Influence of wall shear stress variations on microbial removal along different pipe arrangements during cleaning in place

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The contamination of surfaces by spoilage and pathogenic micro-organisms is of great importance in the food industry. Micro-organisms have a strong tendency to adhere to material surfaces, leading to frequent interruptions for cleaning. In the dairy industry, production lines are usually cleaned using cleaning-in-place systems. In many cases, some bacteria may remain on equipment surfaces after standard cleaning procedures, inducing a risk of products contamination through the equipment. Thus, the design of the equipment, particularly its geometry, is a determining element governing the flow behaviour and thus the hydrodynamic forces at the installation walls that will ensure the removal of the potential contamination.

A series of experiments was carried out on various geometries (straight pipes, sudden or gradual contraction or expansion pipes) in order to study the distribution of the local wall shear stress (mean and fluctuating values) on the circumference along various geometries of the production lines, in order to explain the causes of the observed flow asymmetry. Correlations between wall shear stress and cleanability were carried out, emphasising the link between hydrodynamics and cleanability of the tested loop, especially due to the asymmetry in the flow patterns induced by the association of the various interacting piping elements generating a never fully-developed flow along the device. The two tested configurations and presented in figure 1.

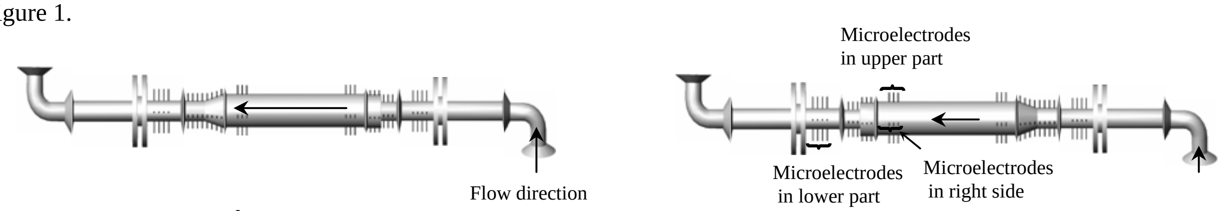

Figure 1 : The two tested configurations.

A set of microprobes, consisting in a 0.4 mm in diameter platinum wire, was mounted flush the different tested elements for various axial and circumferential locations (figure 1). Electrochemical techniques have been proved to be well suited for the study of wall turbulence and for this reason, have been applied in this work to assess the role of the local wall shear stress on the bacterial removal. This method allows to calculate the local mass transfer coefficient and by an analogy between the mass transfer and the momentum transfer, wall shear rates and the corresponding wall shear stress values are obtained.

Cleanability experiments consist in contamination of the different equipment in tested loops with *Bacillus cereus* spores, isolated from a dairy production line and demonstrated to be a relevant test organism in defining the potential risk of contamination in dairy processing lines. The tested items were soiled in dynamic conditions by the circulation of the contaminated water during 1 h at a flow rate of 300 l h^{-1}. After this soiling step, the rig was drained and rinsed for 5 min at 300 l h^{-1} with softened water. Cleaning was then performed with sodium hydroxide (0.5 % w/w) at 60°C for 10 min at 2200 l h^{-1}, the ring was then rinsed for 5 min with cold tap-water at 600 l h^{-1}.

The adhering bacteria remaining after the CIP procedure were counted by moulding of the tested geometries according to the agar overlay technique. This technique uses the agar supplemented by tetrazolium chloride (TTC). After incubation, *Bacillus* colonies appearing in red, were distinguishable at the mould surface and thus were easily countable. Statistical analysis was done using S-Plus software (Seattle, USA) and groups of areas of different hygienic levels were formed. A colour code is attributed to each type of zones as a function of its level of cleanability. Thus, the level of cleanability was determined in each geometry.

The variation of wall shear stress values (mean values and fluctuation rates of current) were compared with the cleanability of the equipment. A wide variability was observed on the residual amount of adhering spores between the different trials. The comparison between configurations 1 and 2 shows a difference in the cleanability level on all tested loops. This result shows an irregular motion of the flow inside the pipes. This irregularity is due to the instability of geometry throughout the line production that gives a not uniform wall shear stress profiles along the pipes. For the two configurations, the local wall shear stresses were found smaller in the lower part than at the right and upper ones. This observation could be explained by the form flow at the outlet the bend localised at the beginning of configurations 1 and 2. Measurements of the wall shear stress and of its fluctuation rate with straight pipes placed upstream and downstream of the tested geometries, showed that the flow asymmetry is caused by the bend placed at the beginning of the configuration 1 and 2. The flow asymmetry is also obtained behind sudden or gradual contraction or expansion pipes. This result was predicted by CFD simulations.