

1 **Title:**

2 Discharged filtrate movement in food materials under application of electrokinetics

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## 17 **Abstract**

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

30

## 31 **Keywords**

32 Electrokinetics; dewatering; food drying; discharged filtrate

## 33 **Abbreviations**

34 A/C ratio: anolyte to catholyte ratio

35 EK: electrokinetic

36 IEP: iso-electric point

37 LCP: lowest conductivity point;

38 OJ: orange juice

39 ME: malt extract

40 NEC: net electrical charge

41 WPD: water profile direction

## 42 1. Introduction

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

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

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

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

72 Despite a fair amount of research on the potential use of an electrical field to improve  
73 dewatering of suspensions, the operational examples of their industrial use appear to be

74 remarkably few and most of the research has been done in the soil, waste and mining areas.  
75 This is not because of the failure of the technology but due to control and operational  
76 difficulties. Advancement in the field of geosynthetics and general material corrosively  
77 properties, has made this a viable option again.

78 In the food processing area, EK applications have been used mainly for analytical  
79 procedures such as protein and enzyme separation; but their use at an industrial scale has  
80 been minimal and the amount of research which has investigated the potential benefits and  
81 application of the technology on foodstuffs has been limited and is mainly in the food waste  
82 area where EK is used to improve the dewatering process to reduce the volume of the waste  
83 (Schmitz, 2004). The use of EK as a low-cost option for dewatering of food by-products  
84 such as fruit peelings was reported more recently by Ng, Plunkett, Stojceska, Ainsworth et al.  
85 (2011) who showed that the technique could be used to reduce the moisture content to around  
86 70-80% in these waste products.

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

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

102 The NEC of most food particles especially protein depends on the isoelectric point  
103 (IEP) of the particle, which is the pH value at which a particle is electrically neutral and  
104 carries no NEC, and the pH of the medium. The net surface charge is affected by the pH of  
105 the liquid in which the particle is submerged (Prasad, 2012). At the IEP pH, the NEC on the

106 particle is 0, since negative and positive charges are equal. This pH value is very important in  
107 electrical food applications especially as the conductivity decreases when the total ion content  
108 decreases by becoming neutral.

109 In this study, different expressions are used to define fluid movements under  
110 application of EK. The direction of the major volume of discharged filtrate (or water) is the  
111 water profile direction (WPD), driving filtrate to the main outlet. When the sample NEC is  
112 positive the WPD is towards the anode and the main outlet filtrate is the anolyte; conversely  
113 when the NEC is negative the WPD is towards the cathode and the main outlet filtrate is the  
114 catholyte. The relative movements in either direction are expressed through the anolyte to  
115 catholyte ratio (A/C ratio); where the anolyte and catholyte refer to the electro-osmotic flows  
116 corresponding to the movement under the impact of the electrokinetic process and/or the  
117 applied pressure towards either the anode or the cathode respectively (Yang, Nakhla & Bassi,  
118 2005).

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

### 129 *1.1. Aims of Study*

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

## 135 **2. Materials and experimental method**

### 136 2.1. Orange Juice (OJ)

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

### 140 2.2. Malt Extract (ME)

141 Malt extract (ME) samples were supplied by Muntons plc (Stowmarket, Suffolk, UK) as dark  
142 dry malt then prepared in the laboratory to produce a ME with a water content around 80%,  
143 using the following method: Dark malt grain was dispensed into water at 52°C (1 part grain:  
144 4 parts water) and stirred with a paddle mixer at 9 rpm at 52°C for 20min. Then the contents  
145 were heated to 65°C, the stirrer speed was increased to 18 rpm and held at this condition for  
146 20min; the temperature was then raised to 89°C, and the stirring speed further increased to 36  
147 rpm for 20min. After this time the sample was allowed to cool down and was kept in  
148 refridgerated at 4°C for a maximum of 24 hours before analysis.

### 149 2.3. Experimental rig

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

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

162 The top electrode was held by a removable top cap, while the bottom electrode was  
163 held on the top of a vertical movable piston moved using a gas actuator (ISO Cylinder 80 x  
164 300 mm, Buckinghamshire, UK, MK8 0AN) providing a pressure up to 6bar. Electrodes were  
165 connected to a controllable power supply (U8002A DC Power Supply, Agilent, 0-30V, 5A,  
166 West Yorkshire, UK, WF12 7TH).

167 *2.4. Analytical methods*

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

173 Normal: Anode at bottom, cathode at top

174 Reversed: Cathode at bottom, anode at top

175 Control: EK turned off

176 To determine the WPD and the optimum orientation of OJ and ME, experiments were  
177 run on 1L of each foodstuff at 30V and 4bar, and one of two pores sizes of filters (0.2 $\mu$ m or  
178 1 $\mu$ m) as shown in Table 1.

