# PS14: การพัฒนาแบบจำลองเงื่อนไขขอบเขตสำหรับ L-mode พลาสมา

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## บทคัดย่อ

งานวิจัยนี้เป็นการพัฒนาแบบจำลองของอุณหภูมิและความหนาแน่นของไอออนและอิเล็กตรอนภายในสภาวะ L-mode พลาสมาโดยใช้ข้อมูลจาก International Pedestal Database ในการคำนวณหาอุณหภูมิและความหนาแน่นของไอออนพลาสมาและอิเล็กตรอนพลาสมา จะหาได้จากกระแสพลาสมา สนามแม่เหล็ก กำลังสุทธิ ความหนาแน่นเชิงเส้นเฉลี่ยของอนุภาค มวลไฮโดรเจน รัศมีหลัก รัศมีรอง และ ค่าความรี (elongation) ผลจากการวิเคราะห์ด้วยวิธีการถดถอยพหุคูณจากข้อมูลจากการทดลองใน L-mode ทั้งหมด 86 ครั้ง จากเครื่อง AUG 61 ครั้ง และเครื่อง JT60U 25 ครั้ง ได้ความคลาดเคลื่อนของค่าเฉลี่ยกำลังสอง (RMSE) ของอุณหภูมิและความหนาแน่นอนุภาคเป็น 24.41% และ 18.81% ตามลำดับ ซึ่งผลที่ได้จะถูกนำไปใช้ในโปรแกรม BALDUR เพื่อทำนายผลของพลาสมาในสภาวะ L-mode ในเครื่องโทคาแมค

**คำสำคัญ:L-mode, BALDUR, พลาสมา, โทคาแมค**

# Models for Predicting Boundary Conditions in L-Mode Tokamak Plasma

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## Abstract

The models for predicting temperature and density of ions and electrons at boundary conditions in L-mode tokamak plasma are developed using an empirical approach and optimized against the experimental data obtained from the latest public version of the International Pedestal Database (version 3.2). It is assumed that the temperature and density at boundary of L-mode plasma are functions of engineering parameters such as plasma current, toroidal magnetic field, total heating power, line averaged density, hydrogenic particle mass ($A_H$), major radius, minor radius, and elongation at the separatrix. Multiple regression analysis is carried out for these parameters with 86 data points in L-mode from AUG (61) and JT60U (25). The RMSE of temperature and density at boundary of L-mode plasma are found to be 24.41% and 18.81%, respectively. These boundary models are implemented in BALDUR code, which will be used to simulate the L-mode plasma in the tokamak.

**Keywords: L-mode, BALDUR, plasma, tokamak**

## 1. Introduction

There are two distinct modes of operation for tokamak experiments, the first is low confinement mode or L-mode and the second is high confinement mode or H-mode. In practice, the energy confinement time ($\tau_E$) of the H-mode is greater than the L-mode by about 2 times. The energy confinement time is defined by the relation

$$\tau_E = \frac{W}{P_L} \tag{1}$$

where $P_L$ is the energy loss rate from the plasma, and W is the total plasma energy which depends on electrons or ions density in volume V and temperature T as

$$W = 3nTV \tag{2}$$

In present tokamaks, when the thermonuclear power is in the steady state, the energy loss is balanced by external auxiliary heating such as neutral beam injection (NBI) or radio frequency (RF), thus if the total power supplied is $P_{heat}$ then $P_L = P_{heat}$, so we can expressed energy confinement time as

$$\tau_E = \frac{3nTV}{P_{heat}} \tag{3}$$

This expression is useful because each of the quantities on the right hand side is measured experimentally. Therefore, for a given plasma discharges, the other plasma parameters such as magnetic field (B), plasma current (I), averaged density ( $\bar{n}$ ), minor radius (a), major radius (R), elongation at separatrix ($\kappa$) and atomic mass of plasma ions (A) are also measured. This information represents the combined data set for discharge under consideration. These overall data are used determine the empirical fit to $\tau_E$ of the form

$$\tau_E = CB^{\alpha_B} I^{\alpha_I} \bar{n}^{\alpha_n} A^{\alpha_A} R^{\alpha_R} a^{\alpha_a} \kappa^{\alpha_\kappa} \tag{4}$$

The constant and exponents $\alpha_j$ can be optimized by statistical regression analysis. Experimental evidence suggests that the transition from L-mode to H-mode requires sufficient heating power, calls threshold power ($P_{th}$) which can be found by Eq. 5.

$$P_{th} = 0.04\bar{n}_e BS \tag{5}$$

This equation from ref.[2] where $\bar{n}_e$ , B and S are average electron density [$10^{20}$ particles/$m^3$], magnetic field [T] and plasma surface area [$m^2$], respectively.

