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Ablation rate calculations with a quasi two dimensional pellet code

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The injection of deuterium pellets into fusion plasmas has recently gained great importance in at least two fields. First, pellets are considered to be suitable for fueling of reactor plasmas, and, second, pellets are used to mitigate the Edge Localized Modes (ELMs) and thus reduce the power load on the divertors. To fully understand the mechanisms of both of these processes, the proper knowledge of the profile of the material deposited by pellets and thus the ablation rate is of crucial importance.

The interaction of pellets with hot magnetized plasmas is a complex and fully 3D phenomenon. It's description implies the solution of partial differential equations in 3D and in toroidal geometry together with the solution of the atomic physical rate equations, radiation transfer and so on. To reduce the complexity to a computationally bearable level, simplifications have to be done. The first and nowadays still widely used approximation for ablation rate calculations is the Neutral Gas Shielding (NGS) model developed by Parks and co-workers [1]. In this approximation the pellet is surrounded by its neutral, quasi steady state spherically expanding cloud. This neutral cloud shields the ambient background plasma, and the ablation rate is calculated by taking this shielding into account. The NGS model was several times further developed by including various phenomena, e.g. electrostatic shielding, atomic physical processes, geometrical effects [2, 3].

It is clear, however, that at some distance from the pellet the initially neutral pellet cloud becomes ionized and confined to the magnetic field lines, and it can not be regarded neither neutral nor spherically symmetric any more. To take into account the shielding effect of the ionized part of the cloud, the Neutral Gas and Plasma Shielding (NGPS) model has been developed [4, 5, 6]. In this approximation the regions close to the pellet are described by the NGS model, and the regions far from the pellet by a one dimensional channel flow of the ionized cloud (because the cloud ions are confined to the magnetic field lines).

The common handling of the spherically symmetric expansion of the neutral cloud and the one dimensional channel flow of the ions, was not yet investigated for hydrogenic pellets in the literature (for carbon pellets see [7]). In this contribution we present a quasi two dimensional (Q2D) computer model, in which the region close to the pellet (with low temperature,

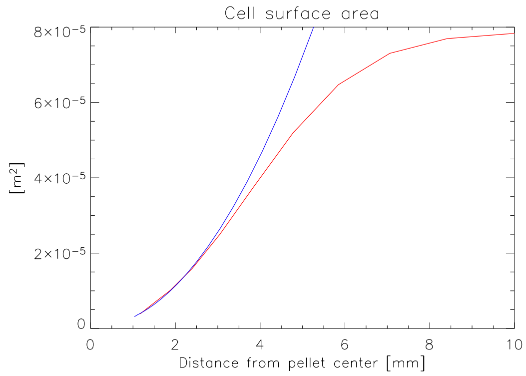

Figure 1: An illustration of the analytic transition from spherical expansion to channel flow - plot of the dependence of the cell surface area as a function of the distance from the pellet center. Blue curve – spherical expansion, red curve – spherical expansion turning into channel flow.

mainly neutral cloud) expands spherically, and the regions further from the pellet (with higher temperature, mainly ionized cloud) have linear expansion. In this multi Lagrangian cell code the surface area between two consecutive cells increases quadratically with the distance from the pellet upto some point where the ionization becomes substantial and later remains constant. The transition from the quadratically increasing cell surface area to the constant cell surface area is smooth and is done analytically. In our model the channel radius, i.e. the distance from the pellet's center to the point, where the spherical expansion turns into channel flow, is an input parameter and is set to 5 mm according to spectroscopical observations of injected hydrogen pellets on ASDEX Upgrade [8]. The realisation of the model in a computer code was done in such a way that either pure spherical expansion of the cells or spherical expansion turning into channel flow could be seledted with a switch. Figure 1 shows a plot of the dependence of the cell surface area as a function of the distance from the pellet center. The deviation from the purely spherical expansion starts already at 3 mm.

We have tested the results of the model against the results of the original NGS model [1]. Figure 2 shows the normalized pressure (normalized to the pressure value on the sonic surface) in the cells, the cells' temperature, the Mach number of the cells' expansion, and the expansion velocity as a function of the distance from the pellet center measured in units of the distance from the pellet to the sonic surface. The agreement with the predictions presented in [1] is remarkable and this fact justifies the applicability of our model for the spherically expanding cloud region around the pellet.

