Impurity Gas Injection into Reversed-Field Pinch Plasmas

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1. Introduction

On the reversed-field pinch (RFP) device, TPE-RX [1] at AIST (major radius 1.72 m, minor radius 0.45 m) which has a graphite-free first wall with molybdenum limiters, an impurity gas injection experiment, using neon, has been conducted.

In tokamaks, radiative cooling of the edge plasma and divertor via impurity gas injection has been studied for solving the power exhaust problem. Improved confinement also occurs with impurity gas injection in some NBI-heated tokamaks [2, 3, 4]. In the RFX RFP device, a radiative mantle has been established in higher electron density discharges with neon gas injection [5].

In normal TPE-RX plasmas, the electron temperature decreases in higher-plasma-current discharges in which magnetic modes always lock to the wall [6]. Radiation loss from iron and molybdenum in the core region or magnetohydrodynamic (MHD) instability due to the increase of plasma resistance are two possible reasons. If the edge can be radiatively cooled with neon gas injection, it is expected that the sputtering of heavier impurities might be relaxed.

We have also compared TPE-RX neon gas injection results to those obtained with neon injection into already-improved-confinement plasmas [7] achieved with the pulsed poloidal current drive (PPCD) in the MST RFP at the University of Wisconsin-Madison.

2. General behavior of neon-gas-puffed discharges in TPE-RX

In TPE-RX experiments, the neon gas (< 6 % of the filling deuterium gas pressure) has been injected at t= 20 ms by the fast electromagnetic valve into higher I_p/N (~10 x10^{-14} A m), I_p = 300 kA plasmas, where N is the column density. Figure 1 shows the time evolution of several parameters both with and without gas injection. With gas injection, the plasma current decays more rapidly, since the plasma resistance (R_P) increases due to the increased Z_{eff} from neon, as shown in Figs. 1(a) and 1(b). Figure 1(c) indicates that the iron-line radiation is enhanced by the physical spattering due to neon. On the other hand, the iron-line radiation decreases in the case of deuterium gas injection, due to the drastic reduction of electron temperature (see Fig. 4). Figure 1(d) indicates the slight increase of the fluctuation around at t= 30 ms after gas injection. Radiative edge cooling may affect the MHD instability of RFP plasmas.

Figure 2 shows line averaged electron densities measured by the CO_2–Helium Neon laser interferometer [8]. Electron densities at r/a= 0.0 and 0.7 (r= 31 cm) increase with neon gas injection, and they peak at t~30 ms. The injected neon almost accounts for the density changes. The ratio, $n_e(r=31) / n_e(r=0) \sim 0.9$ at t=31 ms, as shown in Fig. 2(c). If it is assumed that $n_e(r=31) / n_e(r=0) = \{1 - (r/a)^2\}^{\alpha}$, then the ratio becomes ~0.9 with α ~0.16. In the case of a parabolic density profile, the ratio becomes 0.53 with α =1. Therefore, the electron density profile flattens considerably.

The total radiated power (P_{rad}) measured with a bolometer increases with neon gas injection, peaking at t~30 ms, as shown in Fig. 3(a). In the case of I_P= 350 kA, P_{rad} reaches more than 6 MW and ~60 % of the Ohmic input power. And prior to neon gas injection, radiation power already has been increased. Figures 3(b) shows radial profiles of line integrated radiated power density. In the case of neon gas injection, the location of the radiative neon ions is mainly distributed in the plasma edge.

Figure 4 shows the electron and ion temperatures both with and without gas injection. The core electron and ion temperatures were measured by Thomson scattering and a neutral particle analyzer, respectively. The electron and ion temperatures decreased with neon injection for both I_P= 300 and 350 kA. As a reference, the temperature with deuterium gas injection case is also shown. In this case, the ion temperature is higher than the electron temperature. This is an example of so-called anomalous ion heating. As a result, beta poloidal is similar to that in plasmas without neon injection, if a flat pressure profile is assumed in the neon injection case. However, the energy confinement time decreases due to the rise of the ohmic input power.

