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Models for H-Mode Pedestal Temperature and Predictions for Future Tokamak Designs

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Abstract. Studies of type 1 ELMy H-mode pedestals are carried out using 0 D and 1.5 D approaches. In the 0 D study, predicted pedestal temperatures are compared with 533 data points. The pedestal temperature models, with pedestal width based on magnetic and flow shear stabilization and neutral penetration, yield an RMSE of 32% and 53.4%, respectively, when compared with data. In the 1.5 D studies, the pedestal models are used together with a core transport model in the integrated predictive transport code JETTO. In simulations of type 1 ELMy H-modes using the JETTO code, when a pedestal width model based on neutral penetration is used, the pedestal width and pressure are significantly under-predicted and the ELM frequency obtained is that expected for type 3 rather than type 1 H-mode plasmas. In contrast, the simulations using a pedestal width based on magnetic and flow shear stabilization yield better agreement for the pressure profiles and the ELM frequency is appropriate for type 1 ELMs. Consequently, the simulations indicate that magnetic and flow shear stabilization plays a more significant role in determining the width of type 1 ELMy H-mode pedestals than does neutral penetration. The pedestal temperature model, using a pedestal width based on magnetic and flow shear stabilization, together with the MMM95 core transport model, is used in the BALDUR code to predict the performance of ITER. At the ITER design point, the simulation yields a pedestal temperature of 2.74 keV and an alpha power of 89.3 MW, corresponding to fusion Q of 11.2.

INTRODUCTION

Studies of type 1 ELMy H-mode pedestals are carried out using 0 D and 1.5 D approaches. In the 0 D approach, a model for the pedestal width and a model for the pedestal pressure gradient that is based on the ideal ballooning first stability boundary limiting the gradient, is used with the experimental pedestal density to predict the pedestal temperature, $T_{\rm ped}$. The predicted $T_{\rm ped}$ are compared with the corresponding experimental data. For a pedestal width based on magnetic and flow shear stabilization, the comparison with 533 data points yields an RMSE of 32.0%; whereas, for a pedestal width based on neutral penetration length, the comparison yields an RMSE of 53.4%. In the 1.5 D approach, the pedestal models are used together with a mixed Bohm /gyro-Bohm core transport model [1] in the integrated transport modelling code, JETTO. Simulations of four JET type 1 ELMy H-mode discharges, two with low triangularity and two with high triangularity, are carried out and pressure profiles are compared with the experimental profiles. It is found that the simulations using the neutral penetration model significantly under-predict the width of the pedestal and predict an ELM frequency expected for type 3 H-mode plasmas. In contrast, the simulations using magnetic and flow shear stabilization pedestal width model yield better agreement with the experimental pressure profiles and indicate an ELM frequency of type 1 ELMs. Therefore, it appears that magnetic and flow shear stabilization plays a more significant role than neutral penetration in determining the width of type 1 ELMy H-mode pedestals. The pedestal temperature model with the width based on magnetic and flow shear stabilization is then used together with the MMM95 transport code [2] in the BALDUR code to predict the performance of ITER. At the ITER design point, the simulation yields the pedestal temperature of 2.74 keV and the alpha power of 89.3 MW.

0 D APPROACH FOR H-MODE PEDESTAL MODEL

In this study, we assume that the pressure gradient within the pedestal is constant and limited by the high n ballooning instability:

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$$\frac{\partial p}{\partial r} \approx \left(\frac{\partial p}{\partial r}\right)_c = -\frac{B^2}{2\mu_0 R q^2}\alpha_c \tag{1}$$

where q is the safety factor and α_c is the normalized critical pressure gradient. The scaling of α_c is assumed to depend on the magnetic shear (s) and on the elongation (κ_{95}) and triangularity (δ_{95}) at the 95% flux surface:

$$\alpha_c = 0.4\,s(1+\kappa_{95}^2(1+5\delta_{95}^2))\,. \tag{2}$$

In the results presented in this paper, s and q are calculated at one pedestal width away from the separatrix [3]. In addition, the effect of the bootstrap current, which reduces the magnetic shear in the steep gradient region, is included in the determination of the magnetic shear.

