TIME DEPENDENCE OF GASES FROM PLASMA-WALL INTERACTIONS IN ISX-A*

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Numerous papers have been published concerning radiation damage and thermal properties of first walls in tokamak reactors. However vacuum properties are also important, particularly as regards the adsorption and release of gases during and immediately following tokamak discharges. We have studied the time evolution of working and impurity gases by means of a quadrupole mass spectrometer attached to the ISX-A tokamak. These results were compared with measurements in a similar (304L stainless steel) laboratory vacuum system, with no tokamak discharges.

Light emitted by the plasma in ISX-A limited our observations during the discharge. After termination of the discharge the impurity gas species could be observed, and the partial pressure of both the working and impurity gases rose. The working gas pressure peaked very quickly and decayed whereas the H_2O, CH_4, and CO gases had immediate peaks followed by secondary higher maxima occurring 6-10 sec after the discharge. The partial pressures of the impurity gases typically increased by factors of two to ten and decayed nonexponentially, indicating competition between gas release and pumping. Mass 40 exhibited an anomalous behavior, sometimes increasing and sometimes decreasing in partial pressure.

Laboratory tests were made with a 100-msec-long H_2 puff. The partial pressures of CH_4, H_2O, and CO all exhibited very small intermediate peaks followed by a second rise which began 25 to 50 msec after the beginning of the puff and peaked some 200 — 300 msec later. When Ar was substituted for the H_2 puff the partial pressures of these impurities behaved in a similar manner except that the magnitude of the increase was less.

The pressure rise of the impurity gases following the H_2 puffs varied, depending on the vacuum system configuration, differences in wall preparation of the tokamak and the absence of a plasma in the laboratory systems.

INTRODUCTION

The ISX-A tokamak [1] afforded the opportunity to study vacuum properties of 304L stainless steel as a first wall since this material was utilized exclusively in the construction of the toroidal vacuum chamber. The only exception was Viton which was used as gate valve seals after having been preconditioned by a seperate vacuum bake. The torus was pumped by a liquid nitrogen trapped turbomolecular pump, condunctance limited to 200 ℓ/sec.

During the first 4 months of experiments hydrogen working gas was introduced by pre-filling the torus to a pressure of $\sim 5 \times 10^{-5}$ torr and by maintaining this pressure during a series of tokamak discharges. Overnight and weekend discharge cleaning was employed throughout this time period to ensure good vacuum conditions [2].

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Gas puffing was used exclusively during the last 1-1/2 months of experiments. The gas was introduced by operating a series of fast values just prior to and during the tokamak discharge. Titanium gettering was employed during this time period as an alternate to discharge cleaning. The Ti was deposited over the upper half of the torus at the end of each day and an additional short (10 minute) depositions were made during the day as required.

A UHV stainless steel chamber pumped by either ion pumps or a turbomolecular pump was used in the laboratory tests. The base pressure of this system was 10^{-10} torr.

Residual gases were analyzed and quantified by a quadrupole mass spectrometer (RGA). A small computer controlled the RGA and data acquisition. The output was plotted at the CRT terminal on a semilogrithmic scale [3].

RESULTS AND DISCUSSION

The major impurities observed in ISX-A were carbon and oxygen [4]. These combined with hydrogen to form light hydrocarbons and water which were adsorbed on the torus walls. An increase in the pressure of the working gas caused desorption of these adsorbed gases. This mechanism of impurity production, often called the wall effect, was observed in ISX-A and in the laboratory system as well. The remainder of the gaseous impurities were plasma induced.

A wall effect observed in the laboratory system is illustrated in Fig. 1. The working gas, H_2, was introduced slowly by means of a needle valve. All the impurity levels observed remained essentially constant until a threshold H_2 pressure was attained and then they began to rise. The most abundant impurity in this system, water vapor, began to rise at the lowest threshold, while the least abundant, argon, had the highest threshold. The linear plots were obtained after substracting the background. Also shown in this figure are the results obtained by substituting argon as the working gas.

A fast gas value was installed on the laboratory system to simulate gas puffing on ISX-A. Time resolved measurements of increases in impurity levels are shown in Fig. 2. The working gas, H_2, began to increase almost instantaneously, whereas the rise in mass 28 (the most abundant impurity in this case) began 30 msec later. The rise in mass 40, the least abundant impurity shown, was delayed for 70 msec.

Impurity levels in ISX-A during a sequence of tokamak discharges are illustrated in Fig. 4. After overnight discharge cleaning the torus was prefilled with H_2 to a gauge pressure of 4×10^{-5} torr. The rise in the impurity levels shown by the second set of data points represents the wall effect. Each succeeding set of data points were taken from mass scans which were begun 15 sec after each discharge indicated. Impurity levels rose slightly after the first few discharges as a result of plasma-wall bombardment but then showed little change during the remainder of the sequence.

