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Discharged filtrate movement in food materials under application of electrokinetics

H. Iessa[a], K. Christensen[a], J.A. Hall[b], C.J. Seal[a,*]

[a] Human Nutrition Research Centre, School of Agriculture, Food and Rural Development, Newcastle University, Agriculture Building, Kings Road, Newcastle upon Tyne NE1 7RU, UK
[b] School of Civil Engineering and Geosciences, Newcastle University, Drummond Building, Newcastle upon Tyne NE1 7RU, UK

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ABSTRACT

Orange juice (OJ) and malt extract (ME) samples were treated using an electrokinetic (EK) application to investigate the impact of the pH/Lowest conductivity point (LCP) ratio of experimental materials on the water profile direction and the anolyte to catholyte filtrate ratio. After applying the electric field through samples between two electrodes, filtrate was discharged mainly towards the anode in OJ samples (acidic medium, pH/LCP < 1) and towards the cathode in ME samples (alkaline medium, pH/LCP > 1). Adjusting the orientation of electrodes depending on the results maximised dewatering efficiency under EK by 7.8% in OJ and 11.8% in ME. Changing the pH/LCP ratio by adjusting the starting pH improved dewatering efficiency under EK by 25.7%. The results are used to develop theoretical guidelines to help determine the water profile direction and filtrate outlets for different food materials based on their pH and LCP values. EK is an effective method for dewatering food materials.

1. Introduction

Applying an electric field to a charged liquid or semi-liquid material using two electrodes results in several processes occurring at different components within the material: charged liquid ions, charged liquid particles and the liquid itself (Aziz, Dixon, Usher, & Scales, 2006).

The combined effect of motion and electrical phenomena is commonly referred to as electrokinetics. These phenomena cause a movement of the different components towards one of the electrodes according to the process, the ion number and the charge (+ve or −ve) (Aziz et al., 2006; Hunter, 1993). For example, the movement of charged particles in an aqueous medium to an electrode of opposite polarity is known as electrophoresis (Lockhart, 1981; Weber & Stahl, 2002) which has been used in various applications, such as determining a particle's charge and separating enzymes and proteins. The second type of movement, electro-osmosis, is defined as the displacement of liquid relative to the medium under the influence of an electric field (Lockhart, 1981; Weber & Stahl, 2002). These two processes are used to enhance solid–liquid separation. There is another type of movement under electrokinetics which is produced by the same mechanism as electrophoresis but at the liquid level and works in the opposite direction to the charged ions that move to the opposite polarity electrode under electrophoresis (Aziz et al., 2006).

The benefits of electrokinetic (EK) applications in the area of dewatering were first reported in the mid-1970s by Yukawa, Yoshida, Kobayashi, and Hakoda (1976, 1978). Other researchers continued working on the electro-osmotic and EK application in the area of dewatering such as removing heavy metal contaminants from soil by using an electric field in groundwater (Grundl & Michalski, 1996; Shapiro & Probstein, 1993), enhancing the ultra-filtration process (Zumbusch, Kulcke, & Brunner, 1998), and minimising the radioactive nucleotides level in radioactive materials (Turner & Dell, 1984a,b).

The operational parameters of these processes have been also investigated, such as the use of voltage and constant current conditions (Yoshida, Shinkawa, & Yukawa, 1980; Yukawa, Yoshida, Kobayashi, & Hakoda, 1976, 1978) as well as salt concentration, conductivity, ionic strength, suspension types, electrode material, intermittent current application and the effect of voltage (Aziz et al., 2006).

Despite a fair amount of research on the potential use of an electrical field to improve dewatering of suspensions, the operational examples of their industrial use appear to be remarkably few and most of the research has been done in the soil, waste and mining areas. This is not because of the failure of the technology but due to control and operational difficulties. Advancement in the field of geosynthetics and

Abbreviations: A/C ratio, anolyte to catholyte ratio; EK, electrokinetic; IEP, isoelectric point; LCP, lowest conductivity point; OJ, orange juice; ME, malt extract; NEC, net electrical charge; WPD, water profile direction

* Corresponding author at: Human Nutrition Research Centre, Institute of Cellular Medicine, Leech Building, Newcastle University, Newcastle upon Tyne NE2 4HH, UK.
E-mail address: chris.seal@ncl.ac.uk (C.J. Seal).

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general material corrosive properties, has made this a viable option again.

In the food processing area, EK applications have been used mainly for analytical procedures such as protein and enzyme separation; but their use at an industrial scale has been minimal and the amount of research which has investigated the potential benefits and application of the technology on foodstuffs has been limited and is mainly in the food waste area where EK is used to improve the dewatering process to reduce the volume of the waste (Schmitz, 2004). The use of EK as a low-cost option for dewatering of food by-products such as fruit peelings was reported more recently by Ng et al. (2011) who showed that the technique could be used to reduce the moisture content to around 70–80% in these waste products.

Applying an electric field between two electrodes to suspensions causes a movement of the charged ions and particles towards one of the electrodes (the anode or the cathode) according to their charge type under the influence of electrophoresis which in addition results in water movement in the opposite direction. Negative ions and negatively charged particles, which are dissolved in water, move toward the positively charged anode and water then moves in the opposite direction to the cathode; in the same way, positive ions and positively charged particles move towards the negatively charged cathode and water moves in the opposite direction towards the anode (Aziz et al., 2006).

