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SIMULATION OF ANOMALOUS PINCH EFFECT ON IMPURITY ACCUMULATION IN ITER

V.M. Leonov, V.E. Zhogolev.

NFI, RRC "Kurchatov Institute", Moscow, Russia, e-mail: leo@nfi.kiae.ru

As our previous simulations of ITER scenarios showed [1], using only neoclassical pinch of the bulk plasma and impurities together with the anomalous diffusion in the impurity transport simulations gives flat radial profiles of impurity concentration. Neoclassical thermal diffusion at flat bulk plasma density profile helps to prevent impurities accumulation in the plasma core. However, experiments indicates possibility of anomalous pinch of the main plasma and impurities. It can result impurity accumulation. Anomalous pinch can influence the impurity accumulation by two ways: by increasing of the main plasma gradients and by the anomalous pinch of impurities themselves. The task of this work is to test a relative role of these two possibilities.

ASTRA transport code [2] was used for the description of the bulk plasma parameters evolution. In simulations we used artificial transport coefficients:

$\chi_e = D_e = D_{an} \cdot F_{H\text{-mode}} + \chi_i^{neo}$,

$\chi_i = 2\, D_{an} \cdot F_{H\text{-mode}} + \chi_i^{neo}$,

where anomalous term had parabolic radial dependence

$D_{an} = D_o \cdot (1 + 3 \cdot \rho_N^2)$; $\rho_N = \rho/\rho_{max}$.

In the region of the H-mode external transport barrier (ρ_N > 0.92) transport coefficients of the main plasma have been reduced to the ion neoclassical heat diffusivity level χ_i^{neo} [3] ($F_{H\text{-mode}} = 0$). The normalization coefficient D_o was fitted to obtain the correspondence of the global energy confinement time to the H-mode IPB98(y,2) scaling [4] $\tau_E = \tau_E^{H\text{-}98(y2)}$. As the boundary conditions for the bulk plasma parameters we used some approximations on the basis of B2-Eirine results. Plasma fuelling by gas puffing was simulated using the kinetic equation for neutrals in the slab approximation.

ZIMPUR code [1] has been used for the modeling of transport and radiation of impurities (considering all impurity ions). Radial components of the impurity fluxes include neoclassical and anomalous parts:

$\Gamma_k = \Gamma_k^{nc} - D_{an}\, \partial n_k/\partial \rho - V_{p\_an}\, n_k$,

where neoclassical impurity fluxes Γ_k^{nc} for arbitrary aspect ratio and collisionality was calculated using the NCLASS code [5], D_{an} is anomalous diffusion coefficient (in these simulations was the same as for the bulk plasma),

$V_{p\_an} = k_p\, g(k) \cdot D_{an}\, \rho/a^2$

is the anomalous pinch velocity, *k* is the ion charge and k_p is the normalizing coefficient (was the same for all ions), *g(k)* is the function of ion charge (we consider 3 version of this function: *g(k)=0, g(k)=1* and $g(k)=Z_k/Z_{eff}$). Relations between impurity ion fluxes Γ_{ks} through the separatrix and ion densities n_{ks} were used as the boundary conditions $\Gamma_{ks} = V_\perp\, n_{ks}$, where velocity $V_\perp$ was equal to the velocity of the escaping plasma column bulk plasma electrons for the automatically satisfaction of the ambipolarity requirement. Impurity atomic flux through the boundary was fitted to produce necessary impurity contamination in plasma (for example for necessary level of plasma radiation). The bulk plasma ion concentration (50%D + 50%T) was determined from a quasi-neutrality condition taking into account densities of electrons and of all impurity and helium ions. Thermalized helium pumping speed on the boundary was fitted to produce relation $\tau^*_{He} / \tau_E = 3$.

Investigations have been done for the basic inductive ITER scenario with the plasma current I_p= 15MA, average plasma density $<n_e> = 10.1 \cdot 10^{19} m^{-3}$ and fusion power P_{fus} = 400 MW.

Two problems have been considered: 1) variation of the radial profiles of the bulk plasma parameters and different impurity concentrations (Ar, Be, He) with change of the anomalous pinch velocity value and 2) checking the possibility to control the main characteristics of this regime within the operational limits, and to determine the maximum value of anomalous pinch velocity when control is possible.

These simulations were performed keeping some main discharge parameters constant (to keep the scenario performance): fusion power P_{fus}= 400 MW (by changing of average plasma density by boundary neutral flux control) and radiated power P_{rad} = 47MW (by changing of Ar impurity flux through the separatrix). This helps to keep constant level of power through the separatrix P_{loss}. In this scan boundary conditions for Be and He concentrations were fixed as in the reference inductive scenario.

To characterize different profiles we used peaking factor $f_x = x(0) / < x >$, where $< x >$ is a volume averaged x value.

We produce 3 scans: 1) addition of anomalous pinch in the electron density equation only *g(k)* = 0 (to test the effect of the bulk plasma density profiles picking on the impurities accumulation); 2) addition of the identical anomalous pinch in all plasma components (in the bulk plasma and impurities) *g(k)* = 1 and 3) addition of the anomalous pinch which is proportional to the ion charge *g(k)* = Z_k / Z_{eff} into all plasma components.