3. Characteristics of neon-gas-puffed discharges in MST

In MST experiments, the neon gas (< 15 % of the filling deuterium gas pressure) has been injected at t= 5 ms by a fast electromagnetic valve into moderate I_P/N (~3.7 x10^{-14} A m), I_P = 250 kA standard plasmas. The overall plasma performance with gas injection is similar to the TPE-RX cases. Both radiated and Ohmic input power increase with neon gas injection, as shown in Fig. 5. Further, the sawtooth oscillation has been suppressed due to the decay of plasma current. The electron density increases, and the profile becomes hollow. However, the electron temperature decreases, and the profile flattens. Thus, the electron pressure profile flattens, as shown in Fig. 6. Beta poloidal becomes similar to that in plasmas without neon injection. However, energy confinement time decreases due to the rise of the ohmic input power. Neon gas also has been injected at t= 9 ms into the sawtooth free improved confinement PPCD plasmas. In this case also the electron temperature decreases.

4. Conclusions

Light Z impurity, neon gas has been injected into the TPE-RX and MST RFP plasmas of moderate to high I_p/N conditions to study the confinement characteristics. With neon gas injection, the plasma resistance and radiated power increased, and the plasma current decayed more rapidly. The location of the radiative neon ions is mainly distributed in the plasma edge. With neon gas injection, the electron temperature decreases, but electron density increases, and its profile becomes hollow. The electron pressure profile flattens. As a result, beta poloidal was similar to that in plasmas without neon gas injection. However, the energy confinement time decreased due to the rise of the ohmic input power.

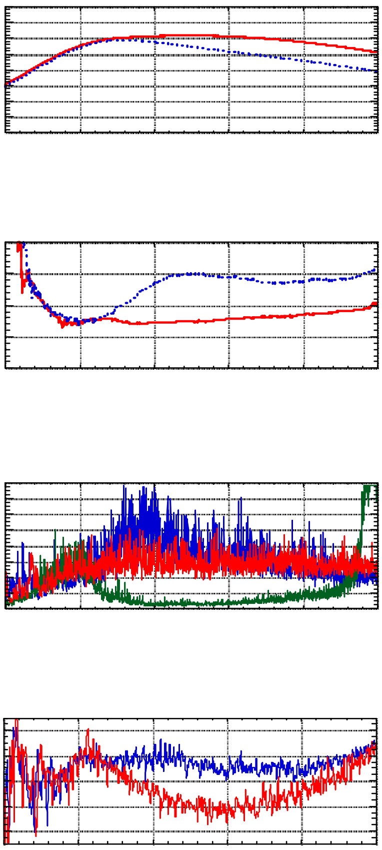

Fig. 1. Time traces of some relevant parameters

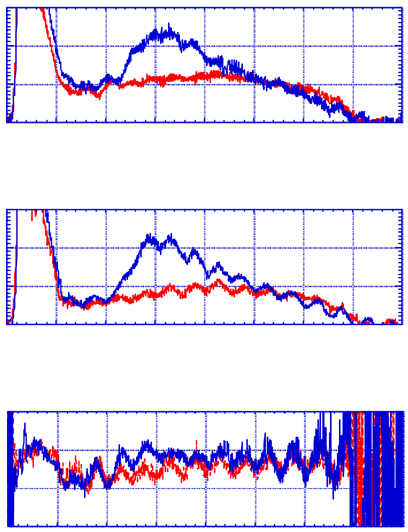

Fig. 2. Line-averaged electron density and ratio.

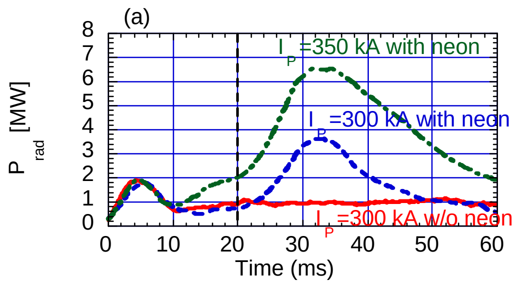

Fig. 3. (a) Total radiated power.