179 The weights of anolyte and the catholyte filtrates were measured every 30 minutes and  
180 the filtrate pooled for each electrode using a sensitive electronic bench scale platform  
181 (Mettler Toledo PBA655/PBA655X, supplied by Northern Balance Ltd., Gateshead, UK)  
182 which was connected to Microsoft Office Excel 2003 through WinCT (RsCom / RsKey /  
183 RsWeight by A&D Company Ltd). The values of the total filtrate weight and dewatering  
184 efficiency (total and net) were compared and the A/C ratio used to show the WPD, to identify  
185 the main outlet, and to estimate the intensity of the EK effect. The pH of the filtrates was  
186 monitored throughout each experiment using a standard pH meter (Martini Instruments Mi  
187 150 supplied by Milwaukee Electronics Kft., Szeged, Hungary); the meter was calibrated  
188 daily using calibration standards (pH4, pH7 & pH10) before use.

189 The lowest conductivity point (LCP) was used in this study instead of IEP due to the  
190 difficulty of measuring the IEP of the food samples. LCP for the initial OJ and ME samples  
191 was determined by titration of the samples with 10% (w/v) NaOH and 10% (v/v) HCl to  
192 adjust the pH of the samples to between 1.5 and 6.0. Conductivity at each pH was  
193 determined using a conductivity meter (Jenway 4510 supplied by Bibby Scientific Ltd.,  
194 Stone, UK).

195 The effect of changing the initial pH of the OJ was investigated by adjusting the pH of  
196 the juice to pH 1.5, 5.0 and 6.5 and then applying EK to the samples at 30V, 4bar with a 1 $\mu$ m  
197 filter in comparison with the fresh juice (pH 3.6).

198 2.5. *Statistical Analysis*

199 Results are presented as means  $\pm$  standard deviation (SD). Significance of differences  
200 between means was determined by analysis of variance and considered significant if  $p < 0.05$   
201 using Minitab 16 Statistical Software (Minitab Inc., PA, USA).



### 202 3. Results

203 For both OJ and ME the discharge filtrate moved almost equally to the two outlets  
204 when EK was not applied under the Control conditions due to the equal pressure at both  
205 outlets and the lack of electric field to drive ions to each electrode (Table 1). The small  
206 increase in the bottom outlet is likely to be due to the additional impact of gravity. When the  
207 EK field was switched on, the difference in between the two outlets increased and the A/C  
208 ratio was  $>1$  for OJ and  $<1$  for ME. For OJ, therefore, the dominant WPD was in the  
209 direction of the anode whereas for ME the WPD was towards the cathode even when the  
210 electrodes were reversed showing that the discharge filtrate was determined by the electrode  
211 charge not the electrode position. An example of the profile of filtrate production for OJ  
212 (panel A) and ME (panel B) is shown in Figure 3.

213 Figure 4 shows the effect of pH on the conductivity of the food samples. The LCP was  
214 at pH 3.2 for the ME and pH 4.0 for OJ. Changing the initial pH of the OJ had an impact on  
215 discharge. At pH values  $<LCP$  the A/C ratio was  $>1$  indicating greater output at the anode  
216 but when the pH was raised above the LCP the A/C ratio was  $<1$  indicating greater discharge  
217 at the cathode under the same EK conditions (Table 1).

218 The total dewatering efficiency (TDE) was calculated as the ratio of the total filtrate  
219 weight to the initial weight of water in the sample; the initial moisture content was 86% for  
220 OJ and 80% for ME. Net dewatering efficiency (NDE) was calculated as the difference  
221 between TDE under EK and TDE for Control (Table 1). EK improved NDE by 7.8% with  
222 OJ in the Normal orientation and by between approximately 5 and 12% under optimal  
223 conditions with ME, but reduced dewatering when the electrodes were in the opposite  
224 orientation.

225

#### 226 4. Discussion

227 Some previous studies have investigated water movements in non-food materials under  
228 the application of EK and observed only one stream (mostly the catholyte) which was  
229 affected by the properties of the samples investigated. Fourie et al. (2007), for instance, used  
230 an applied electric field to dewater mineral sands tailings (kaolinite and quartz) with a pH  
231 value of 6.4. The IEP of kaolinite varies between 3.3 and 5 (Brian & Garrison, 1997). This  
232 basic medium ( $\text{pH} > \text{IEP}$ ) causes water to move toward the cathode, which was the basis for  
233 using six anodes in the test tank to push the water towards the single cathode extracting  
234 outlet. Lamont-Black et al. (2007) also applied EK on three types of thickened kimberlite  
235 slimes from diamond mines in southern Africa with pH values of between 7.88 and 9.53. The  
236 test equipment used an irrigated anode (bottom electrode) and an open-draining cathode (top  
237 electrode). Finally, Aziz et al. (2006) used an alkaline suspension ( $\text{pH} = 10$ ) and collected the  
238 outflow at the cathode, which also acted as a permeable medium.

