Title:

Impacts of operating conditions on efficiency of electrokinetically enhanced filtration for de-watering of orange juice and malt extract.

Authors names and affiliations:

H. Iessa^{a,b}, K. Christensen^{a,b}, J. A. Hall^c and C. J. Seal^{a,d}

^aHuman Nutrition Research Centre, Population Health Sciences Institute, Medical Sciences Faculty, Newcastle University, Catherine Cookson Building, Framlington Place, Newcastle upon Tyne NE2 4HH, UK

^bSchool of Natural and Environmental Sciences, Faculty of Science, Agriculture and Engineering, Newcastle University, Agriculture Building, King's Walk, Newcastle upon Tyne NE1 7RU, UK

^cSchool of Engineering, Material and Manufacturing, Newcastle University, Drummond Building, Newcastle upon Tyne, NE1 7RU, UK

^dCorresponding author. Human Nutrition Research Centre, Population Health Sciences Institute, Medical Sciences Faculty, Newcastle University, Catherine Cookson Building, Framlington Place, Newcastle upon Tyne NE2 4HH, UK

Email: chris.seal@ncl.ac.uk

Abstract

The effects of operational factors on an electrokinetic-enhanced filtration (EKEF) application to dewater orange juice (OJ) and malt extract (ME) was investigated. EKEF improved dewatering of both foodstuffs and resulted in net dewatering efficiencies of 7.4% and 4.9% for OJ and 10.7% and 6.3% for ME after 5.5 h processing under 30V and 15V, respectively. Dry matter content was increased by 19.2% and 15.6% for OJ after 5.5 h and 14.8% and 12.8% for ME after 3.5 h under 30V and 15V, respectively, compared with 14.9% and 10.3% under the control conditions for OJ and ME, respectively.

The EKEF process effectively improved dewatering of high moisture-content foods with positive impacts on process efficiency by increased voltage, pressure, and the pore size of filters. The initial distance between electrodes had a negative impact as the distance increased. EKEF is a useful adjunct to improve high pressure filtration of foodstuffs.

Keywords

Electrokinetics; dewatering; food drying; discharged filtrate

Abbreviations

DE	Dewatering efficiency
EK	Electrokinetic
EKEF	Electrokinetic efficiency
LCP	Lowest conductivity point
ME	Malt extract
NDE	Net dewatering efficiency
OJ	Orange juice
VCP	Voltage crossing point
WPD	Water profile direction

50 **1 Introduction**

51 Under the application of an electric field through a charged liquid with two electrodes, ions
52 and charged particles move towards one or other of the two electrodes (the anode+ or the
53 cathode-) according to their charge (Aziz, Dixon, Usher, & Scales, 2006; Hunter, 1993).

54 Negative ions and negatively charged particles, which are dissolved in water, move towards
55 the positively charged anode and water then moves in the opposite direction to the
56 cathode; in the same way, positive ions and positively charged particles move towards the
57 negatively charged cathode and water moves in the opposite direction towards the anode
58 under the impact of the electrophoresis process (Aziz et al., 2006).

59 The combined effect of motion and electrochemical phenomena is commonly referred to as
60 electrokinetics (EK) (Aziz et al., 2006; Hunter, 1993; Iessa, Christensen, Hall, & Seal, 2018).

61 This technology has been shown to have an effective impact not only in dewatering
62 applications and removal of soluble ions, but also in the removal of insoluble organics in
63 porous media (Aziz et al., 2006). Research on EK has focussed on sludge dewatering, soil
64 remediation from heavy metals and organics contamination (Gladman, de Kretser, Rudman,
65 & Scales, 2005) and waste dewatering.

66 Raats, van Diemen, Lavén and Stein (2002) reported that the solids content in sludge arising
67 from the purification of drinking water could be increased from 17 up to 24% by combining
68 EK dewatering with a belt press in a gravity-driven thickening belt with an additional energy
69 consumption of 60 kWh/t of sludge. The increase in overall dry matter content of the slurry
70 reported in this study was increased as the DV voltage applied across the belt was raised. A
71 high water reduction from 87.8% to 62.6% was also achieved by Yang, Nakhla and Bassi
72 (2005) and Yuan and Weng (2003) in municipal sludge over 41 h at a potential gradient of
73 5.0V/cm using a 6cm long EK dewatering cell.

