

Effect of plasma beam parameters on the plasma-neutrals interaction and generation of hydrocarbons in Magnum-psi

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Introduction

Magnum-psi is an experiment under design for the study of plasma-surface interactions in the regime of extreme heat and particle fluxes in high magnetic fields, allowing to address fusion reactor wall issues [1]. Currently, we investigate the plasma production and transport processes in a pilot version of the experiment: Pilot-psi. In this experiment the plasma produced in a cascaded arc is made to expand in a cylindrical chamber at low pressure. The neutral density is expected to be so low that a fluid description is not valid and information about neutral particles can only be achieved from a kinetic model. We have made use of the EIRENE code, which is based on Monte Carlo neutral particle transport, to model the interaction between the hydrogen plasma and recycling neutrals (H atoms, H₂ molecules, and hydrocarbons) in the expansion vessel [2, 3]. Understanding and control of the erosion-ionization-redeposition cycle is crucial in extending the lifetime of divertor plates in future fusion devices.

Pilot-psi study

For the expanding plasma in Pilot-psi, we have used an experimentally observed plasma profile in a neutral background of 5-10 Pa. This beam can be assumed to have parabolic radial profiles for the density and temperature with a radius of 2 cm and 1 eV peak electron and ion temperature. The beam ends on a carbon substrate and has a length of 69 cm. The dimensions of the cylindrical expansion chamber are 20 cm (radius) by 125 cm (length). Because the hydrogen reacts with the predominantly chemically sputtered carbon, also hydrocarbons are present. For the generation and loss of the neutrals we have used volume (recombination) and surface (association, sputtering) processes. The sputtering process is dominated by chemical sputtering because a temperature of 1 eV is not high enough to

have physical sputtering. We present results of a scan in plasma radius and density, showing the effect of plasma-neutrals interaction when the Lehnert criterion for hydrogen impermeability

$$na > 3 \times 10^{18} \text{ m}^{-2}$$

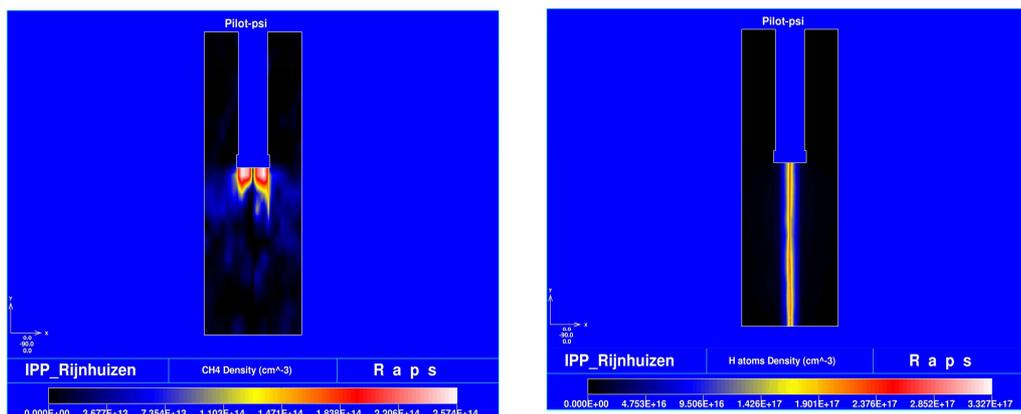


Fig. 1 Density profile of CH₄ (left) molecules and of H (right) atoms in Pilot-psi for the 1 ev electron-ion temperature and plasma density of 10²² m⁻³.

with n the average plasma density and a the plasma radius is exceeded [4]. The Lehnert criterion can be reached by increasing either the number density or the plasma radius. The inlet flow of hydrogen gas with 10% degree of dissociation is 3 slm (standard

liters per minute). For Pilot-psi we have made a scan for the plasma density to meet the Lehnert criterion.

From Fig. 1 we can conclude that hydrocarbon neutrals are unable to penetrate the plasma at a beam radius of 2 cm and a density of 10²² m⁻³. Once they are outside the beam, they move almost collisionless to the wall of the vessel. We have noticed that with an increase of the plasma density from 5·10¹⁹ m⁻³ to 10²² m⁻³ the particle flux of H atoms increases significantly while the flux of H₂ at substrate

increases less sharply (Fig. 2). The first two points in Fig.2 are made when the Lehnert criterion is not satisfied and we see the wide gap between the two curves showing less H

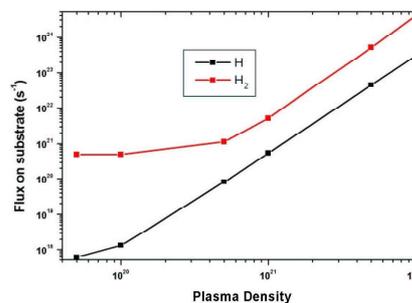


Fig. 2 Comparison of the integrated H₂ and H total flux to the substrate in Pilot-psi for different plasma

