Predictive capability of hydrogenic and impurity density in *L* mode discharges DIII-D Tokamak using Mixed Bohm/gyro-Bohm transport model

W. Buangam[1], T. Onjun[1], and S. Suwanna[2]

[1]*Sirindhorn International Institute of Technology, TU, Pathumthani, Thailand*

[2]*Department of Physics, Mahidol University, Bangkok, Thailand*

1. Introduction

It is widely known that the performance of plasma in low Confinement mode (*L*-mode) condition is lower than that in high Confinement mode (*H*-mode). However, the *L*-mode plasma has several advantages in term of stability and simplicity in operation [1]. Better understanding of plasma in *L*-mode discharges, especially about transport of energy, particle, and impurity, can lead to enhance performance. In fact, retention and recycling of hydrogen from PFCs affect fuelling efficiency, plasma density control and the density of neutral hydrogen in the plasma boundary [2]. Together with the presence of impurity can result in radiation losses and fuel dilution, which leads to a degradation of fusion performance [3]. As a result, it is important to investigate hydrogenic and impurity density distribution in *L*-mode plasma. The work of T. Onjun *et al*. [4] used BALDUR code with either the MMM95 or the Mixed B/gB core transport model to simulate plasma behaviours in tokamak for *L*-mode regime. Electron temperature and electron density profiles from these simulations were compared with experimental data from DIII-D and TFTR but they neglected to observe the hydrogenic and impurity density profiles. This paper is organized as follows: brief descriptions of relevant components of the BALDUR code, including the Mixed B/gB transport model given in section 2; simulation results are described in section 3; and the conclusion is given in section 4.

2. BALDUR integrated predictive modeling code

The BALDUR code is an integrated predictive modeling code [5] developed for self-consistency simulating time evolution of various plasma properties, including electron and ion temperatures, electron and ion densities, helium and impurity densities. The BALDUR code self-consistently computes these profiles by mixing many physical processes together in the form of modules including transport, plasma heating, boundary conditions and etc. It was found that the BALDUR code could yield simulations, which are in agreement with experimental data. For example, in [4,6], the BALDUR simulations yielded an agreement of about 10% relative root mean square (RMS) deviation.

2.1 Mixed B/gB Transport Model

The Mixed B/gB core transport model [7] is a semi-empirical transport model, which is a combination of Bohm (B) and gyro-Bohm (gB) terms. In this work, it is assumed that the impurity transport is the same as the particle transport. Thus, the expressions of transport coefficients in this model are be summarized as following:

$$\chi_i = 0.5\chi_{gB} + 4.0\chi_B,$$

$$\chi_e = 1.0\chi_{gB} + 2.0\chi_B,$$

$$D_H = D_z = (0.3 + 0.7\frac{r}{a})\frac{\chi_e \chi_i}{\chi_e + \chi_i},$$

$$\text{where, } \chi_{gB} = 5\times10^{-6}\sqrt{T_e}\left|\frac{\vec{\nabla}(T_e)}{B_T^2}\right|,$$

$$\chi_B = 4\times10^{-5} R\left|\frac{\vec{\nabla}(n_e T_e)}{n_e B_T}\right| q^2 \left(\frac{T_e\left(\frac{r}{a}=0.8\right)-T_e\left(\frac{r}{a}=1\right)}{T_e\left(\frac{r}{a}=1\right)}\right),$$

where r/a is the normalized minor radius of the plasma, χ_{gB} is the gyro-Bohm contribution, χ_B is the Bohm contribution, T_e is the local electron temperature in keV, B_T is the toroidal magnetic field, and n_e is the local electron density.

3. Simulation results and discussion

In this work, the BALDUR integrated predictive modeling code is used to simulate the radial profiles of hydrogenic and impurity density in *L*-mode scenario from 4 discharges of DIII-D tokamaks. Some important engineering parameters of these discharges are listed in table 1. The simulations, Mixed B/gB anomalous transport model is used to describe both thermal and particle transports. It is assumed that the pedestal hydrogenic and impurity densities in the simulations are the same to those in the experiment.

Table 1. The physical parameters

Tokamak Shot No.	Unit	78281	78106	78283	78109
Type		High ρ_*	Low ρ_*	High ρ_*	Low ρ_*
Type of heating		RF	RF	NBI	NBI
Major radius (R)	m	1.70	1.70	1.69	1.69
Minor radius (a)	m	0.628	0.629	0.618	0.624
Plasma current (I_p)	MA	0.52	1.00	0.465	0.992
Magnetic field (B_T)	T	1.00	2.00	1.00	2.00
Elongation (κ_{95})	-	1.84	1.87	1.86	1.85
Triangularity (δ_{95})	-	0.60	0.60	0.60	0.60
Auxiliary heating power (P_{aux})	MW	0.38	1.50	0.51	2.00
Diagnostic time (t_{diag})	s	2.60	2.55	3.90	3.90

