Optimization of DPF Structures with a 3D-Unit Cell Model

W. Beckert[1], M. Dannowski[1], L. Wagner[1], J. Adler[1]

[1]Fraunhofer IKTS, Dresden, Germany

Abstract

The performance of Diesel Particulate Filters is evaluated by pressure drop and soot charge capacity and is controlled by the properties (permeability, pore distribution, max. soot charge) of the porous wall material and the geometry (channel-shape, -length, wall thickness) of the filter structure. By varying filter structure and material its performance may be optimally adapted to customer specifications. The manufacturing of ceramic filter segments proceeds over an extrusion process and requires expensive design specific tools. An empirical optimization with trial and error cycles in the hardware is extremely costly: a "virtual" optimization process via simulation is more promising. Aim of the presented model is to analyze the influence of filter structure and material parameters on flow and soot deposition. Various structural designs with different channel arrangements exist and can be mapped to a simple repeating unit of the filter structure utilizing symmetry relations (figure 1). Our model geometry involves a filter unit cell, completed by a flow collector and a flow expansion zone ahead and behind the filter, accounting for dynamic pressure drop effects. Code platform was COMSOL Multiphysics®. The physical modes of the model include Navier-Stokes- (channel) and Darcy-Flow (wall) for gas flow, convective mass transport for gas soot load and two transient DOFs (2x transient diffusion mode) for accumulation of soot deposited within the porous wall and, after locally reaching saturation, preceding with soot deposition on a soot layer emerging at its surface. To account for the reduction of the free flow cross-sectional area of the inlet channel with the growing soot layer, the latter was introduced by a moving mesh approach. Soot deposition was implemented by specific source (wall load) /sink (gas load) terms, characterizing the behavior of the porous material by a characteristic (exponential) decay length and saturation concentration value. These parameters were obtained from experimental characterization of disc samples. The results from the 3D-model for empty filters have been compared with a 1D-model based on engineering equations for laminar pipe flow (figure 2). Though Reynolds-Numbers were <1000 strong deviations have been obtained, due to stagnant flow effects from continuous mass loss through the walls. A validation with experimental tests on empty filters confirmed the validity of the model (figure 3). The soot deposition process was reproduced, starting from an empty filter with a gradually deposition of soot in bulk wall, followed- after wall saturation- by growth of a soot layer on the surface. Since the through-wall flow is controlled by the local pressure difference between the channels and is inhomogeneous along the channel, a nonuniform distribution of soot wall charge and soot layer thickness evolved. Local deposition rates changed during the process from permeability varying with soot load. The model showed that the reduction of the open channel sectional area by the growing soot layer has a strong effect on

global pressure characteristics. Evaluation of the model with experimental tests for variations of filter geometry and material selection proved the suitability of the model for performance prediction (figure 4).

Reference

J. Adler, Ceramic diesel particulate filters, International Journal of Applied Ceramic Technology, 2 (6) (2005), pp. 429–439
A.G. Konstandopoulos, M. Kostoglou, N. Vlachos, E. Kladopoulou, Advances in the science and technology of Diesel particulate filter simulation, Adv.Chem. Eng. 33 (2007) 284–294

Figures used in the abstract

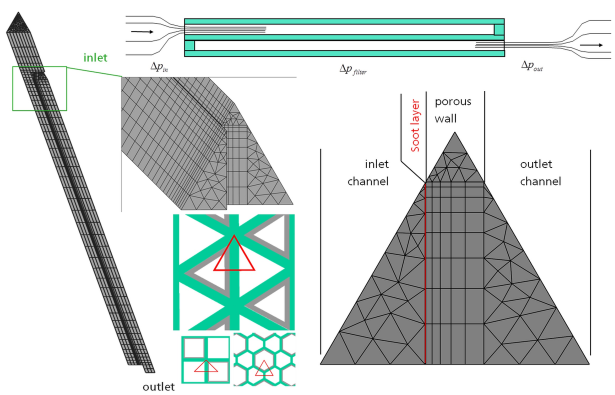

Figure 1: Unit cell geometry of Diesel Particulate Filter structure used in the model

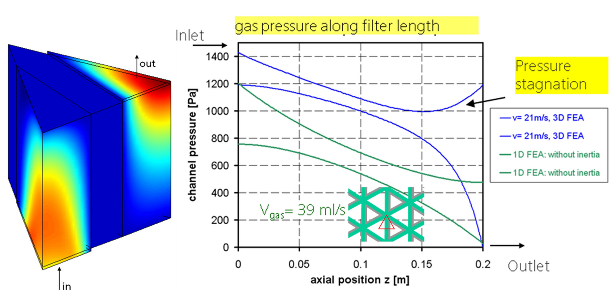

Figure 2: Results from the 3D-Model (left: velocity distribution, axially distorted display) compared with 1D-pipe flow (green lines) model with identical flow rate reveal deviations due to stagnation pressure effects.

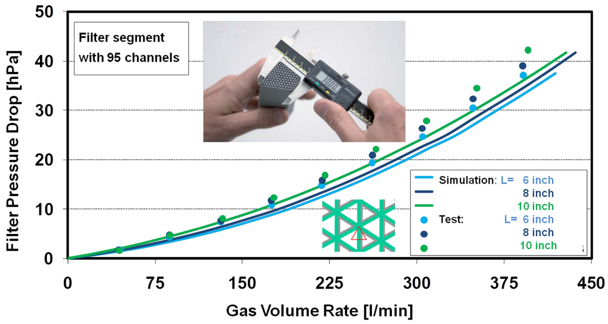

Figure 3: Model verification from experimental filter segment characterization

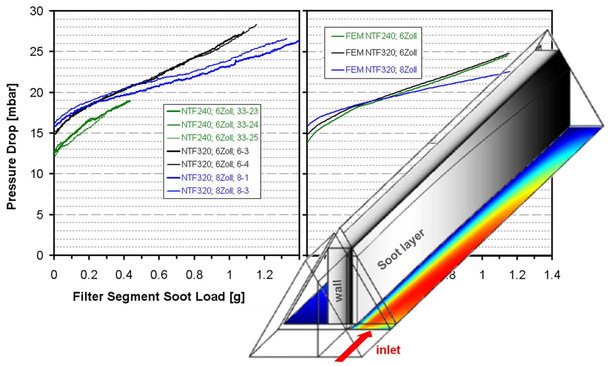

Figure 4: Comparison of experimental (left) and model (right) results for effect of soot charge on pressure drop. The 3D sketch illustrates results for velocity distribution (colored), wall soot charge (gray level) and soot layer thickness (gray level)