74 Besides the sludge dewatering area, studies have focussed on EK remediation of soil,
75 implanting two electrodes in soil beds either vertically (Ho, Athmer, Sheridan, & Shapiro,
76 1997) or horizontally (Ho et al., 1999) achieving removal of more than 90% of the metals;
77 this metal removal was also observed in an improved EK process using a cation selective
78 membrane in front of the cathode to prevent the precipitation of metals in the vicinity of
79 the cathode (Li, Yu, & Neretnieks, 1998). Cundy and Hopkinson (2005) and Yang, Nakhla and

Bassi (2005) investigated a potential application of EK using a ferric ion remediation and stabilization technique to decontaminate and consolidate soil.

Studying EK applications has not been limited to soil dewatering and mineral removal areas, research has also focused on EK removal of neutral soluble or insoluble organic compounds from soil. For example, greater than 90% removal of hydrophobic polycyclic aromatic hydrocarbons (PAHs) by EK has been reported by Maini, Sharman, Knowles, Sunderland and Jackman (2000) in bench- and pilot-scale experiments, while in another study, Ho et al. (1999) reported 98% removal efficiency of p-nitro-phenol in a pilot EK unit.

The operational parameters of these processes in non-food materials have been investigated, such as the use of voltage and constant current conditions (Yoshida, Shinkawa, & Yukawa, 1980; Yuan et al., 2003; 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).

In the food processing area, EK applications have been used mainly for analytical procedures such as protein and enzyme separation; but their use in industrial scale applications has been minimal and the amount of research which has investigated the potential benefits and application of the technology on foodstuffs has been limited. Limited research has mainly been in the food waste area where EK has been used to improve the dewatering process to reduce the volume of the waste by removing the water component (Rathore & Guttman, 2003). However, none of these studies discussed the principles of applying EK on different types of food materials or the impact of the factors which control this application. The only recent study was reported by Ng et al. (2011) who investigated the impact of EK on dewatering of food waste (brewer's spent grain, orange, melon and mango peel, and cauliflower trimmings) at two applied voltages (15V and 30V) compared with a 0V control. The power consumption of the application under the three applied voltages was compared with the power consumption needed to dewater the same volume of water using conventional thermal methods. The results indicated that the EK process combined with mechanical dewatering could reduce the moisture content 77% to 68% for orange peel, from 78% to 71% for brewer's spent grain, from 80% to 73% for mango peel, from 91% to 74% for melon peel and from 92% to 80% for cauliflower trimmings. The total moisture reduction showed a strong correlation with electrical conductivity ($R^2 = 0.89$). The energy

consumption for dewatering of all samples was evaluated and was found to be up to sixty times more economical compared with thermal processing (Ng et al., 2011).

This research aimed to investigate the impact of the EK application and its operational factors (applied voltage, pressure, filter pore size and the distance between the electrodes) on dewatering efficiency. The objective was to use two different liquid foodstuffs, fresh orange juice (OJ) and malt extract (ME) as test materials to better understand the EK process in order to identify optimum operational conditions for dewatering of these products.

2 Materials and experimental method

Details of the samples used and the experimental rig have been described in detail previously (Iessa et al., 2018). The EK rig was a modification of the 'Rosli cell' described by Jones, Lamont-Black, Glendinning and Pugh (2005) previously used for dewatering soil. The pierced titanium electrode discs were held in an acrylic tube and could be fixed up to a maximum of 500 mm apart, with a maximum contained volume of 4 L. The rig was used in a vertical orientation with the top electrode fixed; the bottom electrode could be moved upwards within the cylinder using a moveable piston fitted with a gas actuator (ISO Cylinder 80 x 300 mm, Buckinghamshire, UK). A filter disc was fitted to the inner surface of each electrode to retain solids within the cell contents.

The orange juice (OJ) was a commercial product with an initial dry matter content of approximately 14%. The malt extract (ME) was supplied by Muntions plc (Stowmarket, Suffolk, UK) as a dry product which was mixed and reconstituted in the laboratory to produce an extract with an initial dry matter content of approximately 20% (Iessa et al., 2018).