Overnight Ti sublimation affected initially lower levels of H_2, H_2 and CO in the sequence shown in Fig. 4. Gas puffing was utilized to introduce the working gas, allowing the Ti layer to remain unsaturated for several discharges. Impurity levels remained more than an order of magnitude below those shown in the previous example. The 10 minute Ti deposition was inadequate to return these levels to their original values.

Time resolved behavior of the major impurities in ISX is shown in Fig. 5. After termination of the discharge these species rose and reached their maximum values within 6 to 10 sec. The abundant production of CH_4 during the discharge resulted in this species becoming the dominant

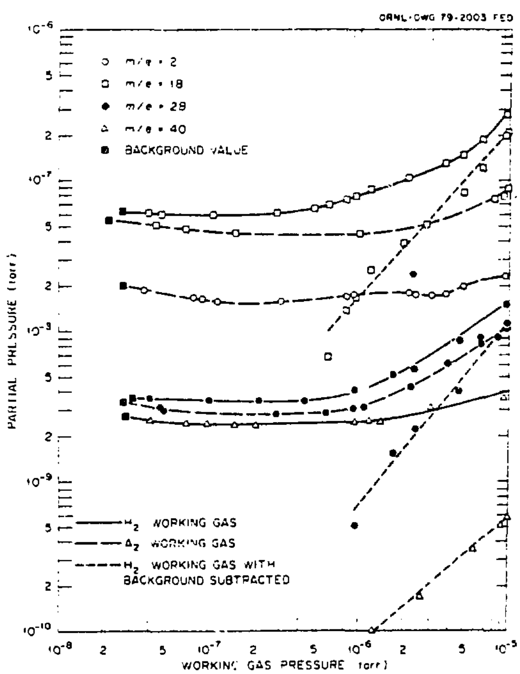


Fig. 1. The wall effect illustrating the rise in impurity levels above background as the working gas pressure increases.

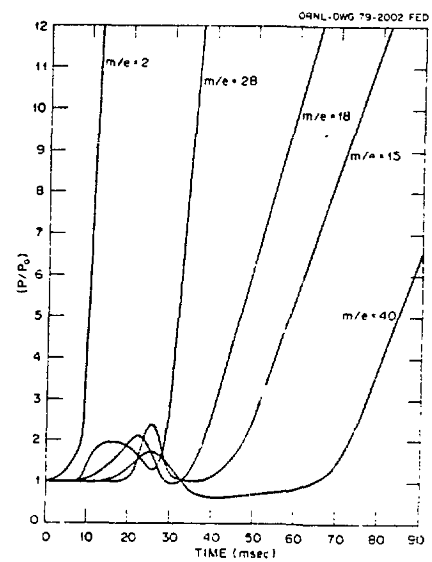


Fig. 2. Time resolved increases in impurity gases and working gas (H_2).

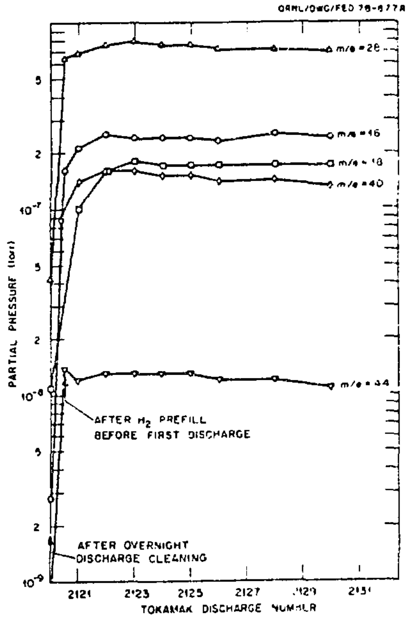


Fig. 3. Impurity levels during a sequence of tokamak discharges. A constant H_2 pressure was maintained throughout this sequence.

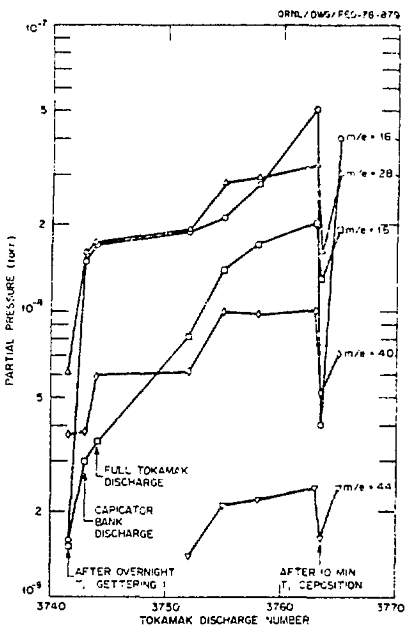


Fig. 4. Impurity levels during a sequence of tokamak discharges with gas puffing and Ti gettering between discharges.

