Helium Recycling Studies for Iter Plasmas with Internal Transport Barrier

G. Kamelander, G. Weimann, M. Pachole, G. Sdouz

Austrian Research Centers, A-2444, Seibersdorf

Introduction

Longtime pulses of fusion plasma discharges in the order of 1000 s are one of the principal goals of ITER or ITER-FEAT. Steady-state operation of plasmas with high power amplification factor Q is an other option for plasma operation proposed at the IAEA-conferences of Montreal [1] and Yokohama [2] and based on experiments at Tore Supra, e.g. Ref.[3], JET and other devices. In those references it has been shown that the requirements of steady-state ITER operation can be fulfilled by reversed shear (RS) modes. Numerical simulations have been performed sustaining the fusion plasma with a non-monotonous q-profile as a consequence of a hollow and non-inductive plasma current. By means of the combined action of axial fast wave (FW) heating and off-axial lower hybrid (LH) heating a current drive is produced. The FW and LH power as well as the external power voltage are actuators to keep the safety factor profile close to a prescribed q-profile. The current drive is completed by a bootstrap (BS) current becoming the dominant current component of the stationary plasma current. The hollow current density profile produces an internal transport barrier (ITB) improving the confinement of the plasma considerably. Steady-state scenarios based on ITB are referred to as advanced scenarios. The thermal ion conductivity with ITB as a function of the plasma radius is shown in Fig.1. The hollow current profile in steady-state composed of current drive and BS-current is presented in Fig.2 for a typical advanced scenario for ITER.

In the actual paper we investigate the role of helium ash in advanced scenarios which has been just estimated in Refs.[2] to [3]. All calculations presented in this paper have been performed by means of the 1½ dimensional ASTRA-code [4] based on the fluid model.

Transport model

In addition to the diffusion equation for the electric field the energy balance equation for electrons and ions are solved by ASTRA. The heat conductivity for electrons is composed of a neoclassic and of an anomalous part

$$\chi_e = \chi_{e,an} + \chi_{e,neo} \tag{1}$$

where the anomalous part is a combination of Bohm conductivity χ_B and gyroBohm conductivity χ_{gB}

$$\chi_{e,an} = \alpha_B \chi_B F_{se} + \alpha_{gB} \chi_{gB} \tag{2}$$

F_{se} is a shear function depending on magnetic shear and is fitted from experiments. α_B and α_{gB} are constants fitted from experiments. See Ref. [5].

A similar relation is used for ion heat conductivity

$$\chi_{i,an} = \alpha_B \chi_B F_{si} + \alpha_{gB} \chi_{gB}. \tag{3}$$

For helium transport we use a two group model with a continuity equation for the fast alphas

$$\frac{\partial n_\alpha}{\partial t} = \nabla \cdot \left(D_\alpha \nabla n_\alpha \right) + S_\alpha - \frac{n_\alpha}{\tau_{SD}} \tag{4}$$

and for the helium ash

$$\frac{\partial n_{he}}{\partial t} = \nabla \cdot \left(\Gamma_{he} \right) + \frac{n_\alpha}{\tau_{SD}} + S_{rec} . \tag{5}$$

We have found that the detailed modeling of the fast group is not very important for the results of our study. For this reason we estimated the fast diffusion coefficient by $D_\alpha \approx 0.1$ in accordance with literature. S_α represents the thermonuclear source and n_α / τ_{SD} denotes the slowing down source. The helium flux is given by

$$\Gamma_{he} = -D_{he} \nabla n_{he} + V_{pinch} \tag{6}$$

It has been assumed that the diffusion coefficient is also composed of a neoclassical and an anomalous part

$$D_{he} = \beta_{he} \chi_{i,an} + \chi_{i,neo} \tag{7}$$

where β_{he} has been assumed to be 0.5. The inward pinch in Eq.(6) is also composed of a neoclassical and a an anomalous part as described in Ref.[6].

Recycling Source Model

The recycling source has been modeled following Ref.[7]

$$S_{rec} = S_0 \exp\left(-\frac{1-r}{\lambda_i} \right) \tag{8}$$

where r is the normalized radial coordinate and λ_i the ionization length. S_0 is obtained by normalization

$$R_{eff} \frac{N_{he}}{\tau_{he}} = \int S_{rec} \, dV \tag{9}$$

R_{eff} is the effective recycling factor, N_{he} the total helium inventory and τ_{he} the particle confinement time.