Figure 3 shows a comparison of main physical quantities (heavy particle and hydrogen atom

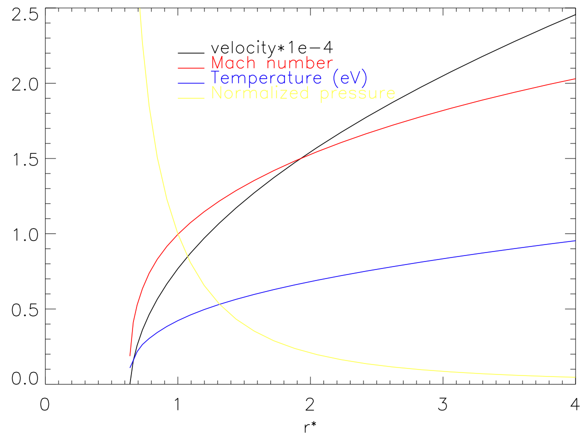

Figure 2: The normalized pressure in the cells, the cells' temperature, the Mach number of the cells' expansion, and the expansion velocity as a function of the distance from the pellet center in units of the position of the sonic surface.

density, cell temperature, and energy flux) as a function of the distance from the pellet's center for the pure spherical expansion (blue curve, NGS model) and spherical expansion turning into channel flow (red curve, Q2D model). In these calculations the background plasma electron density was $5 \cdot 10^{18} \mathrm{m}^{-3}$, the background plasma electron temperature was 1 keV and the pellet radius was 1 mm. The difference in the heavy particle density is mainly due to the geometrical factor of how the cells' volume increase (upto about 10 mm quadratically then linearly), the difference in the hydrogen atom density reflects both the above geometrical factor and the difference in the cloud electron temperature (and thus the ionization degree), and the difference in the energy flux is due to the shielding of the incident energy flux by the ionized cloud particles. The incident energy flux at a distance of a few millimeters from the pellet is one order of magnitude higher in the NGS case than in the Q2D case. Despite this huge difference, the resulted ablation rates differ much less. They are $1.8 \cdot 10^{23}$ s^{-1} and $1.1 \cdot 10^{23}$ s^{-1}. This is due to the fact, that the ablation rate is governed mainly by the shielding of the neutral cloud close to the pellet, where the expansion is spherical and the influence of the ionized part of the cloud on the ablation rate, where the expansion is linear, is much smaller.

The linearly expanding part of the pellet cloud was compared to the predictions of the well tested linear model of Lengyel and coworkers [9]. A reasonable agreement in the expansion dynamics was found.

We have compared the predictions of our Q2D model for the two separate regions around an ablating pellet (for the spherically expanding, and the linearly expanding part), against two

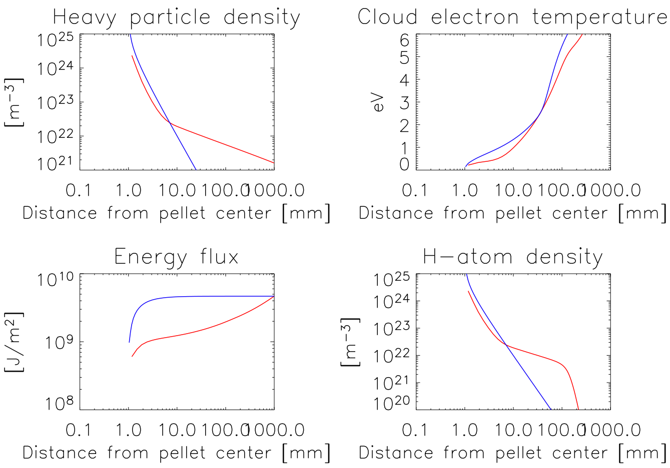

Figure 3: The comparison of the model's results for pure spherical expansion (blue curve) and spherical expansion turning into channel flow (red curve).

models that describe well these regions (but only one at a time). We have found good agreement, so one could conclude that our model can well be used to describe the expansion of the whole cloud surrounding the pellet.

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