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Cleaning of dried starch adhered to stainless steel using electrocleaning. Optimization of the experimental conditions

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ABSTRACT

An electrocleaning device was used to study the cleaning of dried starch adhered to stainless steel. Different cleaning parameters such as voltage, temperature, cleaning time, pH of the washing solution, polarity and previous wetting time were studied in relation to cleaning efficiency. Optimal cleaning conditions, according to energy savings and cleaning efficiency criteria, were determined: 20 °C, NaOH aqueous solution (pH 13), soiled substrate connected to the cathode, direct current voltage of only 5 V and 20 min without a previous wetting time. Under these conditions, the detergency found for cleaning difficult-to-remove dry starch was 65.7 ± 3.4%. The detergency found by electrocleaning was 52% higher than without current. High detergency results were achieved in the electrocleaning device using lower temperature and less time than those normally used in the food industry.

1. Introduction

The process of cleaning different soils in the food industry (protein, fat, carbohydrates, minerals or biofilms) is considered a critical operation. The formation of deposits on process surfaces, such as tanks, pipes, and heat exchangers can degrade performance in heat-transfer operations, increasing pressure drops and product contamination (Fryer & Asteriadou, 2009). The latter factor may lead to the appearance of biofilms (Barish & Goddard, 2013), a chronic source of microbial contamination which may compromise food quality and represent a significant health hazard (Bernardes et al., 2012), as well as cross-contamination in equipment used for processing different products (Thammathongchat, Hagiwara, & Sakiyama, 2010). Generally the cleaning procedures are standardized. However, cleaning protocols must be optimized for each application depending on the soil types that needs to be removed and the surface or material to be cleaned (Suárez, Díez, García, & Riera, 2012). Specific cleaning protocols seek to reduce energy consumption as well as improve surface protection and biodegradability of the waste water of the cleaning processes. This implies the study of the operational conditions (e.g. temperature, pH) and cleaning methods.

In the food industry, starch is currently attracting increased attention owing to its usefulness in different products because it contributes greatly to the textural properties of many foods such as soups, sauces, ice cream, beer, etc. (Singh, Singh, Kaur, Singh, & Singh, 2003; Singh, Kaur, & McCarthy, 2007). The thermal, rheological, and physicochemical properties of the starch gel produced in the manufacturing process change depending on the starch origin, grain morphology, and amylose and amylopectin concentration. When the starch molecules are heated in an excess of water, their crystalline structure breaks down and water molecules bind with the hydroxyl groups of amylose and amylopectin by hydrogen bonds, causing greater solubility and swelling (Soto & Oliva, 2012). When the gel is dried the internal structure collapses and water evaporates in a reversible process. This product adheres strongly to equipment surfaces, hindering the cleaning process. The strength of the adhesion depends on the interaction between the starch and the surface material (Liu, Christian, Zhang, & Fryer, 2002, Liu, Fryer, Zhang, Zhao, & Liu, 2006).

Cleaning and disinfecting in the food industry usually entails CIP (Cleaning In Place) systems. CIP is an automatic cleaning method, applied to remove residues from complete items of industrial equipment and pipeline circuit by circulating chemical solutions and rinsing water through food-production equipment that remains assembled in its production system (Moerman, Rizoulières, & Majoor, 2014). Different works that simulate the cleaning in a CIP system have been made to analyze the detersive efficiency of various cleaning solutions using different surfaces and soils (protein, fat, and carbohydrates) (Jurado-Alameda, Bravo Rodríguez,

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Altmajer Vaz, and de Cassia Siqueira Curto Valle (2011); Jurado-Alameda, Altmajer-Vaz, García-Román, and Jiménez-Pérez (2014); Jurado-Alameda, Herrera-Márquez, Martínez-Gallegos, and Vicaria (2015a)).

In addition to CIP systems, new cleaning and disinfection methods have been developed in the food industry based on water or salt-solution electrolysis. Electrolyzed water (EW) is produced by passing a diluted salt solution through an electrolytic cell, within which the anode and the cathode are separated by a membrane (Huang, Hung, Hsu, Huang, & Hwang, 2008). Two types of water are produced simultaneously: electrolyzed oxidizing (EO) water with a low pH (2.3–2.7) is produced from the anode side, while electrolyzed reduced (ER) water with a high pH (10.0–11.5) is produced from the cathode side. A disadvantage of the use of electrolyzed water is the generation of halogenated compounds which can affect water toxicity and corrode metal surfaces. Furthermore, cleaning procedures for metal surfaces using direct current (electrocleaning) have been used in fields other than food industry (metallurgy, …). To this end the surface to be cleaned is connected to the negative pole of a DC source and immersed in an alkaline solution ($pH > 11$) which is in contact with an electrode connected to the positive pole (Chen, 2006; Naganuma, Nakasuzi, Ono, & Seo, 1973).

In the present work an experimental device for electrocleaning of stainless steel surfaces is described and used to remove dried starch adhered to stainless steel. The influence of different factors on the cleaning efficiency was assessed. The results led to the definition of optimal conditions for the cleaning process in this experimental device, according to energy savings and cleaning efficiency criteria.