The pedestal temperature, when the pedestal width is based on magnetic and flow shear stabilization of drift modes [4], that is $\Delta = 2.42\rho s^2$ (where ρ is the ion gyro-radius), is given by

$$T_{\rm ped}[\mathrm{keV}] = 1.89\left(\frac{B}{q^2}\right)^2\left(\frac{M_i}{R^2}\right)\left(\frac{\alpha_c}{n_{\rm ped\,19}}\right)^2 s^4 \tag{3}$$

where B is the toroidal magnetic field, $M_{\rm i}$ is the hydrogenic mass, and $n_{\rm ped\ 19}$ is the electron density at the top of the pedestal in units of 10^{19} m^{-3}. Note that Eq. (3) is non-linear in $T_{\rm ped}$ because s and q are functions of the pedestal width, which in turn is a function of the pedestal temperature. Also, the bootstrap current that reduces the magnetic shear also depends on the collisionality, which is also a function of the pedestal temperature.

For the other pedestal width model considered in this paper, that is the pedestal width based on the penetration length of neutrals at the edge of plasma, $\Delta = (2.6\mathrm{x}10^{27})/n_{\rm ped}^{3/2}$ [3], the pedestal temperature is:

$$T_{\rm ped}[\mathrm{keV}] = 10.2\left(\frac{B}{q}\right)^2\left(\frac{1}{R}\right)\left(\frac{\alpha_c}{n^{5/2}_{\rm ped\ 19}}\right) \tag{4}$$

Note that Eq. (4) is also a non-linear equation, as described previously.

Both pedestal width models are used in the prediction of the pedestal temperature for 533 data points of type 1 ELMy H-mode discharges. The data points are obtained from the International Pedestal Database version 3.1 (http://pc-sql-server.ipp.mpg.de/Peddb/). The pedestal temperature model with $\Delta = 2.42\rho s^2$ yields an RMSE of 32.0% while the model with $\Delta = (2.6\mathrm{x}10^{27})/n_{\rm ped}^{3/2}$ yields the RMSE of 53.4 %. The comparison between the pedestal temperatures from both models and experimental data are shown in Fig. 1.

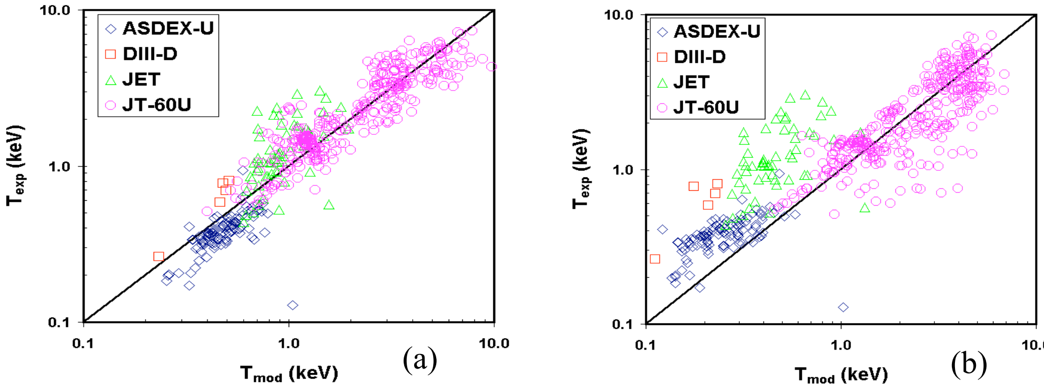

FIGURE 1. Predicted pedestal temperatures using $\Delta = 2.42\rho s^2$ (a) and $\Delta = (2.6\mathrm{x}10^{27})/n_{\rm ped}^{3/2}$ (b) compared with 533 experimental data points from International Pedestal Database. The numerical coefficients in the expressions for Δ are chosen to minimize the RMSE.

1.5 D APPROACH FOR H-MODE PEDESTAL MODEL

Modelling of plasma parameters within edge transport barrier are explicitly included in simulations using the 1.5 D transport modelling JETTO by imposing the boundary conditions at the separatrix. Two main assumptions are made about the edge barrier. First, it is assumed that all anomalous transport within the pedestal is nullified starting from the top of the barrier outward so that all elements of the transport matrix within the barrier are equal to the ion neo-classical thermal conductivity, calculated at the top of the pedestal. The second assumption regards the width of the pedestal. The two pedestal width models, which are used in the 0 D approach, are used in the 1.5 D simulations of the JET discharges described below.

