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EFFECT OF PUMP LIMITER THROAT ON PUMPING EFFICIENCY

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EFFECT OF PUMP LIMITER THROAT ON PUMPING EFFICIENCY

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1. INTRODUCTION

The necessary control of plasma edge density has led to the development of pump limiters to achieve this task. On Tore Supra, where a large part of the program is devoted to plasma edge studies, two types of such density control apparatus have been implemented, a set of pump limiters and the pumps associated to the ergodic divertor (magnetically assisted pump limiters) [1].

Generally two different kinds of pump limiters can be used, those with a throat which drives the plasma from the open edge plasma (SOL) to the neutralizer plate [2], and those without or with a very short throat [3]. We are interested here in this aspect of the pump limiter concept, i.e. on the throat effect on neutral density build-up in the vicinity of the pumping plates (and hence on pumping efficiency). The underlying idea of this throat effect can be readily understood ; indeed while the neutral capture in pump limiters without throats is only a ballistic effect, on expects the plasma to improve the efficiency of pump-limiters via plasma-neutral-sidewall interactions in the throat. This problem has been studied both numerically and analytically.

The paper is divided as follows. In section 2, we describe the basic features of pump-limiters which are modelized by the numerical code "Cézanne". Section 3 is devoted to the throat length effect considering in particular the neutral density profile in the throat and the neutral density buil-up as a function of the throat lenght. In section 4, we show that the "plugging effect" occurs for reasonnable values of throat lengths. An analytical value of the "plugging length" is discussed and compared to the values obtained numerically.

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2. MODEL FOR NEUTRAL-PLASMA-SIDEWALL INTERACTIONS IN THE PUMP LIMITER THROAT

2.1 Goals of the study

For the purpose of this study we split the pump limiter in four areas accordin to the underlying dominant physics involved (see Figure 1).

- The pumping volume where the pumping plates sit and which we consider as filled by H_2 (D_2) molecules at a very low temperature.
- The neutralizer plate where the plasma hits the wall is reemitted as H (D) atoms or H_2 (D_2) molecules either towards the pumping volume or towards the throat.
- The throat, parallel to the magnetic field, along which the plasma flows to the neutralizer while the neutrals channel towards the edge plasma.
- The muzzle of the throat where the neutrals reach the open edge plasma.

In this paper we deal with the third area where the physics involved in the neutralize plate volume and in the muzzle only appear as limit conditions.

