SIMULATION OF GAS OSCILLATION EXPERIMENTS ON ASDEX UPGRADE

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Abstract. Discharges with modulated neutral gas inflow are modelled by two scaling expressions for the anomalous inward drift using a special version of the 1.5-D BALDUR transport code. The computed phase angles between the oscillating electron density and the influx rate of deuterium atoms are compared with DCN interferometer measurements. It is found that a new scaling $v_{in}/D \propto n_0$ with n_0 being the neutral deuterium density yields the observed small phase angles whereas the old scaling independent of n_0 does not.

Introduction

Gas oscillation experiments usually are conducted to determine profiles of the anomalous diffusion coefficient D and the anomalous inward drift velocity v_{in}. Due to a lack of knowledge, possible dependences of these transport coefficients on plasma parameters were not taken into account so far in the evaluations [1]. In the present paper, simulations of such gas oscillation experiments on ASDEX Upgrade are used to test scaling relations for v_{in}.

Transport Model

A special version of the 1.5-D BALDUR predictive transport code [2, 3] which also includes a scrape-off layer (SOL) modelling is applied. In the confinement zone, empirical electron and ion heat diffusivities χ_e and χ_i, respectively and empirical coefficients D are used, setting $\chi_i = \chi_e$ and $D = 0.6\ \chi_e$. Ohmic plasmas are modelled with an ohmic scaling relation $\chi_e \propto n_e^{-1}\ T_e^{-1}\ q^{-1}$. For ELMy H-mode plasmas, a comprehensive scaling law for χ_e is applied [4] which is based in part on the ITERH92-P ELMy H-mode scaling of the thermal energy confinement time [5]. In the present work, the anomalous inward drift velocity is modelled by the old scaling expression

$$\frac{v_{in}(x)}{D(x)} = C_v\ \frac{2x}{\varrho_w x_s^2}\ \left(m^{-1}\right) \tag{1}$$

and a new scaling recently discovered

$$\frac{v_{in}(x)}{D(x)} = F_0\ Z_{eff}(x)\ n_0(x)\ \frac{2x}{\rho_w x_s^2} \quad \left(m^{-1}\right) \tag{2}$$

with $F_0 = 1.29 \times 10^{-15}$ and n_0 in m^{-3} [6]. The n_0 dependence was inferred from transport analysis of the bulk and edge regions in an ASDEX Upgrade high-density H-mode discharge [7]. Note that the dimensionless factor C_v provides a measure of the peakedness of density profiles. The coordinate x is the effective radius of a flux surface ρ normalized to the effective radius of the wall contour ρ_w (in m) and $x_s = \rho_s/\rho_w$ denotes the separatrix ($x_s = 0.88$ in the calculations). The source as well as the density and temperature profiles of deuterium atoms are computed by a Monte Carlo code. In the phase prior to the gas oscillation, density feedback is applied to control the influx rate of deuterium atoms Φ_D such that the measured line average density is reached. The flux Φ_{Db} immediately before the beginning of the gas modulation is kept and serves as reference for the oscillating flux of D atoms. The time dependence of Φ_D is assumed to be a half-sine like that of the experimental influx rate of deuterium molecules at the gas valve.

$$\Phi_D = \Phi_{Db} \left\{1 + a_{os}\left[sin(\omega_{os}t_{os}) - \tfrac{1}{\pi}\right]\right\} \tag{3}$$

for positive values of sine and

$$\Phi_D = \Phi_{Db} \left\{1 - \tfrac{a_{os}}{\pi}\right\} \tag{4}$$

for nonpositive values of sine. Here, a_{os} and ω_{os} are the oscillation amplitude and frequency, respectively and $t_{os} = t - t_b$ where t_b marks the beginning of the gas modulation. The $1/\pi$ term compensates for the time averaged net flux due to the half-sinusoidal time function. In order to ensure sufficient temporal resolution and accuracy of the calculations, the upper limit of the time step was set 2.5 ms and the n_0 profile was recomputed at each time step.