## 2. Modeling

The empirical models for predicting temperature and density in L-mode tokamak plasma are developed using the experimental data obtained from the latest public version of the International Pedestal Database (version 3.2). The temperature and density scaling are found using the power scaling law which can be expresses in engineering parameters such as temperature T [eV], plasma current $I_P$ [MW], toroidal magnetic field $B_T$ [T], total heating power $P_{heat}$ [MW], line averaged density $n_{l,20}$ [$10^{20}$ particles/$m^3$], hydrogenic particle mass $A_H$[amu], major radius [m], minor radius [m], inverse aspect ratio ε [a/R] and elongation at the separatrix κ. These models are carried out with the engineering parameters with 86 data points in L mode from AUG(61) and JT60U(25).

The predicted results of the temperature in L-mode tokamak plasma from empirical model using the power scaling law for temperature can be expressed as

$$T = CI_P^a B_T^b P_{heat}^c n_{l,20}^d A_H^e R^f \varepsilon^g \kappa^h \tag{6}$$

And the power scaling law for density in L-mode tokamak plasma can be expressed as

$$n_{20} = C I_P^a B_T^b P_{heat}^c T^d A_H^e R^f \varepsilon^g \kappa^h \tag{7}$$

Where C, a, b, c, d, e, f, g, h are the constants, they can find by fitting experimental data of engineering parameters in L-mode from database using statistic multiple regression analysis. In tokamak plasma has some density can find by plasma current and plasma area in toroidal coil, calls Greenwald density [$n_{gr}$] can be expressed as

$$n_{gr} = \frac{I_P}{\pi a^2} \tag{8}$$

where $I_P$ and a are plasma current and minor radius, respectively. If the unit of plasma current in [MA] and minor radius in [m], the unit of Greenwald density in order of $10^{20}$ particles/$m^3$.

## 3. Results

### 3.1 Predicting temperature in L-mode tokamak plasma

It is found that the fitting to the set of data is carried out with the engineering parameters with 86 data points in L- mode from AUG(61) and JT60U(25) using statistical multiple regression analysis, the optimal values of parameters in the empirical scaling law for temperature in Eq. 6 are given in Table 1.

Table 1 The optimal values of parameters in the empirical scaling law for temperature model

| constant | value | standard error |
|---|---|---|
| C | 13.6046 | 2.16423 |
| a | 0.82811 | 0.20246 |
| b | 0.11195 | 0.18870 |
| c | 0.54028 | 0.12370 |
| d | -1.29042 | 0.20980 |
| e | 0.08942 | 0.12291 |
| f | -0.34365 | 1.21514 |
| g | 1.89952 | 2.68230 |

| | | |
|---|---|---|
| h | 6.74053 | 2.18751 |
| RMSE | 24.41 % | |

The model for predicting temperature in L-mode tokamak plasma from these optimal values in Eq. 6 and table 1 can be expressed as

$$T = 13.60 \frac{I_P^{0.83} B_T^{0.11} P_{heat}^{0.54} A_H^{0.90} \varepsilon^{1.90} \kappa^{6.74}}{n_l^{1.29} R^{0.34}} \quad (9)$$

It is found that the root mean square error (RMSE) of the scaling law for temperature is 24.41%. This empirical model for temperature is plotted against the experimental data obtained from the latest public version of the International Pedestal Database (version 3.2) is shown in Fig. 1.

