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Research Note

An experimental system for extraction of pectin from orange peel waste based on the o-core transformer structure

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ABSTRACT

An experimental system based on the o-core transformer structure was established and used to extract pectin from orange peel waste. Unlike other electric-field-assisted techniques, it avoids the use of powered electrodes. The acidic solvent acts as the secondary coil connected to a purpose-made glass chamber which forms a closed loop. Then the induced electric field in the system appears to be under the influence of alternating magnetic flux based on *Faraday's law of induction*. We found that an increase in the excitation voltage causes enhancement of the pectin yield. Increasing frequency from 20 to 200 kHz had a negative impact on pectin yield partially due to the increased impedance of the primary coil. The ionic conduction was enhanced at the same excitation voltage since there are more free ions in the mixture at lower pH. This means that a lower impedance in the mixture is conducive to extraction. This multidisciplinary technique combines the transformer concept with the electric-field-assisted process, thus providing a reference for the application into agricultural by-products treatment.

1. Introduction

Pectin is a useful food additive that exists abundantly in plant materials. It can function as a gel and as a thickening agent. There are many reports on the extraction of pectin from agricultural by-products by treating it with various inorganic acid solutions (Chan & Choo, 2013; Vriesmann, Teófilo, & de Oliveira Petkowicz, 2012). In order to improve the extraction efficiency of valuable compounds, food engineers have investigated other techniques and their optimal conditions, such as, ultrasonics (Parniakov et al., 2015), microwaves

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(Leone, Tamborrino, Romaniello, Zagaria, & Sabella, 2014), pulsed electric fields (PEF) (Lai, Parameswaran, Li, Baez, & Rittmann, 2014; Luengo, Álvarez, & Raso, 2013; Yu, Gouyo, Grimi, Bals, & Vorobiev, 2016), and moderate electric fields (MEF) (Sensoy & Sastry, 2004). More intensive cell damage causes an increase in the amount of extraction. This can be attained by the use of an alternating electric field to cause reversible electro-permeability (Lebovka, Shynkaryk, & Vorobiev, 2007).

An induced electric field in an electrolyte solution is caused by the use of inductive methodology, that is, an alternating magnetic flux generating an alternating voltage based on *Faraday's law of induction* (Bleil, 1972, chap. 1). For example, the conductivity of seawater could be detected by an induced voltage and current in the seawater, which would act as a secondary coil under the action of alternating magnetic flux based on the transformer structure (Pryor, 2013). An experimental system has also been established to detect the salt content in pickled cucumbers using terminal voltage, on the juice, which acts as the secondary coil influenced by alternating magnetic flux (Jin et al., 2015). Additionally, it was also found that a rapid accumulation of solid matters in the salted juice was caused by the influence of induced electric field, owing to the enhancement of ionic conduction.

A large amount of orange can be processed into juice after being squeezed directly. However, as a by-product of the processing, the peels are always discarded as waste, and are not used for further processing. But the content of pectin, essential oil, and pigment in the peel has a high value and could be extracted by use of appropriate unit operations (Marín, Soler-Rivas, Benavente-García, Castillo, & Pérez-Alvarez, 2007).

There have been no research studies using induced electric field-assisted extraction (IEFAE) of pectin from agricultural residue owing to the lack of a special-purpose reactor and technical means. Therefore, to explore the technology for biomass treatment, we established an experimental system based on the o-core transformer structure and used it to extract pectin from orange peel waste. We compared this system with the conventional heating extraction method, and investigated the effects of excitation voltage, frequency, temperature and pH on pectin yield to verify the effectiveness of this method.

2. Materials and methods

2.1. Experimental system

The schematic diagram of the experimental system is shown in Fig. 1. It contains of a power source; a circulating water bath; a ferrite o-core; a primary coil; a glass spiral (the supporting tube of the secondary coil); a glass chamber; a sample inlet; a solution inlet; and a sand filter (100 mesh). The glass reactor is shown in Fig. 1d. The extractant acts as a secondary coil conductor (the supporting tube is a glass coil with sixteen turns, $N_S = 16$), that is connected to the glass chamber and forms a closed loop. Agricultural wastes are located in the glass chamber and immersed in the solvent. The operation of the system involves an excitation voltage (U_P) at appropriate frequencies applied on the primary coil ($N_P = 160$) winding along the core, leading to an alternating magnetic flux generated in the ferrite o-core. Ultimately, an alternating induced electric field appeared in glass chamber to assist processing of the sample. The equivalent circuit of the proposed system, also shown in Fig. 1b corresponds to a transformer, where U_P is the excitation voltage on the primary coil, E_P is the induced voltage in the primary coil, U_S is the terminal voltage on the secondary coil, E_S is the induced voltage in the secondary coil, N_P is the primary coil turns, and N_S is the secondary coil turns. I_P and I_S are the currents in the primary and secondary coils respectively. There is an overall impedance Z_{load} of the mixture filling the glass chamber $= U_S/I_S$. Then, if the primary and secondary coils are assumed to be an ideal transformer (no leakage flux, zero winding resistance, infinite permeability, and zero core loss), the relationship can be written as follows (Kulkarni & Khaparde, 2012):

$$\frac{E_P}{E_S} = \frac{U_P}{U_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P} = \alpha \quad (1)$$

where α is the ratio of the transformer. If the coil has zero-resistance (neglect leakage reactance), then $E = U$.

The impedance of the primary coil (Z_P) is between 83.3 and 945.7 Ω when the frequency ranges between 20 and 200 kHz, detected by an impedance analyser (65120B, Wayne Kerr Electronic. U.K). The input power (P_{in}) of the system was calculated by Equation (2) (Kulkarni & Khaparde, 2012):

$$P_{in} = U_P I_P = \frac{U_P^2}{Z_P} \quad (2)$$

2.2. Extraction of pectin from orange peel waste

All solvents and chemicals used in this study were of analytical grade and purchased from Sinopharm Chemical Reagent Co., Ltd., Shanghai, China.

Raw materials were obtained from a local juice processing factory near Wuxi, China. The orange peels were cut into small cubes (approximately $3 \times 5 \times 5$ mm^3) and soaked in a water bath at 95 °C for 5 min to inactivate the enzymes. Then they were dried at 55 °C until they reached constant weight. Afterwards, the dried peel was ground in a laboratory dry blender. Finally, the ground dried peels were treated three times with isopropanol (85% vol.) at 70 °C for 20 min and then dried, crushed, and passed through a 60-mesh sieve to obtain a powdered sample. The sample was stored in a dry environment prior to the experimental treatments.

About 10 g of the dried orange peel powder was weighed and placed in the glass chamber using the sample inlet. Later, extractant with pH of 2, 3, and 6.8 (made by diluting hydrochloric acid solution) was poured through the solvent inlet to fully immerse the powder, ensuring the glass spiral (the supporting tube of the secondary coil) was filled with the extractant with no air bubbles. The volume of the liquid in the glass chamber was 104.7 mL. Thus, the ratio of the dried peel/extractant (not including the liquid in the glass coil) was about 1:10 (w/v).

The extraction process was performed under different conditions. Various excitation voltages from 0 to 300 V at between 20 and 200 kHz, were applied to the primary coil using a