Summary for the final report

Experimentally supported basis models for a feasible numerical cleaning simulation

The aim of the project was to develop or refine numerical models suitable for the various cleaning mechanisms that have a good prediction quality of the cleaning time and computation durations that are practicable for SMEs. The approach combines a flow simulation (CFD) of the cleaning fluid for an arbitrary shape of the part to be cleaned with a boundary condition that models the behavior of the soiling. The models were to be developed and tested using the findings and measurement data obtained in previous projects, supplemented by further experimental and numerical investigations on geometrically simple test cases.

The four cleaning mechanisms of diffusive dissolution, cohesive separation, viscous shifting and adhesive detachment are a model concept developed from previous projects on the overarching topic of "industry-compatible cleaning simulation", which are now also firmly established in industry, and which subdivides the complex topic and makes it accessible for modeling.

For diffusive dissolution/cohesive separation, the existing approach from the IGF projects "Development of a process model for jet cleaning in the food industry 1+2" (17805 N, 18733 BR) was further developed. The original approach requires the resolution of both the boundary layer for mass transport and the flow boundary layer. Since their extent differs by an order of magnitude, the model was enhanced to include a wall function for mass transport. As a result, cleaning simulations in the plane channel could be carried out with a resolution reduced by a factor of 32 while maintaining the same prediction quality. This is a significant improvement of the previous model, especially with regard to the industrial applicability of the numerical models by SMEs due to the practicable computing times. A transfer to other test cases has been carried out numerically and was validated within the framework of the project using further cleaning tests.

For viscous shifting, no sufficient cleaning success could be achieved for petroleum jelly at room temperature with water within the scope of experimental possibilities. Further tests showed that an increase in temperature is useful, but can only be achieved experimentally to the extent that a transient heating of the petroleum jelly layer takes place. Moreover, an isothermal test at increased temperature would not correspond to industrial practice. This discrepancy between the transient temperature change in the experiment and the initially assumed and modelled temperature constancy in the simulation also becomes clear through a significant deviation between the respectively determined cleaning times. In consultation with the project committee, the research institutions have therefore decided to deviate from the original concept and work on transient heating and thus the temperature dependence of model parameters already in the current project. An initial flow model with temperaturedependent coefficients was created for this purpose. First, the flow model was used to generate a model for predicting the cleaning of the petroleum jelly. The model was validated using cleaning experiments in a channel flow. This cleaning model was also parameterized exclusively through laboratory tests. Based on this model, the essential requirements for a boundary condition model for viscous shifting could be worked out. For its implementation, the possibility of specifying a wall slip velocity available in OpenFOAM can be used.

For the adhesive separation, the objective was completely achieved using the example of a ketchup soiling. The swelling process of the ketchup soil was analyzed using layer thickness measurements and transferred to a numerical model. With the information on the layer thickness growth, the test parameters can be specifically adjusted in the binding force test setup and thus the course of the cohesive binding forces through a swollen soil layer can be measured with spatial resolution. By varying the soaking time and optically evaluating the remaining amount of soil, adhesive failure can be detected and thus the adhesion force can be described as a function of the water mass fraction. These two sub-models were implemented into the numerical removal model and allow a prediction of the local cleaning time. For this purpose, the diffusion of water into the soil layer is calculated on the basis of the previously calculated flow and the local water mass fraction is determined. An equivalent stress is calculated from the acting pressure and shear stresses (face and top of the soil layer), also depending on the thickness of the layer. If this exceeds the adhesion force, which depends on the local water mass fraction, detachment and convective removal of the soil occurs. Due to the decoupled calculation of flow and soil behavior, practicable calculation times are also given for this model for SMEs. The model was successfully validated on the basis of the local cleaning times in the plane channel flow and a sudden expansion for different amounts of soil and flow velocities, as well as for partially soiled surfaces for different lengths and distances of soiling.

In view of the challenging objective of generating models that can be parameterized exclusively from laboratory tests, the model for adhesive detachment was extended to cohesive separating within the scope of the project. The model was tested for a starch soil, and the results obtained are promising. With this newly formulated model, the basis is laid for modelling the transition between the cleaning mechanisms of adhesive separation and cohesive separation, which is the focus of the follow-up project. With the temperature- or concentration-dependent properties of the soilings included in the models, the bridge to viscous shifting is also prepared.

The totality of all the goals achieved and targeted so far for the topic of "industry-compatible cleaning simulation" illustrates the systematic, continuous and at the same time goal-oriented approach.

IVLV members can download the complete final project report from our homepage. All you need is to register in the section “My IVLV”. Non-members can request the final report from the IVLV office at office@ivlv.org.

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