2.1 Analytical method

Different values of the investigated factors (applied voltage, pressure, filter pore size and the distance between the electrodes) were applied to OJ and ME samples to investigate the impact of EK under different operational conditions on the efficiency of the filtration process. Three different voltages (0, 15 and 30V) and three different pressures (2, 3 and 4bar) were tested on OJ samples with the anode as the bottom electrode, using a 0.2 μ pore

filter, and 5.5 h duration. These experiments were repeated on ME samples under one pressure only (4bar), with the cathode as the bottom electrode, and using a 1 μ pore filter and 3.5 h duration.

Bottom electrode charge was chosen to maximise the EKEF by directing water downwards supported by gravitational action. Our previous experiments (Iessa et al., 2018) had demonstrated that the water profile direction (WPD) for OJ was towards the anode as the pH of the OJ (3.6) was less than the lowest conductivity point (LCP, 4). In contrast the WPD for ME was towards the cathode because the pH of the ME (4.55) was greater than the LCP (3.2). Thus, the anode was chosen to be as the bottom electrode for OJ experiments while the cathode was chosen as the bottom electrode for ME experiments.

To investigate the impact of the filter pore size, two filters (0.2 μ and 1 μ) were used, the other experimental conditions were 4bar pressure and three voltage values 0, 15 and 30V and 5.5 h duration for OJ samples, and 4bar pressure and two voltage values 0, and 30V and 3.5 h duration for ME.

The impact of distance between electrodes was tested for ME samples only. The initial distance between the two electrodes depends on the sample volume and three volumes of ME were used (0.5, 1 & 1.5L) which resulted in distances between electrodes of 17, 35 & 52 mm, respectively for the fixed inner diameter of 192 mm. Each distance was investigated at 0V and 30V at 4bar pressure and for 2 h.

The impact of these conditions on the dewatering efficiency (total and net) was then compared with control measurements made at 0V with no EK.

2.2 Calculations and statistical methods

Dewatering efficiency was calculated in two ways: (a) total dewatering efficiency (TDE) was calculated as the ratio of the total filtrate weight (the anolyte and the catholyte combined together) to the initial weight of the water in the sample. The initial moisture content was 86% for OJ and 80% for ME and (b) net dewatering efficiency (NDE) which was calculated as TDE minus the efficiency of the control (without EK).

Results are presented as mean values $\pm$ standard deviation (SD). Significance of differences between mean values was determined by analysis of variance (ANOVA) and considered significant if $p < .05$ using Minitab 16 Statistical Software (Minitab Inc., PA, USA).

3 Results

The data in table 1 shows that there was a positive NDE ($P < 0.001$) after applying EK by up to 7.4% in OJ experiments and up to 10.7% in ME experiments. This NDE was significantly higher at an applied voltage of 30V compared with 15V under 2 and 3bar pressure with an increase in the total filtrate weight with increasing voltage. However, the difference between 15V and 30V was not significant in OJ samples under 4bar pressure ($P = 0.093$). As expected, when EK voltage was applied the filtrate moved towards the anode with an Anolyte/Catholyte ratio (A/C ratio) > 1 for OJ samples, and towards the cathode with an A/C ratio < 1 for the ME samples. This movement was greater at 30V compared with 15V, while the difference between the anolyte and catholyte was smaller under no EK (0V, control) with a slight increase at the bottom outlet.

Table 1 also shows the change in the discharged filtrate weight over time under the three different pressure values of 2, 3 and 4bar. Increasing the applied pressure increased the flow rate over time and improved the net dewatering efficiency by up to 13.7%. The impact of increasing pressure was greater for 4bar of pressure compared with 3 and 2bar in all experiments ($P < 0.001$). However, increasing the pressure from 2bar to 3bar showed a significant impact only when no voltage was applied under control EK conditions; no significant impact was seen when the voltage was applied ($P < 0.001$ under 0V, $P = 0.777$ under 15V and $P = 0.232$ under 30V).

Figure 1 shows the time series flow rates for OJ under the three applied voltages for the three applied pressures. These show that over the full 5.5 h of treatment applying 30V achieved a higher cumulative total filtrate, but up to a specific time cumulative total filtrate at 15V was higher before the cumulative total filtrate at 30V accelerated and crossed the 15V line at the voltage crossing point (VCP). Values for the VCP and related concomitant measurements are summarised in Table 2.