239 In contrast, Yang et al. (2005) used oily sludge ( $\text{pH} 5.3 - 5.6$ , IEP 5.9) and experienced  
240 outlet streams at both electrodes but with a higher electro-osmotic flow towards the anode  
241 since in this case  $\text{pH} < \text{IEP}$  and positive charges on sludge particles predominated. Yang et al.  
242 (2005) focused on the two flows reporting their volumes different applied voltage conditions.  
243 Studies on the use of EK as a low-cost method for reducing the water content of ether whole  
244 foods or food waste by-products have been limited. Ng et al. (2011) dewatered food by-  
245 products which were all acidic (range pH 6.4 to 3.7) and demonstrated higher outflow from  
246 the anode for all of the products tested. The effluent discharged at the anode for each product  
247 had a lower pH than that produced at the cathode and this was dependent on the voltage  
248 applied across the cell. The results presented here support these observations and suggest  
249 that the method could be applied to foodstuffs such as OJ which have a relatively high water  
250 content. The advantages of using this method rather than using heating methods in  
251 potentially preserving heat-sensitive nutrients such as vitamins is an area which warrants  
252 further investigation.

253 Thus WPD depends on the net charge of the suspension; when the net charge is positive  
254 ( $\text{pH} < \text{IEP}$ ), the positive ion content is higher than the negative ion content and the ion  
255 movement is towards the cathode under electrophoresis while the WPD is in the opposite  
256 direction under EK towards the anode and the A/C ratio is  $>1$ , while it is toward the cathode  
257 when the net charge is negative ( $\text{pH} > \text{IEP}$ ) and the A/C ratio is  $<1$ . This was demonstrated in

258 this study (Table 1) where the WPD was expected to be towards the anode for OJ where  
259  $\text{pH}=3.6 < \text{LCP} = 4$ , and towards the cathode for ME where the  $\text{pH}=4.55 > \text{LCP} = 3.2$  when  
260 the EK was on. Under control conditions with no EK for both products the discharge filtrate  
261 moved almost equally towards both electrodes due to the pressure on both outlets. In each  
262 case, regardless of electrode orientation, the bottom outlet showed a small increase in  
263 discharge due to the additional impact of gravity confirming that under EK, WPD is related to  
264 the electrode charge not to the electrode position. These effects are summarised in Figure 3.

265 Net dewatering efficiency (NDE) was significantly affected by the electrode  
266 orientation, with opposite effects for the two products as predicted by their differing net  
267 charges (Table 1). Figure 3 shows that over time filtrate discharge rate decreased. This was  
268 due to caking of the product at the electrodes as dewatering progressed. EK had a positive  
269 effect on OJ in the normal orientation but a negative effect when the electrodes were  
270 reversed. In contrast, for ME, EK improved NDE under reversed conditions compared with  
271 the normal orientation.

272 Each food material has its own natural chemical properties, but adjusting the initial pH  
273 could play a positive role in improving the EK process. For non-food samples, Aziz et al.  
274 (2006) adjusted the sample pH to increase the alkalinity of the medium to pH 10 using  
275 sodium hydroxide, enhancing migration to the cathode. In the present study, adjusting the pH  
276 of OJ either above or below the LCP ( $\sim 4$  for OJ) impacted on dewatering efficiency with  
277 greater effects the further above or below the LCP (Table 1). This effect was due to the  
278 change in conductivity which was higher the further the pH from the LCP (Figure 4) as  
279 expected with the greater number of charged ions under these conditions.

280 For higher filtration yield and energy saving, gravity can be used to support the  
281 movement of the discharged liquid when EK is applied by designing the equipment with the  
282 WPD to the main outlet in line with gravity. The orientation of the anode and the cathode in  
283 the EK equipment must take into account the chemical properties of the foodstuff together  
284 with the impact of all forces that affect particle movement in such foodstuffs. In the current  
285 model, to concentrate foodstuffs in a vertical cell, two forces are used: (A) an electrical force  
286 generated by applying a voltage between two horizontal electrodes across the sample, and (B)  
287 a mechanical force generated by applying a pneumatic pressure ram. A small additional  
288 effect of gravity is evident in the vertical cell.

289 Figure 5 shows the electrode set-up and the forces that affect water movement under  
 290 three orientations (Control, Normal and Reversed) and in two mediums (acidic  $\text{pH} < \text{IEP/LCP}$ )  
 291 and basic  $\text{pH} > \text{IEP/LCP}$ ). Where:

292  $F_C$ : sum of the forces pushing particles to the cathode.

