Summary for the final report
Spray jet simulation for periodically working, moving cleaning nozzles with an innovative, grid-free approach and analytical replacement model (SpraySim)

Across all industries, the pursuit of efficiency and environmental protection strongly influences the development and design of automated cleaning processes. This is particularly true in the food industry, where the time spent on cleaning can amount to up to 25% of the machine working time due to high product standards and large product variety. Low consumption of cleaning agents, water, and energy are the declared goal.

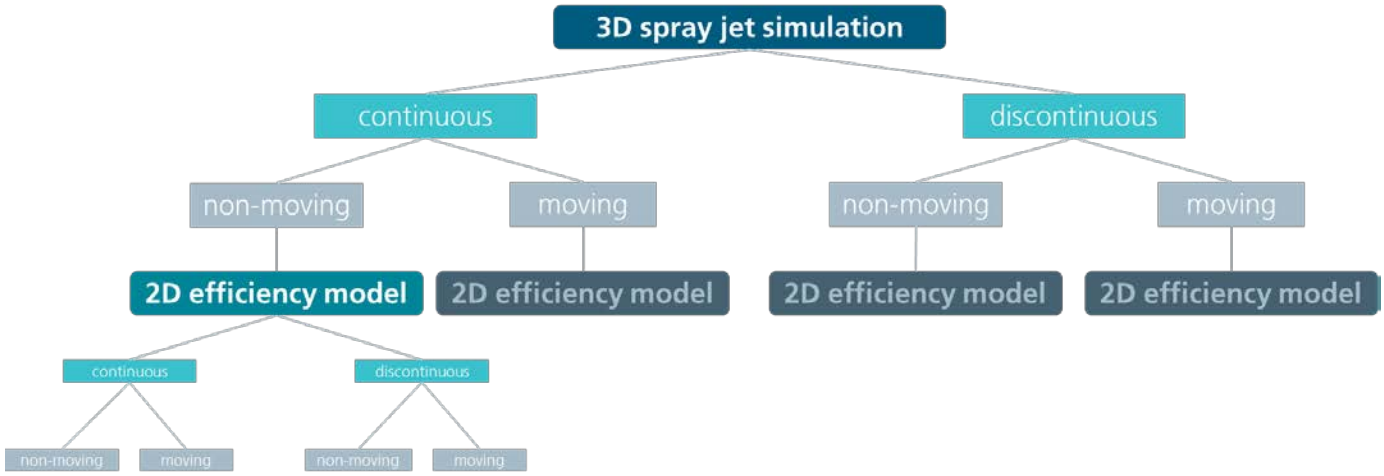
Up to now, companies have not exploited the great optimization potential in adapting the geometry of the nozzles used to generate spray jets for non-immerged systems – such as open surfaces and tanks. The reasons for this are the experimentally and experience-driven design practice as well as the very limited understanding of the effective processes during cleaning. In experiments, these can only be spatially and temporally resolved to a limited extent and are difficult to access in the case of thin films. Although numerical flow simulation methods promise a high-resolution insight into the flow field, companies rarely use them at present because they cannot obtain meaningful results with a reasonable computational effort. Typical computation times are in the range of several weeks.

This is where the "SpraySim" project comes in, with the aim of developing an efficient and easily accessible numerical simulation of disintegrated spray jets with industrially relevant computation times in the order of a week. To represent not only static nozzles but also dynamic and discontinuous spray jets, we chose the innovative, grid-free simulation tool MESHFREE (www.meshfree.eu). The software is developed and implemented by research institution 1 (Fraunhofer ITWM), so that we could easily integrate new features necessary for the project.

A prerequisite for the development of this new approach was the cooperation with research institution 2 (Fraunhofer IVV). There, e.g. experiments for the measurement of the flow field – with the aim of validation – as well as for the measurement of the cleaning effect took place. Cleaning results in combination with the simulation-based, high-resolution information on the flow field allowed the derivation of correlations between local stresses and the cleaning effect. These generate a deeper understanding of the cleaning processes and allow for the first-time simulation-based predictions of the cleaning effect as well as optimization strategies.

We achieve the necessary efficiency by a two-stage model approach. In the 3D spray jet model, we simulate the flow away from the wall including the disintegration near the nozzle and record the resulting droplet distribution in space and time. Subsequently, we feed the recorded data into a more performant 2D efficiency model that simulates the film flow at the wall similar to a shallow water approach. The two models, including the correlations between local impact and cleaning effect identified in the project, are incorporated into an easy-to-use simulation platform that is available free of charge upon request.

During the project, it became apparent that the numerical resolution for the 3D spray jet simulations with MESHFREE had to be higher than originally assumed to achieve the necessary quality. Therefore, the 3D spray jet simulations are significantly more complex, especially for the discontinuous (at least two periods must be executed for the respective frequency) and moving case (a sufficiently far movement must be achieved) – even if the computing times are lower than those of commercially available simulation tools at 1-2 weeks. To achieve the original project goal, we have adjusted the project strategy in such a way that the user is able to generate the necessary input for the faster 2D simulations with as few 3D spray jet simulations as possible. These in turn are designed so flexibly that the desired parameter combinations (continuous/discontinuous, non-moving/moving, distance) can be easily implemented based on the users' input, see left branch in the following illustration.



Within the scope of the project, we investigated only thin layers of soil, for which the effects of the layer geometry and removed contaminants on the impact are negligible in a first approximation. Furthermore, the project was limited to spray jets of water at room temperature impinging on a flat, soiled surface. In general, the surface geometry is easily interchangeable in MESHFREE and is not limited to this case. The 3D spray jet model developed also allows the influence of surface tension due to detergent additives on droplet formation to be studied in future research. For reasons of complexity, we did not address this aspect in the project.

Together with the project-accompanying committee (PA), two geometry variants for flat jet and full-cone nozzles from the companies Lechler GmbH and Spraying Systems Manufacturing Europe GmbH were defined for the majority of the investigations, representing typical moving and non-moving spray jet nozzles. The evaluation of the transferability of the simulation approach to different geometries additionally included a special nozzle from FDX Fluid Dynamix GmbH. In accordance with the PA's recommendations, we selected the following industrially relevant contaminants: Pudding, rice pudding, ketchup.

The MESHFREE simulations developed in the project and the knowledge gained about the relationships between the impact on the surface and the cleaning effect can be used across all industries.

Manufacturers of cleaning nozzles can use the simulations at an early stage during nozzle development with the help of the simulation platform – even before manufacturing the first prototype. In particular, the geometric adaptation of nozzles to special cleaning tasks using e.g. additive manufacturing methods becomes more attractive, which can significantly expand the business field of nozzle manufacturers. The simple interface of the simulation platform makes it possible for less experienced users to apply the software. This is particularly beneficial for SMEs, which usually do not have their own simulation department and the corresponding expertise.
Furthermore, the software platform allows CFD service providers to offer support in the evaluation of cleaning processes as well as in the new development of cleaning systems. This enables the mostly small engineering companies to expand their service portfolio.
Manufacturers of complete cleaning systems for food, beverages, or pharmaceutical products can expand their range to include discontinuously operating, efficiency-enhancing systems. This enables the reduction of cleaning times and costs and, with the time gained, an increased production output while maintaining a constant cleaning effect. Legal requirements for the manufacture of hygienic and high-quality products can thus continue to be met.
Smaller suppliers to the automotive industry can also benefit from the project results by developing and producing efficient and innovative automated cleaning systems for component cleaning equipment.

IVLV members can download the complete final German 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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