

Numerical simulation of droplet-fiber-interactions in water/diesel coalescence filters

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With modern diesel combustion engines it is common to use fibrous coalescence filters for the separation of dispersed water droplets from diesel fuel to protect the injection system components from hazardous corrosion, cavitation or fouling effects. The separation efficiency of these filters is not only dependent on the properties of the filter element or the single fibers, like fiber diameters, surface roughness or porosity, but also on interfacial effects like the interfacial tension and the contact angle of water droplets on the fiber surfaces and the characteristics of the disperse water/diesel system (water content and droplet size distribution).

The latest developments in diesel fuel quality led to diesel mixtures with varying types and amounts of biocontents and additives which act like surfactants and change the physical properties of the fuel. One result is a lowered interfacial tension between water and fuel which has led to a stabilization of the water droplets. Biodiesel, whose addition to conventional diesel fuel is regulated by law, has the same effect on the physical features as the above mentioned additives. As a consequence of these fuel modifications the coalescence filters often fail in water separation and separation efficiencies become impossible to predict.

For an improved understanding of the water/diesel separation process in coalescence filter media our idea is to study theoretically the different factors which impact the interaction of dispersed water droplets in diesel fuel on single fibers of a coalescer filter. For this task the computational fluid dynamics (CFD) tool OpenFOAM[®] is applied in order to get an insight in the basic process of liquid-liquid separation with coalescence filters. The results show the different outcomes of the droplet separation and give an idea whether the droplets attach on the fibers or if they are entrained by the diesel stream.

The simulation model regarding the water/diesel separation has to include interfacial phenomena and must account for the reconstruction of free surfaces and correct contact angles between the fluid and the solid and for the surface roughness. Therefore the Volume-of-Fluid method is applied and specific numerical features are added to predict correctly the interaction between the water/diesel system and single filter fibers.

Before simulating the water/diesel system and in turn the impact of a single water droplet on a fiber, for which almost no published data can be found in literature the simulation model was validated with reference to the interaction phenomena of falling droplets in air with varying fluid properties on plane solid surfaces. The simulation results are compared to published data in literature both qualitatively and quantitatively to evaluate the predictive quality of the model, see Fig. 1 and Fig. 2 [1].

For further improvement of the free surface model a dynamic contact angle model is implemented. The OpenFOAM[®] solver is modified to capture effects of surface roughness. The interfacial tension between water and diesel is varied in the range for diesel with low to high additive contents. The different types of fibers with respect to their wettability are considered by applying high static contact angles for lipophilic filter media and low static contact angles for hydrophilic filter media. With these models the behavior of a single droplet during its impact and spreading on a single fiber is examined.

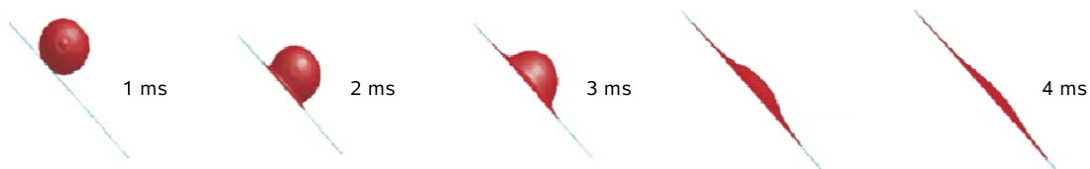


Fig. 1: Predicted spreading of a 2.72 mm water droplet in air impacting at 1.55 m/s (Weber number $We = 90$) on a 45° inclined glass surface, extracted from [1].

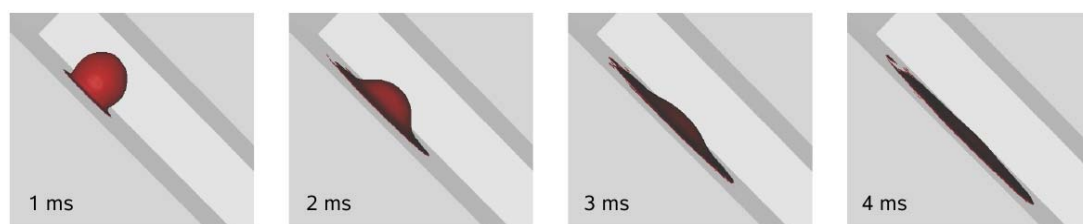


Fig. 2: Own simulation results with OpenFOAM[®] of a 2.72 mm water droplet in air impacting at 1.55 m/s ($We = 90$) on a 45° inclined glass surface.

In further steps modelling and simulation investigations of filtration with fiber structures and different filter compositions as well as the entire coalescence process will be regarded. Based on these results the filtration process can be further optimised.

- [1] Siddhartha F. Lunkad, Vivek V. Buwa, K.D.P. Nigam, Numerical simulations of drop impact and spreading on horizontal and inclined surfaces, *Chemical Engineering Science* 62 (2007) 7214 – 7224.

Biographical Sketch Dagmar Winkler

Born in Olesno, Poland, on September 8th, 1983

Studies of Environmental Engineering from 2004 to 2009 at the University of Stuttgart and graduated with a diploma degree

Research assistant at the Institute of Mechanical Process Engineering at the University of Stuttgart since 2010, working on the field of water/diesel separation