293  $F_A$ : sum of the forces pushing particles to the anode.

294  $P$ : Pressure.

295  $g$ : Gravity.

296  $EK_C$ : EK toward the cathode.

297  $EK_A$ : EK toward the anode.

298  $EK_T$  (Total EK) =  $|EK_C - EK_A|$

299 Three differing scenarios are considered to explain the significance of these factors on WPD:

300 Case (1): Control, no EK

301 Water is influenced by the impact of pressure which pushes water equally toward both  
 302 outlets and gravity which pushes water downwards.

303  $F_{\text{Top}} = P - g$

304  $F_{\text{Bottom}} = P + g$

305 WPD is almost equal toward both outlets with a small increase for the bottom outlet and  
 306 Anolyte  $\approx$  Catholyte, A/C ratio  $\approx 1$  (Figure 5(A))

307 Case (2): EK is on and  $\text{pH} < \text{IEP/LCP}$

308 This scenario is equivalent to using OJ. In addition to Control forces, water is  
 309 influenced by the electric field which pushes water towards either the anode or the cathode  
 310 determined by the ratio of the positive and negative ion content. Since the NEC is positive  
 311 ( $\text{pH} < \text{IEP/LCP}$ ),  $EK_A > EK_C$  and the  $EK_T$  is towards the anode.

312 ➤ WPD is toward the anode (the bottom in the Normal orientation and the top in the  
 313 Reversed orientation) as the NEC is positive and ion movement is towards the cathode.

314 ➤ Anolyte  $>$  Catholyte  $\Rightarrow$  A/C ratio  $> 1$

315 ➤ Normal orientation (anode at the bottom) (Figure 5(B))

316  $F_C = P - EK_T - g$

317  $F_A = P + EK_T + g$

318 ➤ Reversed orientation (cathode at the bottom) (Figure 5(C))

$$319 \quad F_C = P - EK_T + g$$

$$320 \quad F_A = P + EK_T - g$$

321 In this case the optimal orientation is the Normal position with the main outlet, the  
322 anolyte, at the bottom to combine the effects of EK, pressure and gravity.

323

324 Case (3): EK is on and  $\text{pH} > \text{IEP/LCP}$

325 This scenario is equivalent to using ME. Since the NEC is negative ( $\text{pH} > \text{IEP/LCP}$ ),  $EK_A <$   
326  $EK_C$  and the  $EK_T$  is towards the cathode.

327 ➤ WPD is toward the cathode (the top in the Normal orientation and the bottom in the  
328 Reversed orientation) as the NEC is negative and ion movement is toward the anode.

329 ➤ Anolyte < Catholyte  $\Rightarrow$  A/C ratio < 1

330 ➤ Normal orientation (anode at the bottom) (Figure 5(D))

$$331 \quad F_C = P + EK_T - g$$

$$332 \quad F_A = P - EK_T + g$$

333 ➤ Reversed orientation (cathode at the bottom) (Figure 5(E))

$$334 \quad F_C = P + EK_T + g$$

$$335 \quad F_A = P - EK_T - g$$

336 In this case the optimal orientation is the Reversed position with the main outlet, the  
337 catholyte, at the bottom to combine the effect of EK, pressure and gravity.

## 338 5. Conclusion

339 For the two food products tested, application of EK technology to enable dewatering  
340 was shown to be effective under a range of conditions. The starting pH and the IEP/LCP  
341 properties of the food materials were key determinants of dewatering efficiency and affected  
342 the WPD in each material. Controlling these factors and adjusting the orientation of  
343 electrodes to maximise dewatering efficiency under EK, pneumatic pressure and gravity is  
344 key to the future application of EK technologies in the food industry. EK technologies have  
345 the potential for low-cost dewatering of foodstuffs and warrant further investigation.

346

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**Table 1. Filtrate parameters and dewatering efficiency under differing EK conditions for orange juice and malt extract**