In the left hand side of Fig.1 one can see dependence of normalized density profiles of bulk plasma and impurities versus the value of anomalous pinch (k_p variation) which

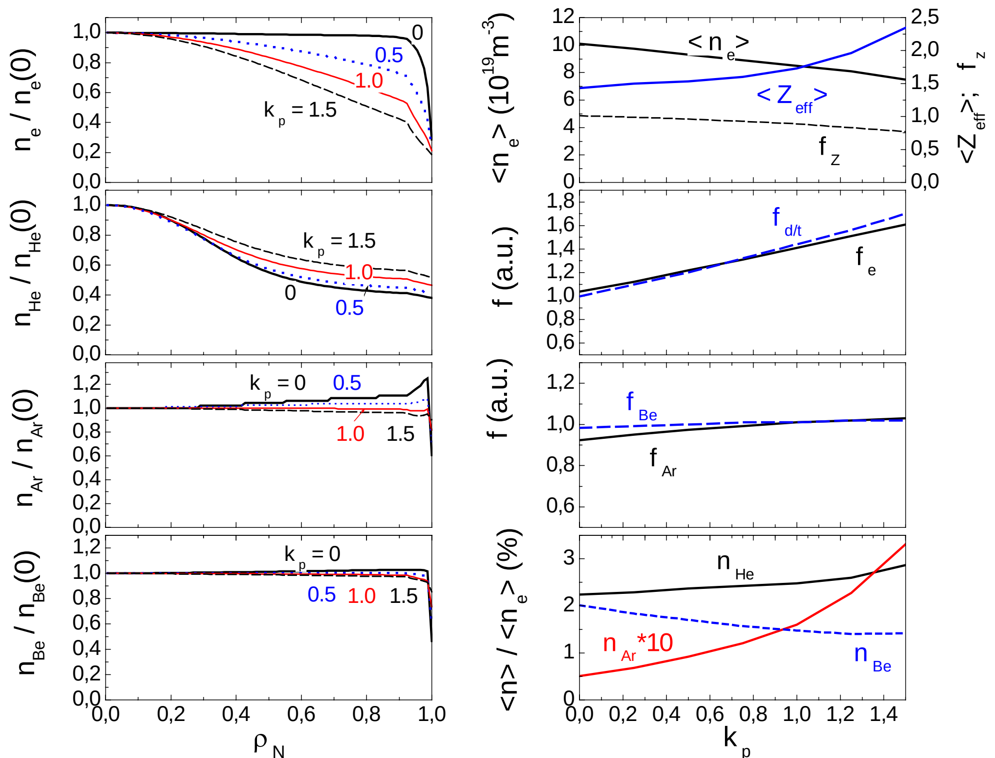

Fig.1

was introduced in the electron density equation only (*g(k)* = 0). In this case change of He density profile was small. Simulations for this case showed that increase of the bulk plasma density profile peaking does not result in the impurities accumulation (impurity density profiles stay flat). The reason of this is the prevailing of the anomalous impurity diffusion under the neoclassical impurity pinch. Right hand side demonstrates some decrease of $< n_e >$ and increase of the Ar contamination in plasma which were necessary for the discharge quality keeping. It results in increase of $<Z_{eff}>$ value due to increase of argon and helium contamination. In the same time Z_{eff} (ρ) profile peaking factor f_Z slightly decreases.

Fig.2 demonstrates dependence of plasma parameters versus anomalous pinch value when the identical anomalous pinch has been added to all plasma components