Simulations, have been carried out, using the JETTO code with the pedestal width given either by $\Delta = 2.42\rho s^2$ or by $\Delta = (2.6\mathrm{x}10^{27})/n_{\rm ped}^{3/2}$, for 4 JET discharges. These discharges have approximately the same current, 2.5 MA;

magnetic field, 2.6 to 2.7 T; and elongation, 1.7. However, the triangularity for two of the discharges is low, 0.25 and 0.32, and, for the other two discharges, is high, 0.45 and 0.49. These JET discharges are all type 1 ELMy H-mode discharges. The core transport model, which is used in these simulations, is the mixed Bohm/gyro-Bohm model.

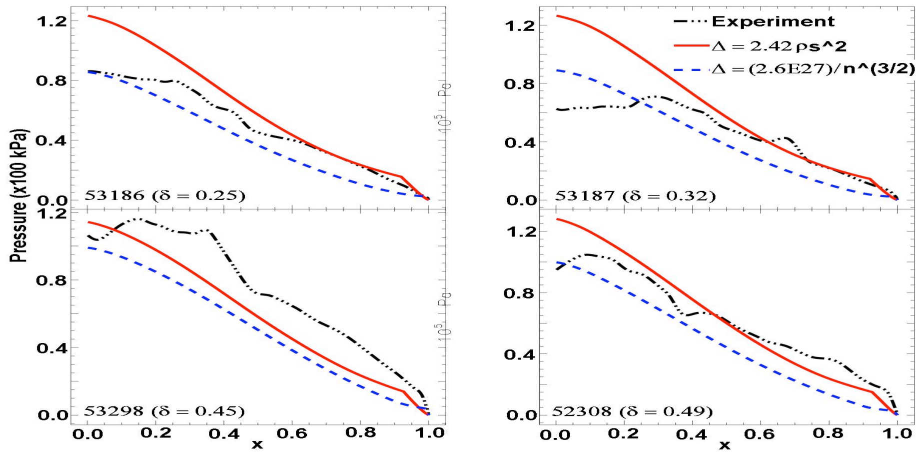

FIGURE 2. Predicted pressure profiles using $\Delta=2.42\rho_s^2$ (solid line) and $\Delta=(2.6\mathrm{x}10^{27})/n_{ped}^{3/2}$ (dashed line) compared with the experimental pressure profiles (dot-dashed line) for 4 JET discharges.

The simulations with the pedestal width based on magnetic and flow shear stabilization yields a pedestal width of about 3 cm while the simulations with the width based on neutral penetration results in a much narrower width, less than 1 cm, for all 4 discharges. The narrow pedestal widths that result from using the neutral penetration model yield a significant under-estimation of the pedestal pressure for all 4 discharges, as shown in Fig. 2. Simulations, which use the shear stabilization pedestal model, yield better agreement for the low triangularity discharges than for the high triangularity discharges. This might be due to better access to second stability for high triangularity discharges.

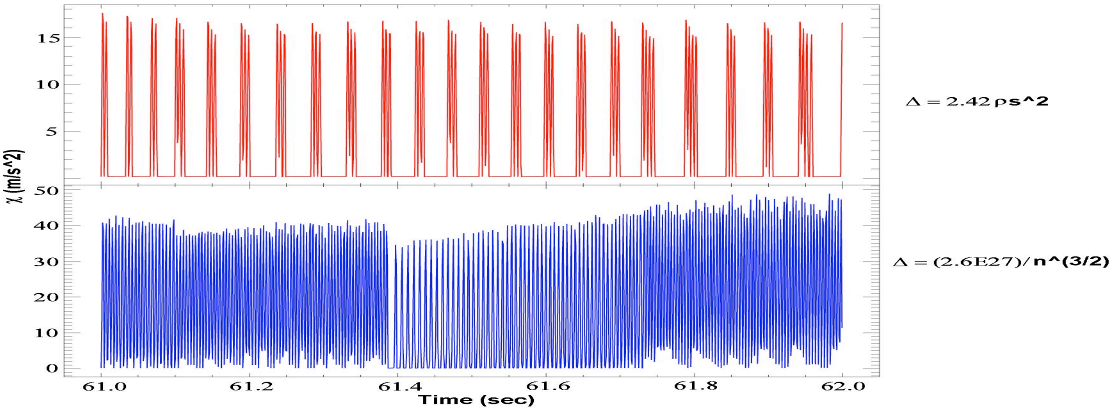

FIGURE 3. Time evolution of the ion thermal diffusivity on the top of the barrier for discharge 53186 from 2 pedestal models using Mixed Bohm/gyro-Bohm core model.