Results and Discussion

The analysis of high-density H-mode discharges was found to be impaired both by the small modulation amplitudes of the electron density and by the ELM (Edge Localized Mode) activity. So, emphasis is put on an ohmic deuterium discharge (No. 8005, $\bar{n}_e = 4.1 \times 10^{19}\ m^{-3}$, $I_p = 1.0\ MA$ and $B_t = 2.5\ T$) with gas modulation at 5 Hz. Figure 1 presents the central and peripheral line average densities H1 and H4, respectively, from DCN interferometry [1], the edge D_α signal and the influx rate Φ_{D_2} of deuterium molecules at the gas valve. Evaluation has shown that the rise of the D_α signal is delayed against the rise of Φ_{D_2} by about 12 ms. This time delay is caused by the transit time of deuterium molecules between the gas valve and the plasma edge [8] where they become dissociated and ionized. The D_α signal further shows that the experimental quantities n_0 and Φ_D have a sinusoidal time behaviour like Φ_{D_2} until about 20 ms after the maximum which justifies the above assumption made for $\Phi_D(t)$.

The first step is to correctly model the density and temperature profiles in the phase before the gas oscillation. Then, simulations with the v_{in}/D scalings of Eqs (1) and (2) are carried out and compared with the line average densities from DCN interferometry. The measured relative modulation amplitude of $\bar{n}_e$ defined by $(\bar{n}_{emax} - \bar{n}_{emin})/(\bar{n}_{emax} + \bar{n}_{emin})$ amounts to 2.1 % which is attained in the simulations at $a_{os} = 0.2$. Applying Eqs (1) and (2) yields almost the same density modulation amplitudes which prevents discriminating between the inward drift scalings. We therefore focus on the phase angles. The predicted phase difference between the maximum of the oscillating electron density and that of Φ_D is checked against experimental results. Applying the scaling of Eq. (1) with $C_v = 0.4$ in the bulk and an empirical fit for the v_{in}/D profile strongly rising with radius near the separatrix [7] yields the profile of the phase difference shown in Fig. 2 (dashed curve). Note that the coordinate r is the minor half-axis of a flux surface, the separatrix position in the midplane being at 50 cm. The phase angles of the $\bar{n}_e$ and $n_e(r = 44\ cm)$ modulations are 74 and 40 °, respectively and significantly exceed the corresponding values measured by DCN interferometry of 45 and 15 °. It is stressed that the time scale for building up the density profile depends on the particle diffusion and particle pinch. Experimentally, a given phase is found to propagate inward much faster than computed. The new scaling $v_{in}/D \propto n_0$ should do better owing to the additional oscillating inward term $n_e\tilde{v}_{in} \propto n_e\tilde{n}_0$ in the continuity equation and the rapid response of n_0 to Φ_D. Using Eq. (2) in the interior plasma and near the separatrix indeed results in smaller phase angles as shown in Fig. 2 (solid curve). The corresponding phase differences of the $\bar{n}_e$ and $n_e(r = 44\ cm)$ oscillations are 42 and 19 °, respectively and agree with the experimental values. In a control run, the v_{in} profile computed with Eq. (2) immediately before the start of the gas oscillation is kept. Applying it during the gas modulation phase (no oscillation of v_{in} due to $\tilde{n}_0$) yields the upper curve in Fig. 3 which almost matches the profile obtained with Eq. (1) (see dashed curve in Fig. 2). This shows that the smaller phase angles of the lower curve in Fig. 3, calculated with Eq. (2), are caused by the oscillating inward term $n_e\tilde{v}_{in}$. We conclude that the n_0 dependent scaling of Eq. (2) yields the small phase angles observed in the gas oscillation experiment whereas the old scaling independent of n_0 does not.

Simulations of a high-density H-mode discharge (No. 7486, $\bar{n}_e = 7.6 \times 10^{19}\ m^{-3}$, $I_p = 1.0\ MA$, $B_t = 2.5\ T$ and $P_{NI} = 2.6\ MW\ (D^0 \rightarrow D^+)$) with gas modulation at 10 Hz support the above results. Again, applying Eq. (2) yields smaller phase angles than Eq. (1), but the reduction at the edge is only by a factor of 1.3. The reason is that at high plasma density n_0 is diminished due to poor neutral particle penetration, so that the additional term $n_e\tilde{v}_{in} \propto n_e\tilde{n}_0$ resulting from Eq. (2) contributes less.

