Maximization of Cleanability in Progressive Cavity Pumps by CFD Optimization

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Introduction: In hygienic applications thorough cleaning of pumps is of substantial importance, since remaining residue would contaminate the food product and make it unfit for consumption. Thus, evidence is to be given about the pump's cleaning capabilities by EHEDG certification. To further increase transparency and reliability, EHEDG has changed the certification process (certification notice, 21.02.2017) and introduced recertification every 5 years. Hence, any pump has to repeatedly prove its acceptability and its state-of-the-art design regarding most recent technological enhancements. Cleanability, therefore, becomes an over-time-evolving requirement and attains even more importance in pump design.

Background: For conveying of highly-viscous products progressive cavity pumps (PCP) are a natural choice. However, when cleaning in a conventional PCP design, near-wall detachment and dead space areas are likely to arise. This impairs the cleanability by:

1. sharp deflection of the inflow downstream to the inlet port,
2. dividing of inflow at the stagnation point above the mechanical seal,
3. insufficient undercurrent of mechanical seal at bottom of suction casing.

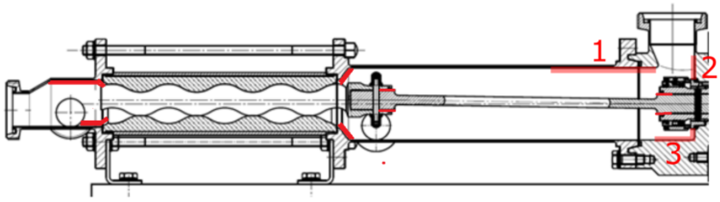

Fig. 1: Critical areas (red) for cleaning in a progressive cavity pump. Presented CFD results for wall zones 1,2 and 3

Due to lower wall friction these areas are most critical for cleaning. Over the past years, effort has been spend by various PCP manufacturers to optimize pump casings in order to improve cleaning capabilities (e.g. tangential inlet ports). In the present study, a further optimized pump geometry was developed based on CFD-simulations and compared to conventional geometries. The novel pump geometry exhibits significantly improved flow characteristics from an induction of a swirl flow inside the pump's suction casing. It has recently proven to pass the aforementioned EHEDG tests successfully.

Material & Methods: Two different suction casing geometries were investigated: one with tangential inlet port geometry similar to commercially available PCPs (referred to as case A) and one realizing the swirl flow optimized inlet port geometry (newly developed, referred to as case B) (cf. Fig. 2). The optimized port geometry is also tangential but exhibits a particular asymmetric cross-section reduction, whereby inflow is purposefully directed onto the critical wall zones and swirl flow is significantly enhanced (cf. Fig. 2a).

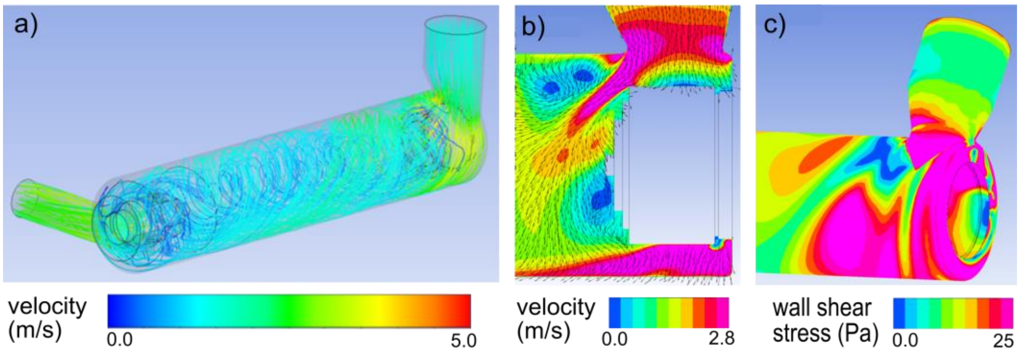

Fig. 2: CFD results for the optimized geometry (case B): a) Streamline plot colored by local velocity; b) velocity contour plots in a cross section at the inlet port area; c) Wall shear stress in a contour plot at outer walls.

For design and comparison of flow effects, CFD simulations were carried out as follows. The commercial flow solver Ansys CFX R18 was used to solve the incompressible Reynolds-averaged Navier-Stokes equations. Time and space was second order discretized and the SST turbulence model was applied together with the automatic wall-function treatment. The cleaning fluid was treated as water at room temperature. Inlet exhibits fixed Dirichlet-condition with velocity of *1.5 m/s* (EHEDG test condition), whereas total outlet mass flow was split onto $3/4^{th}$ via CIP-pipe and $1/4^{th}$ via pump stator. The pressure level was fixed at both outlets to *1.5 bar*. Outer walls were modeled as hydraulically smooth. The rotating elements, i.e. coupling rod, joint, etc. were fixed in central position and modelled frozen rotor with a fixed rotational speed of *400 rpm* at the inner walls. The grid contains a total number of approx. *7* mio. cells. It was split into a locally refined tetra-prism grid around the pump inlet area and the CIP-port as well as a swept structured grid in the intermediate O-ring area around the coupling rod. If not otherwise mentioned steady-state simulations were applied, whilst transient simulations were conducted to investigate turbulent fluctuation effects.

