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Cleaning of filter media by pulsed flow – Establishment of dimensionless operation numbers describing the cleaning result

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ABSTRACT

The demand for cleaning-in-place (CIP) equipment in the pharmaceutical and food industries is steadily increasing. In filtration processes, the filter medium is the worst to clean. Thus, in this paper, a cleaning method for filter media is presented and the cleaning experiments are evaluated referring to their cleaning grades. Cleaning is by a pulsed flow generated by a fast switching solenoid valve, which is connected to a nozzle in front of the filter medium. In the study, parameters like frequency, velocity of the pulse, pulse duration and distance between nozzle and filter medium are varied and it will be discussed which operating conditions achieve the best cleaning results. The aim of the cleaning method is to increase the cleaning grades of the filter media, to reduce the consumption of the cleaning solution and, hence, to minimize the process costs. In this paper, also a dimensionless operation number is developed, by means of which the cleaning behavior of different filter media can be predicted. The investigations showed that the cleaning grade increases with decreasing intervals between two pulses and that the pulse duration has no significant influence on the cleaning grade. In summary it can be stated, that cleaning by pulsed flow is a promising cleaning method for filter media.

1. Introduction

Safe and efficient cleaning of processing equipment is an important demand in the pharmaceutical, biotechnology and food industries. Such cleaning ensures high product quality by avoiding cross- contamination but leads to down times of the production line and, hence, to higher costs. To reduce these costs, it is necessary to realize a faster and more efficient cleaning. This can be achieved by plant construction on the basis of hygienic design criteria. Different methods like the EHEDG – cleaning test and the Qualified Hygienic Design Test (EHEDG 1993a,b,c, 2000; VDMA 2000) are available to test the cleanability of tank and pipe components.

A series of publications have been dealing so far with the cleaning of surfaces. The investigations have been mainly carried out for applications in the dairy industry (Beck et al., 2005; Gillham et al., 1999; Graßhoff and Reuter, 1983; Hofmann, 2007; Welchner, 1993). Here the surfaces were mostly plate heat exchangers used for uperisation of milk. The milk residuals on the plate exchanger form a fouling layer which is difficult to clean and diminishes the efficiency of heating. Mainly in the above mentioned publications, a continuous flow for cleaning and WPC (whey protein concentrate) based gel as model contamination were used. With these investigations, the kinetics of the cleaning process could be physically described but the cleaning results were not satisfactory. Therefore, in the recent years, cleaning by pulsed flow became more and more established. A pulsed flow is imposed on a stationary flow with frequencies of 1 Hz. Thus, the shear stresses applying to the particles increase and the cleaning result improves. Edwards and Wilkinson (1971) reviewed the applications of the pulsed flow. Ziskind et al. (2000) considered the particle oscillatory motion on surfaces caused by mechanical vibrations of the surfaces. They showed that the oscillation depends on the frequency and direction of the external force. An oscillating force can induce weakening and breaking of the bonds between particle and surface. Gillham et al. (2000) examined the influence of a laminar pulsed flow with low frequencies and high velocity amplitudes during pipe cleaning using, as in recent studies, WPC gel as contamination. In addition, the investigations showed that the laminar pulsed flow can improve the cleaning result for the cleaning of surfaces. In contrast, Blel et al. (2009a, 2009b) investigated the effect of pulsating turbulent flows on wall shear stress components in cylindrical pipes. They showed that the pulse flow causes an increase in the velocity gradient at the wall of the pipe, which is responsible for the better cleaning experiment. The pulse generating systems used in the above mentioned publications were reciprocating pumps or

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steady flow pumps in combination with bellow or piston apparatus (Bode et al., 2007; Gillham et al., 2000). Solenoid valves are also often used as pulsation generators (Blel et al., 2009a; Redkar and Davis, 1995; Kuberkar et al., 1998).

Further application of pulsed flows can be found in the field of micro-, ultra- and nanofiltration in cross flow processes (Argüello et al., 2003; D'Souza and Mawson, 2005; Daufin et al., 1991; Field et al., 2008; Gan et al., 1999; Hong et al., 2005; Kazemimoghadam and Mohammadi, 2007; Kuzmenko et al., 2005; Li and Elimelech, 2004; Liang et al., 2008; Liikanen et al., 2002; Lim and Bai, 2003; Madaeni and Ghaemi, 2007; Madaeni and Mansourpanah, 2004; Mugnier et al., 2000; Muñoz-Aguado et al., 1996; Sayed Razavi et al., 1996; Toraj, 2001; Weis et al., 2003; Xu et al., 1995). In these publications the focus is on the removal of the fouling layer, which is formed on the membrane during the filtration and which reduces the permeate flux. Thereby only the flux respectively its regeneration is considered. In these investigations also different pulse generating methods are used: For example pneumatically respectively magnetically operated piston systems, fast switching solenoid valves or rotation valves (Jones et al., 1999; Kuberkar et al., 1998; Ma et al., 2000).

