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A new online-method for the characterization of detached particles while cleaning starch fouling layers

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ABSTRACT

This work presents a new method for an online measurement of particles detached from a starch fouling layer during a cleaning process. This was achieved by designing the Automated Particle Analyser for Cleaning (APAC) by combining a flow channel with a laser diffraction particle size analyser. A method for the online measurement of particle size for different sets of parameters (flow velocity, temperature and addition of Sodium Hydroxide) was developed, monitoring cleaning progress and behaviour. The influence of the variation of the parameters on the progress of cleaning as well as their balance could be shown. Low temperature or velocity cause increasing cleaning time and vice versa. Overall detachment of small particles indicating cohesive failure could be observed as characteristic for starch based fouling layers. A narrow particle size distribution (PSD) of small particles indicates a cohesive failure and a steady disintegration of the fouling layer from top to bottom. On the contrary a PSD of larger size and broader shape prevails for adhesive failure and detachment of large patches of the fouling layer.

1. Introduction

Cleaning of piping and equipment in food processing presents itself as challenging (Fryer & Asteriadou, 2009; Liu, Fryer, Zhang, Zhao, & Liu, 2006; Wilson, 2005). Due to high requirements in quality and subsequently hygiene a complete cleaning of residuals, germs and therefore fouling, is essential. Even traces of contaminants can lead to impairments in product quality and ultimately hazardous effects on health. In order to achieve failure-free operation of the plant extensive knowledge on cleaning behaviour of various kinds fouling has to be in focus. Moreover environmental effects of the cleaning process gain importance as well as the costs maintenance, fuel, etc. (Fryer, Christian, & Liu, 2006; Pritchard, 1988). Gordon (Gordon, Brooker, Chew, Wilson, & York, 2010) as well as Liu (Liu et al., 2006a) identify swelling as crucial for the cleaning process. Swelling occurs by diffusion of water or cleaning agent into the fouling matrices as the cleaning media gets in contact with the fouling layer. As a direct result of the swelling both adhesive and cohesive forces are reduced and the fouling is more susceptible to shear stress. For detachment of either patches or particles of the fouling layer both adhesive and cohesive forces have to be overcome. The strength of the respective forces depends on several characteristics such as the fouling form or age. To characterize the cleaning behaviour commonly temperature and pressure at the inlet and outlet are measured complemented by optical inspection. Local fouling and cleaning behaviour may be assessed through the thermal fouling resistance R_f by a series of temperature measurements distributed throughout the measurement section (Schoenitz, Warmeling, Augustin, & Scholl, 2014; Schöler et al., 2012). Furthermore imaging methods are applied for instance measurement of the fluorescence intensity of the fouling layer throughout the cleaning process (Joppa, Köhler, Rüdiger, Majschak, & Fröhlich, 2016; Köhler, Weyrauch, Boye, Mauermann, & Majschak, 2016). In addition the discharging cleaning media can be analysed for instance by performing a total protein assay (Bode et al., 2007), measurement of total organic carbon or bound nitrogen content in a TOC/TN_b analyser (Boxler, Augustin, & Scholl, 2014) or UV spectrometry (Otto, Zahn, Hauschild, Babick, & Rohm, 2016). Whether the cleaning progress is achieved by dissolution or detachment due to adhesive or cohesive failure of the fouling layer is uncertain especially without optical evaluation. In this regard, the particle size distribution of detached fouling particles while cleaning has not been investigated so far. While varying parameters for effective cleaning processes such as velocity, temperature or chemical agents as stated by Sinner (Wildbrett, 2006) the corresponding particle size distributions of detached fouling

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particles can offer an insight in the predominant cleaning mechanisms such as cohesive or adhesive failure and dissolution of the fouling deposit as well as its time-dependent progress.

2. Materials and methods

2.1. Materials

There are various kinds of model soils used in research on food fouling and cleaning such as gelatine (Gordon et al., 2012), egg yolk (Helbig, Föste, Augustin, Scholl, & Majschak, 2015), starch (Föste, Schöler, Majschak, Augustin, & Scholl, 2013; Jurado Alameda, Altmajer Vaz, García Román, & Siqueira Curto Valle, 2015; Linderer & Wildbrett, 1993; Mauermann et al., 2012; Schöler et al., 2012) and whey protein (Liu et al., 2006b; Mauermann et al., 2012) which all resemble fouling occurring in industrial production processes (Fryer & Asteriadou, 2009; Toure, Mabon, & Sindic, 2013). First, trials in order to implement and validate a method for the investigation as well as characterization of detached particles were carried out using waxy maize starch (C-Tex Instant 12616, Cargill) as a model fouling layers based on investigations performed by Schöler (Schöler, 2011). Starch exhibits high swelling characteristics in aqueous media as well as cohesive failure (Schöler et al., 2012) and requires harsh conditions for cleaning. Due to its cohesive nature the starch fouling can also be referred to as a Type 3 fouling for which a hot chemical cleaning fluid is recommended (Fryer & Asteriadou, 2009). Whereas starch is a broadly based area with regard to origin (maize, potato, wheat, etc.), processing as well as modification, thus properties vary widely (BeMiller & Whistler, 2009). The fouling layers were prepared by spreading an aqueous solution of starch (15 g/L) of 1 mm thickness on stainless steel plates (20 mm × 80 mm, 1.4301/304). The starch solution itself is prepared by slowly adding the starch powder to deionized (DI) water at 35 °C and constant stirring for 30 min. The spreading is followed by drying in a climate chamber (KBF 115, BINDER GmbH, Germany) at 23 °C and constant humidity of 50% for 24 h (Lang, Linderer, Wildbrett, & Stifter, 1991; Schöler, 2011). Afterwards the fouling layers had suffered extensive loss of volume due to the drying. Deionized (DI) water was used in the cleaning experiments in order to investigate the effects of velocity and temperature. A solution of 0.25% Sodium Hydroxide was used to determine the effects of chemical agents on cleaning behaviour.