Experimental conditions	Anolyte (g)	Catholyte (g)	Total (g)	Anolyte (%)	Catholyte (%)	A/C ratio	Flow rate (g/min)	Total Dewatering efficiency (%)	Net Dewatering efficiency (%)
<b>Set 1: Orange Juice, 1L, 30V, 4 bar, 0.2 µm filter, 5.5 hours</b>									
Control <sup>1</sup>	239±7 (B)	222±4 (T)	461±11	51.9	48.1	1.08	1.40	59.6	
Normal <sup>2</sup>	330±11	192±4	522±15	63.2	36.8	1.72	1.58	67.4	7.8
Reversed <sup>3</sup>	193±6	116±3	309±9	62.5	37.5	1.67	0.93	39.9	-19.7
<b>Set 2: Malt Extract, 1L, 30V, 4 bar, 1.0 µm filter, 3.5 hours</b>									
Control	202±5 (B)	171±8 (T)	373±13	54.2	45.8	1.19	1.78	46.7	
Normal	139±4	188±6	327±9	42.6	57.4	0.74	1.56	40.9	-5.8
Reversed	221±5	247±6	467±11	47.2	52.8	0.89	2.22	57.4	11.8
<b>Set 3: Malt Extract, 1L, 30V, 4 bar, 0.2 µm filter, 2 hours</b>									
Control	80±6 (B)	77±4 (T)	158±9	51.0	48.9	1.04	1.32	19.8	
Normal	90±4	110±4	201±7	45.1	54.9	0.82	1.67	25.1	5.3
Reversed	99±3	122±7	220±9	44.8	55.2	0.81	1.84	27.5	7.8
<b>pH-adjusted Set: Orange Juice, 1L, 30V, 4 bar, 0.2 µm filter, 3 hours</b>									
Control	218±5	203±6	421±10	51.8	48.2	1.07	2.34	54.4	
pH 1.5	343±4	277±5	620±10	55.3	44.7	1.24	3.44	80.1	25.7
pH 3.6	263±4	202±6	465±10	56.5	43.5	1.30	2.58	60.0	5.6
pH 5.0	211±5	222±5	433±10	48.6	51.4	0.95	2.40	55.9	1.5
pH 6.5	243±3	327±4	569±7	42.6	57.4	0.74	3.16	73.5	19.1

<sup>1</sup>Control, 0V, no EK application<sup>2</sup>Normal, Cathode at the top (T) of the cell<sup>3</sup>Reversed, Cathode at the bottom (B) of the cell<sup>4</sup>In the control situation with no EK the filtrate appears at the bottom (B) or top (T) outlet