Results: For case A, large dead space areas at the deflection zone as well as below the mechanical seal are prominent. For case B a well pronounced swirl flow is discernable in the entire suction casing, cf. Fig. 2a), whereas dead space regions are vanished and smaller ones have been shifted away from the wall to the inner fluid domains that are uncritical for wall cleaning, cf. Fig. 2b). Moreover, fluid is accelerated by the CFD-optimized inflow geometry, which additionally increases cleaning capabilities. An expressive indicator for the cleaning quality is the wall shear stress, cf. Fig. 2c. For case A significant wall zones with very low shear stress are discernable close to the critical wall zones. However, for case B the overall wall shear stress is intensively increased by the optimized inlet port geometry. The remaining small areas with low wall shear stress of case B are uncritical, as they temporally shift over the outer wall surface by turbulent fluctuations.

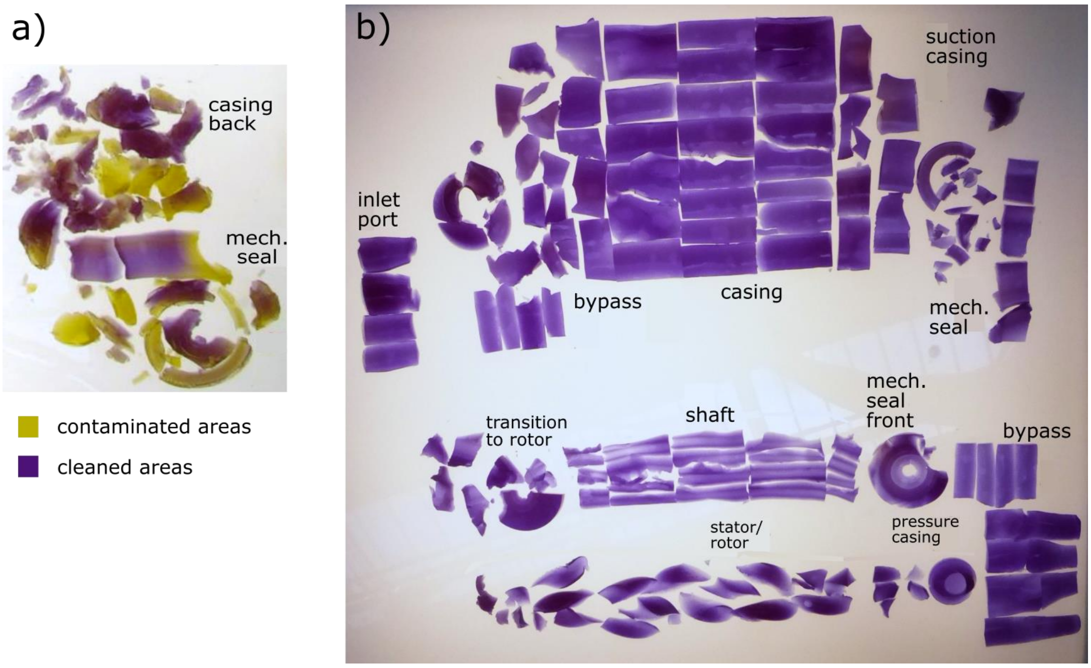

Fig.3: EHEDG cleaning test results: a) Exemplary results of a conventional pump geometry with contaminated areas (case A, only zones 1, 2 and 3); b) SEEPEX optimized swirl flow geometry (case B, whole pump)

Discussion on Applicability in Food Processing: The achieved CFD findings were confirmed on a prototype pump in official EHEDG certification tests. In three individual EHEDG tests no remaining residue were observed. Fig. 3a) and b) show the resulting culture medium that was filled inside the pump after culture fluid contamination and subsequent cleaning. The test outcome represent best possible EHEDG cleaning results, since there was no contaminated area observable within any area of the optimized pump.

Conclusions: The purposeful induction of swirl flow by an asymmetrical cross-section reduction significantly increases the wall sheer forces and reduces dead space areas effectively. Due to the enhanced cleaning capabilities of this inlet port geometry, the overall cleaning results were maximized. This, in turn, increases the cleaning efficiency within the hygienic process in terms of CIP-time, temperature and concentration of cleaning fluid. Moreover, it enables the application of less sharp cleaning fluids, which increases the lifetime of pump components and take effect on environmental acceptability and suitability for food products. In consequence, the maximization of cleanability enables the new pump design for highest hygienic requirements.

Keywords: Progressive Cavity Pump, EHEDG cleaning test, CFD-Simulation, improved cleaning capabilities.