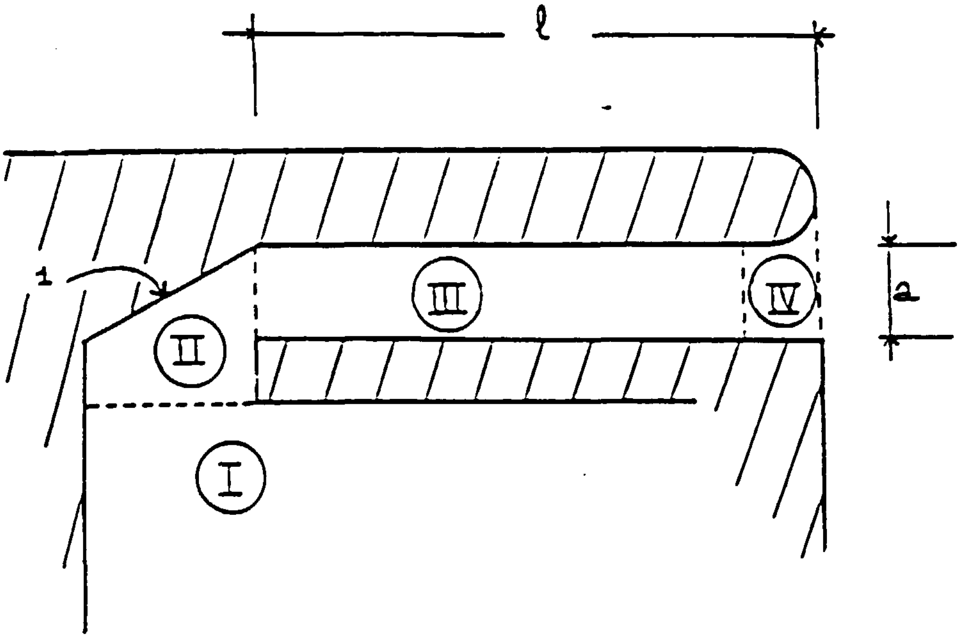

Figure 1 : The pump-limiter and the four parts considered
I - The pumping volume
II - The neutralizer plate volume
III - The throat which is at the core of the present study
IV - The muzzle
The plasma enters the pump limiter at the muzzle and flows along the magnetic field to the neutralizer plate (1).

Our present study aims at relating the edge plasma parameters, namely the plasma density and temperature (n_p(EP), T_p(EP)) and the normalized length L=l/a (wher l and a are respectively the length and width of the throat) to the neutral density i the vicinity of the neutralizer plate n_N(NP) and in a lesser way to the plasma power flow entering the throat Q_p(EP) and that driven to the neutralizer plate Q_p(NP).

The relation between $n_N(NP)$ and $n_p(EP)$, $T_p(EP)$ will be interesting to understand the pumping efficiency and the different measurements available on the pump limiter. The effect of the length L on the pumping efficiency is clearly an important issue for the future development of the apparatus. The "plugging effect" which is related to this last effect is also investigated. The loss of power flow to the neutralizer due to neutral power transport to the sidewalls of the throat can also prove to be important to study neutralizer plate physics or technological outlooks such as power deposition.

2.2 The numerical code "Cézanne"

Phenomenological descriptions of the physics have been considered which enable to select the leading parameters of the problem. Such specific aspects can in turn be investigated by more precise codes such as Degas [4].

The code is based on 1D time independent equations for both the plasma (single fluid) and the neutrals. For the latter the fluid treatment is adequate since the bouncing on the throat sidewalls acts as collisions and together with the neutral-plasma interaction ensures a small mean free path. This description of the neutrals is original when compared to the Monte Carlo codes available.

Several atomic processes are involved in the throat. In the present stage of the code we have included ionization and charge exchange. The power loss by ionization is computed as a function of plasma density and temperature [5]. The interactions between the neutrals and the sidewalls (bouncing effect) are described phenomenologically. One assumes a momentum and energy loss proportional to the momentum and the energy of the neutrals [6]. Two different coefficients are used for these losses.

All along the throat the neutrals are considered as atoms H (D). These neutrals are assumed to be created by Franck-Condon dissociation [7], yielding 3 eV to each atom, or by direct reemission from the neutralizer plate, the energy of the neutrals being that of the incoming ion with a loss equivalent to the energy loss of the neutrals on the sidewalls. The balance between "Franck-Condon" neutrals and "neutralizer" neutrals depends on the physics of the neutralizer plate and on the geometry of the apparatus (angle between the neutralizer plate and the axis of the throat, etc.) For the present results, we have considered that all neutrals are created by Franck-Condon dissociation.

At the muzzle of the throat we have assumed that the average velocity of the neutrals is of the order of the sound velocity $(5\ kT_N/3\ m_N)^{1/2}$. Very weak dependence with respect to this last criterion has been observed.

The geometrical effect of direct outgoing neutrals (with no bouncing on the sidewalls) is not taken into account here. A new version of the code including this effect and hence a more realistic description of the muzzle limit condition is now being investigated.

3. EFFECT OF THE THROAT LENGTH

3.1 Neutral flux profile in the throat

The leading effect we are interested in is the neutral outflow decrease which is a direct consequence of the role played by the plasma on neutral confinement. The observed decrease of neutral flux as the neutrals channel towards the open edge plasma is the result of the balance between ionization and neutral-sidewall interactions as well as charge exchange. In Figure 2, for given values of edge plasma density and temperature we show the neutral flux profile for different values of the throat length L (L=l/a). As L is increased the profile reaches a standard shape with an exponential decrease of neutral flux which vanishes when L is large enough. Thus when the throat is longer than a typical value, there is no neutral flux outgoing at the muzzle. Any further increase of L does not modify the neutral flux profile. The "plugging regime" has been reached.