2.2. Experimental setup

Fig. 1 shows the flow chart of the test rig. The APAC (Automated Particle Analyser for Cleaning) consists of a frequency-controlled gear pump P1 (H7R, Verder Deutschland GmbH & Co. KG, Germany), a valve V4 for flow reduction of the pump, three magnetic valves, three calibrated thermocouples of type K, a magnetic inductive flow sensor (IFS 5000 F/SC 100 AS, KROHNE Messtechnik GmbH, Germany) as well as a flow channel for the installation of fouling samples. For characterization of the detached particles, online analyzation is performed by a laser diffraction particle size analyser HELOS with an integrated dispersing unit QUIXEL (Sympatec GmbH, Germany). For detection and characterization of particle size distributions (0.18 µm–3500 µm) a minimum optical density of the detached particles is required which limits the capabilities of the analyser. The minimum optical concentration is determined by various factors including material, transparency, the lens set, particle shape and size, etc. The particle size determination was performed by applying the Fraunhofer diffraction theory, which is applicable as an estimation for relatively large and non-transparent particles (>50 µm) without knowledge of the refractive index of the particles. However, the results show particles of sizes below 10 µm. Therefore, particle size approximation by applying the Mie theory is recommended, which was not available at the time (de Boer, de Weerd, Thoenes, & Goossens, 1987). The particle sizes presented are a mere approximation but sufficient to give a first glance on feasibility of the presented method.

The test rig and analyser are completely controlled and automated by a PC via LabVIEW. For transmission of voltage and current signals, all sensors are connected to a data acquisition unit (Agilent 34970A, Keysight Technologies, USA). The rig is capable of operating in two modes, recirculating or once-through cleaning operation. The latter benefits from no subsequent shear stress related to the circular flow of the media within the system. Nonetheless, all tests were performed by maintaining a circular flow. This results in an accumulation of detached particles in the cleaning fluid thus increasing optical density for better analysis. With regard to sampling, it is possible to perform automated sampling and if desired feedback of the samples. The sampling rate as well as sample size are user configurable. However, both depend on the set volumetric flow rate since the sampling is performed by redirection of the flow (see Fig. 1, V1).

A prepared fouling plate is clamped into the flow channel (see Fig. 2), which itself is easily assembled and disassembled by screws. The clamps also direct the flow of the media in the inlet and outlet area to minimize turbulences.

All initial experiments were conducted maintaining a fixed set

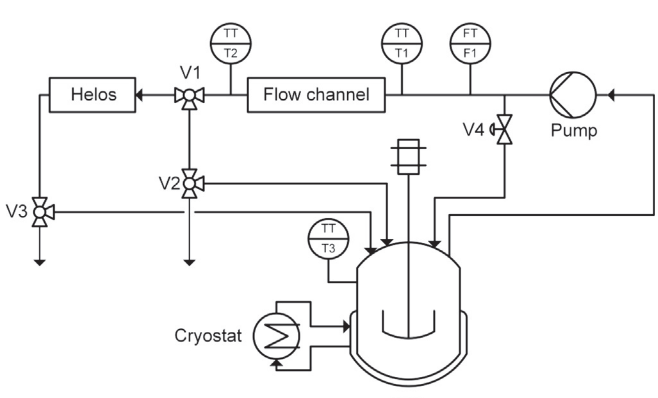

Fig. 1. Flow chart of the APAC test rig.

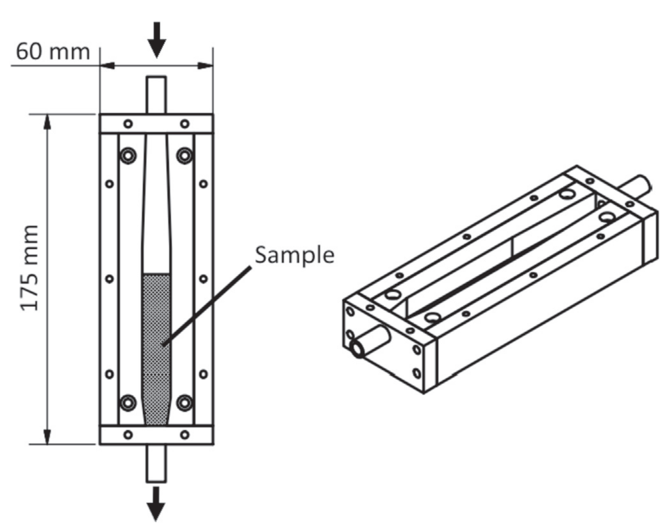

Fig. 2. Stainless steel flow channel with Perspex inspection window.