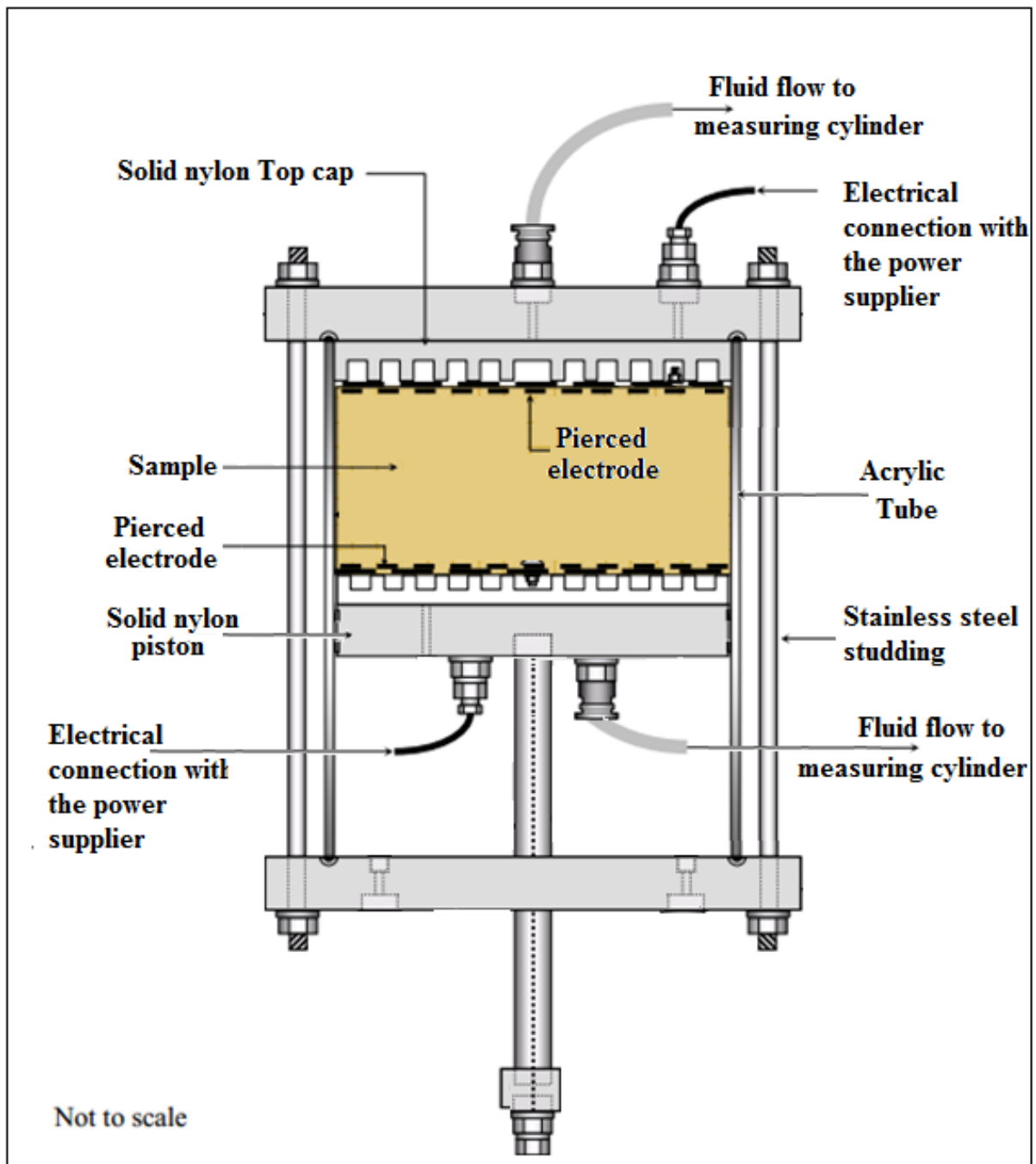


Figure 1. Electrokinetic dewatering cell, edited from Jones, Lamont-Black, Glendinning & Pugh (2005)

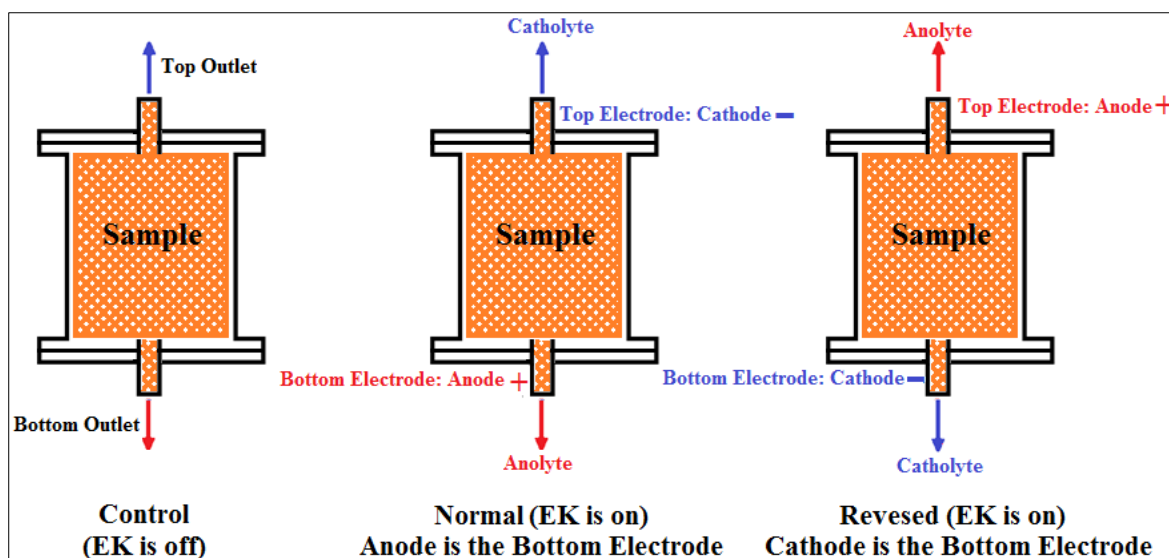


Figure 2. Specifications of the electrode orientation during Control, Normal and Reversed EK operation.

