HYDROGEN RECYCLE MODELING IN TRANSPORT CODES*

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In this note, we outline the hydrogen recycling models now used in Tokamak transport codes and set forth the method by which realistic recycling models are being added. Present models use arbitrary recycle coefficients and therefore do not model the actual recycling processes at the wall. A model for the hydrogen concentration in the wall serves two purposes:

1) it allows a better understanding of the density behavior in present gas puff, pellet, and neutral beam heating experiments and

2) it allows us to extrapolate to long pulse devices such as EBT, ISX-C and reactors where the walls are observed or expected to saturate. Several wall models are presently being studied for inclusion in transport codes.

Transport Model

The hydrogen ion density is governed by the equation

$$\frac{\partial n_i}{\partial t} = \frac{S_T}{V} h(r) + \frac{1}{r}\frac{\partial}{\partial r} r D \frac{\partial n_i}{\partial r} - \frac{n_i}{\tau_{\parallel}}$$

where $S_T = S_G + S_R$ is the total cold neutral source rate due to external feed (S_G) and recycling (S_R) and V is the plasma volume. Figure 1 shows the geometry and a radial plot of the typical values of the individual terms in the density equation. For most cases, $S_R >> S_G$ and a recycling model is therefore important in determining the density of the plasma. The shape of the neutral ionization profile ($h(r)$) is determined by a variety of neutral transport models which include the effects of neutral ionization and charge-exchange in the plasma as well as neutral reflection at the wall.

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The scapeoff loss time $\tau_{\parallel}$ is determined by assuming flow to the limiter at approximately the ion thermal velocity.

Present Recycle Model

The model now used in most transport codes is illustrated in figure 2. The ion fluxes in this figure are:

$\Gamma^{+} = -D \frac{\partial n_i}{\partial r}\Big|_{r=a_s}$ = total diffusive ion flux out of plasma

$\Gamma_L^{+} = \frac{1}{A_L} \int \frac{n_i}{\tau_{\parallel}} d^3 r$ = ion flux to limiter

$\Gamma_{\omega}^{+} = -D \frac{\partial n_i}{\partial r}\Big|_{r=a}$ = ion flux to wall

The neutral particle fluxes are:

$\Gamma_L^{\circ} = \frac{A_L}{A} R_L \Gamma_L^{+}$ = neutral recycle source from limiter tip

$\Gamma_{\omega}^{\bullet} = R_{\omega} \Gamma_{\omega}^{+}$ = neutral recycle source from wall

where R_L, R_{ω} are arbitrary recycle coefficients for the limiter and wall, respectively, and

Γ_H° = hot neutral c-x flux from plasma

Γ_R° = reflected flux from wall

Γ_G = flux due to external cold gas feed.

The ion flux diffusing from the plasma into the scrapeoff is recycled at the wall and limiter tip. In this model, $\Gamma_R^{\circ} = \Gamma_H^{\circ}$ which means that all neutrals which are emitted cold from the limiter or wall are eventually absorbed in the plasma. Thus, the recycle rate is completely determined by the arbitrary recycle coefficients R_L, R_{ω} and any particles lost from the discharge are lost in the transition from ions to neutrals; i.e., there is no wall pumping of neutrals.

Neutral Pump Model

A simple modification of the present model is to assume the wall pumps all the hot c-x neutrals which are not reflected

Proposed Wall Model

The modifications to the recycle model which are needed to add a wall model are shown in figure 3. The various fluxes to the wall (both ions and neutrals) are partly reflected and partly absorbed in or on the wall. The wall model then calculates the buildup of hydrogen in the wall and the resulting release by desorption to the plasma constitutes the additional recycle flux needed to make the total recycle coefficient $0.9 \leq R \leq 1.0$ as is usually observed.

Thus, the additional wall modelling which is needed breaks into two parts:

1) limiter - assuming the limiter is saturated, we need a model for the energy spectrum of the neutral flux (Γ_L^c) recycled from the limiter. Reflected neutrals may have an energy enhanced by the plasma sheath potential at the limiter surface while the desorbed fraction will be thermal. The average energy is important because it determines the penetration depth of the limiter-recycled neutrals into the plasma and hence the neutral level and fueling rate of the plasma center.