Although electrokinetic phenomena cause movement of ions and water (discharged filtrate) towards the two outlets, the discharged filtrate volumes at each outlet are not equal. The percentage of water volume moving towards each electrode depends on overall charge of the suspension, the net electrical charge (NEC). If the NEC is positive the direction of the major volume of discharged filtrate is towards the anode as the positive ions move towards the cathode. In contrast, if the NEC is negative the direction of the major volume of discharged filtrate is towards the cathode.

The NEC of most food particles especially protein depends on the isoelectric point (IEP) of the particle, which is the pH value at which a particle is electrically neutral and carries no NEC, and the pH of the medium. The net surface charge is affected by the pH of the liquid in which the particle is submerged (Prasad, 2012). At the IEP pH, the NEC on the particle is 0, since negative and positive charges are equal. This pH value is very important in electrical food applications especially as the conductivity decreases when the total ion content decreases by becoming neutral.

In this study, different expressions are used to define fluid movements under application of EK. The direction of the major volume of discharged filtrate (or water) is the water profile direction (WPD), driving filtrate to the main outlet. When the sample NEC is positive the WPD is towards the anode and the main outlet filtrate is the anolyte; conversely when the NEC is negative the WPD is towards the cathode and the main outlet filtrate is the catholyte. The relative movements in either direction are expressed through the anolyte to catholyte ratio (A/C ratio); where the anolyte and catholyte refer to the electro-osmotic flows corresponding to the movement under the impact of the electrokinetic process and/or the applied pressure towards either the anode or the cathode respectively (Yang, Nakhla, & Bassi, 2005).

Many of the previous studies which investigated these movements reported data on only one stream, mostly the catholyte. For example, Yuan and Weng (2003) reported only catholyte data during dewatering of municipal sludge cake and similarly Habibi (2004) also report the movement of liquid toward the cathode during EK dewatering of oily sludge from a crude oil storage tank. However, some other studies have investigated two streams such as Yang et al. (2005) who measured the two filtrates and found that applying EK to oily sludge increased both streams but resulted with unequal-weighted streams where the balance was in favour of the anolyte. Ng et al. (2011) also report data for both anode and cathode streams, but in this study the flow to the cathode was consistently higher than to the anode for all of the food by-products tested.

1.1. Aims of study

This research aimed to investigate the movement of the discharged liquid under the impact of EK represented by WPD as the main direction and A/C ratio as the ratio of the discharged liquid volume out flow at each electrode. The objective was to develop theoretical guidelines for designing and setting up the rigs needed to apply EK by determining the main fluid outlet according to the chemical properties of the foodstuff.

2. Materials and experimental method

2.1. Orange juice (OJ)

A commercial orange juice (OJ) was purchased fresh for use in the experiments. Labelling indicated that the juice contained 16 orange fruits per 1 L orange juice. The water content was 86.1% and the initial pH was 3.6.

2.2. Malt extract (ME)

Malt extract (ME) samples were supplied by Muntons plc (Stowmarket, Suffolk, UK) as dark dry malt then prepared in the laboratory to produce a ME with a water content around 80%, using the following method: Dark malt grain was dispensed into water at 52 °C (1 part grain: 4 parts water) and stirred with a paddle mixer at 9 rpm at 52 °C for 20 min. Then the contents were heated to 65 °C, the stirrer speed was increased to 18 rpm and held at this condition for 20 min; the temperature was then raised to 89 °C, and the stirring speed further increased to 36 rpm for 20 min. After this time the sample was allowed to cool down and was kept in refridgerated at 4 °C for a maximum of 24 h before analysis.

2.3. Experimental rig

A series of bench-scale experiments were conducted in the EK dewatering cell shown in Fig. 1. The experimental rig was developed by modifying the 'Rosli cell' described by Jones, Lamont-Black, Glendinning, and Pugh (2005), used to test the effects of EK on dehydrating water from soil. This cell was modified and redesigned taking into account the differences between the soil and foodstuffs in terms of physical (dry matter and viscosity) and chemical properties (composition, acidity and gas production).

The dimensions of the cell were OD = ~200 mm, 4 mm wall thickness and 500 mm length, creating a sample tube with a capacity of up to 4 L. The cell tube was made of acrylic while other parts were made of nylon. The electrodes were pierced disks of titanium. Two pieces of filter paper (0.2 µm or 1 µm according to the experiment, Whatman, Sigma-Aldrich Company Ltd, Dorset, England) were attached to the inner sides of the anode and cathode to retain solids.

The top electrode was held by a removable top cap, while the bottom electrode was held on the top of a vertical movable piston moved using a gas actuator (ISO Cylinder 80 × 300 mm, Buckinghamshire, UK, MK8 0AN) providing a pressure up to 6 bar. Electrodes were connected to a controllable power supply (U8002A DC Power Supply, Agilent, 0–30 V, 5A, West Yorkshire, UK, WF12 7TH).

2.4. Analytical methods

For a typical arrangement in the laboratory process, the electrodes were arranged horizontally; the charges of the top and bottom electrodes (anode or cathode) were chosen according to the experiment and sample material (as the WPD was different according to the food material due to the difference between the initial chemical properties of the products). The following orientations were used (Fig. 2):

Normal: Anode at bottom, cathode at top