First studies on cleaning of filter media were carried out by Stahl et al. (2007). They developed a microbiological test method to determine the cleanability of filter media. The test method was based on the EHEDG cleaning test method for pipes. In the next publication (Stahl et al., 2013), the authors considered the cleaning behavior of particle loaded filter media with the help of a continuous flow. Here, parameters like the mesh size and fiber diameter of metal woven filter media are examined. Also, a new model of particle adhesion forces and wall shear stress distribution was created using a CFD software simulation. The investigations showed that the purely hydrodynamic cleaning has limitations due to the adhesion forces of the particles.

The intent of this work is to show that the pulsed flow cleaning of filter media is a promising method by means of which a higher cleaning efficiency of filter media can be achieved. For an evaluation of the cleaning process and determination of the cleaning grade it is important to consider the filter media directly. In the presented work the same monodisperse fluorescent particles as in the publication of Stahl et al. (2013) are used as model contamination and the particles, which are retained on the filter media, can be counted using a microscope. Therefore, the focus is on the cleaning grades of the filter media and not on the permeate flux as in the works below. The pulses are generated using a solenoid valve which is connected to a nozzle installed in front of the filter medium. With the help of the device it should be observed to what extent a pulsed flow through a nozzle or a nozzle assembly, which can be fixed in an industrial centrifuge above the filter drum in front of the filter medium, leads to a better cleanability of the filter medium compared to a constant flow through the nozzle.

In the study parameters like the frequency, the velocity of the pulse, the pulse duration, the pause between two pulses and the distance between nozzle and filter medium are varied. With the help of the findings and results of this work it will be possible to know which factors influence the cleaning process and which optimisations can be carried out.

2. Materials and methods

2.1. Filter media and particles

For the investigations three different filter media are compared. In Table 2-1 the examined filter media and their characteristics are shown. The filter media differ in material, porosity, and filter thickness. The three filter media have a plain reverse dutch weave (PRD) and they are super calendered. At the calendering process the filter media are pressed through two rolls at a definite temperature and a definite pressure. By this treatment, the filter surface becomes smoother than non-calendered surfaces. The smoother surfaces lead to a better cake discharge during the filtering process. For the examinations, the filter media were cut to a circular area with a diameter of 30 mm. To ensure an optimal sealing during the process, a rubber coating was deposited on the edge of the filter medium (width of 5 mm). The circular area through which the cleaning fluid flows hence has an diameter of 25 mm.

The particles, with which the filter medium is contaminated, are monodisperse, fluorescent particles with a particle sizes of 10, respectively 5 µm (microparticles® GmbH, Berlin). Most of the experiments were done with the 10 µm particles. Only for the comparison between the continuous and the pulsed flow, examinations with 5 µm particles were carried out. The particles are made of melamine-formaldehyde resins and the fluorochrome is put in the interior of the particle during the manufacturing process. The used fluorescence marker is 7-amino-4-methylcoumarin (AMC). The fluorescence allows the particle counting of remaining particles on the filter medium with a fluorescent microscope.

2.2. Contamination

Cleaning experiments must be preceded by contaminating the filter medium. Contamination is carried out in a contamination unit which is similar to a pressure strainer. A highly diluted suspension of particles is forced through the filter medium in such a way that only single particles remain on the filter medium. To evaluate the cleaning process and thus to determine a cleaning grade of the experiment, the particle number before and after a cleaning experiment must be identified. With the help of a fluorescent microscope pictures of the filter medium were taken, and after converting the pictures into binary images, the particles can be counted with the open source software ImageJ. Before and after each cleaning process, pictures at the same positions are taken and particles are counted applying the same method. Hence, it is possible to calculate the cleaning grade G of the particles on the filter medium after the cleaning process (see Eq. 2-1). The cleaning grade consists of the difference between 1 and the retention R of particles. The retention R was already used in former publications (Stahl et al., 2013; Weigl, 2003).

$$G = 1 - \mathrm{R} = 1 - \frac{N_{\text{after}}}{N_{\text{before}}} \tag{2-1}$$

N_{after} is the number of particles located on the filter medium after the cleaning process and N_{before} the number of particles before the cleaning process. Unfortunately, it is not possible to count all particles throughout the filter area, as for a satisfactory depth of field over the whole area more than 300 images would be necessary. Thus, two pictures in the center of the filter medium were used for the determination of the cleaning grade. Only for the examinations concerning the homogeneity of the cleaning process, pictures along the radius of the filter area were taken (see Section 3.3).

2.3. Pulsation flow device

At the Institute of Mechanical Process Engineering at the KIT (Karlsruhe Institute of Technology), a pulsation flow device was developed. It consists of two pressure vessels (vessel 1 and vessel 2 in Fig. 2-1 left), a fast switching solenoid valve generating flow pulses of 1 Hz, a nozzle, which is connected to the solenoid valve, a relapse valve and a filter holder. Vessel 1 has a volumetric capacity of 99 l and vessel 2 of 20 l. The distance between nozzle and filter medium is set to 17 mm for the experiments in Section 3.1-3.3. In Section 3.4 the distance is varied between 9 and 17 mm. The