Simulator for Automotive Evaporative Emissions Restraint Systems

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Abstract

Fuel vapor restraint systems are widely used in vehicles to avoid discharge of volatile hydrocarbons from fuel tanks. Until 2020, nearly 10% of all fossil fuels shall be replaced by biofuels upon which bioethanol plays an important role [1]. The topic of this work is the proper operation of fuel vapor restraint systems depending on the composition of bioethanol-fuel-blends. Beyond experimental work on loading activated carbons commonly used in fuel restraint systems, a simulation model for the adsorption/desorption process inside the carbon bed was developed and implemented with COMSOL Multiphysics® software.

Within a research project [2], the simulator ACES (Active Carbon Fuel Emissions Simulator) was developed. The model describes a multicomponent gas flow through an adsorber bed with adsorption/desorption mass transfer to/from active carbon under non-isothermal and unsteady conditions (see [2],[3],[4],[5],[6],[7]). Main parts of the model are the conservation laws for mass, species concentrations and heat in the gas phase, the loading of adsorbent with adsorbed species mass, the adsorption isotherms of adsorbed species and the adsorption kinetics. The mathematical equations are set up using a mathematical interface and a chemical interface of the Chemical Reaction Engineering Module [8]. The time dependent solution of this set of equations is achieved with the fully coupled solution approach.

The simulation was set up for the loading of a moisturized active carbon bed in a cylindrical adsorber with a gas mixture of pentane, ethanol and nitrogen. Pentane is used here as a reference gas instead of gasoline with standard specifications. Experiments are performed up to the total loading of the active carbon beds with pentane [2]. The simulations were run under the same conditions, and the thermodynamic conditions inside the bed are recorded over time.

Figure 1 to Figure 3 show the temperature, the molar fraction of pentane and the loading of pentane on the active carbon after 32 min from process start. The simulation shows that there is a small mass transfer zone at the loading front with large gradients in many thermodynamic quantities. Due to adsorption heat, the temperature increases up to 130°C depending on adsorption conditions. Molar fractions of pentane and ethanol in the gas phase nearly become zero at the adsorption front. Thus, the adsorber works in a very efficient mode. The loading equilibria for the gas components are strongly temperature dependent which results in a strong multiphysics coupling between energy and mass

transfer calculations.

In the experiments, temperature probes are installed at certain points inside the bed. In simulations with COMSOL, these probes are reflected with the Point Probe facility. Figure 4 shows an example of measured and simulated temperature probes for an experiment. It can be seen that the points of temperature increase, the rate of increase and the maximum temperature of each probe are reproduced well within the simulation.

The ACES simulator is an experimental proved simulation tool for the loading of active carbon canisters with fuel gases. In actual research ACES is used to simulate periodical adsorption and desorption in automotive driving circles.

Reference

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[3] G. A. Lavoie et al., Carbon canister modelling for evaporative emissions: adsorption and thermal effects, International Spring Fuels & Lubricants Meeting, 961210, 1-22 (1996)
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Figures used in the abstract

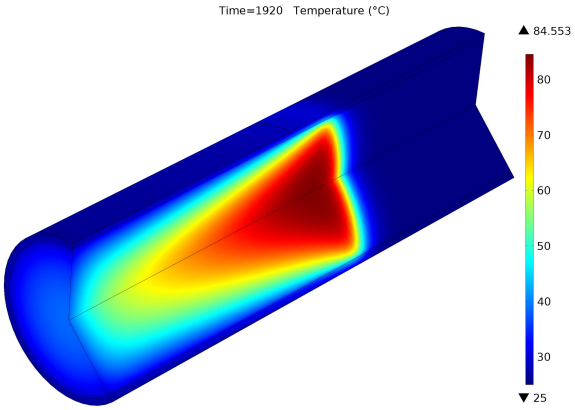

Figure 1: Temperature field inside the active carbon bed at t = 32 min after process start.

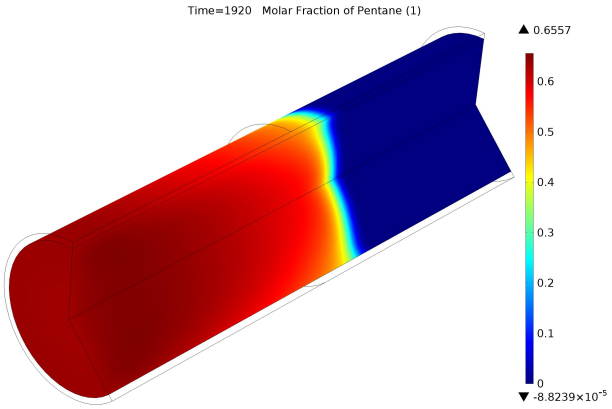

Figure 2: Pentane molar fraction field inside the active carbon bed at t = 32 min after process start.

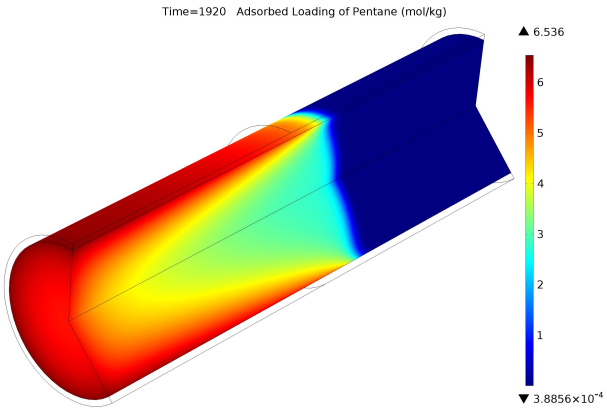

Figure 3: Pentane adsorbent loading field inside the active carbon bed at t = 32 min after process start.

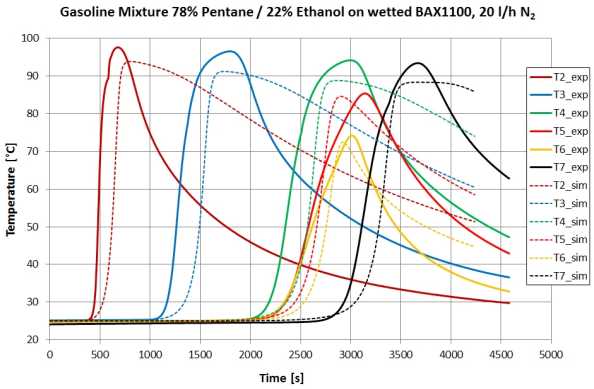

Figure 4: Temperature point measurements inside the adsorber – experimental findings and simulation.