2) wall - the purpose of the wall model is to determine the flux of desorbed thermal neutrals from the wall due to diffusion from the bulk, hydrogen sputtering, photon desorption and any other process which depends on the wall concenttation. This model may be either a point model for total number in the wall as proposed by McCracken (3) or a Fick's-law diffusion model for the concentration in the wall as proposed by, for example, Wilson <u>et al</u>. (4) or Weinhold <u>et al</u>. (5). In addition to allowing fewer arbitrary parameters (such as R_L and R_w) in the recycling model, the wall model is especially necessary for modeling long pulse, nearly-saturated devices such as ISX-C and EBT. The effects of wall impurity levels on recycling may be included. Finally, a wall model adds "inertia" to the recycle rate since this rate is dependent

on the wall concentration and no longer depends linearly on the ion flux (Γ^{+}). This inertia may be necessary to obtain steady-state transport solutions for the neoclassical EBT model ([illegible]).

Data Requirements

Two processes which may be important in determining the effective neutral reflection rate from the wall and for which data are lacking are hydrogen-hydrogen sputtering and reflection at low energies.

As the walls staturate the hot c-x flux from the plasma (Γ_w^{o}) directly sputters some hydrogen from the wall. This raises the reflection coefficient and may ultimately limit the amount of hydrogen trapped on the surface. Measurements and calculations are needed for reflection from saturated walls.

The ion flux incident on the wall (Γ_w^{+}) and the fraction of the neutral flux recycled by desorption from the limiter (Γ_L^{o}) which directly strikes the wall are at low energy ($\lesssim$ 10ev). These fluxes constitute a sizable fraction of the total recycled flux and thus the reflection coefficient at these low energies has an important effect on the total recycle rate. Measurements and calculations of low energy neutral reflection coefficients are therefore needed.

References

1. Oen, O. S. and M. T. Robinson, *Nuclear Instrum. and Method*, *132*, 647,1976.
2. Audenaerde, K. *et. al.*, SPUDNUT: A transport code for neutral atoms in plasma, to appear in *J. Comput. Phys.*
3. McCraken *et al.*, Re-cycling experiments in the DITE Tokamak, *Nucl. Fus.*, *18*, 35, 1978.
4. Wilson, K. L. and M. I. Baskes, Deutrerium trapping in irradiated 316 stainless steel, *J. Nucl. Mat.*, *76-77*, 291, 1978.
5. Weinhold, P., *et al.*, Numerical simulation of hydrogen release from and volume distribution in first wall materials, First Top. Meet. on Fusion Reactor Mat., Miami Beach, 1979.
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according to a wall reflection model (for example, a model based on the results of Oen and Robinson (1)). The flux to the limiter is typically $\Gamma_L^+ = 10^{18} - 10^{19}$ cm^{-2}s^{-1}, thus we let $R_L = 1$ since the limiter quickly saturates at this flux. Another assumption of the model is that almost all the flux Γ^+ goes to the limiter with very little diffusing all the way to the wall. In the limit $R_L = 1$, $\Gamma_w^+ = 0$, all the ions are recycled into neutrals and the only particles lost from the discharge are those c-x neutrals not reflected at the wall by the Oen-Robinson reflection model. With these assumptions, an equivalent total recycle coefficient may be derived as follows:

let $r_w \equiv \dfrac{\Gamma_R^0}{\Gamma_H^0}$ = average wall reflection coefficient

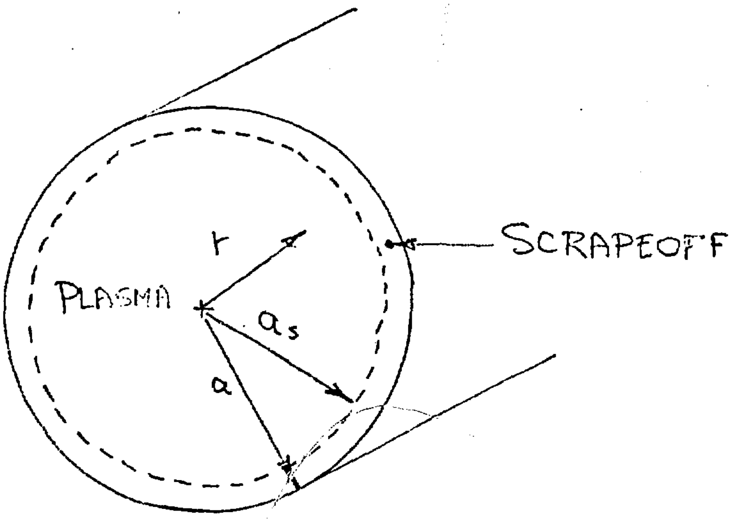
$r_p \equiv \dfrac{\Gamma_H^0}{\Gamma_{COLD} + \Gamma_R^0}$ = average plasma reflection coefficient