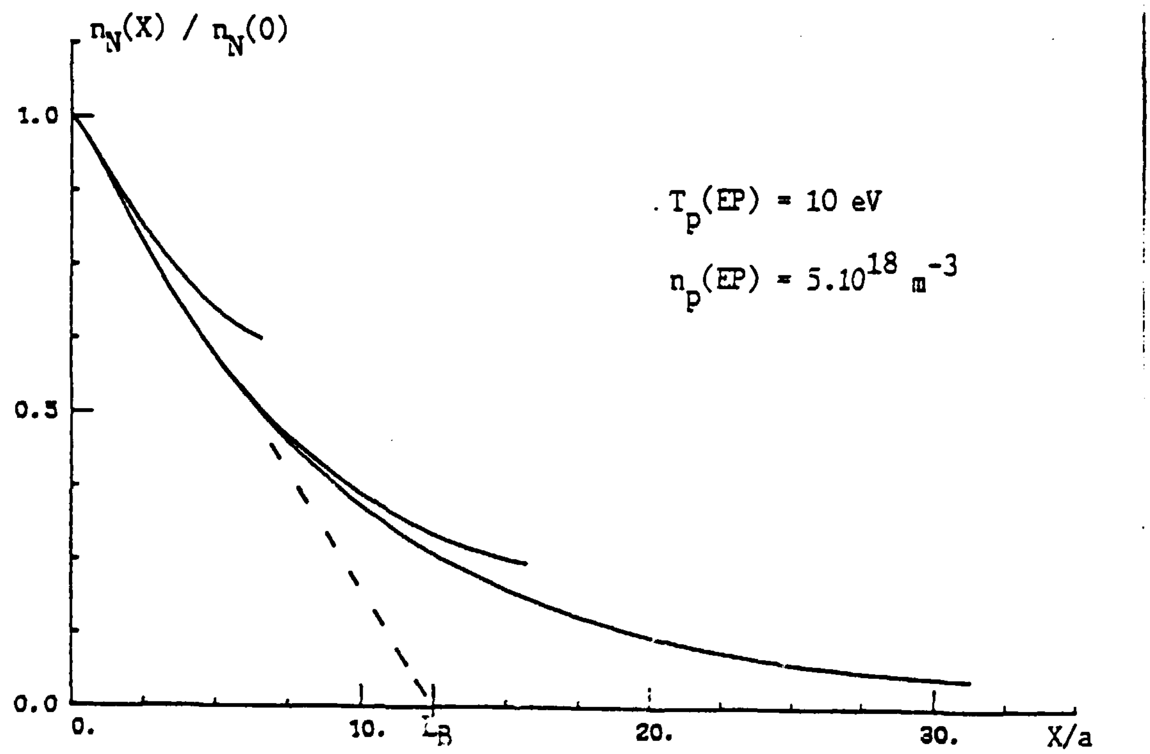

Figure 2 : Neutral flux normalized value (with respect to the maximum value at the neutralizer plate X=0) versus the distance X along the throat. Three throat ratios (L=l/a) are considered $L_1 \simeq 6$, $L_2 \simeq 16$, $L_3 \simeq 30$. The decay length is $L_B \simeq 12$ (the analytical value is $L_B \simeq 14$, see Eq. (1)).