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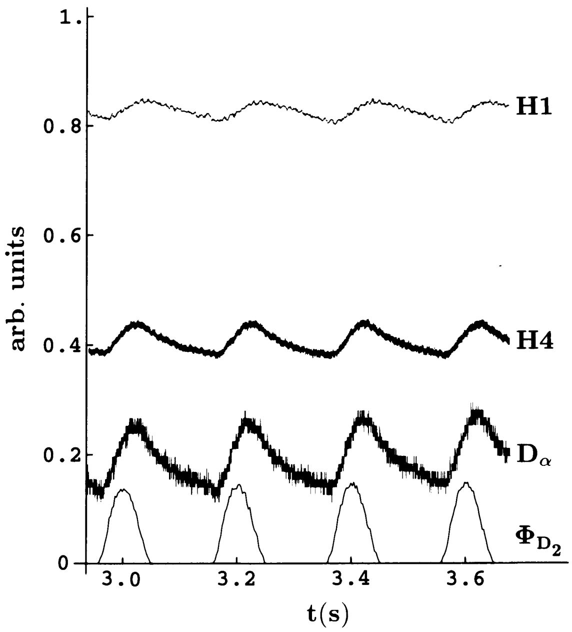

Fig. 1. Temporal evolutions of central and peripheral line average densities H1 and H4, respectively, from DCN interferometry, edge D_α signal and influx rate Φ_{D_2} of deuterium molecules at the gas valve.

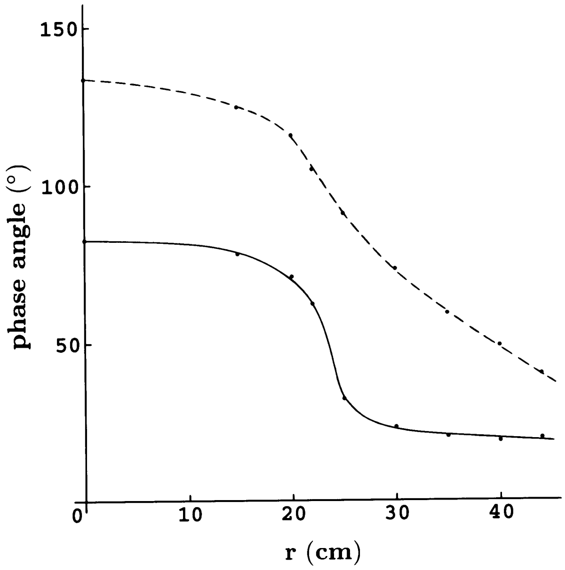

Fig. 2. Profiles of phase difference between n_e and Φ_D oscillations computed with Eq. (1) setting $C_v = 0.4$ (dashed curve) and with Eq. (2) (solid curve). The minor half-axis of a flux surface is denoted by r.

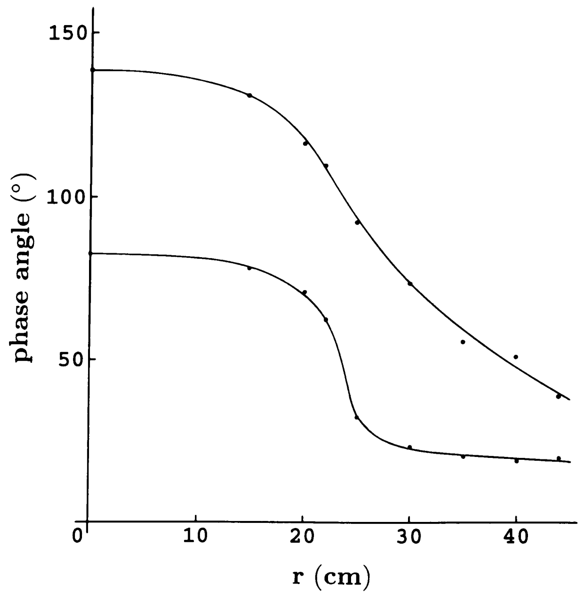

Fig. 3. Profiles of phase difference between n_e and Φ_D oscillations computed with Eq. (2). The upper curve is obtained in a control run where the v_{in} profile immediately before the gas oscillation is kept and applied during the gas modulation phase.