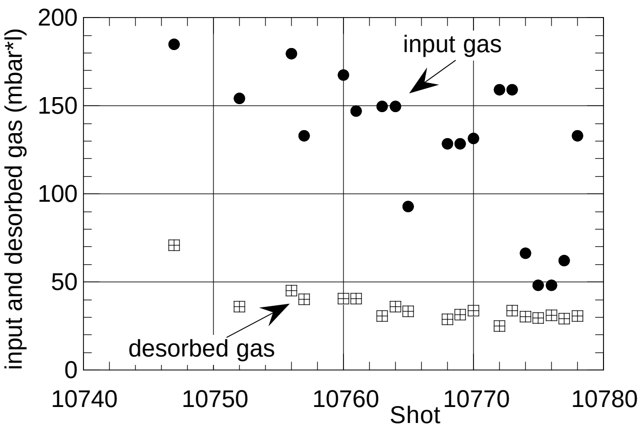

Fig.5 - Injected and extracted gas in a session after boronisation with Diborane and the wall temperature at 280°C

The effects of the strong wall recycling on the main plasma parameters may be observed essentially on the electron density. It is found [2,3] that the gradient of the electron density at the edge scales strongly with the average density value and, within the experimental uncertainty, quite independently of the plasma current. Considering that the energy confinement time in RFP's scales positively with density, one may deduce that since high densities are associated to high recycling at the wall, the latter is not detrimental per se as to the plasma performance.

Strong recycling does not seem to negatively affect the impurity content either. In fact the effective charge Z*eff* decreases with the electron densities [3]. The high density associated to the strong recycling increases the impurity screening by reducing the ionisation length. It is found that the carbon yield in RFX does not scale significantly with the hydrogen particle flux from the wall as deduced by the H_α light. This is different from what is found in the divertor regions of several Tokamaks [5,6], probably due to a higher incidence of the physical sputtering in RFX. An exception to the latter statement is represented by the inboard side of the vessel of RFX where, due to outward shift of the plasma column by 1- 1 5 cm from the axis, the interaction with the wall is lower and where therefore chemical sputtering may be the dominant impurity mechanism. This is shown in Fig. 6 where the carbon yield appears to decrease while the hydrogen flux increases. In any case carbon yield does not increase with the recycling coefficient.

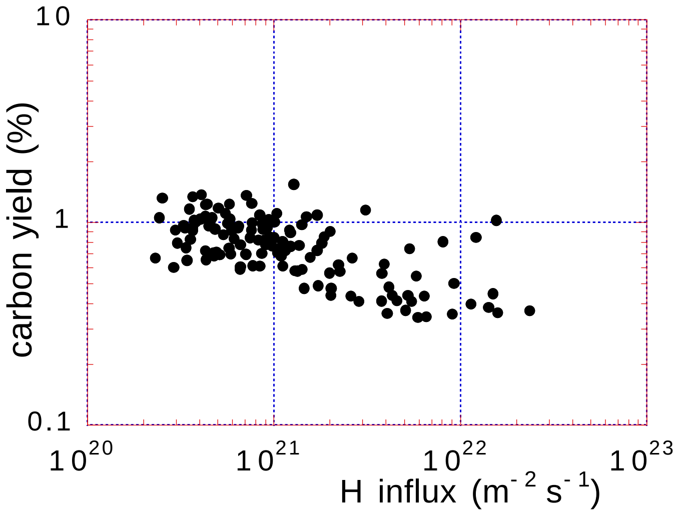

Fig. 6- Carbon Yield (from C^{1+})as a function of the hydrogen influx at the inboard side of the vessel

Summary - Boronisation is the wall conditioning technique that better allows low recycling regimes and a good density control both with the wall at room temperature or baked up to 280°C. Boronisation increases by ten times the reservoir capability of the wall before it reaches saturation in agreement with what found in Tokamaks with graphite walls. On the other hand high recycling regimes do not appear to be detrimental as to the plasma performances.

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