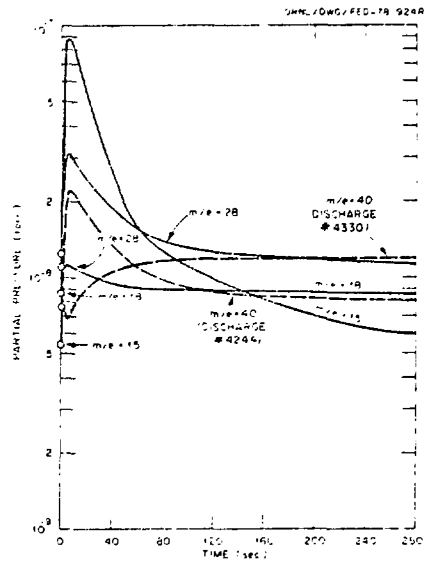


Fig. 5. Time resolved behavior of the major impurities in ISX-A.

impurity immediately after the discharge. The non-exponential decay of CO and H_2O indicates competition between gas release and pumping. The behavior of mass 40 is also displayed in this figure. The partial pressure of this species sometimes increased and sometimes decreased after the discharge.

Hydrogen light emitted by the plasma and detected by the quadrupole indicated the behavior of the working gas influx during the discharge, as shown in Fig. 6. The usual behavior of H_2 gas is illustrated in (a), when a solid H_2 pellet [5] is injected into the plasma at 80 msec in (b) and during a series of H_2 gas puffs in (c).

CONCLUSIONS

The observed rise in the levels of impurity gases associated with tokamak discharges in ISX-A was the combined result of desorption induced by the working gas (wall effect) and plasma-wall interactions. The wall effect produced an increase in the level of an impurity species only after a threshold pressure had been reached by the working gas. The value of the threshold pressure was inversely proportional to the background partial pressure of the observed species and was not the same for all species. In time resolved studies with 100 msec H_2 gas puffs, delays as long as 70 msec were measured before an increase in the partial pressure of a trace impurity such as mass 40 was observed. However, only 30 msec were required for the H_2 gas to reach the threshold pressure for mass 28, the dominant impurity. Thus, in a tokamak discharge, the onset of the wall effect, may be delayed significantly by careful control of background impurity levels. The wall effect was also observed in laboratory experiments with argon as the working gas but increases in partial pressures of the impurities were less significant. Plasma-wall interactions caused a less significant rise in contaminant levels than the wall effect.

Z_{eff}, the effective nuclear charge, may be expressed as

$$Z_{eff} = \frac{\sum_i Z_i^2 n_i}{n_e}$$

where n_i is the density of protons and impurity ions with charge Z_i and n_e is the electron density. This parameter describes plasma quality in terms of total impurities from all sources. Although no relationship was observed between Z_{eff} and the background pressure, a relationship was found to exist between Z_{eff} and impurity and hydrogen residual gas atoms computed from RGA scans taken 15 seconds after the discharge. This relationship is shown in Fig. 7.

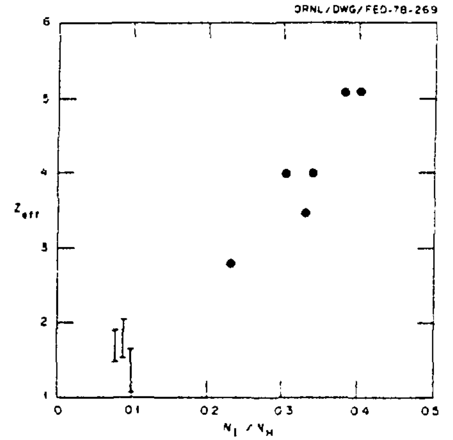
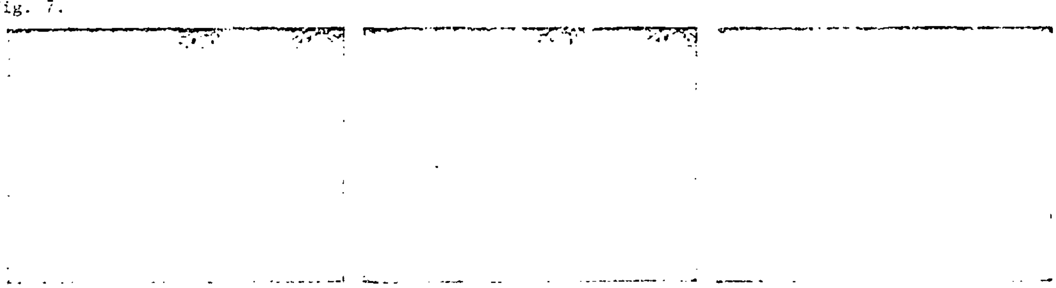


Fig. 7. Z_{eff} (computed from conductivity measurements coupled with $T_e(0)$ scans) and N_I/N_H (computed from RGA scans) where N_I is the number of impurity atoms and N_H is the number of hydrogen atoms in the residual gas 15 seconds after the discharge



(a) (b) (c)

Fig. 6. Time resolved behavior of the hydrogen light signal detected by the RGA (a) during a normal tokamak discharge (b) during a discharge with solid pellet injection at 80 msec and (c) during a discharge with multiple gas puffs.

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