3.2 Neutral density build-up as a function of the throat length

The "plugging effect" which is described in the previous section can also be found if one considers the density build-up at the neutralizer plate $n_N(NP)$. This is the case in Figure 3 where $n_N(NP)$ is computed versus different values of the throat length L. Two outstanding characteristics of the dependence are to be underlined. First one finds a strong build-up of the neutrals even for small values of the throat length. This result is directly related to the physics of the neutralizer, i.e. to the value of $T_N(NP)$ which has been selected (limit condition). The second characteristic is the weak dependence of the neutral density build-up with respect to the throat length. The variation only indicates a saturation (at a value comparable to the first values)

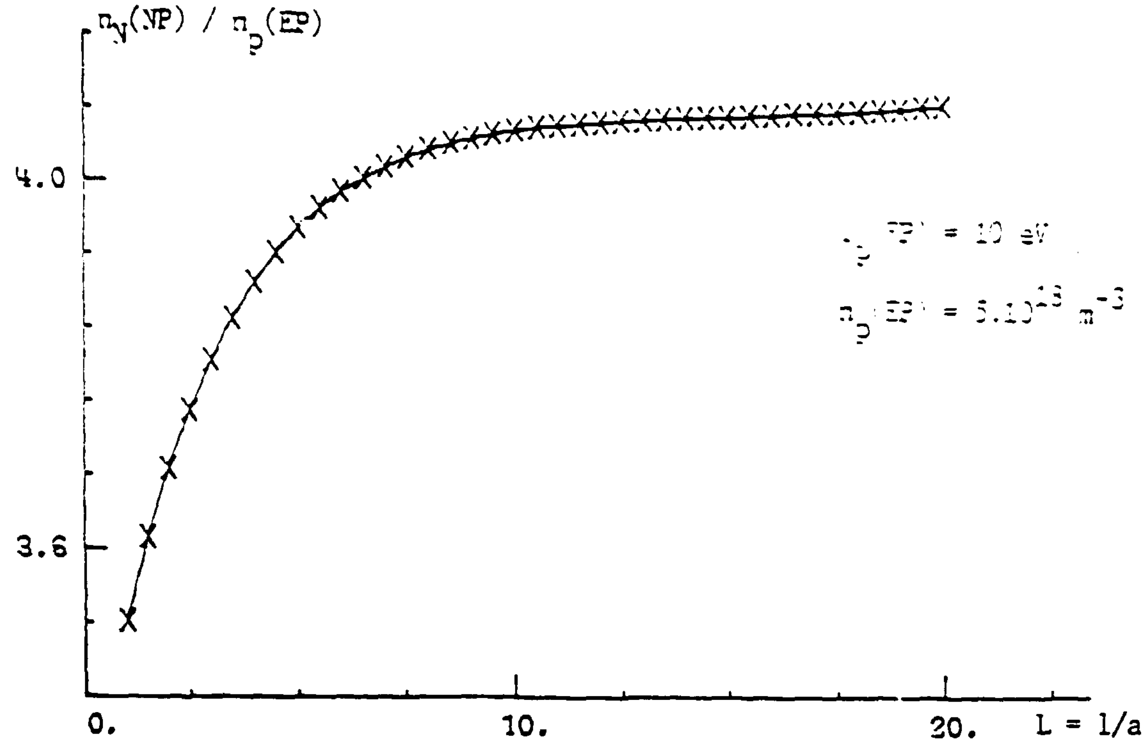

Figure 3 : Ratio between neutralizer plate neutral density, $n_N(NP)$, and edge plasma density, $n_p(EP)$, versus different throat ratios ranging from 1 to 30.

4. "PLUGGING EFFECT"

An exponential decay law for the particle flux is found if one assumes that the plasma density and temperature and the neutral temperature and average velocity reach constant values (the other quantities being vanishingly small). The decrement of this exponential decay is the "plugging length" L_B.

$$L_B = (L_I\ L_p)^{\frac{1}{2}}\ (1 + L_p/L_{CX})^{-\frac{1}{2}} \tag{1}$$

where L_I, L_{CX} are respectively the neutral ionization and charge exchange mean free paths, and where L_p is the length rate of momentum loss on the sidewalls. These lengths are those derived from the edge plasma temperature and density and from the "plugging regime" neutral thermal velocity (i.e. when $L > L_B$). Through this last effect the "plugging length" depends on the neutral thermal velocity $(kT_N/m_N)^{\frac{1}{2}}$ which is driven by a balance between the charge exchange power gain and sidewalls power loss.