2. Materials and methods

2.1. Soiling agent and substrate

The solid substrate was a set of spherical wads of stainless-steel fibers (AISI 410). The wads measured roughly 2 cm in diameter and weighed between 0.80 and 0.85 g. Commercial cornstarch called Maizena® was used as the soiling agent. An aqueous solution of gelatinized cornstarch (8% w/w) was prepared by heating the solution at 70 °C for an hour with constant stirring (Souza & Andrade, 2002). The gel thus prepared was allowed to cool at room temperature and left to stand for at least 12 h before being used. The spherical stainless steel wads were soiled with starch gel in the following way (Fig. 1): 1) the wad surface was uniformly impregnated with the soil by submersion in the starch gel; 2) the soiled wads were placed on a grate and dried for 12 h in an oven at 60 °C; 3) the dried wads were removed and weighed. The quantity of starch retained was determined by weight difference between clean and soiled wads. This quantity should be as constant as possible. A group of five wads, each one of them containing 0.25 ± 0.03 g of dry starch, which means 1.25 ± 0.15 g of total adhered soil, was used in each single washing test. Table 1 summarizes the composition of the dried starch, obtained by drying at 110 °C to a constant weight. The Kjeldahl method (AOAC Method 960.52) was used for protein determination, using a conversion factor of 6.25. Fats were determined by Soxhlet method after acid hydrolysis (AOAC Method 922.06). The carbohydrate content was calculated by the arithmetic difference from the rest of the components (Weende Method). Determination of moisture was made by drying in oven (AOAC Method 925.10). Ashes were determined by incineration in a muffle furnace (AOAC Method 923.03). A Inductively Coupled Plasma Spectrometer (ICP-OES) was used for salt determination from the ash. For the analysis of Ca, Mg, K, and Na, 15 g of soil were placed in ceramic crucibles and calcined in a furnace at 550 °C for 1 h. The ash was weighed (0.1 g), placed in solution of 6 mL HNO_3/HF (1/1) and heated in an oven at 160 °C to dryness. Then 4 mL of HNO_3 were added, kept 1 h at 80 °C, and once cooled the mixture was diluted to 100 mL. The minerals were analyzed using a Perkin Elmer Optima 8300 ICP-OES Spectrometer. The specific wavelengths for each element were Na-589.695 nm, Ca-317.943 nm, K-766.490 nm and Mg-285.228 nm.

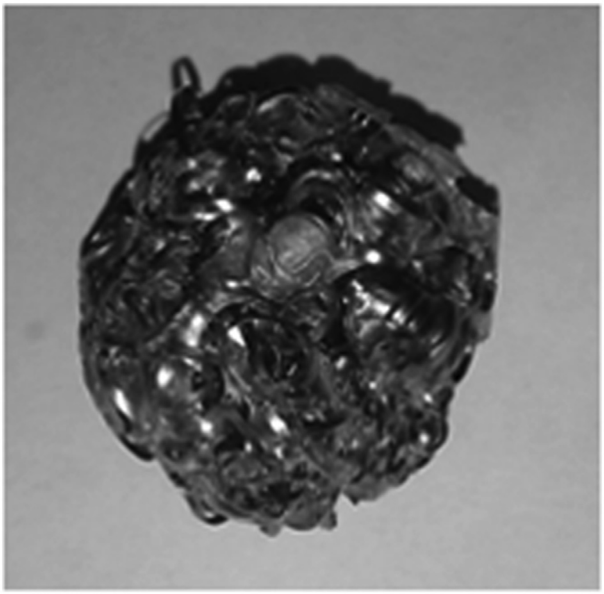

Fig. 1. Example of spherical wad of stainless-steel fibers with dry starch adhered.

Table 1
Composition of dried starch.

Composition	Concentration
Protein (g/100 g)	0.37
Fat(g/100 g)	0.42
Carbohydrates (g/100 g)	90.37
Moisture (g/100 g)	7.84
Na (mg/100 g)	46.55
Ca (mg/100 g)	38.96
K (mg/100 g)	290.36
Mg (mg/100 g)	32.55
Ash (g/100 g)	0.99

2.2. Electrocleaning device and influential cleaning parameters

Vicaria, Jurado, and Herrera-Márquez (2014) developed and patented a procedure and device for cleaning hard surfaces based on using a direct current to cause the electrolysis of water in different aqueous solutions. This device has been used to clean dry starch adhered to stainless steel. The procedure is based on the circulation of direct current between two electrodes connected to a generator (TS3021S, Thandar Instruments). This generator provides direct current at constant intensity or voltage. One of the electrodes is connected to the fiber wads of stainless steel to be cleaned and the other to a stainless-steel wad of a mass similar to the sum of the masses of the five wads to be cleaned (4.1 g). Between the electrodes there is a washing solution that covers them and that completes the circuit. Fig. 2 shows a scheme of the experimental device and its parts: 1) a heater (Tectron 3473200, P-Selecta) with stirring that allows control and change of the test temperature; 2) thermostatically controlled bath; 3) a tray holding the cleaning solution; 4) 1 L of cleaning solution; 5) stainless-steel wads soiled with dry starch that act as an electrode; 6) electrode of opposite