



Application of turbulent pulsating flows to the bacterial removal during a cleaning in place procedure. Part 2: Effects on cleaning efficiency

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ABSTRACT

Pulsating turbulent flows effects on cleaning in place procedure of straight pipes were investigated for various pulsations parameters (frequency and amplitude) and mean velocities of the flow. Pulsations generation was made with a new system which allows high amplitude of pulsations. Experiments showed the contribution of the different pulsation parameters, in the removal of adhered bacterial spores, in addition to the effect of the mean velocity of the flow. A high level of the cleaning rate is observed despite the reduction of the magnitude of the mean velocity. This result can be explained by the effect of the two pulsations parameters (amplitude and frequency) which ensure a high wall shear rate. The study of the cleaning kinetics has shown the increase of the removal constant rate of spores using pulsed flow in comparison with the use of a steady turbulent flow.

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1. Introduction

To ensure food safety of products, efficient cleaning procedures are needed. However, the costs of these procedures are important (productivity losses, energy cost, cleaning chemicals and their environmental impact (Sandu and Singh, 1991)). It is therefore pertinent to optimise the cleaning cycles in order to obtain both environmental and economic improvements. On the other hand, it was shown that the key parameter in cleaning enhancement is the wall shear stress components imposed by the flow at the equipment surface (Blel et al., 2007; Grasshoff, 1992; Lelièvre et al., 2002a). The contribution of the fluctuating component of the shear rate in addition to the mean value on bacterial removal is put forward in the literature (Blel et al., 2007; Lelièvre et al., 2002a).

High values of wall shear stress can be achieved using larger flow velocities and are used in some commercial cleaning in place (CIP) systems to reduce cleaning time (Celnik et al., 2006). However, wall shear stress components can be increased using transient flow. Indeed, Pérez-Herranz et al. (1999) showed that pulsating flows allow to enhance mass transfer due to the increase of the local velocity gradient at the wall.

Different works have been carried out on the use of pulsating flow during cleaning. The term pulsating covers a wide range of applications which differ according to the pulsations frequency.

Ultrasonic cleaning, especially with high frequency and low amplitude waves, is a recent cleaning technique. It was tested by Mott et al. (1997) for biofilm removal and by Grasshoff (1997) for the cleaning of cheese moulds, but its application to dairy equipment is limited by the penetration depth of ultrasound waves, especially for heat exchangers (Grasshoff, 1997). Niemczewski (2007) showed that water cavitation phenomenon, induced by the ultrasonic cleaning, allows a high cleaning rate of organic deposition. The application of compressible waves, in cleaning process, was also studied by Brizzolara et al. (1999) using acoustic pulsating waves for controlling and preventing biological fouling at equipment surfaces. Experimental works of Hankinson and Carver (1986) on the removal of dried milk deposits using a pulsation system inducing a water hammer phenomenon showed no effect on the deposit removal. They deduced that the generated shear forces were lower than the adhesion ones of the deposit.

Dynamics and applications of pulsed flow in cylindrical pipes were studied by Edwards and Wilkinson (1971). The pulsed flow was generated by imposing a harmonic pressure gradient to a steady flow, thus increasing local shear rate and pressure at the interface deposit/liquid (Gillham et al., 2000). Ziskind et al. (2000) studied the effect of mean and fluctuating shear stress components on the particles removal from the wall. They have shown the interest of oscillating flows in particles removal when the mean shear stress is not high enough. Flow oscillations can induce the weakening and the breaking of the bonds between particles and the adhesion support. Studies of protein deposits cleanability

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Nomenclature

D	pipe diameter (m)	X_{factor}	dimensionless form of the tested factor level
k	effective removal rate constant (min^{-1})	X_0	mean of extreme factor levels (factor unit)
k'	effective deposition rate constant (min^{-1})	X_1	factor level (factor unit)
$N(t)$	instantaneous number of adhered spores (CFU/cm^2)	X_2	half-interval of the experimental domain of the factor (factor unit)
N_R	residual number of adhered spores (CFU/cm^2)	v, v_{max}	average and maximum velocities (m/s)
N_0	initial number of adhered spores (CFU/cm^2)	v_p	amplitude of the pulsations (m/s)
Re_{max}	maximum Reynolds number: Dv_{max}/ν (dimensionless)	ν	kinematic viscosity (m^2/s)
Re	average Reynolds number: Dv/ν (dimensionless)		
Re_p	pulsating Reynolds number: Dv_p/ν (dimensionless)		

under pulsating flow were carried out by Farries and Patel (1993). These authors showed that the low frequencies (0.1–2 Hz) and the large amplitude pulsations increase the removal rate of the protein deposits. Gillham et al. (2000) works were conducted on the detachment of protein deposits by laminar pulsating flow at low frequencies (≤ 2 Hz) and high amplitude of pulsations. They showed an enhancement of cleaning rates under this flow conditions. In addition, these authors found that the cleaning rate peaks coincide with the thermal conductivity decrease of the deposited layer. This result proves that pulsations can induce the breaking of the deposition matrix.

