Comparison of Analytic Model for Density Profile to UEDGE Simulations*


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Key Points

♦ Plasma density and neutral density must obey continuity equations
♦ These equations have been used to derive a simple analytic model for edge density profiles
♦ Simple model is consistent with several features of edge density profiles in DIII-D - widths and gradients
♦ Here, model is compared to the far more sophisticated neutrals model in the UEDGE code
♦ Agreement between the two models is reasonable
  o Widths agree within better than 30% - gradients within factor of two
An Analytic Model Is Formulated to Relate Pedestal Width to Pedestal Height

\[
\frac{\partial n}{\partial t} + \nabla \cdot \Gamma = S
\]

\[
\Gamma_e = D \frac{dn_e}{dx}
\]

\[
\Gamma_n = n_n V_n
\]

\[
n_e(x) = n_{e,\text{ped}} \tanh[C - x / \Delta_{ne}]
\]

\[
C = 0.5 \sinh^{-1}(U)
\]

\[
U = \sqrt{D_s \tau \| \sigma_i V_e / V_n \} E_{n_e,\text{ped}} D_c / D_s}
\]

\[
\Delta_{ne} = 2 V_n / (\sigma V_e E n_{e,\text{ped}})
\]

Steady-state, slab geometry, fuelling assumed to be localized poloidally, flux surface expansion accommodated, separate but fixed D in SOL and core, profile effects neglected, neutral collisions neglected, $T_d$ taken as 0.5 $T_i$, impurities neglected, pinch neglected, neutrals assumed to be equilibrated with ions, dependence of ionization cross section on temp neglected, model valid for temp in range 0.02 - 0.3 keV
Model Predicts Qualitative and Quantitative Dependence of Experimental Width $W_{ex}$ on $n_{e,ped}$

- Theoretical width $W_{th}$ is defined to emulate $W_{ex}$
- $W_{th}$ is distance from 12% to 88% of $n_{e,ped}$ in model function
- Parameters in model are typical values
Model Predicts The Qualitative Dependence: Maximum $\nabla n_e \sim n_{e,ped}^2$ (limit of $n_{sep} = 0$)
UEDGE is a Sophisticated 2-D Edge Modeling Code

- UEDGE solves fluid equations in 2-D
  - Models from typically $\psi_n = 0.98$ to divertor plate
- Obtains profiles of temperature, density and velocity for a multi-species plasma with neutrals
  - Anomalous perpendicular transport is specified
  - Classical transport parallel and perpendicular to B
- Neutral transport treated with a fluid model
  - Navier-Stokes model coupled to ion parallel flow via CX
  - Perp transport is diffusive, arising from CX and neutral-neutral collisions
- Neutral source from recycling, beams and impurities
Technique for Comparing UEDGE and Analytic Model

♦ Scan of pedestal density was performed with UEDGE with other parameters constant
  o Fixed plasma shape, current and field
  o Fixed beam power, heat and particle diffusion coefficients

♦ Scan of pedestal density was performed with analytic model with input parameters taken from UEDGE
  o $D = 0.075 \text{ m}^2/\text{s}$ (SOL and core)
  o $E = 7.2$ (7.0 - 7.7 in UEDGE)
  o $T_i = 0.15 \text{ keV}$ (0.11 - 0.18 in UEDGE)

♦ Compare density profiles, widths and gradients
Comparison of Density Profiles from UEDGE and Analytic Model

UEDGE

UEDGE: Closed Divertor [#101560.3700, P_c = 3.5 MW]

Analytic Model

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ni = 4.75e19 m^-3
ni = 5.0e19 m^-3
ni = 5.5e19 m^-3
ni = 6.0e19 m^-3
ni = 6.5e19 m^-3
ni = 7.0e19 m^-3
Comparison of Widths from UEDGE and Analytic Model

UEDGE
(TANHFIT to model profile)

Analytic Model

![Graph showing comparison of widths from UEDGE and Analytic Model.](image-url)
Comparison of Gradients from UEDGE and Analytic Model

UEDGE

Analytic Model - non-zero $n_{sep}$

\[ \n_e (\text{ped}) \times 10^{19} \text{ m}^{-3} \]

\[ \n_e (\text{ped}) \times 10^{21} \text{ m}^{-4} \]
Gradients from Analytic Model with Non-Zero Density at Separatrix

\[ \nabla n_e (10^{21} \text{ m}^{-4}) \sim (n_e,\text{ped})^2 \]

\[ n_e (\text{ped}) (10^{19} \text{ m}^{-3}) \]
Discussion

♦ Both a simple analytic model and the sophisticated UEDGE model produce similar density profiles, for similar input parameters
  o Both models show a narrowing and steepening of $n_e$ profile as $n_{e,ped}$ is increased
  o Widths are within ~ 30% or less, gradients within ~ factor of two
  o Results valid for low edge temperature (a few hundred eV or less)
♦ These results provide support for the use of the simple model to guide experiments and examine trends in the data
♦ The larger question remains: Does edge neutral source play a significant role in formation of H-mode $n_e$ profile?
♦ Can we find ways in which the continuity equations are satisfied and the neutral source is not important?