JET-P(95)49

Numerical Simulation of ELM Free H and Hot Ion H Modes JET Plasmas

A Cherubini, M Erba, V Parail, E Springmann, A Taroni.

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK.

Preprint of a Paper to be submitted for publication in
Plasma Physics and Controlled Fusion

October 1995

ABSTRACT.

An empirical model for anomalous transport which contains both Bohm and gyroBohm terms is proposed and tested on the set of JET discharges which include L, H and hot-ion H mode.

1. INTRODUCTION.

It was shown on JET [1] that L-H transition has a global character: all plasma transport coefficients reduce abruptly at the time of the transition, not only near plasma edge but far inside the plasma volume up to the position of the q=1 surface. On the contrary, transport in the central part of the plasma column is not affected by the transition. Recent work shows that such a global feature is usual for all kind of heat pulses initiated near the plasma edge. These include cold pulse produced by the injection of impurities, and giant ELMs initiated by the short MHD events. All these pulses show a very fast speed of propagation of information which can not be explained by the conventional theory of the diffusive processes with reasonable level of the nonlinearity like $\chi_e \propto |\nabla T_e|^n$ where $n \geq 1$. On the contrary, propagation of a heat pulse from the plasma centre (triggered by a sawtooth crash, for example) does not exhibit such a global character. The existence of such an asymmetry (together with the fact that global confinement tends to be Bohm like in the L-mode but gyroBohm in the H-mode [2]) suggests that there are at least two sources of plasma turbulence. One of them is localised near the separatrix and is likely to be controlled by the pressure or by the temperature gradient. Due to either toroidal or non-linear coupling this turbulence produces global structures which extend far inside the plasma column and are probably responsible for the Bohm-type scaling law for L-mode plasmas. The second source of plasma turbulence is probably distributed over the whole plasma volume. It has no global features and could lead to a gyroBohm-type scaling law for the H-mode.

2. THE MODEL.

We will use an empirical model in which all transport coefficients consist of two parts. The first one is a Bohm-type model, previously used [3] to simulate L and H-mode heat transport on JET. We multiply our original expression by the relative electron temperature gradient just inside the separatrix:

$$\chi_{Bohm} = C_{Bohm} \frac{|\nabla nT|}{nB_T} a^2 q^2 \left| \frac{\nabla T_e}{T_e} \right|_{\rho=1} ; \quad \left\langle \frac{\nabla T_e}{T_e} \right\rangle_{\rho=1} = \frac{T_e(\rho=0.9) - T_e(\rho=1)}{a \cdot T_e(\rho=1)} \qquad (1)$$

Global modifications of the transport coefficients during L-H transition and other kinds of heat pulses which are originated near the plasma edge are now triggered by changes in the electron temperature profile just inside the separatrix. In the L-H transition this change is caused by the formation of a narrow transport barrier near the separatrix which leads to the formation of a temperature pedestal. In the cold pulse triggered by laser blow-off of an impurity a sudden drop in the edge electron temperature is caused by the additional source of impurity radiation. In giant ELMs a similar reduction of the electron temperature could be attributed to a short MHD event. To describe the residual core transport (which is particularly important in the H-mode) we add a simple gyroBohm term to both electron and ion thermal diffusivities. Together with the ion neo-classical term these three coefficients form the following expressions for the electron and ion thermal diffusivities:

$$\chi_{\perp}^{e,i} = C_{GB}^{e,i} a \frac{|\nabla T_e|}{B_T} \rho_s^{*} + c_B^{e,i} \frac{|\nabla n T_e|}{n B_T} a^2 q^2 \left\langle \frac{\nabla T_e}{T_e} \right\rangle_{\rho \approx 1} + \chi_{neo}^{e,i} \qquad (2)$$

where ρ_s^{*} is the normalised ion Larmor radius.

3. BOUNDARY CONDITIONS.

The boundary conditions can be obtained by integrating the heat flux across the separatrix:

$$\chi_{\perp}^{e,i} n \nabla T_{e,i} \approx -\frac{\Delta}{L_{\parallel}} n T_{e,i} \left(\frac{\chi_{\parallel}^{e,i}}{L_{\parallel}} + \frac{5}{2} c_{sol} \right) \qquad (3)$$

where Δ is the SOL width: $\Delta \approx \sqrt{\chi_{\perp}^{\min} L_{\parallel} / \left(c_{sol} + \chi_{\parallel}/L_{\parallel}\right)}$. This kind of boundary condition was used to model the L-mode plasmas. A problem arises when we tried to use formula (3) for modelling H mode discharges. It follows from our numerical simulations that for these shots we can reproduce the experimentally observed ion and electron temperature near the separatrix only if we assume that perpendicular transport inside the transport barrier and in the SOL is of the order of the ion neo-classical one. A similar conclusion has been recently derived from the analysis of H-mode density and temperature profiles near the separatrix in DIII-D [4]. Equation (3) needs to be modified in this case because the SOL width Δ becomes less than the ion banana width. We use the simplest assumption that the only mechanism of ion heat flow through the separatrix is given by the direct losses of the banana ions [5] which leads to the following boundary conditions for ion's heat and particle flows:

$$\chi_i n \nabla T_i \approx -2.2 n T_i \chi_i^{neo} / \varepsilon \rho_{\theta i} \qquad (4)$$

We can still use expression (3) as a boundary condition for the electron heat flow if we assume that the remaining magnetic turbulence keeps electron energy transport on a level which exceeds the ion energy neo-classical transport.

