§24. Quasilinear Carbon Transport in Impurity Hole Plasma

Mikkelsen, D.R. (Princeton Plasma Physics Laboratory), Tanaka, K., Nunami, M., Sugama, H.

It is important to understand the transport mechanism responsible for impurity hole plasmas discovered [1] in LHD so impurities can be controlled. This will be especially important in power plants because the impurities reduce the reactivity of the plasma and they may cause significant energy loss via radiated power. In impurity hole plasmas the carbon density has a 'hollow' shape, see Fig. 1, and the carbon flows outward from the deep core. Purely diffusive transport would move carbon from the region of higher density in the periphery to fill in the region of reduced density, so some kind of convective transport must be at work.

Neoclassical transport theory is quite complicated for impurities [2], and present estimates do not yet have a firm basis. Furthermore, the strong flows measured near the plasma edge suggest the possibility that flows may play a significant role in determining the sign of the radial electric field where the carbon density is hollow, but in this region there is no flow measurement and the radial electric field is not measured [3]. The sign of the radial electric field is very important for impurity transport so reliable predictions could be difficult without more measurements that can determine this parameter.

Turbulence might produce convective flows, so we have used the gyrokinetic code GS2 [4] to calculate the quasilinear carbon flux for the experimental conditions of shot 113208. The presence of turbulence is suggested by density fluctuations measured in the region with strong outward convective flux [5], and ITG modes are known to be unstable there and to produce significant ion heat flux [6].

The gyrokinetic calculations reported here include kinetic treatments of electrons and the three main ion species: hydrogen, helium and carbon. The geometric coefficients in the gyrokinetic equations are derived from a VMEC equilibrium based on experimental data. The measured electron and ion temperatures provide important inputs to the calculations. The dependence of the linear growth rates on electron and ion temperature gradients demonstrate that ITG modes are the most unstable, and that the measured ion temperature gradient is far from the threshold.

The carbon density fraction and carbon density gradient parameter vary greatly during the impurity hole phase of the discharge, so we made quasilinear estimates of the carbon flux for four times (those shown in Fig. 1) and three radii, r/a-0.5, 0.6, 0.7, located where the carbon density is strongly hollow. At each time and location the carbon density gradient parameter was scanned from slightly positive to strongly negative values.

The quasilinear estimates of the carbon flux were made for a wide range of mode wavenumbers that extends above and below the fastest growing mode, the mode with peak heat flux, and the mode that produces the peak carbon flux. The sign of the carbon flux is found to depend most critically on the sign of the carbon density gradient parameter, see Fig. 2. In every case the carbon flux is inward when the density is hollow, and the flux becomes outward only for positive values. This means the quasilinear carbon transport is almost entirely diffusive, and the modes studied here do not provide an explanation of the impurity hole phenomenon.

1) K. Ida et al., Phys. Plasmas 16, 056111 (2009).
2) J. M. Garcia-Regaña et al., Plasma Phys. & Controlled Fusion 55, 074008 (2013).
3) K. Nagaoka et al., Nucl. Fusion 51, 083022 (2011).
4) W. Dorland, et al., Phys. Rev. Lett. 85, 5579 (2000).
5) K. Tanaka et al., Plasma Fusion Res. 5, S2053 (2010).
6) M. Nunami, et al. , Phys. Plasmas 19, 042504 (2012).

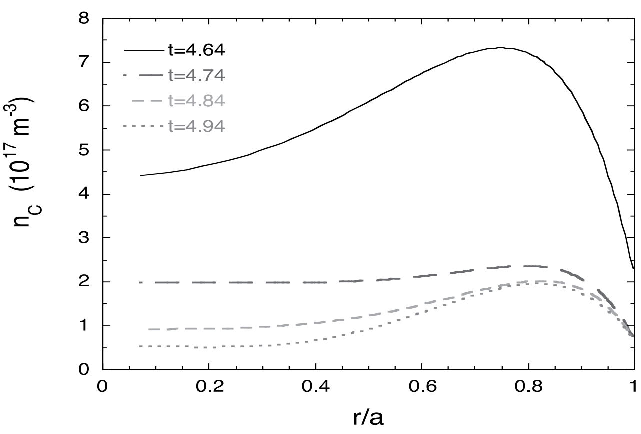

Fig.1 Measured carbon density profile at four times following TESPEL injection in shot 113208.

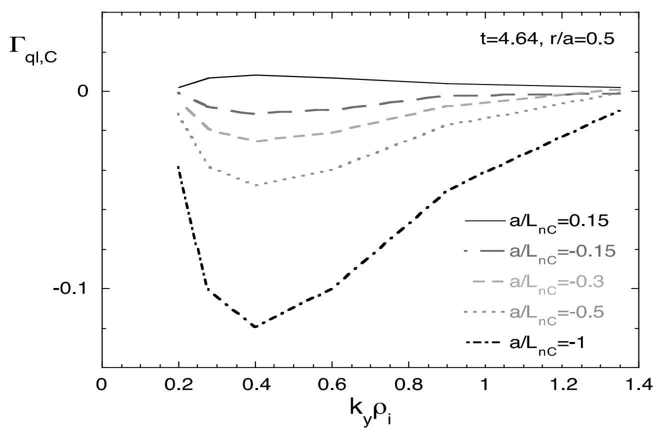

Fig.2 Wavenumber spectrum of the quasilinear carbon flux at r/a=0.5, for a range of values for the carbon density gradient parameter. Experimental parameters measured at t=4.64 sec were used in the calculations.