The change in the cumulative total filtrate using filters with two different pore sizes (0.2 μ and 1 μ) is shown in Table 3. Comparing the cumulative total filtrate of the two filter pore sizes showed that the larger filters pore size gave a significantly ($P<0.05$) total filtrate. NDE of increasing the filter pore size was 7.7% under 0V, 17.3% under 15V and 19.6% under 30V for OJ; and 21.8% under 0V and 26.5% under 30V for ME.

Table 4 and Figure 2 show that the greater the distance between the rig electrodes the lower the EK dewatering efficiency as the accumulated total filtrate was reduced from 32.6% with 17mm distance (0.5L) to 19.8% and 13.4% with 35mm distance (1L) and 52mm distance (1.5L), respectively for OJ. For ME, the cumulative total filtrate was reduced from 53.9% with 17mm distance (0.5L) to 27.5% and 15.4% with 35mm distance (1L) and 52mm distance (1.5L), respectively. In addition, Figure 2 shows that the electric current intensity was higher with smaller distance between electrodes.

4 Discussion

The impact of the applied voltage on the dewatering efficiency for non-food materials has been previously discussed in several studies which have shown that dewatering efficiency is increased as the voltage across the material is increased (Buijs, Van Diemen, & Stein, 1994; Raats et al., 2002; Yang et al., 2005). This positive impact of increasing voltage was also seen in the OJ and ME used in the current study and is a direct consequence of the applied voltage driving the movement of ions through the test material matrix as predicted by Ohm's Law [$I=V/R$, where I is the current in amperes, V is the voltage and R is the resistance in ohms]. Since water movement depends on ion movement, increasing the voltage applied on the same material with the same conductivity increases the electric current intensity by increasing the quantity of the charged particles moving to the opposite electrode which speeds up the water movement to the other electrode (Aziz et al., 2006; Horowitz & Hill, 2015).

The final total filtrate weight was higher under 30V compared with 15V in both OJ and ME experiments. However, the mean value of OJ total filtrate over time was higher under 15V than its value under 30V in the OJ experiments, while it was higher under 30V in the ME experiments. Figure 1 showed that up to a specific time the outcome of applying 15V was greater before the 30V impact accelerated and crossed the 15V line at the VCP. Data in

225 Table 2 show that the VCP occurred after around 40% of juice had been removed as filtrate.
226 The distance between the electrodes was 34.5mm with 1L volume at the beginning of the
227 experiments and decreased over time as the water was removed. It is interesting that the
228 VCP occurred when the distance between electrodes reached approximately 18mm in the
229 three experiments which could be the reason behind this phenomenon as the impact of
230 voltage is influenced by the distance between the electrodes. This value may also have
231 been affected by the dry matter content which was around 24% when the VCP was seen
232 since conductivity is influenced by both dry matter content and ion drift velocity through
233 the conducting medium (Semat & Katz, 1958).

234 The results confirm that the higher the voltage used in the EK process the better the
235 filtration process efficiency but increasing the applied voltage also increases power
236 consumption during the drying process. Therefore using lower voltage values and then
237 increasing the voltage gradually as the VCP is approached could be one of the ways to
238 improve the process and decrease the negative impact on food quality compounds, as well
239 as decreasing the power consumption.

240 Pressure has a positive impact on improving the efficiency of the EK filtration process
241 (Doran, 2013). However, increasing the pressure from 2bar to 3bar showed significant
242 impact only when the voltage was 0V under control conditions while it had no significant
243 impact when the voltage was applied.

244 In addition to the effects of pressure, filter pore size can also affect the filtration process
245 outcome and efficiency (Zare & Kargari, 2018). Comparing the NDE between the two sizes
246 of the filter pore used in this study (0.2 μ and 1 μ), it is clear that the larger the filter pore size
247 the higher the NDE. Bigger pores allow more particles to go through the filters which in turn
248 slows down the cake formation at the filter surface and reduces the negative impact of cake
249 formation on the water flow rate. Under the same conditions, the pressure values used to
250 increase the dewatering process may carry more particulate material through the larger
251 pore filters, but in the latter case, cake formation at the surface of the filter would be faster
252 which would slow down the filtration process. However, the bigger the pores, the more the
253 loss of particles with the filtrate, and this could be a disadvantage to the overall concentrate
254 product quality.

