An Asymptotic Solution Approach for Real Time Simulation of Aftertreatment Reactors in HiL Environments

Santhosh Gundlapally, Ryan Dudgeon, Syed Wahiduzzaman
Gamma Technologies, Westmont, IL 60559, USA

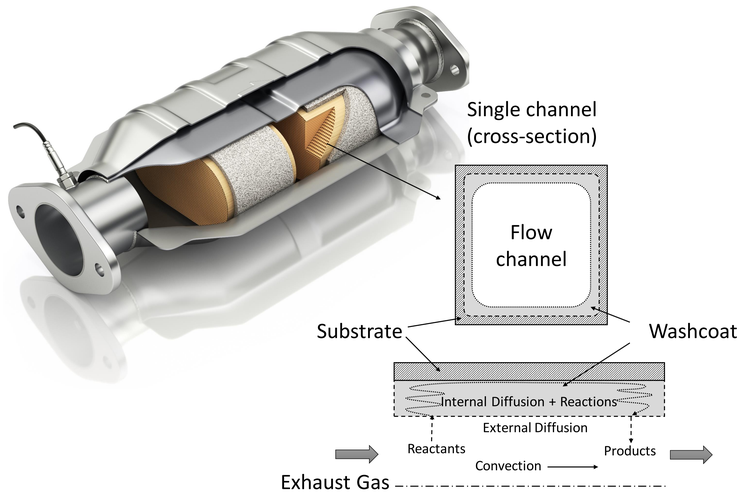
Motivation

- Model-based control of AT reactors
- Account for pore diffusion phenomenon
- Reduce control algorithm development time
- Reduce number of physical sensors used in a vehicle

Objective

Assess the validity of asymptotic solution for wide range of operating conditions in variety of AT reactors. Quantify the computational advantage of asymptotic solution by simulating various emission test cycles. Verify the Real Time capability of AT reactor models on HiL systems.

Detailed Model



- 1+1D model is most widely used for research and design purpose
- System of stiff differential-algebraic equations
- ODE solvers based on BDF methods are predominantly used
- Can be solved in real time on a typical PC but not on HiL systems with a small fixed time step (~ 100 ms)

Asymptotic Solution

- Analytical solution of diffusion-reaction equations inside washcoat
- Reduces 1+1D model to 1D model
- Negligible computational overhead due to asymptotic solution

References:
Bissett, E. J. (2015). An Asymptotic solution for washcoat pore diffusion in catalytic monoliths. Emission Control Science and Technology, 1(1), pp 3-16.
Gundlapally, S.R., Dudgeon, R., Wahiduzzaman, S. (2018). Efficient Solution of Washcoat Diffusion-Reaction Problem for Real-Time Simulations. Emission Control Science and Technology, 4(2), pp 90-102.

Region 1 solution

Average washcoat concentrations

$$\frac{d\bar{\omega}^{(1)}}{dt} = K * (\omega_g - \omega_s) + R^{(1)}(\bar{\omega}^{(1)}) + R^{(2)}(\bar{\omega}^{(2)})$$

$$\frac{d\bar{\omega}^{(2)}}{dt} = \bar{\omega}^{(1)} - \bar{\omega}^{(2)} + \frac{D_{inv}^{(1)}}{6} * R^{(1)}(\bar{\omega}^{(1)}) + \left(\frac{D_{inv}^{(1)}}{2} + \frac{D_{inv}^{(2)}}{3}\right) * R^{(2)}(\bar{\omega}^{(2)})$$

$$\omega_s = \bar{\omega}^{(1)} - \frac{D_{inv}^{(1)} * R^{(1)}(\bar{\omega}^{(1)})}{3} - \frac{D_{inv}^{(1)} * R^{(2)}(\bar{\omega}^{(2)})}{2}$$

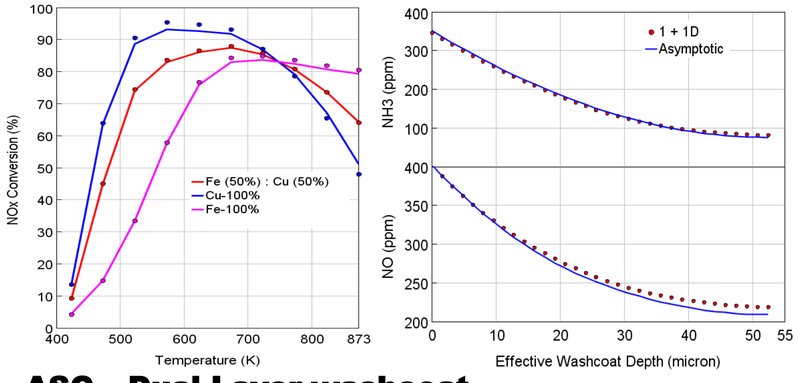
Washcoat profiles

$$\omega = \bar{\omega}^{(1)} + D_{inv}^{(1)} * R^{(1)}(\bar{\omega}^{(1)}) * \left[\frac{1}{6} - \frac{1}{2}(1-\hat{x})^2\right] + D_{inv}^{(1)} * R^{(2)}(\bar{\omega}^{(2)}) * \left(\hat{x} - \frac{1}{2}\right)$$