where Γ_{COLD} = total cold gas feed rate due to recycling and external feed. Then the recycle coefficient is

$$R = \frac{\Gamma_{COLD} - \Gamma_H^0 + \Gamma_R^0}{\Gamma_{COLD}}$$

$$= \frac{1 - r_p}{1 - r_p r_w}$$

Typical values for the reflection coefficients are derived from a neutral transport code (SPUDNUT (2)) which includes Oen-Robinson reflection of hot c-x neutrals. This is the same code which is used in the transport code to calculate $h(r)$. For present day devices, $r_p \cong 0.4$, $r_w \cong 0.7 \Rightarrow R \cong 0.83$. This value for R is too small to allow the transport model to reproduce the observed density level and time behavior in Tokamaks. We are therefore led to the need to add a model for the hydrogen concentration in and desorption from the wall.



$$\frac{\partial n_i}{\partial t} = \frac{S_T}{V} h(r) + \frac{1}{r}\frac{\partial}{\partial r} r D \frac{\partial n_i}{\partial r} - \underbrace{\frac{n_i}{\tau_{\parallel}}}_{\text{in Scrapeoff}}$$

$$\underset{\substack{\uparrow \\ \text{Total} \\ \text{Source}}}{S_T} = \underset{\substack{\uparrow \\ \text{External} \\ \text{feed}}}{S_G} + \underset{\substack{\nwarrow \\ \text{Recycle} \\ \text{Source}}}{S_R} \qquad \text{Typically, } S_R >> S_G$$