The impact of the distance between electrodes on the performance of EK was investigated in earlier studies on non-food materials; these studies reported the negative impact of sample thickness in the filtration enhancement under the application of EK. For example, Lamont-Black, Jones, Glendinning, Huntley, and Fourie (2007) investigated the impact of EK on soil dewatering at two sample thicknesses of 35mm and 50mm under three voltage values 0V, 15V and 30V, where the percentage of the solid content was measured after 35min. The results showed that the solid content increased from about 59% to about 73% for the 50mm thickness under the higher voltage 30V compared with the control, while it increased from about 62% to about 83% for the same sample at 35mm thickness under the higher voltage 30V compared with the control, suggesting that the lower thickness was better for dewatering. Yang, Nakhla and Bassi (2005) also investigated this impact by comparing the net dewatering efficiency under 0V, 10V, 20V and 30V in three thicknesses 4, 6 and 8cm. the NDE was only 13% at 8cm while it increased to 16.1% and 29.1% at 6cm and 4 cm, respectively, confirming the benefit of reducing the distance between the electrodes. This negative impact of the distance between electrodes is most likely due to the higher electric current intensity with smaller sample thickness as the electrodes are closer increasing the EK efficiency. This impact on electric current may be because of the increase in the electrical resistance when the distance between the electrodes increases as concluded in Chang, Song and Gye (2019); increasing the electrical resistance on the other hand reduces the current intensity at constant voltages according to Ohm's law.

5 Conclusion

For the two food products tested, application of EK technology to enable dewatering was shown to be effective under a range of conditions; and achieved net dewatering efficiencies up to 7.4% and 4.9% after 5.5hrs for OJ and 10.7% and 6.3% for ME after 3.5hrs of processing under 30V and 15V respectively. The performance of the EK process, and hence the dewatering efficiency was dependent upon several parameters including the applied voltage, applied pressure, the pore size of filters and the initial distance between electrodes. Increasing the voltage had a significant positive impact ($P<0.001$) by increasing the electric current intensity under the same conductivity, applying a lower voltage at the start of the dewatering process, and then increasing the applied voltage would improve the dewatering

efficiency and save energy. Pressure and filter pore size also had a significantly positive impact ($P < 0.001$) on the total process efficiency as increasing pressure and pore size reduces the caking impact and speeds up the filtrate flow rate through the filters. The distance between the two electrodes had a negative impact on EK efficiency by reducing the capacitance of the operating system.

Acknowledgements and conflicts of interest

HI gratefully acknowledges the receipt of the Syrian Higher Education Capacity Building Project (HECBP) scholarship. The authors have no conflicts of interest to declare.