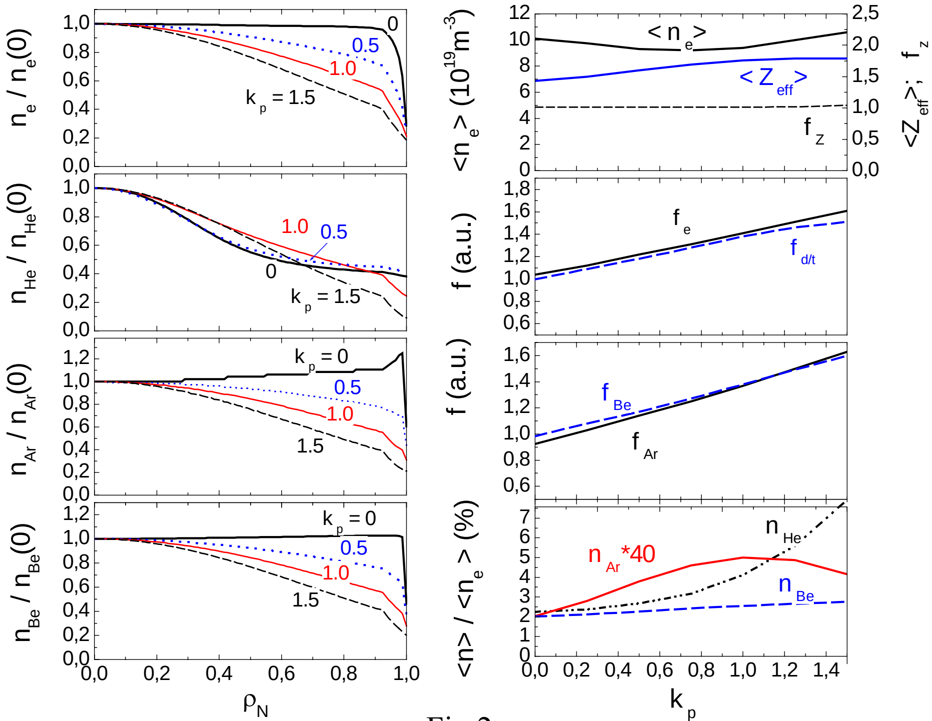

Fig.2

(for the bulk plasma and impurities) *g(k)* = 1. Normalized density profiles of bulk plasma and impurities at different anomalous pinch values are shown in the left hand side of this figure. One can see that change of He density profile is small. In this case impurity density profiles are similar to the bulk plasma density profiles. Increased accumulation of impurities is absent. Peaking factors of the bulk plasma density profiles and impurities density profiles are similar and profile of Z_{eff} stay flat. He contamination increases.

Results of addition of the anomalous pinch with the velocity, proportional to (Z_k / Z_{eff}), for all plasma components (bulk plasma and impurities) are shown in Fig.3. Change of He density profile in this case was small. Impurities accumulation and impurities profiles sharpening increases with impurity charge. Be and He percentage increases and some sharpening of Z_{eff} profile and increase of $< Z_{eff} >$ takes place. Discharge quality can be keeping in this case by some increase of $< n_e >$ and control of Ar seeding into the plasma.

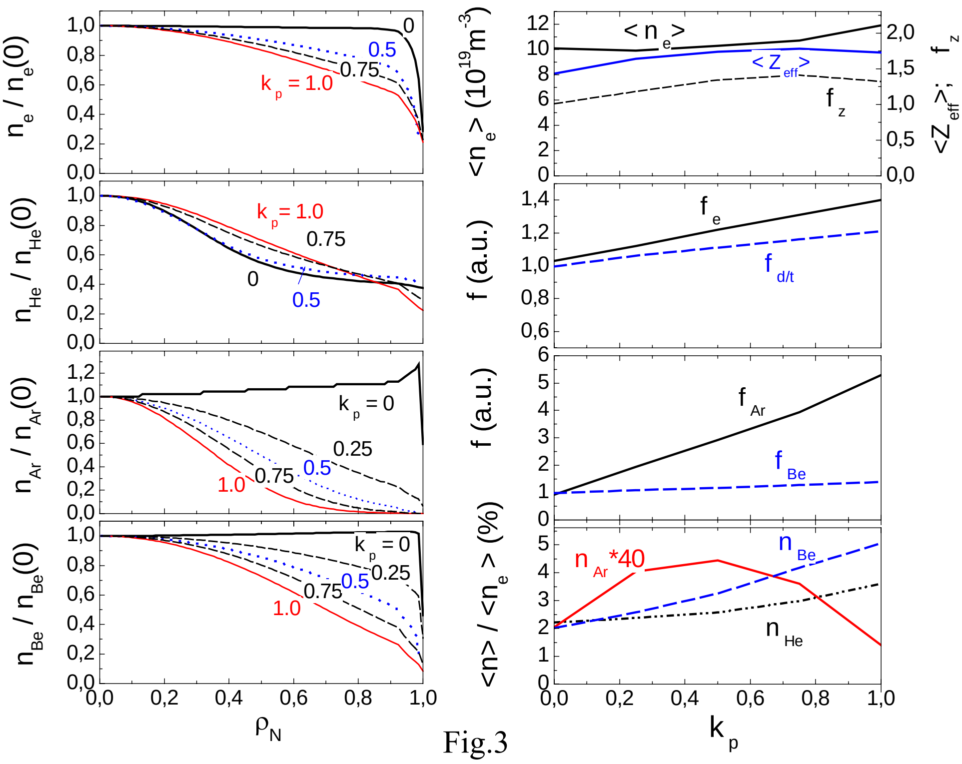

Fig.3

CONCLUSIONS

The modeling of the parametric dependencies of impurity accumulation versus the value of anomalous pinch velocity showed that:

Increase of the bulk plasma density profile peaking (without increasing of the anomalous pinch of impurities) has small effect on the impurities accumulation (impurity density profiles stay flat). The reason of this is the prevailing of anomalous impurity diffusion under the neoclassical impurity pinch. In this case discharge quality can be keeping by some decrease of $< n_e >$ and increase of the Ar flux into the plasma.

In the case of equal anomalous pinch velocities of the bulk plasma and impurities, impurity density profiles are similar to the bulk plasma density profiles and profile of Z_{eff} stays flat (increased accumulation of impurities is absent). To keep the total radiation power in this case it is necessary to increase the Ar seeding into the plasma.

If anomalous pinch velocity proportional to the ion charge one indicates impurities accumulation which increases with impurity charge (It results in some sharpening of $Z_{eff}(\rho)$ profile). Change of He density profile is small. Some increase of $< n_e>$ and control of the Ar seeding into the plasma help to keep the discharge quality in this case.

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