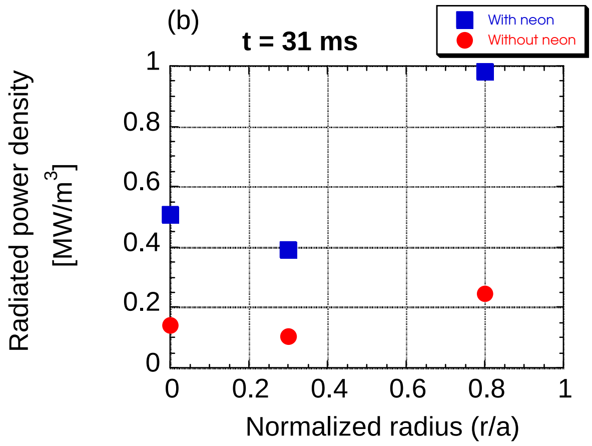

Fig. 3(b) Line integrated radiated power density.

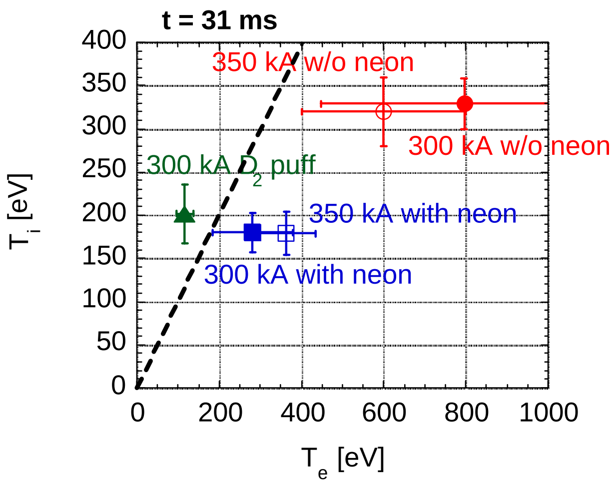

Fig. 4. Electron and ion temperatures in TPE-RX.

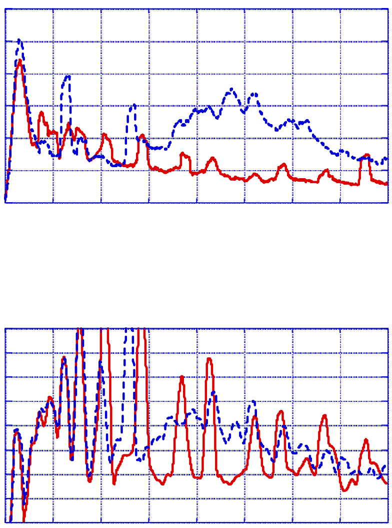

Fig. 5. Time traces of Ohmic power and radiated power.

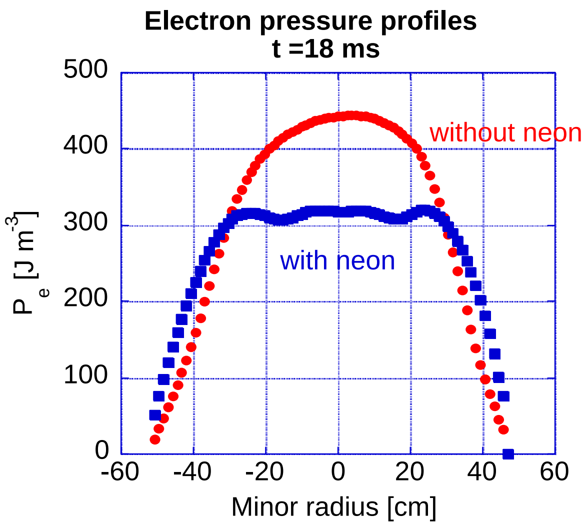

Fig. 6. Electron pressure profile in MST.

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