3.1 Profile comparison

The simulation results by using B/gB transport model for ρ_* scan with RF heating in DIII-D discharge 78281 and 78106 are shown in figure 1. It can be seen that the simulation results for high ρ_* in discharge 78281 can be predicted electron and ion temperature profile better than that in low ρ_* in discharge 78106. The low ρ_* in discharge 78106 can be predicted electron and ion temperature profile quite well only at the edge plasma region and over predicts in the core plasma. In additional, the simulation results for electron, deuterium and impurity density profiles are the same that is the simulation results for high ρ_* in discharge 78281 can be predicted electron, deuterium and impurity density profiles better than that in low ρ_* in discharge 78106. The electron and deuterium density profiles are lower than the experiment all of the profile while the simulation results are higher than the experiment all of the profile for impurity density profiles. Furthermore, The simulation results by using B/gB transport model for ρ_* scan with NBI heating in DIII-D discharge 78283 and 78109 are similar with ρ_* scan with RF heating in DIII-D discharge 78281 and 78106. The exception for this similarity is the impurity density profile because the low ρ_* in discharge 78109 can be predicted impurity density profile better than that in high ρ_* as shown in figure 2.

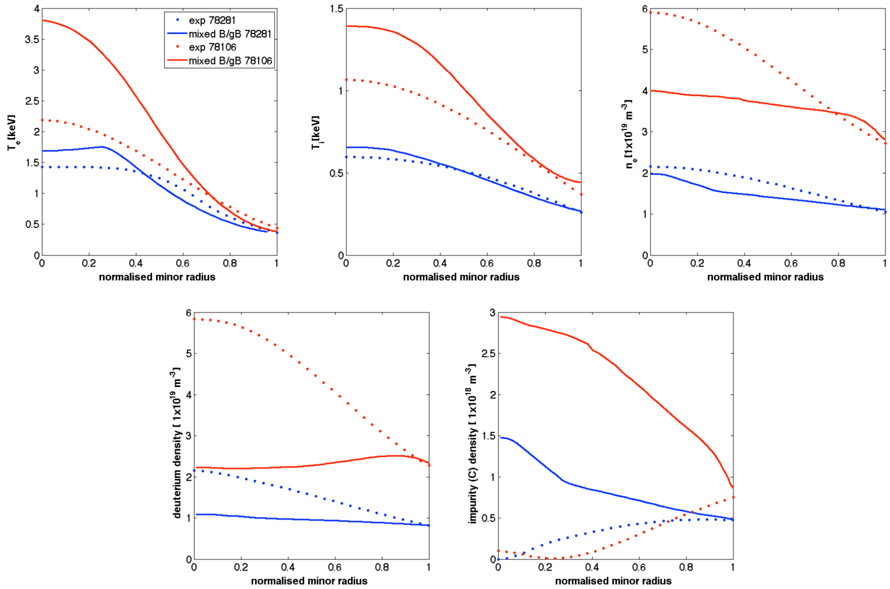

Figure 1. Electron and ion temperature, electron, hydrogenic (deuterium) and impurity (carbon) density profiles produced by simulations using the Mixed B/gB model compared with experimental data for ρ_* scan with RF heating in DIII-D discharge 78281 and 78106.

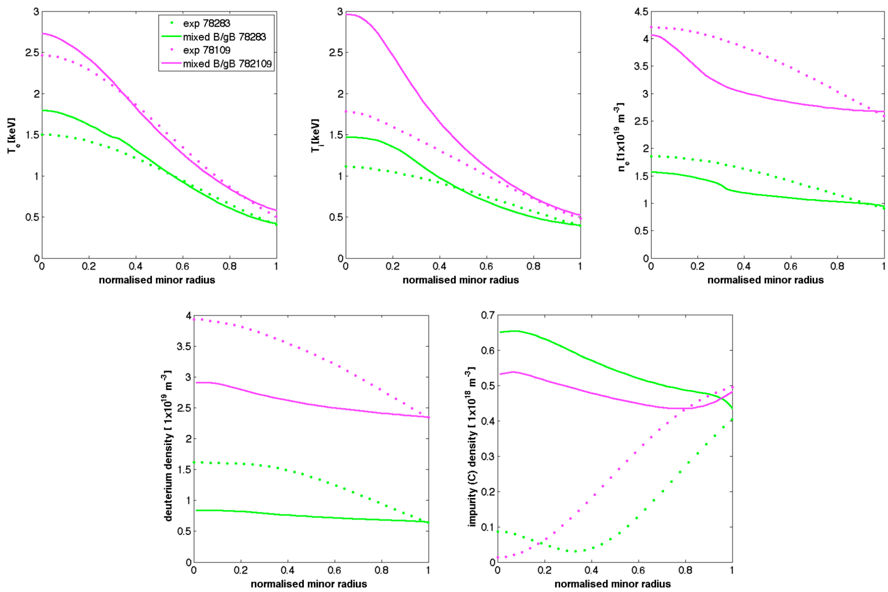

Figure 2. Electron and ion temperature, electron, hydrogenic (deuterium) and impurity (carbon) density profiles produced by simulations using the Mixed B/gB model compared with experimental data for ρ_* scan with NBI heating in DIII-D discharge 78283 and 78109.

