Modelling of Massive Gas Injection with Tokamak Code TOKES for ITER Disruption Mitigation Design

I.S. Landman¹, S.E. Pestchanyly¹, Y. Igkitkanovy¹, R. Pitts²

¹Karlsruhe Institute of Technology, IHM, P.O. Box 3640, 76021 Karlsruhe, Germany
²ITER International Team, Cadarache, France

Introduction: In tokamaks the damage to PFCs after the disruptions can be mitigated using massive gas injection (MGI) of noble gases into confined plasma during the thermal quench (TQ). The gas gets ionized and the plasma contamination results in fast plasma radiation energy and radiative power gets below melting point \(T_{\text{cool}}\) TQ time \(\tau_{\text{cool}}\) weakly increases with injector length \(L\). Increasing \(\theta_{\text{MGI}}\) from 10⁵ s⁻¹ by 5 times significantly increases \(\tau_{\text{cool}}\) from 6 ms to 30 ms. Two times melting \(\tau_{\text{cool}}=4\) ms is needed. Several powerful fluxes accompany plasma cooling, which makes \(\tau_{\text{cool}}\) a stochastic variable. For blending wall, melt free MGI is hardly predictable because \(\tau_{\text{cool}}\) is obtained for the needed narrow range of \(\theta_{\text{MGI}}\) (5 to 6 ms) in vicinity of \(T_{\text{cool}}\). Furthermore, magnetic energy release at cooling front (with following plasma-to-wall transformation into radiation) is not taken into account. Therefore some other material is most desirable loaded position.

Validation of suggested scaling for thermal transport is needed. \(\tau_{\text{cool}}\) varies depending on injector position, injected gases and appearance of runaways during TQ, which makes validation of the model a challenge. Ref. [4] with TQ validation in DIII-D experiment: TQ occurs at \(t_{\text{TQ}}\) cooling wave remarkably increases over 6 cm and line density increases over 20 cm. For MGI, \(\theta_{\text{MGI}}\) = 2×10²⁶/s (in some ‘average sense’).

Conclusions: TOKES simulations for ITER’s argon injection demonstrated that at maximum inflow \(\dot{J}_{\text{gas}} = 2×10^{16} \text{ions}/\text{s} \cdot \text{cm}²\) the gas gets below melting point \(T_{\text{cool}}\) time \(\tau_{\text{cool}}\) weakly increases with injector length \(L\). Increasing \(\dot{J}_{\text{gas}}\) from 10⁵ s⁻¹ by 5 times significantly increases \(\tau_{\text{cool}}\) from 6 ms to 30 ms. Two times melting \(\tau_{\text{cool}}=4\) ms is needed. Several powerful fluxes accompany plasma cooling, which makes \(\tau_{\text{cool}}\) a stochastic variable. For blending wall, melt free MGI is hardly predictable because \(\tau_{\text{cool}}\) is obtained for the needed narrow range of \(\dot{J}_{\text{gas}}\) (5 to 6 ms) in vicinity of \(T_{\text{cool}}\). Furthermore, magnetic energy release at cooling front (with following plasma-to-wall transformation into radiation) is not taken into account. Therefore some other material is most desirable loaded position.

Validation of suggested scaling for thermal transport is needed. \(\tau_{\text{cool}}\) varies depending on injector position, injected gases and appearance of runaways during TQ, which makes validation of the model a challenge. Ref. [4] with TQ validation in DIII-D experiment: TQ occurs at \(t_{\text{TQ}}\) cooling wave remarkably increases over 6 cm and line density increases over 20 cm. For MGI, \(\dot{J}_{\text{gas}}\) = 2×10²⁶/s (in some ‘average sense’).

Conclusions: TOKES simulations for ITER’s argon injection demonstrated that at maximum inflow \(\dot{J}_{\text{gas}} = 2×10^{16} \text{ions}/\text{s} \cdot \text{cm}²\) the gas gets below melting point \(T_{\text{cool}}\) time \(\tau_{\text{cool}}\) weakly increases with injector length \(L\). Increasing \(\dot{J}_{\text{gas}}\) from 10⁵ s⁻¹ by 5 times significantly increases \(\tau_{\text{cool}}\) from 6 ms to 30 ms. Two times melting \(\tau_{\text{cool}}=4\) ms is needed. Several powerful fluxes accompany plasma cooling, which makes \(\tau_{\text{cool}}\) a stochastic variable. For blending wall, melt free MGI is hardly predictable because \(\tau_{\text{cool}}\) is obtained for the needed narrow range of \(\dot{J}_{\text{gas}}\) (5 to 6 ms) in vicinity of \(T_{\text{cool}}\). Furthermore, magnetic energy release at cooling front (with following plasma-to-wall transformation into radiation) is not taken into account. Therefore some other material is most desirable loaded position.

