# Numerical Simulation of Forced and Static Smoldering Combustion

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## Abstract

The combustion process within a burning cigarette encompasses many physical and chemical phenomena. Understanding the formation of toxic products during pyrolysis and char oxidation and their subsequent transport away from the burning zone is a topic of significant interest. Numerical simulation of cigarette combustion is challenging due to its multi-physics nature and the fast transients exhibited during the transition between the forced- and natural- smoldering portions of a smoking cycle. The presence of reaction terms make the system of equations stiff and distributions of temperature and species concentrations can exhibit steep gradients.

Transient, two-dimensional (axisymmetric) simulations of a burning cigarette subject to realistic smoking cycles were performed using COMSOL Multiphysics®. The computational domain consists of a porous packed bed of tobacco and a filter surrounded by a thin, porous paper and a region of surrounding air. The governing equations include overall mass conservation for the gas phase, momentum conservation equations for the free flow and porous regions, conservation equations for individual gas species, separate thermal energy conservation equations for the gas and solid phases (local thermal non-equilibrium prevails) and evolution equations for various solid densities. Many sub-models and auxiliary equations are required to determine the thermo-physical, reaction and transport properties of the system. All such properties are calculated dynamically as a function of the local state variables.

The predictions of the reacting flow model have been validated against experimental data for solid and gas temperatures and oxygen mass fraction profiles with quite reasonable agreement. The impact of different smoking conditions and the variation of paper properties have been analyzed in terms of their effects on the distributions of temperature, species and char density, as well as on global quantities. While most of the energetically significant species and processes that control the large-scale evolution of a burning cigarette have been included, ongoing work is focused on the incorporation of important, energetically minor species into the model.