296 References

- 297 Aziz, A. A. A., Dixon, D. R., Usher, S. P., & Scales, P. J. (2006). Electrically enhanced dewatering (EED)
298 of particulate suspensions. *Colloids and Surfaces A: Physicochemical and Engineering*
299 *Aspects*, 290(1–3), 194-205.
300 <https://doi.org/http://dx.doi.org/10.1016/j.colsurfa.2006.05.020>.
- 301 Buijs, P. J., Van Diemen, A. J. G., & Stein, H. N. (1994). Efficient dewatering of waterworks sludge by
302 electroosmosis. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 85(1), 29-
303 36. [https://doi.org/https://doi.org/10.1016/0927-7757\(94\)02741-2](https://doi.org/https://doi.org/10.1016/0927-7757(94)02741-2).
- 304 Cundy, A. B., & Hopkinson, L. (2005). Electrokinetic iron pan generation in unconsolidated
305 sediments: implications for contaminated land remediation and soil engineering. *Applied*
306 *Geochemistry*, 20(5), 841-848.
307 <https://doi.org/https://doi.org/10.1016/j.apgeochem.2004.11.014>.
- 308 Doran, P. M. (2013). Chapter 11 - Unit Operations. In P. M. Doran (Ed.), *Bioprocess Engineering*
309 *Principles (Second Edition)* (pp. 445-595). London: Academic Press.
- 310 Gladman, B., de Kretser, R. G., Rudman, M., & Scales, P. J. (2005). Effect of shear on particulate
311 suspension dewatering. *Chemical Engineering Research and Design*, 83(7), 933-936.
312 <https://doi.org/https://doi.org/10.1205/cherd.04328>.
- 313 Ho, S. V., Athmer, C., Sheridan, P. W., Hughes, B. M., Orth, R., McKenzie, D., . . . Shoemaker, S.
314 (1999). The Lasagna Technology for in situ soil remediation. 1. Small field test. *Environmental*
315 *Science & Technology*, 33(7), 1086-1091. <https://doi.org/10.1021/es980332s>.
- 316 Ho, S. V., Athmer, C. J., Sheridan, P. W., & Shapiro, A. P. (1997). Scale-up aspects of the Lasagna™
317 process for in situ soil decontamination. *Journal of Hazardous Materials*, 55(1), 39-60.
318 [https://doi.org/https://doi.org/10.1016/S0304-3894\(97\)00016-2](https://doi.org/https://doi.org/10.1016/S0304-3894(97)00016-2).
- 319 Hong, C.-H., Chong, S.-H., & Cho, G.-C. (2019). Theoretical Study on Geometries of Electrodes in
320 Laboratory Electrical Resistivity Measurement. *Applied Sciences*, 9(19), 4167.
321 <https://www.mdpi.com/2076-3417/9/19/4167>.
- 322 Horowitz, P., & Hill, W. (2015). *The Art of Electronics*. New York, USA: Cambridge University Press.
- 323 Hunter, R. J. (1993). *Introduction to Modern Colloid Science*, Oxford University Press, New York, 1993.
324 (illustrated, reprint ed.): Oxford University Press.
- 325 Iessa, H., Christensen, K., Hall, J. A., & Seal, C. J. (2018). Discharged filtrate movement in food
326 materials under application of electrokinetics. *Food Chemistry*, 247, 1-7.
327 <https://doi.org/https://doi.org/10.1016/j.foodchem.2017.12.007>.
- 328 Jones, C., Lamont-Black, J., Glendinning, S., & Pugh, R. (2005). New Applications for Smart
329 Geosynthetics. *Waste Containment and Remediation*, 142, 1-15.
- 330 Lamont-Black, J., Jones, C. J. F. P., Glendinning, S., Huntley, D. T., & A.B, F. (2007). Laboratory
331 evaluation of the potential for electrokinetic belt filter press dewatering of Kimberlite slimes.
332 *Proceedings of the Tenth International*
- 333 *Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth Australia, 147-
334 152.
- 335 Li, Z., Yu, J.-W., & Neretnieks, I. (1998). Electroremediation: removal of heavy metals from soils by
336 using cation selective membrane. *Environmental Science & Technology*, 32(3), 394-397.
337 <https://doi.org/10.1021/es9703584>.
- 338 Maini, G., Sharman, A. K., Knowles, C. J., Sunderland, G., & Jackman, S. A. (2000). Electrokinetic
339 remediation of metals and organics from historically contaminated soil. *Journal of Chemical*
340 *Technology & Biotechnology*, 75(8), 657-664. [https://doi.org/10.1002/1097-4660\(200008\)75:8<657::Aid-jctb263>3.0.Co;2-5](https://doi.org/10.1002/1097-4660(200008)75:8<657::Aid-jctb263>3.0.Co;2-5).
- 341 Ng, S. K., Plunkett, A., Stojceska, V., Ainsworth, P., Lamont-Black, J., Hall, J., . . . Russell, D. (2011).
342 Electro-Kinetic Technology as a Low-Cost Method for Dewatering Food By-Product. *Drying*
343 *Technology*, 29(14), 1721-1728. <https://doi.org/10.1080/07373937.2011.602199>.