Results

We have investigated an advanced scenario for ITER-like geometry with an reduced minor radius (a=1.8) to approach ITER-FEAT. The plasma has been initially heated by ohmic power and afterwards by central fast waves and off-central lower hybrid waves according the heating scheme presented in detail in Ref. [2]. 2000 seconds after beginning of the discharge the fusion power is increased by density control. 300 MW are the nominal fusion power. The temporal evolution of fusion power and auxiliary power is shown in Fig.3. The simulation has been performed under the assumption of a high recycling factor of 93 %. From this figure we find that the breakeven point is reached after 2500 s and that a quasi steady-state is takes place after 4000 s. There are still minor oscillations of output power which can easily been managed by the control system. These power oscillations are in context with high helium recycling.

As already mentioned the helium source consists of a thermonuclear source and of a boundary source due to recycling. Both source densities are shown in Fig.4 for a plasma with a recycling of 50 %.

The simulations are very sensitive to the boundary condition. In our simulations we have assumed that the density is proportional to the density gradient. That assumption is equivalent to an extrapolation length. In Fig.5 the helium particle flux is drawn as a function of the minor radius. Fur low recycling the flux is almost constant near to the plasma edge. If recycling is enhanced the existence of a boundary source becomes important with the consequence of a flux peak near the plasma edge. The peak dominates the flux profile if 50 % recycling is passed. In Fig.5 the flux profile for 90 % recycling is also presented. We note a dramatic increase of helium flux if high recycling is approached.

The strong dependence of plasma characteristics on helium recycling is shown in Fig.6 with the helium confinement factor and the auxiliary power (FW- plus LH-power), necessary to maintain the plasma in steady-state with 300 MW nominal fusion power, as functions of the recycling factor. From this figure we find that effective helium confinement and auxiliary power depend only weakly on recycling if the factor is less than 60 % and that there is a strong dependence on (effective) recycling if 90 % are approached.

Conclusion

The helium concentration has been calculated self-consistently with the ion transport model. We have investigated the helium fraction and the confinement factor as a function of the effective recycling factor. This quantity is not exactly known and must be found from experiments. Furthermore the is a strong dependence of open parameters in the boundary conditions. The helium fraction is not much influenced by ITB because helium content and helium density profile is dominated by recycling and boundary conditions.

References

[1] D. Boucher et al., Proceedings of the 17th IAEA Fusion Conference, Montreal 1996, F1-CN-64/FP-22

[2] D. Moreau, I. Voitsekhovitch, Proceedings of the 18th IAEA Fusion Conference, Yokohama 1998, F1-CN-69/CD2/EX9/1

[3] Equipe Tore Supra, Plasma Phys. Control. Fusion, 38 (1996), A25

[4] G. V. Pereverzev, P.N. Yushmanov et al., Report IPP 5/42 (1991)

[5] A. Taroni, M. Erba, E. Springmann and F. Tibone, Plasma Phys. and Control. Fusion, 39, 261, (1997)

[6] I. Voitsekhovitch et al., 2nd Europ. Workshop on “Role of electric field in plasma confinement and exhaust”, Maastricht, June 19-20, 1999

[7] G. Kamelander, X Litaudon, D. Moreau, I. Voitsekhovitch, Helium Transport in Advanced Tokamaks, Submitted to Nucl. Technology.

Acknowledgment

The work has been performed in EURATOM-ÖAW association. Thanks to the support of CEA/Cadarache (D.Moreau) and IPP (G. Pereverzev). Furthermore we express our thanks to the Computer Center of the University of Vienna for the access to the alpha cluster.