For several values of edge plasma parameters, $T_p(EP)$ ranging from 10 to 200 eV and $n_p(EP)$ ranging from 2 to 200 $10^{18}\ m^{-3}$, we have computed the "plugging length" given by the neutral flux decrease (see Figure 4). Excellent agreement is found between the numerical values and the analytical values.

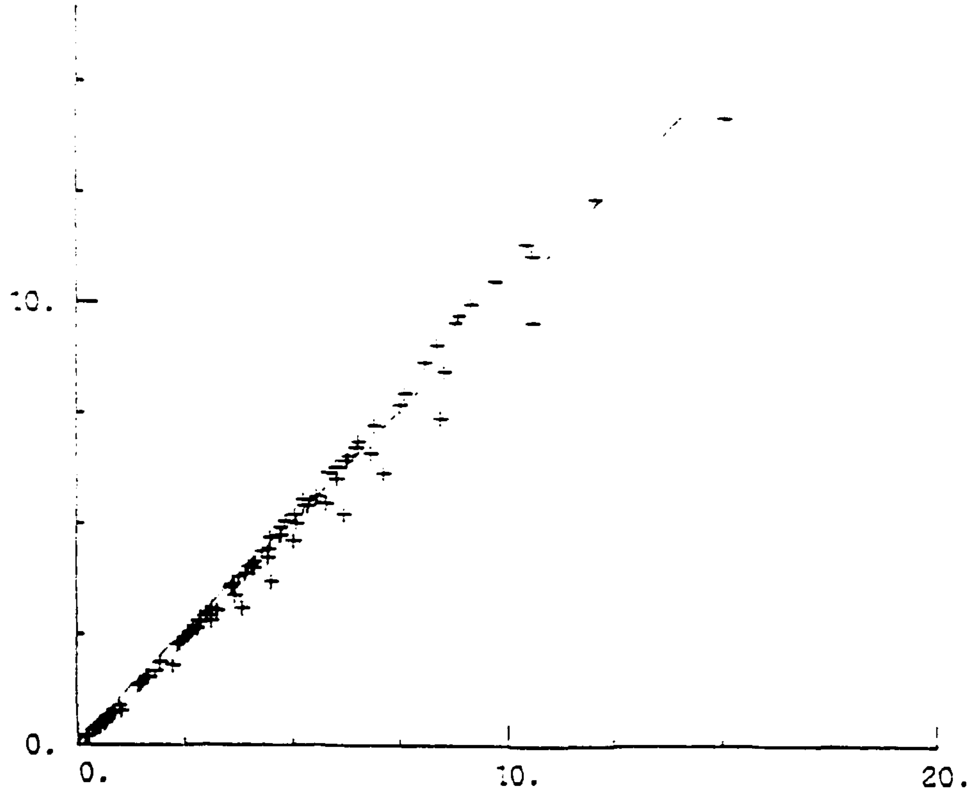

Figure 4 : Computed value of the "plugging length" (normalized by the throat width a) versus the analytical values derived from Eq. (1).

5. CONCLUSION

The "plugging length", which is the minimum throat length to obtain the pump limiter highest efficiency, is derived. Excellent agreement is found between the analytical value and those obtained with the numerical code "Cézanne". We also show that the throat effect on neutral density leads to a strong build-up as long as the neutral temperature at the neutralizer plate is low and as long as the amount of direct outgoi neutrals (with no bouncing on the sidewalls) is small. Such conditions are readily ful filled whenever the throat length is larger than the "plugging length" (L_B). These results show that the best regime for the pump limiter (owing to the actual values of the throat length to throat width ratios $l/a \simeq 3$) will be obtained in cold and dense edge plasmas where $l_B/a \simeq 3$, i.e. $T_p(EP) \simeq 10$ eV and $n_p(EP) \simeq 40 \cdot 10^{18}$ m^{-3}.

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