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Application of biocides in the process of sucrose extraction from sugar beet: Effect on sucrose content, number of *Leuconostoc* colonies and wet pulp characteristics

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A B S T R A C T

This research investigated the application of different extraction biocides in the sugar beet processing stages. The simulation of industrial processes of sugar beet extraction and beet pulp pressing is conducted using the laboratory-scale equipment. Statistical significance analysis of influence of input factors on observed responses is performed by response surface method (Box-Behnken design). Special interest was dedicated to the biocide influence on the wet pulp pressability characteristics. Multiple effects of application of chlorine dioxide on quality parameters of intermediates (diffusion juice sucrose content and number of *Leuconostoc* colonies, wet pulp pressability) are compared to the standard biocides used in sugar industry. Results indicate that the application of chlorine dioxide corresponded with the best pulp pressing characteristics with 5–15% more efficient mechanical dewatering of the wet pulp compared to the other samples, significantly affecting the potential energy consumption. The use of chlorine dioxide lowered the potential energy consumption in the range from 168 to 335 MJ per tonne of wet pulp. All the biocides used in this study showed remarkable biocide effectiveness against mesophilic bacteria *Leuconostoc mesenteroides* reducing the number of colonies in the range from 82 to 99%.

1. Introduction

In the sugar manufacturing process, beet cossettes are desugared in the extraction step using continuous-countercurrent diffusers providing two valuable products: sugar beet juice and wet pulp (desugared cossette). Sugar beet juice is further processed through purification, evaporation and crystallisation stages while the wet pulp, still containing an economically significant amount of sucrose, is directed to the pulp treatment stage. Pulp treatment stage involves an energy intensive two-step process of pulp pressing and drying, aiming to lower the moisture content of the wet pulp from 90% to 10% and therefore to recover a considerable amount of sucrose to the extraction step (Asadi, 2006; Šušić et al., 1994; Van der Poel, 1998).

Partial reduction (60–70%) of the moisture content of the wet pulp using low-cost mechanical dewatering instead of fossil fuelled thermal drying represents an essential step in achieving an economically sustainable energy consumption of a sugar plant.

Moreover, sugar beet processing industry is identified as one of the biggest energy-consumers in the field of food and chemical industry (Maravić et al., 2015). According to the European Association of Sugar Producers (CEFS), specific energy consumption was 314.9 kWh Mg^{-1} beet in 1998 (IPPC, 2003). Due to the high latent heat of the water, wet pulp drying consumes large amount of thermal energy and fuel resulting in significantly higher processing costs and environmental problems. The previous reports of several authors stated that approximately 25% of the total energy consumption of an average sugar plant is used to dry wet pulp (Madaeni & Zereshki, 2010; Unger, 1975; Zaragosa, Randall, & Camirand, 1982).

Therefore, efficiency of the pulp pressing step has a vital function in the control of the total processing costs. However, wet pulp pressability depends both on pressing machine used and wet pulp characteristics (Prati & Maniscalco, 2013).

The extraction step has the biggest impact on defining the of wet beet pulp characteristics. A wide range of factors including diffuser type, extraction operating conditions, chemicals added to diffusion

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water (pressing aids, biocides, etc.) influence the physical and chemical properties of the wet pulp (Asadi, 2006; Buttersack, Bliesener, Footurcheh, & Buchholz, 1992). Previous investigations mainly referred to the influence of the pressing aids on the beet pulp press efficiency (Buttersack et al., 1992; Prati & Maniscalco, 2013), however, there are no reports regarding particular influence of an application of biocides on dewatering of a beet pulp.

The application of biocide during the process of sugar extraction prevents excessive microbial activity, inversion of sucrose, formation of lactic, butyric and other undesirable acids. It is particularly important to suppress the activity of mesophilic bacteria *Leuconostoc mesenteroides* in order to prevent synthesis of the extracellular homopolysaccharide dextran which can lead to serious difficulties in further processing. In the past, sugar industry used numerous biocides such as sulphur dioxide, formalin, hypochlorous acid, sodium hypochlorite, etc. (Van der Poel, 1998; Asadi, 2006). Furthermore, in recent years, the application of chlorine dioxide as a biocide in sugar plant diffusers is steadily increasing. Chlorine dioxide is a powerful oxidizing agent with a great effectiveness towards a broad spectrum of microorganisms (Gómez-López, Rajkovic, Ragaert, Smigic, & Devlieghere, 2009). On the basis of the available toxicological data, the International Agency for Research on Cancer and Agency for Toxic Substances and Disease Registry classified chlorine dioxide and sodium chlorite in a group of agents not classifiable as to its carcinogenicity to humans (IARC, 1991; ATSDR, 2004). In addition, recent study showed that a solution of ClO_2 and its by-products administrated to rats, at a dosage estimated to be 120 times higher than the human dosage, during 3 months was not toxic (Qingdong, Guangming, & Li, 2006).