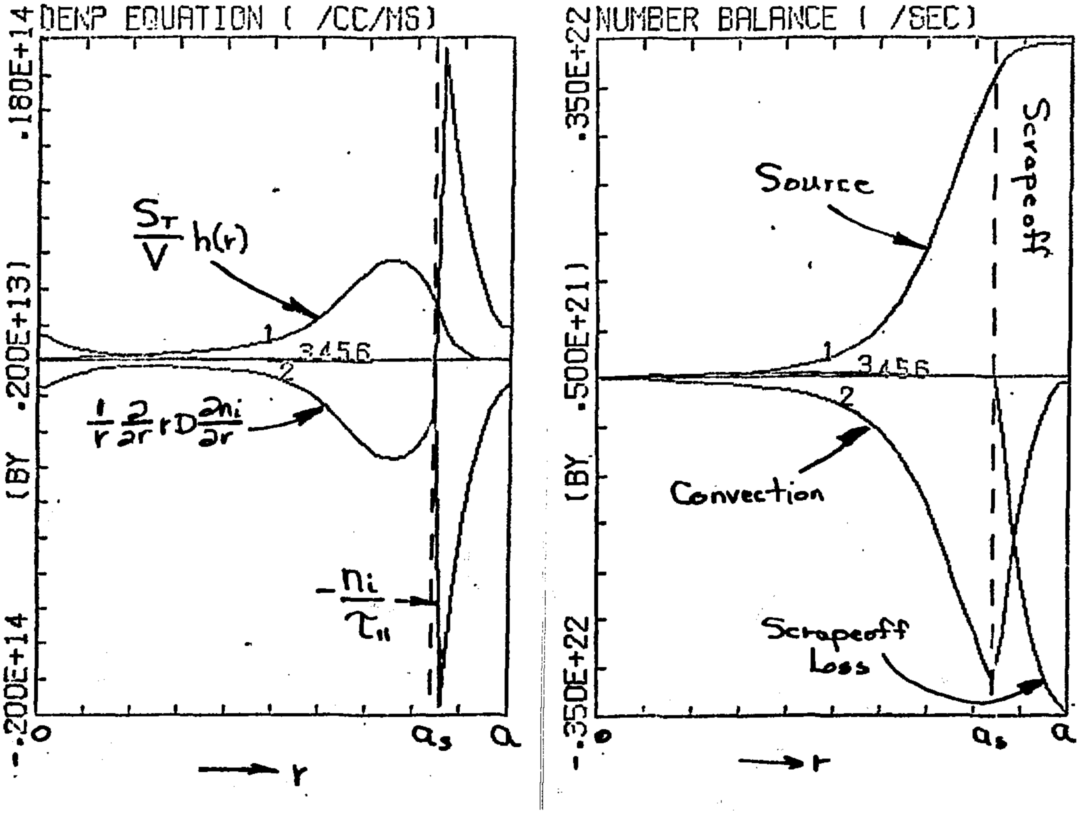
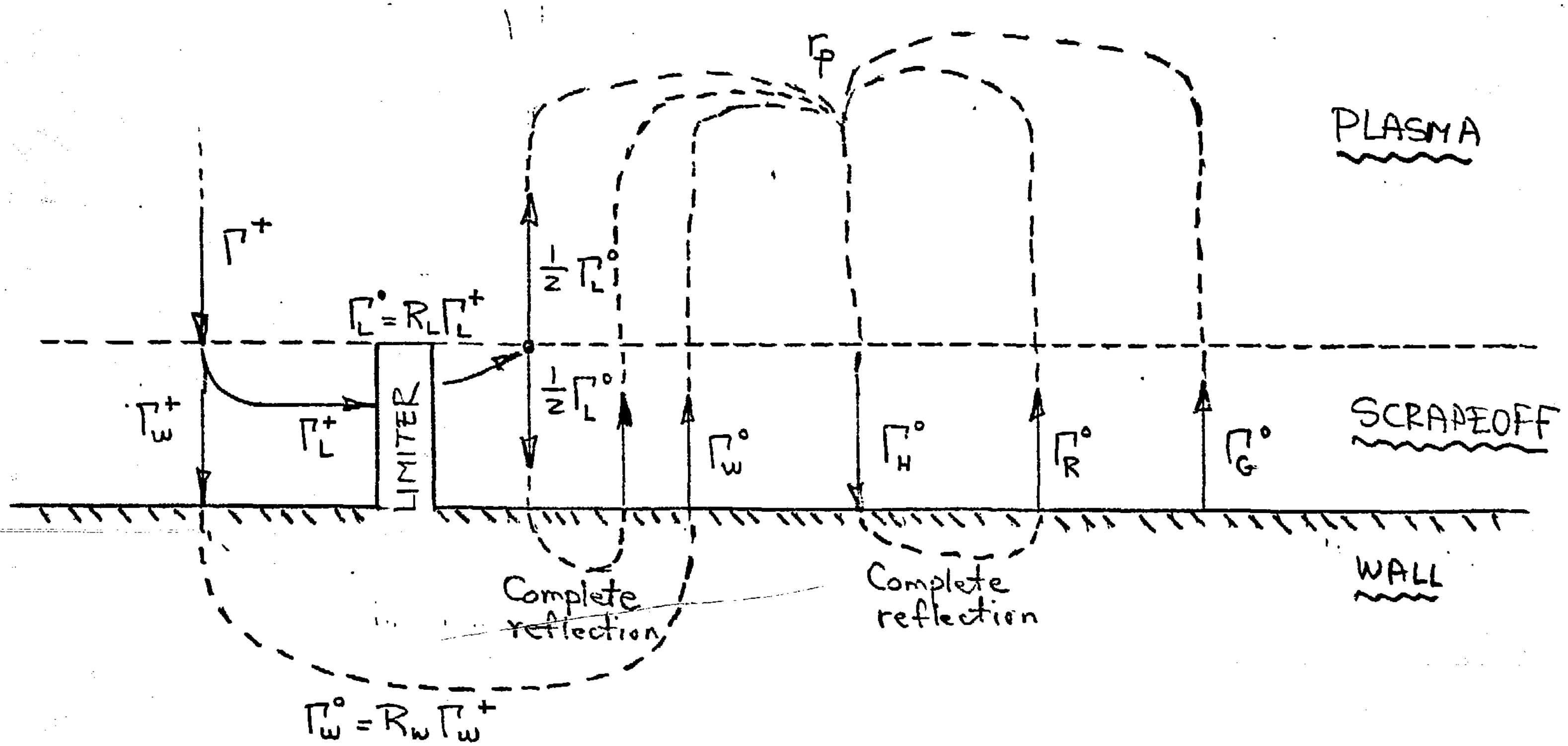