Validation of suggested scaling for thermal transport is needed. \(\tau_{\text{cool}}\) varies depending on injector position, injected gases and appearance of runaways during TQ, which makes validation of the model a challenge. Ref. [4] with TQ validation in DIII-D experiment: TQ occurs at \(t_{\text{TQ}}\) cooling wave remarkably increases over 6 cm and line density increases over 20 cm. For MGI, \(\dot{J}_{\text{gas}}\) = 2×10²⁶/s (in some ‘average sense’).

Conclusions: TOKES simulations for ITER’s argon injection demonstrated that at maximum inflow \(\dot{J}_{\text{gas}} = 2×10^{16} \text{ions}/\text{s} \cdot \text{cm}²\) the gas gets below melting point \(T_{\text{cool}}\) time \(\tau_{\text{cool}}\) weakly increases with injector length \(L\). Increasing \(\dot{J}_{\text{gas}}\) from 10⁵ s⁻¹ by 5 times significantly increases \(\tau_{\text{cool}}\) from 6 ms to 30 ms. Two times melting \(\tau_{\text{cool}}=4\) ms is needed. Several powerful fluxes accompany plasma cooling, which makes \(\tau_{\text{cool}}\) a stochastic variable. For blending wall, melt free MGI is hardly predictable because \(\tau_{\text{cool}}\) is obtained for the needed narrow range of \(\dot{J}_{\text{gas}}\) (5 to 6 ms) in vicinity of \(T_{\text{cool}}\). Furthermore, magnetic energy release at cooling front (with following plasma-to-wall transformation into radiation) is not taken into account. Therefore some other material is most desirable loaded position.

Validation of suggested scaling for thermal transport is needed. \(\tau_{\text{cool}}\) varies depending on injector position, injected gases and appearance of runaways during TQ, which makes validation of the model a challenge. Ref. [4] with TQ validation in DIII-D experiment: TQ occurs at \(t_{\text{TQ}}\) cooling wave remarkably increases over 6 cm and line density increases over 20 cm. For MGI, \(\dot{J}_{\text{gas}}\) = 2×10²⁶/s (in some ‘average sense’).

Conclusions: TOKES simulations for ITER’s argon injection demonstrated that at maximum inflow \(\dot{J}_{\text{gas}} = 2×10^{16} \text{ions}/\text{s} \cdot \text{cm}²\) the gas gets below melting point \(T_{\text{cool}}\) time \(\tau_{\text{cool}}\) weakly increases with injector length \(L\). Increasing \(\dot{J}_{\text{gas}}\) from 10⁵ s⁻¹ by 5 times significantly increases \(\tau_{\text{cool}}\) from 6 ms to 30 ms. Two times melting \(\tau_{\text{cool}}=4\) ms is needed. Several powerful fluxes accompany plasma cooling, which makes \(\tau_{\text{cool}}\) a stochastic variable. For blending wall, melt free MGI is hardly predictable because \(\tau_{\text{cool}}\) is obtained for the needed narrow range of \(\dot{J}_{\text{gas}}\) (5 to 6 ms) in vicinity of \(T_{\text{cool}}\). Furthermore, magnetic energy release at cooling front (with following plasma-to-wall transformation into radiation) is not taken into account. Therefore some other material is most desirable loaded position.

Validation of suggested scaling for thermal transport is needed. \(\tau_{\text{cool}}\) varies depending on injector position, injected gases and appearance of runaways during TQ, which makes validation of the model a challenge. Ref. [4] with TQ validation in DIII-D experiment: TQ occurs at \(t_{\text{TQ}}\) cooling wave remarkably increases over 6 cm and line density increases over 20 cm. For MGI, \(\dot{J}_{\text{gas}}\) = 2×10²⁶/s (in some ‘average sense’).