It follows from (4) that in the banana regime the ion heat flow does not depend on the temperature near the separatrix $Q_i \propto n_i^2(\rho = 1)$. This feature allows us to explain the experimentally observed fact that the energy confinement time in hot-ion H modes, formally defined as $\tau_E = W/(P_{tot} - dW/dt)$ grows almost linearly with time together with the total energy content W. **This feature can not be explained by the standard scaling laws but from the point of view of the boundary condition (4) such a behaviour is natural because in the banana regime neo-classical regime losses at constant density do not depend on plasma energy and therefore do not provide a steady state solution of the energy balance equation:** $dW/dt = P_{tot} - \alpha n_i^2(\rho \approx 1) \approx const.$ **This fact could explain the wide range of H factors observed in JET H-modes.**

4. NUMERICAL ANALYSIS.

We performed a numerical analysis of the various JET shots which include discharges with L and H modes with different H factor and discharges with cold pulses produced by laser ablation and giant ELMs. Let's start from the "standard" L-H transition from the 94-95 experimental campaign which shows a fast global modification of the electron temperature far inside the plasma volume. We used model (2) together with boundary conditions (3),(4). We assumed that both electrons and ions obey L-mode boundary condition (3) before transition. At the time of the L-H transition we change the ion boundary condition to the neo-classical one (4); the L-mode boundary condition is still applied to electrons but with reduced value of Δ. A direct comparison of the simulated evolution of T_e with the experimental one (Figure 1) allows us to conclude that the model can reproduce experiments quite well. It is worth to remind here that unlike in our previous results [3] now we do not change any of the numerical coefficients c_α^β in the model. The observed very fast global modification of the transport

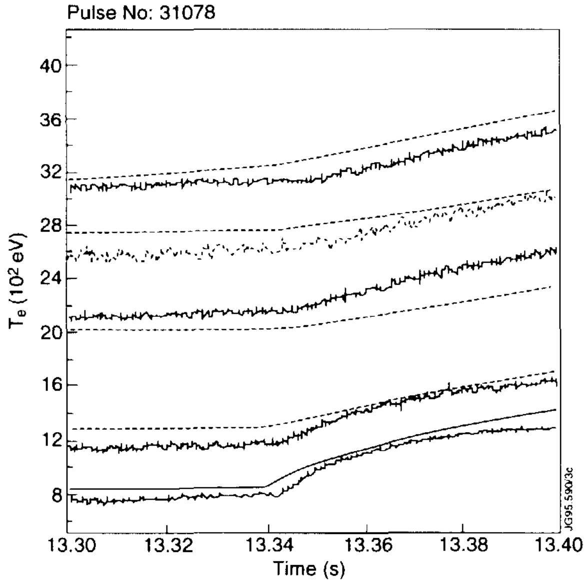

Figure 1. Temporal evolution of the electron temperature (measured and calculated) during L-H transition

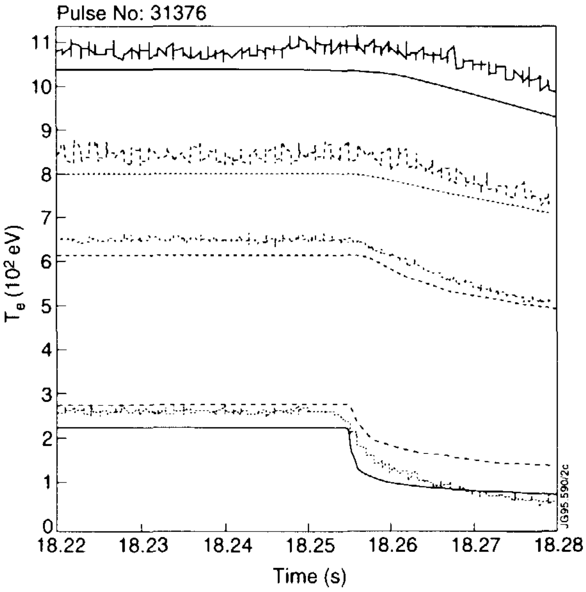

Figure 2. Temporal evolution of the electron temperature (measured and computed) during cold pulse propagation.

coefficients is the result of the emergence of a transport barrier (expressed as a modification of the boundary conditions) and subsequent heating of the plasma edge. The model also works for cold pulses. In these cases the fast drop of the edge temperature (caused by different reasons) leads to a global increase of transport coefficients and a subsequent cooling of the entire plasma volume (Figure 2).