Fig. 1



$$\Gamma_w^\circ = R_w \left(-D\frac{\partial n_i}{\partial r}\right)\bigg|_{r=a}$$

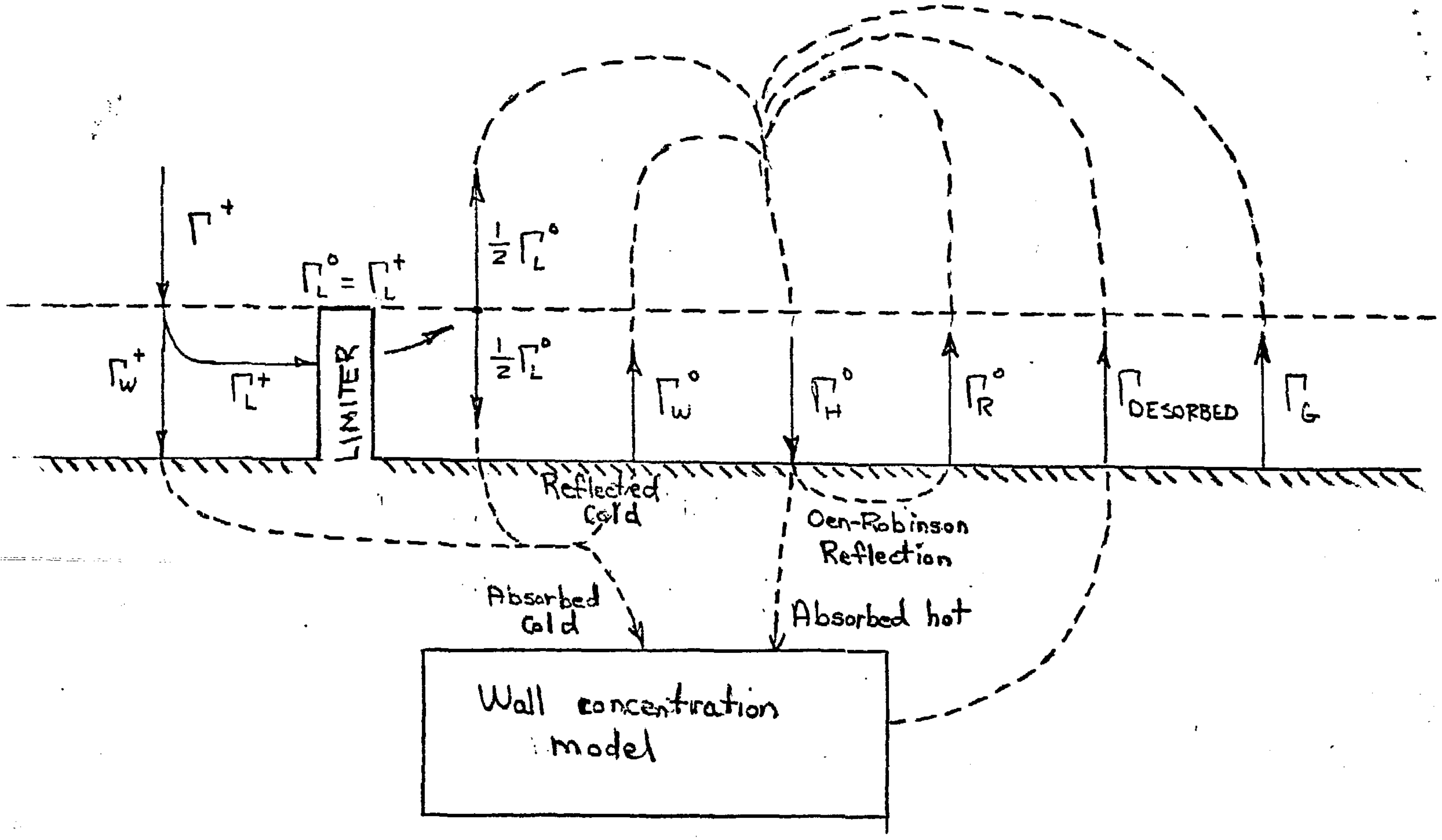
Wall Recycle

$$\Gamma_L^\circ = \frac{1}{A} R_L \int \frac{n_i}{\tau_{\parallel}} d^3r$$

Limiter Recycle

PRESENT RECYCLE MODEL

Fig. 2



RECYCLING WITH WALL MODEL

Fig. 3