Fig. 3 shows, for the two pedestal models, the time evolution of the ion thermal diffusivity on the top of the barrier for the JET discharge 53186 (δ= 0.25). Note that the ELM frequency, when using the neutral penetration model (bottom panel), is very high and characteristic of type 3 ELMy H-mode plasmas; whereas, the ELM frequency, when using the magnetic and flow shear stabilization (top panel), is characteristic of type 1 ELMy H-mode plasmas. Although the results using the magnetic and flow shear stabilization yield better agreement with experiment, it cannot be concluded that the penetration of neutrals does not play any role in the determination of the width of the pedestal, only that neutral penetration is not the main mechanism, which determines the pedestal width of type 1 ELMy H-mode plasmas.

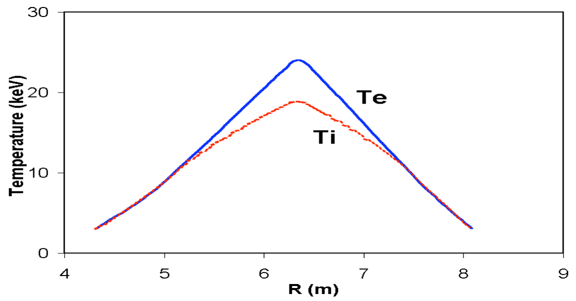

FIGURE 4. Electron and ion temperatures of ITER predicted using the combination of the MMM95 core transport model and the pedestal temperature model.

PREDICTIONS FOR ITER

The simulation for ITER has been carried out using the BALDUR code with the MMM95 core transport model and with the boundary conditions predicted by the pedestal model based on magnetic and flow shear stabilization. The parameters for ITER are R = 6.2 m, a = 2.0 m, I_p = 15 MA, B = 5.3 tesla, κ_{95} = 1.7 and δ_{95} = 0.33. The simulation is carried out with the auxiliary heating power P_{aux} = 40 MW and the impurity concentration of 2% Be plus 0.12% Ar plus the accumulation of Helium ash, which remains below 2% in the simulation. At the ITER design point, with the line-average density of 84% of the Greenwald density (= $I_p[\mathrm{MA}]/\pi a[\mathrm{m}]^2 \; 10^{20}$ particles/m^3), the predicted pedestal temperature is 2.74 keV. Fig. 4 shows the electron and ion temperature profiles predicted using the MMM95 core transport model and pedestal temperature based on magnetic and flow shear stabilization. The alpha power, P_α, predicted by the BALDUR code simulations is 89.3 MW, which corresponds to a fusion Q = 11.2 ($Q = 5P_\alpha/P_{aux}$).

CONCLUSIONS

In the 0 D approach, two theory-motivated models have been developed for the temperature at the top of the pedestal at the edge of type 1 ELMy H-mode plasmas. The pedestal temperatures predicted from the combination of the pedestal width model (either based on the magnetic and flow shear stabilization or the neutral penetration) together with the pressure gradient, from the ideal ballooning instability, yield RMSE of 32.0% and 53.4%, respectively, when compared with 533 data points. In the 1.5 D approach, these pedestal width models have been used together with the predictive integrated modelling code, JETTO, to simulate the JET triangularity H-mode discharges. It is found that the simulations from the neutral penetration model significantly under-predict the width of the pedestal and result in the ELM frequency of type 3 H-mode plasmas. On the other hand, the simulations from the magnetic shear and flow shear stabilization yield better agreement for the pressure profiles and the ELM frequency of type 1. At the ITER design point, the fusion performance predicted using MMM95 core transport model together with pedestal model based on magnetic and flow shear stabilization yields the alpha power of 89.3 MW, which is corresponding to a fusion Q = 11.2.

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REFERENCES

1. Erba, M., Aniel, T., Basiuk, V., *et al., Nuclear Fusion* **38**, 1013 (1998).
2. Bateman, G., Kritz, A.H., Kinsey, J.E., *et al., Phys.* Plasmas **5,** 1793 (1998).
3. Onjun, T., Bateman, G., Kritz, A.H., and Hammett, G., "Models for the pedestal temperature at the edge of H-mode tokamak plasmas," submitted to Physics of Plasmas.
4. Sugihara, M., Igitkhanov Y., Janeschitz G., *et al., Nuclear Fusion* **40**, 1743 (2000).