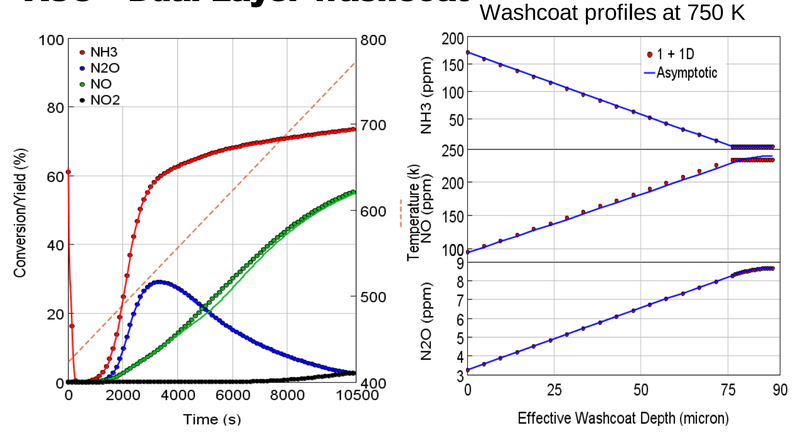
$$\omega = \bar{\omega}^{(2)} + D_{inv}^{(2)} * R^{(2)}(\bar{\omega}^{(2)}) * \left[\frac{1}{6} - \frac{1}{2}(2-\hat{x})^2\right]$$

Comparisons

SCR – Dual Layer washcoat



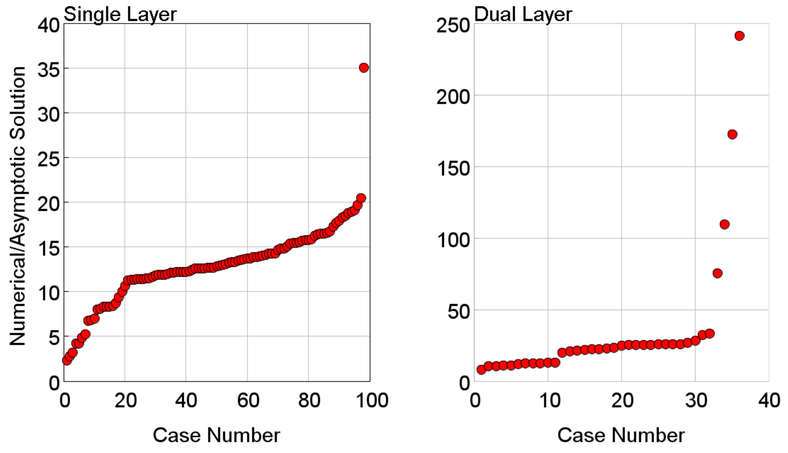
ASC – Dual Layer washcoat



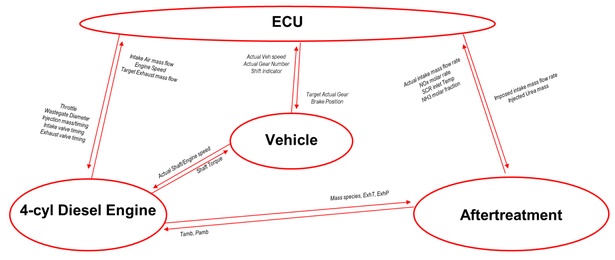
Test Cycles

Over 100 cases consisting of various test cycles (FTP, NEDC, WLTP, etc.) and different reactors (TWC, DOC, SCR, AOC, LNT) are simulated. For numerical solution, discretization length of 5 μm is used in the washcoat layers.

Speedup Factor

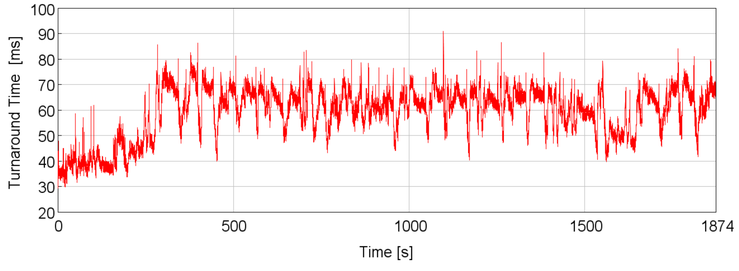


HiL Simulations



DOC + DPF + Dual layer SCR

- NI Veristand • FTP75
- Engine + Vehicle – 1 ms sampling time • AT - 100 ms sampling time



Summary

Asymptotic solution is found to be up to two orders of magnitude faster than the 1+1D model while maintaining similar level of accuracy. The Real Time capability of the asymptotic solution is verified by HiL simulations.