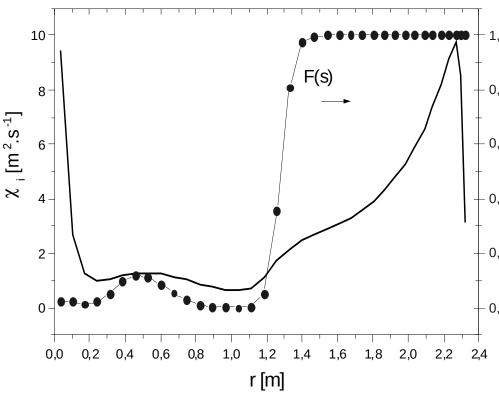

Fig.1: Shear function and ion conductivity profile with ITB

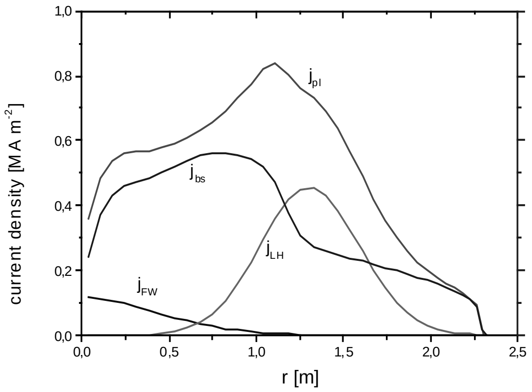

Fig.2: Current density in steady-state

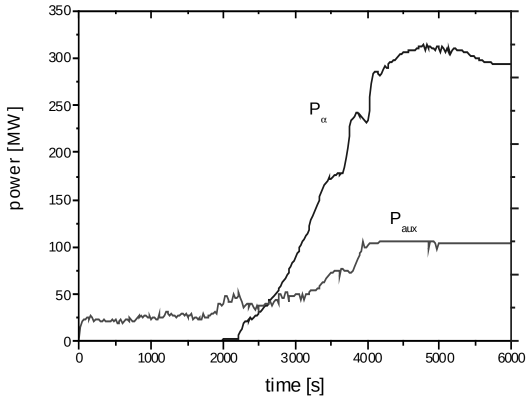

Fig.3: P_α and P_{aux} vs. time

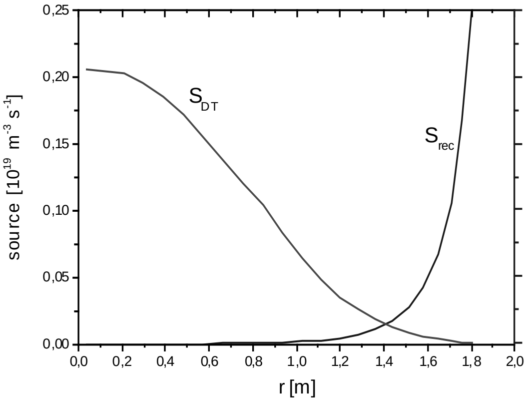

Fig.4: Source densities at steady-state at R_{eff}=0.5

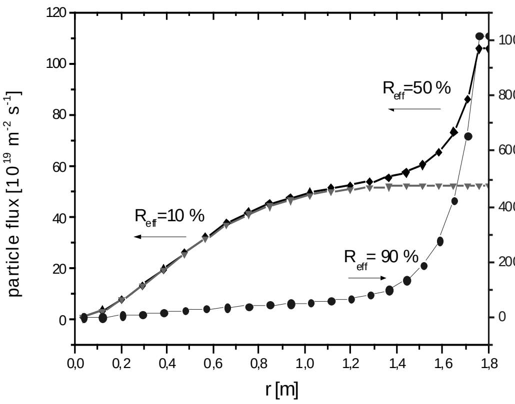

Fig.5: helium flux at steady-state

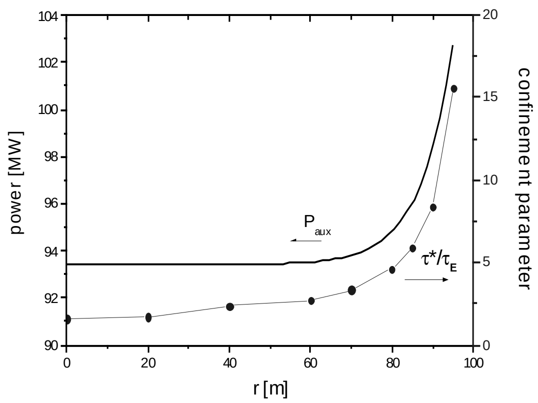

Fig.6: Auxiliary power vs. recycling