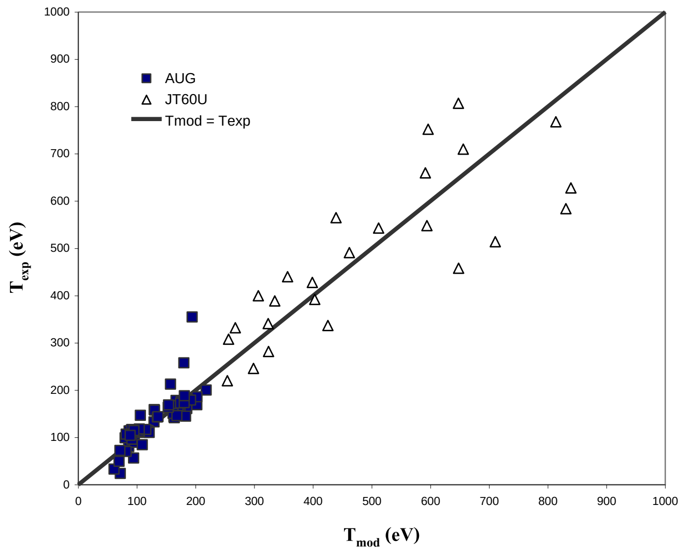


Figure 1 The empirical model for predicting temperature is plotted against experimental data

### 3.2 Predicting density in L-mode tokamak plasma

The empirical model for predicting density in L-mode tokamak plasma is developed using experimental data from the same source of temperature model. The optimal values of engineering parameters in the scaling law for density in Eq.7 are given in Table 2.

Table 2 The optimal values of parameters in the empirical scaling law for density model

| constant | value | standard error |
|---|---|---|
| C | 1.36125 | 1.65398 |
| a | 0.61570 | 0.14121 |
| b | -0.44470 | 0.13591 |
| c | 0.51113 | 0.06428 |
| d | -0.15316 | 0.07192 |
| e | 0.28640 | 0.08667 |
| f | -2.74234 | 0.84872 |
| g | -0.66285 | 2.07348 |
| h | -0.15316 | 1.78435 |
| RMSE | 18.81 % | |

The model for predicting density [$10^{20}$ particles/$m^3$] in L-mode tokamak plasma from these optimal values in Eq. 7 and table 2 can be expressed as

$$n_{20} = 1.36 \frac{I_P^{0.61} P_{heat}^{0.51} A_H^{0.29}}{B_T^{0.44} R^{2.74} \varepsilon^{0.66} \kappa^{0.16} T^{0.15}} \tag{10}$$

It is found that the root mean square error (RMSE) of the scaling law for density is 18.81%. The comparison between the ratio of the density predicting in empirical model from Eq.10 with the Greenwald density and the ratio of the corresponding experimental data from database to the Greenwald density is shown in Fig.2.

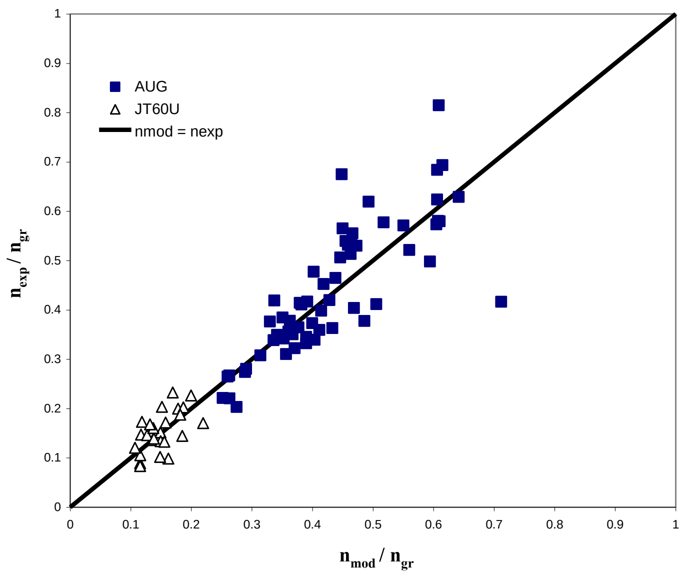


Figure 2 The ratio of predicting empirical model for density to the Greenwald density is plotted against the ratio of experimental data to the Greenwald density

## 4. Discussions and Conclusion

The models for predicting temperature and density in L-mode tokamak plasma are developed using an empirical approach. Using the engineering parameters of AUG and JT60U tokamak from the latest public version of the International Pedestal Database (version 3.2), the RMSE of pedestal temperature and density are found to be 24.41% and 18.81%, respectively. These boundary models will be implemented in BALDUR code, which will be used to simulate the L-mode tokamak plasma.

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