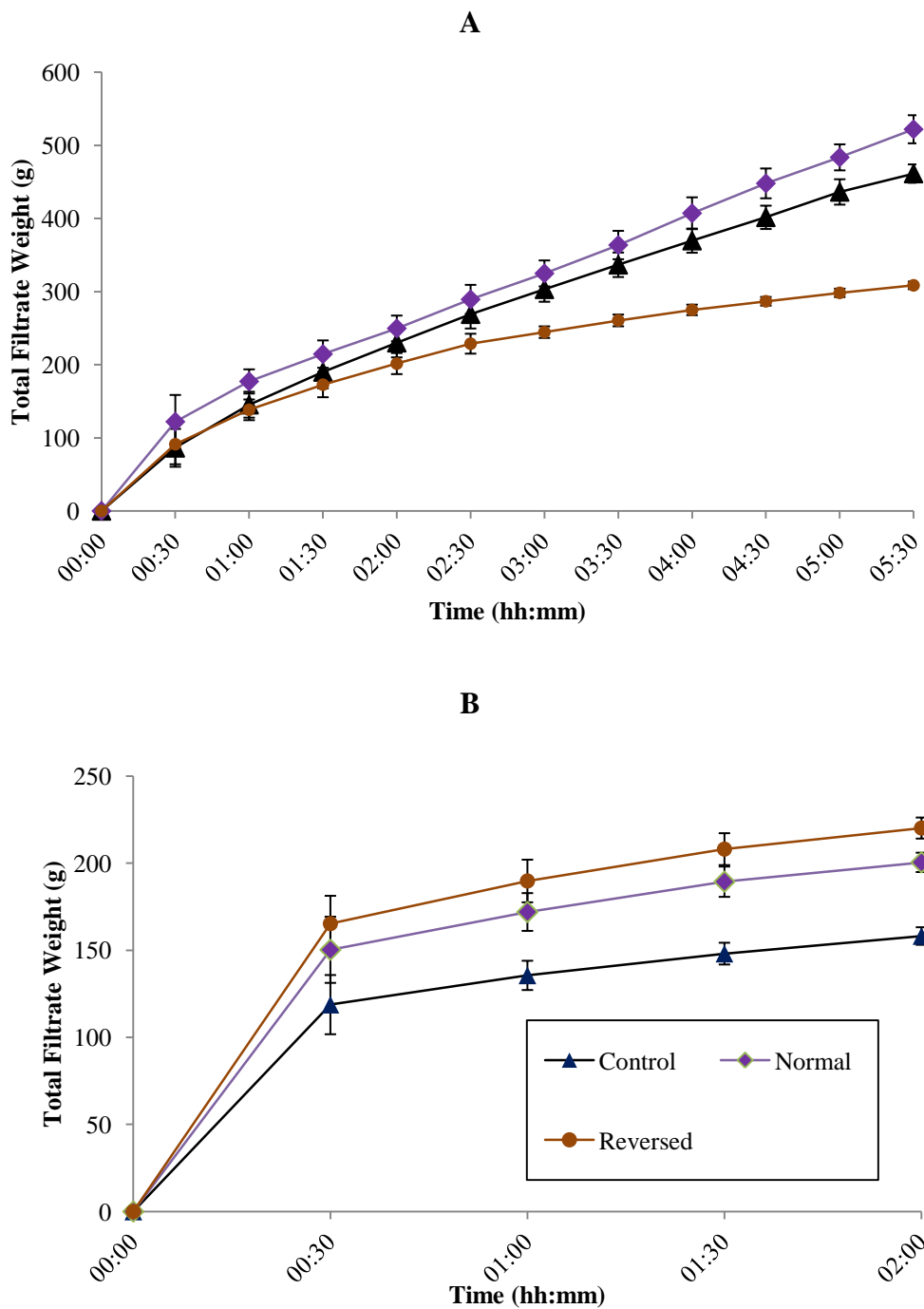


Figure 3. Profile of total filtrate output for orange juice (panel A) and malt extract (panel B) with 0.2  $\mu\text{m}$  filter. Control is no EK application, Normal is cathode at the top, Reversed is cathode at the bottom. Values are means  $\pm$  SD.