- Raats, M. H. M., van Diemen, A. J. G., Lavèn, J., & Stein, H. N. (2002). Full scale electrokinetic dewatering of waste sludge. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 210(2), 231-241. [https://doi.org/https://doi.org/10.1016/S0927-7757\(02\)00380-1](https://doi.org/https://doi.org/10.1016/S0927-7757(02)00380-1).
- Rathore, A., & Guttman, A. (2003). *Electrokinetic Phenomena. Principles and Applications in Analytical Chemistry and Microchip Technology*. Boca Raton: CRC Press.
- Semat, H., & Katz, R. (1958). Physics: Chapter 28 Electrical Conduction in Liquids and Solids. Retrieved from: <https://digitalcommons.unl.edu/physicskatz/154> Accessed August 2020.
- Yang, L., Nakhla, G., & Bassi, A. (2005). Electro-kinetic dewatering of oily sludges. *Journal of Hazardous Materials*, 125(1–3), 130-140. <https://doi.org/http://dx.doi.org/10.1016/j.jhazmat.2005.05.040>.
- Yoshida, H., Shinkawa, T., & Yukawa, H. (1980). Comparison between electroosmotic dewatering efficiencies under conditions of constant electric current and constant voltage. *J. Chem. Eng. Jpn.*, 13, 414–417.
- Yuan, C., & Weng, C. (2003). Sludge dewatering by electrokinetic technique: effect of processing time and potential gradient. *Adv. Environ. Res.*, 7, 727–732.
- Yukawa, H., Yoshida, H., Kobayashi, K., & Hakoda, M. (1976). Fundamental study on electroosmotic dewatering of sludge at constant electric current. *J. Chem. Eng. Jpn.*, 9, 402–407
- Yukawa, H., Yoshida, H., Kobayashi, K., & Hakoda, M. (1978). Electroosmotic dewatering of sludge under condition of constant voltage. *J. Chem. Eng. Jpn.*, 11, 475-480.
- Zare, S., & Kargari, A. (2018). Chapter 4 - Membrane properties in membrane distillation. In V. G. Gude (Ed.), *Emerging Technologies for Sustainable Desalination Handbook* (pp. 107-156): Butterworth-Heinemann.

Table 1. Impact of voltage (0, 15 and 30V) on EK dewatering efficiency of orange juice (OJ) and malt extract (ME).

Material	Experimental conditions	Total Filtrate Weight (g)	Dry Matter Content (%)	A/C Ratio *	Flow Rate (g/min)	Dewatering efficiency (%)	
						Total	Net
Orange Juice [†]	<u>At 2 bar</u>						
	Control (0V)	367	23.6	1.1	1.11	47.4 ^a	Control
	15V	405	25.4	1.6	1.23	52.3 ^b	4.9
	30V	413	25.9	1.4	1.25	53.4 ^c	6.0
	<u>At 3 bar</u>						
	Control (0V)	387	24.6	1.0	1.2	49.9 ^a	Control
	15V	406	25.5	1.5	1.2	52.5 ^b	2.6
	30V	427	26.6	1.6	1.3	55.2 ^c	5.3
	<u>At 4 bar</u>						
	Control (0V)	462	28.8	1.0	1.4	59.7 ^a	Control
	15V	473	29.5	1.6	1.4	61.1 ^b	1.4
	30V	519	33.1	1.7	1.6	67.1 ^b	7.4
Malt Extract [‡]	<u>At 4 bar</u>						
	Control (0V)	373	30.3	1.2	1.8	42.4 ^a	Control
	15V	428	32.8	0.9	2.0	48.7 ^b	6.3
	30V	467	34.8	0.9	2.2	53.1 ^c	10.7
Orange Juice [†]	<u>At 0V</u>						
	Control (2bar)	367	23.6	1.1	1.11	47.4 ^d	Control
	3 bar	387	24.6	1.0	1.2	49.9 ^e	2.5
	4 bar	462	28.8	1.0	1.4	59.7 ^f	12.3
	<u>At 15V</u>						
	Control (2bar)	405	25.4	1.6	1.23	52.3 ^d	Control
	3 bar	406	25.5	1.5	1.2	52.5 ^d	0.2
	4 bar	473	29.5	1.6	1.4	61.1 ^e	8.8
	<u>At 30V</u>						
	Control (2bar)	413	25.9	1.4	1.25	53.4 ^d	Control
	3 bar	427	26.6	1.6	1.3	55.2 ^d	1.8
	4 bar	519	33.1	1.7	1.6	67.1 ^e	13.7

* A/C analyte/catholyte ratio

[†] OJ bottom electrode anode; 0.2μ filter; 5.5 hours

[‡] ME, bottom electrode cathode; 1.0μ filter; 3.5 hours

^{a,b,c}; values for each voltage within each pressure with different superscripts are significantly different, P<0.05

^{d,e,f}; values for each pressure within each voltage with different superscripts are significantly different, P<0.05

378 **Table 2.** Voltage crossing points (VCP) properties for orange juice under different pressures
 379 (2, 3 and 4bar), anode as the bottom electrode and 0.2 μ filter for 5.5hours.