However, relative high price combined with large amounts of chlorine dioxide needed for application in sugar plant diffusers represent a significant limitation considering a serious lack of economic justification for its use (Jin, Deshwal, Park, & Lee, 2006).

The multiple effect of the application of chlorine dioxide on the wet pulp pressability, sucrose content and a number of *Leuconostoc* colonies in a raw sugar juice will be investigated in this paper. The effect of various extraction conditions will also be discussed. Moreover, the same analysis will be conducted using two more biocides, sodium hypochlorite and alkyl dimethyl benzyl ammonium chloride, in order to make the comparison with the effect of chlorine dioxide.

2. Materials and methods

2.1. Raw materials and methods

Sugar beet (*Beta vulgaris*) cossettes used in this study were obtained after slicing the field-cultivated beet roots produced in the province of Vojvodina, Serbia. An appropriate quality of cossettes was provided: less than 8% of mash content and Silin number in the range from 6 to 7 m. Due to the extremely bad weather conditions in Serbia, the sugar beet root from season 2014/2015 had an unusually low sugar content ranging from 11 to 16%. In normal conditions, higher sugar content (16–20%) would have contributed to a proportionally higher polarisation of a diffusion juice, compared to the results obtained in this study. However its influence on the changes of other results presented in this paper would be negligible due to the small impact of the sugar content increased over 16% on the number and characteristic of sugar storage cells (parenchyma cells), and other factors that could have influenced the presented results (Draycott, 2006; Šušić et al., 1994).

All the experiments were conducted using the laboratory-scale equipment. The extraction of sugar beet cossettes was performed in the modified extractor simulating the continuous-countercurrent extraction conditions industrially employed in a sugar plant diffuser (Asadi, 2006; Silin, 1967). The modified extractor is illustrated in Fig. 1.

The extraction water was prepared through addition of $CaCO_3$ in the required amount to obtain the desired water hardness of 40 °dH, 60 °dH and 80 °dH. After $CaCO_3$ is fully dissolved, and the water thermostat has reached the preselected temperature (50 °C, 60 °C or 70 °C) a corresponding biocide was added in the required concentration. For the purpose of biocide, three most commonly used biocide agents were selected: sodium hypochlorite (NaHC), alkyl (C12-16) dimethylbenzyl ammonium chloride (ADAC), chlorine dioxide (CD).

Conception of this extractor was based on the principle of a countercurrent diffuser battery, containing multiple sections, where extraction water was manually moved from section 1 to section 5 (manually decanting through the metal sieve) every 10 min. The cossettes were introduced one after the other from section 1 to section 5. As the cossettes remained in the introduced section, and extraction water was moved further towards section 5, the extraction regime where fresh water is constantly in contact

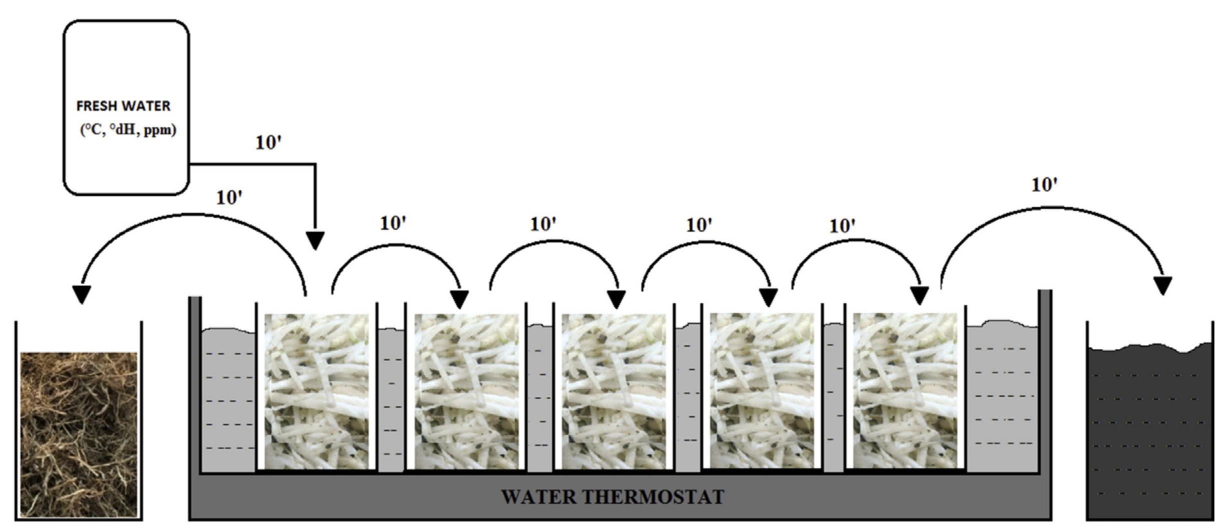

Fig. 1. Countercurrent extraction of sugar beet cossettes.