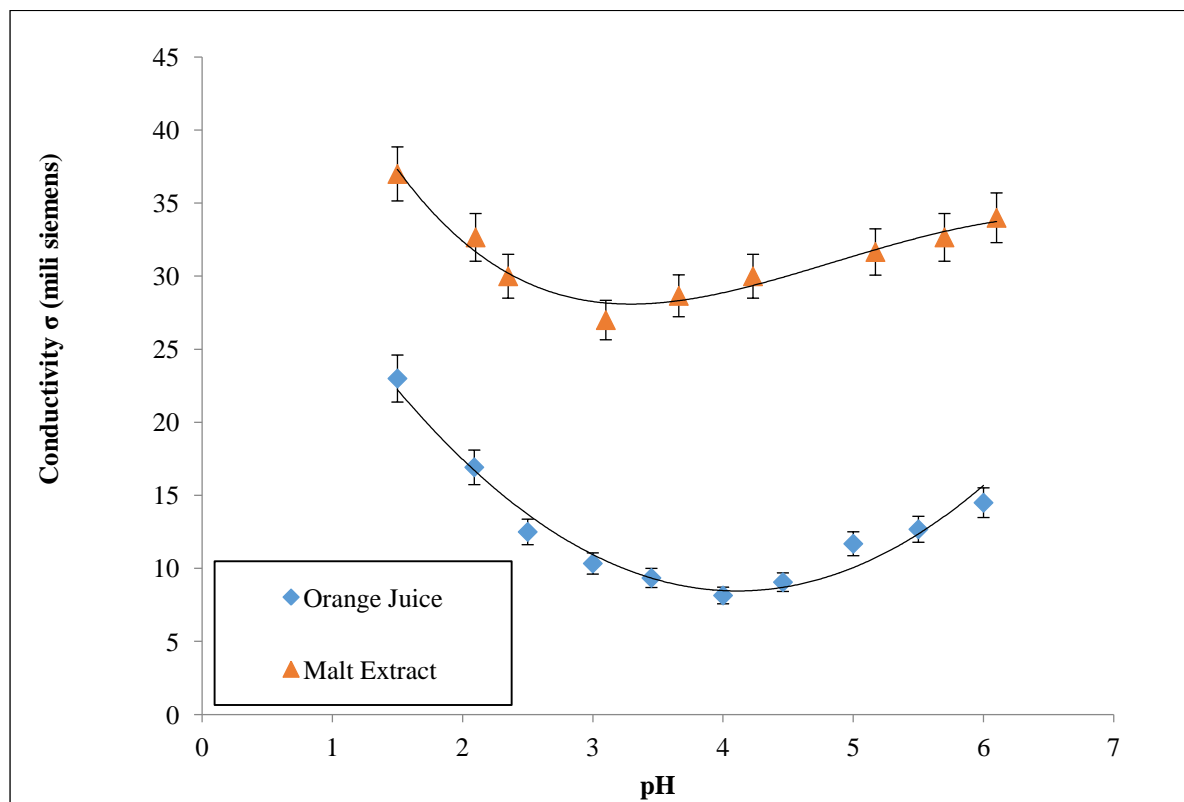


Figure 4. Change in conductivity of OJ and ME under different pH conditions. Values are means  $\pm$  SD

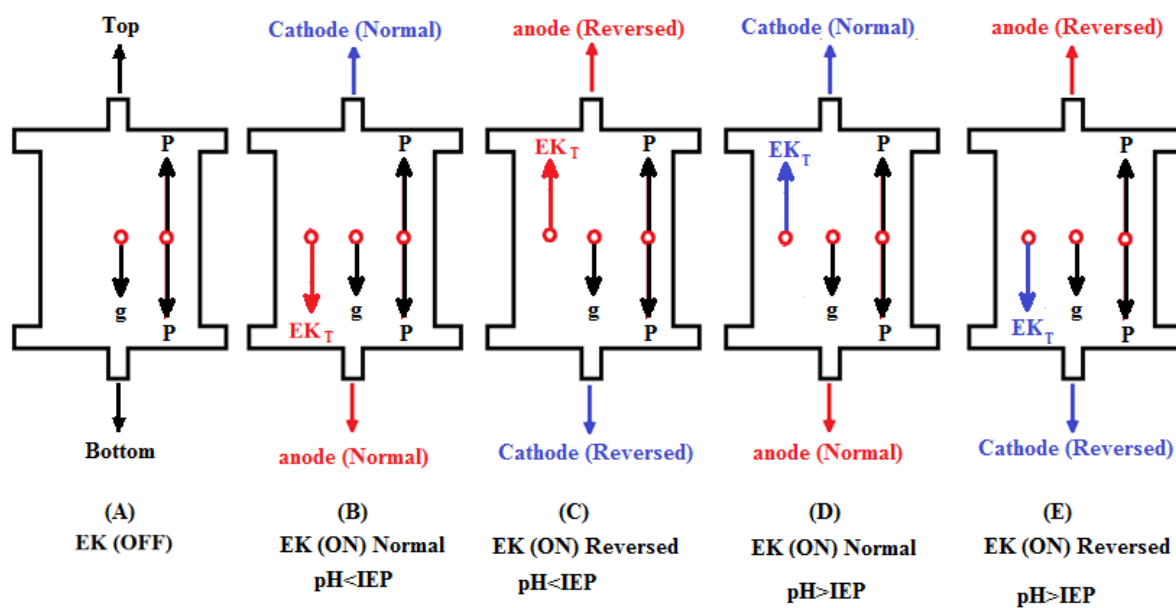


Figure 5. Forces affecting water movement inside the experimental cell under different orientations; A. Control situation, B. Normal situation and acidic medium when  $\text{pH} < \text{IEP}$ , C. Reversed situation and acidic medium when  $\text{pH} < \text{IEP}$ , D. Normal situation and basic medium when  $\text{pH} > \text{IEP}$ , and E. Normal situation and basic medium when  $\text{pH} > \text{IEP}$ .

1 Discharged filtrate movement in food materials under application of electrokinetics

2 H. Iessa, K. Christensen, J.A. Hall and C.J. Seal

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- Dewatering of foods by electrokinetics is investigated.
- Water flow direction is determined by pH and lowest conductivity point (LCP).
- In acidic foods (e.g. orange juice),  $\text{pH/LCP} < 1$ ; water moves to the anode.
- In alkaline foods (e.g. malt extract),  $\text{pH/LCP} > 1$ ; water moves to the cathode.
- Controlling pH and electrode orientation maximises dewatering efficiency.

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