Pressure (bar)	Time (hh:mm)	Total Filtrate (g)	Total Filtrate (%)	Concentrate (%)	Concentrate Dry matter (%)	Distance between Electrodes (mm)
2	~04:45	377	41.9	58.1	24.1	18
3	~04:15	351	39.0	61.0	23.0	19
4	~03:40	384	42.7	57.3	24.4	18

380

Table 3. Impact of filters pore size (0.2 μ and 1 μ) on the EK dewatering efficiency of orange juice and malt extract.

Material	Experimental conditions	Total Filtrate Weight (g)	Dry Matter Content (%)	A/C Ratio *	Flow Rate (g/min)	Dewatering efficiency (%)	
						Total%	Net%
Orange Juice [†]	<u>Control (0V)</u>						
	0.2 μ Filter	462	28.8	1.0	1.4	59.7 ^a	Control
	1 μ Filter	521	33.3	1.1	1.6	67.4 ^b	7.7
	<u>15V</u>						
	0.2 μ Filter	473	29.5	1.6	1.4	61.1 ^a	Control
	1 μ Filter	607	43.0	1.6	1.8	78.4 ^b	17.3
	<u>30V</u>						
	0.2 μ Filter	519	33.1	1.7	1.6	67.1 ^a	Control
	1 μ Filter	671	55.1	1.3	2.0	86.7 ^b	19.6
	<u>Control (0V)</u>						
Malt Extract [‡]	0.2 μ Filter	166	23.6	1.1	1.1	20.7 ^a	Control
	1 μ Filter	340	28.9	2.3	2.3	42.5 ^b	21.8
	<u>30V</u>						
	0.2 μ Filter	228	25.2	1.5	1.5	28.5 ^a	Control
	1 μ Filter	440	33.3	2.2	2.9	55.0 ^b	26.5

* A/C analyte/catholyte ratio

[†]OJ bottom electrode anode; 0.2 μ filter; 5.5 hours

[‡]ME, bottom electrode cathode; 1.0 μ filter; 3.5 hours

^{a,b,c}; values for each pore size within each voltage with different superscripts are significantly different, P<0.05

389 **Table 4.** Impact of initial distance between electrodes (17, 35 and 52 mm) on the EK
390 dewatering efficiency of malt extract.

Experimental conditions	Total Weight of Filtrate (g)	Dry Matter Content (%)	A/C ratio *	Flow Rate (g/min)	Dewatering efficiency (%)	
					Total	Net
<u>0V^c</u>						
0.5L/17mm:	141	27.9	0.9	1.2	32.6 ^a	Control
1L/35mm:	158	23.8	1.3	1.3	19.8 ^b	-12.8
1.5L/52mm:	160	22.4	1.6	1.3	13.4 ^c	-19.2
<u>15V^c</u>						
0.5L/17mm:	233	37.5	0.8	1.9	53.9 ^a	Control
1L/35mm:	220	25.7	0.8	1.8	27.5 ^b	-26.4
1.5L/52mm:	185	22.8	0.9	1.5	15.4 ^c	-38.5

391 *A/C analyte/catholyte ratio

392 ^cME, bottom electrode cathode; 4bar; 2 hours

393 ^{a,b,c}; values for each distance between electrodes within each voltage with different

394 superscripts are significantly different, P<0.05

Figure 1. Change in OJ accumulated total filtrate over time under three voltage values (0, 15 & 30V) and three pressures (2, 3 & 4 bar), (anode as the bottom electrode, 0.2μ filter for 5.5 hours). Each value is expressed as mean ± standard deviation (n=3)

Fig. 2. Impacts of the distance between electrodes (17, 35 and 52 mm) on malt extract (ME) accumulative total filtrate and electric current intensity; cathode as the bottom electrode, 0 & 30V, 4bar pressure, 0.2 μ filter for 2hr duration. Each value is expressed as mean (n=3).