However, pulsating flows are often difficult to use due to the complexity of the pulsation generation systems and also by the high number of variables governing this type of flow (Gillham et al., 2000). It can also be related to the drawback of possible equipment damaging that could induce some pulsation generators due to eventual water hammer. Pulsating flows can be produced by reciprocating pumps or by steady flow pumps together with pulsing generator like bellows or piston apparatus (Gillham et al., 2000). The advantage of these pulsation systems in cleaning processes, in comparison with the application of compressible waves (as acoustic pulsation or ultrasonic system), consists in the facility to fit them in a CIP system.

Given that the application of harmonic pulsations in turbulent flow plays a relevant role in mass and heat transfers enhancement (Pérez-Herranz et al., 1999), the present study investigates the effect of this flow arrangement on the detachment of adhered *Bacillus cereus* spores from a series of stainless steel pipes under pulsating flow conditions produced by the system described in

the first part of this paper (Experimental analysis of wall shear stress in a cylindrical pipe). Different pulsation conditions were compared to the steady flow at high Reynolds number and influences of both amplitude and frequency of pulsations, in addition to the mean fluid velocity, on the amount of spore removal are discussed. Finally, removal kinetics of spores are carried out, under steady and pulsating flow conditions, in order to determine the influence of pulsations in the control of cleaning duration.

2. Materials and methods

2.1. Pulsations generator system

The generation of pulsations was carried out with a new system which allows producing high amplitudes of pulsations for a turbulent flow rate at high Reynolds numbers and ensuring a perfect stability of the whole installation. Details on the pulsations generator system are given in the first part of this paper (Blé et al., submitted for publication).

The pulsations generator consists of two-way flow (Fig. 1). The first way, containing a solenoid valve (ASCO/JOUOMATIC authorized for food applications) allows the generation of a jet fluid flow at high velocity. The second way induces a steady flow component which allows a net flow different from zero at the exit of the pulsation unit when the solenoid valve is closed. In comparison with the interrupter flow method described in the literature (Lemlich, 1961) which can induce water hammer phenomenon, the second way, used in this system, allows the attenuation of the interruption flow effects generated by the solenoid valve on the equipment. A

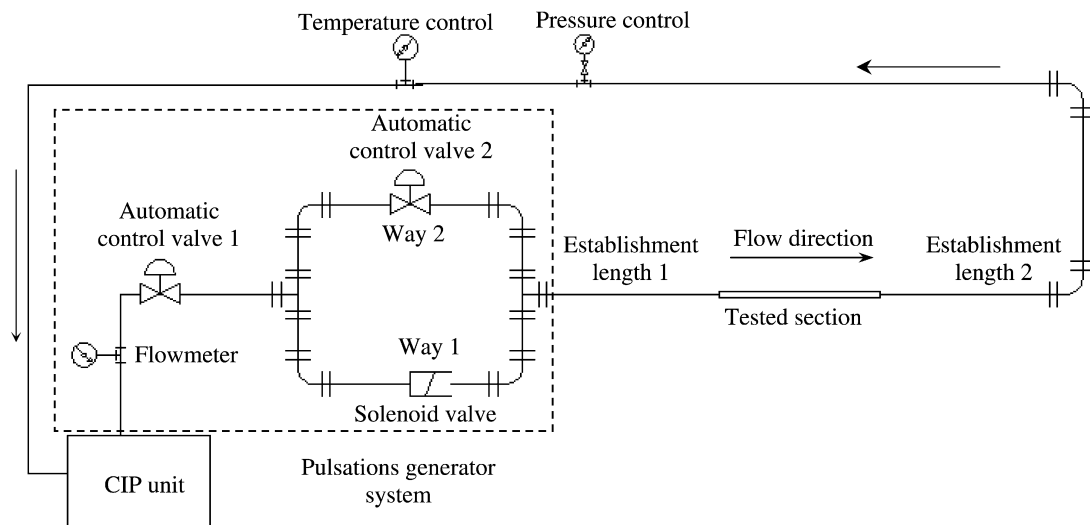


Fig. 1. Schematic diagram of the pulsation generation system and the tested section.

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