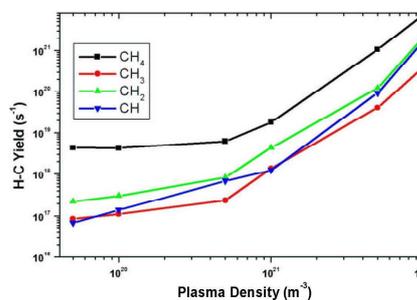


Fig. 3 Comparison of Hydrocarbon yields in Pilot-psi for different plasma densities.

flux to the substrate. Also at a low plasma density, it is difficult to keep the mobile H atoms within the beam, while the H₂ density is still high in that case. The yields of different Hydrocarbons born or generated in the vessel of Pilot-psi are plotted in Fig. 3. The yield of all hydrocarbon molecules increases with the increase in plasma density. CH₄ is produced by recombining bulk ions (H⁺), and from atoms & molecules reflecting from the surfaces, while CH₃, CH₂ and CH are produced from the ions (H₂⁺, CH₄⁺, CH₃⁺, CH₂⁺, CH⁺)-plasma interaction and molecules reflecting form the surfaces.

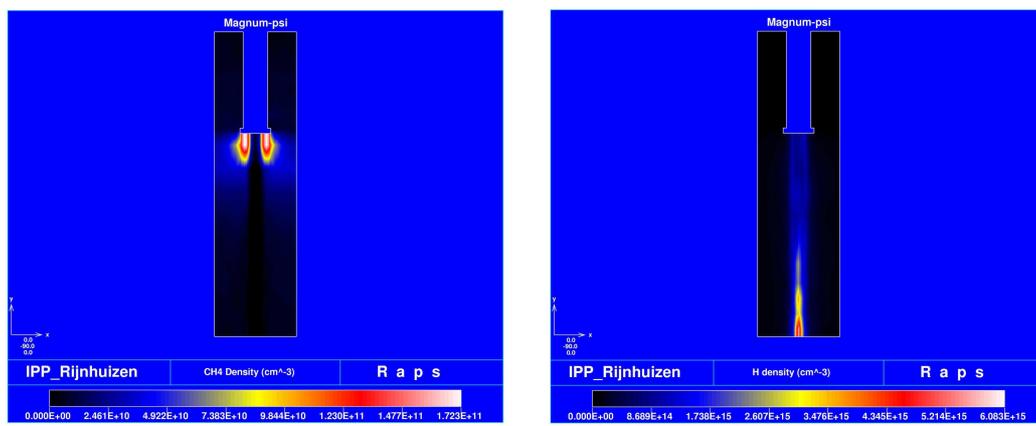


Fig. 4 Density profile of CH₄ (left) molecules and of H (right) atoms in Magnum-psi for the 1 eV electron-ion temperature and plasma density of 10²¹ m⁻³.

Magnum-psi study

In addition, we present the results for the Magnum-psi device, with dimensions of 40 cm (radius) by 3 m (length). For Magnum-psi we are injecting 25 slm of Hydrogen gas. Fig. 4 is the result of a simulation for a peak plasma density 10²¹ in Magnum-psi. Here we can again observe that CH₄ is absent in the beam area, which shows that a plasma of 1 eV temperature is well able to ionize CH₄. We still find a high density of Hydrogen atoms in the beam coming to the substrate.

Conclusions

With the EIRENE code we have computed the density profile of various neutrals as well as the yield of hydrocarbons when a low-temperature hydrogen plasma beam interacts with a carbon substrate. The density profile of atomic hydrogen shows that with a high value of the Lehnert parameter, it is possible to keep the H atoms within the plasma beam. Hydrocarbon neutrals are unable to penetrate the plasma already at a beam radius of 2 cm and move quickly to the walls of vessel. We have observed the same behaviour for a beam

with a larger radius (10cm). With increasing of plasma density the production of hydrocarbons is also increased. CH₄ is present in a larger amount because it is produced by recombining ions in the beam. After production, most CH₄ is moved out of the beam to the walls of the vessel, while the remaining CH₄ is quickly ionised explaining the virtual absence of neutral CH₄ inside the beam itself.

Future work

We will develop a 1D-plasma model to have a more consistent description to show the effect of plasma-neutrals interaction when the impermeability of the plasma beam is enhanced in Magnum-psi. In the near future we will compare our simulation results with the experimental data for production of Hydrocarbons in pilot-psi.

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