3.2 Statistical analysis

The relative root-mean-square deviation (RMSD) is used to quantify the comparison between the simulations and the experiments. This is computed based on the difference between simulation profiles and experimental data. The RMS deviation for hydrogenic (deuterium) and impurity (carbon) density are defined as

$$\sigma_x = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(\frac{X_j^{exp} - X_j^{sim}}{X_{max}^{exp}}\right)^2}$$

where X_j^{exp} and X_j^{sim} are the j^{th} data point of the experimental and simulation profiles, respectively, while X_{max}^{exp} is the maximum data point of the experimental profile of X as a function of radius which has N points in total.
The relative offset of impurity (carbon) density is defined as

$$f = \frac{1}{N}\sum_{j=1}^{N}\left(\frac{X_j^{exp} - X_j^{sim}}{X_{max}^{exp}}\right)$$

This statistical analysis is used for comparing the simulation profiles and experimental profiles. The results of the statistical analyses for simulations are presented in figures 3. It can be seen in figure 3 that the RMS deviations vary from discharge to discharge. The RMS deviation for electron, ion temperature, electron and deuterium density vary from 4.72% to 41.60% while impurity density varies from 60.86% to 281.46%. The offsets are also shown in figure 3 vary from about -0.01% to -0.29% for electron and ion temperature and vary from about 0.11% to 0.35% for electron and deuterium density and vary from -0.45% to -2.57% for impurity density.

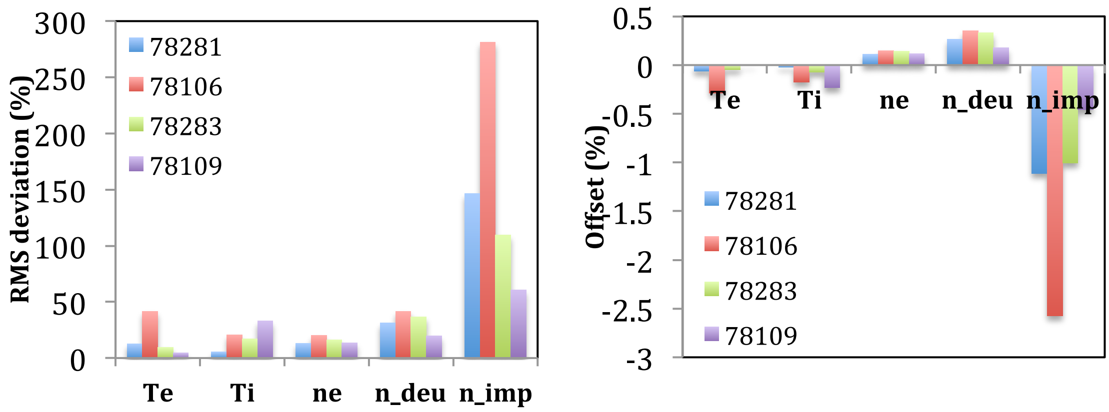

Figure 3. RMS deviation (left) and offset (right) for electron and ion temperature, electron, hydrogenic (deuterium) and impurity (carbon) density profiles produced by simulations using the Mixed B/gB model compared with experimental data for DIII-D discharge 78281, 78106, 78283 and 78109.

4. Conclusion

It was found that the simulation results by using Mixed B/gB transport model in *L*-mode discharges DIII-D can be predicted electron and ion temperature and electron and deuterium density profile in an acceptable range of 4-40% RMS deviation. However, it fails to predict the impurity density profile (60-281% RMS deviation) when the assumption that the impurity transport is similar to the particle transport.

References

1. J. Wesson et al., *Tokamak* (New York: Oxford University Press), 1997, 175.
2. G. Federici et al., Nucl. Fusion, 2001, **41**, 1967.
3. P. C. Stangeby et al., *The plasma boundary of magnetic fusion devices* (UK: Institue of Physics Publishing), 2000, 277.
4. T. Onjun et al.,Phys. Plasma, 2001, **8**, 975-985.
5. C E. Singer et al., Comput. Phys. Commun., 1988, **49**, 275-398.
6. D. Hannum et al., Phys. Plasmas, 2001, **8**, 964-974.
7. G. Bateman et al., Phys. Plasmas, 1998, **5**, 1793-1799.