Up to this point we tested the potential ability of the model to explain an "unusual" plasma behaviour in the different dynamic situations. Equally important is the question how the model fits steady state profiles and global plasma characteristics in discharges with varying plasma parameters. This has been tested in a series of representative JET shots (both in L and in H-mode). The main discharges parameters are summarised in the Table.

Shot	mode	$<n_e>_{20}$	I_p(M)	B_t(T)	P_{in}(M)
19649	L	0.28	3.0	3.0	15.0
19691	L	0.29→0.39	3.1	3.1	9.0
26087	VH	0.19→0.30	3.2	2.8	15.0
26095	VH	0.11→0.30	3.2	2.8	14.2
30591	H/VH	0.15→0.36	2.4	2.7	15.0
30725	H	0.72→0.84	3.1	2.2	6.1
33643	VH	0.14→0.44	3.7	3.4	18.0
35356	H	0.15-0.35	2.8	2.8	12.0

The basic conclusion which follows from the modelling is that within experimental accuracy the model fits the experimental data for L and H-mode with different H factor in JET provided that the boundary conditions for T_e and T_i are chosen properly (Figure 3). Nevertheless much more work remains to be done to prove the validity of the model. In particular better knowledge and proper modelling of the density near the separatrix is required.

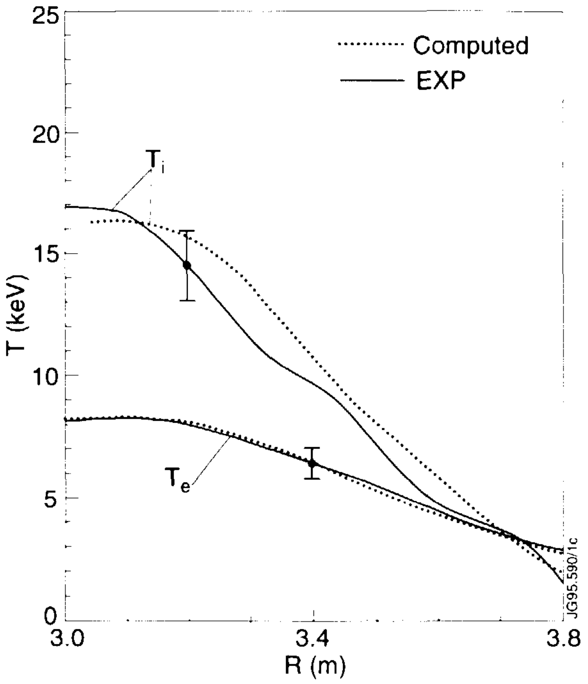

Figure 3. Experimental and computed ion and electron temperature profiles at the end of the ELM free phase of shot #30591

5. CONCLUSIONS.

An empirical model for the electron and ion thermal diffusivities is proposed and tested on a set of JET discharges which includes L and H modes with different enhancement factor. The model suppose that there are two independent sources of plasma turbulence. One source (leading to Bohm like transport) is localised in the outer part of plasma column and produces transport coefficients which are mainly responsible for the energy confinement in the L-mode. This source is abruptly reduced at the time of the L-H transition owing to the formation of the narrow transport barrier near the separatrix and subsequent emergence of the edge temperature pedestal. The second source of the turbulence (leading to a gyroBohm like transport) is important only in the plasma core and is more relevant for energy confinement in the H-mode plasmas.

A new type of the boundary conditions for the H-mode plasmas has been introduced which suppose that the only mechanism of ion energy losses is the direct neo-classical loss of the trapped particle. This boundary condition leads to a continuous growth of the energy content in the case when the plasma is in the banana regime near the separatrix. This situation is probably realised in the best hot ion H modes on JET. On the contrary, the energy content should saturate if ions near the separatrix are in the plateau regime.

REFERENCES.

[1] Cordey, J.G., et al., Plasma Physics and Contr. Fusion, **36**, A267, (1994)

[2] Balet, B., et al., 22 EPS Conf. on Contr. Fus. and Plasma Phys., Bournemouth, UK 1995, P003.

[3] Parail V.V., et al., 15th Int. Conf. on Plasma Physics and Contr. Nuclear Fusion Research, Seville, Spain 1994, CN-60/A-2-II-3.

[4] W. Mandl, et al., Nuclear Fusion **35**,(1995), 347.

[5] Hinton, F.L., Chu, M.S., Nuclear Fusion **25**, (1985), 347.