Food processing waste dewatering by electro-osmosis

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Orsat, V., Raghavan, G.S.V. and Norris, E.R. 1996. Food processing waste dewatering by electro-osmosis. Can. Agric. Eng. 38:063-067. As a result of changing waste-handling technologies, many industrial food processing wastes now being fed to animals were once considered to be without economic value. Other factors which have increased the interest in wastes utilization as animal feed include increasing costs of disposal and transportation and increasing environmental restrictions. This has brought about the necessity of separating the solid waste from the liquid waste for potential reuse of both fractions. This study examines the use of pressure alone and pressure combined with an electric field for dewatering purposes. Separation trials were conducted at various combinations of pressure and electric current with three types of food wastes. The results indicated that combining an electric field with mechanical dewatering can increase the percent solids from 30 to 49% for brewer’s spent grain (BSG), from 23 to 53% for apple pomace, and from 11 to 67% for vegetable waste. The dewatering improvement of combining an electric field to mechanical dewatering is of the order of 2 to 8% (increase in solids) depending on the applied electric field and the produce being dewatered. All separation trials yielded an energy consumption, per kilogram of water removed, considerably less when compared to thermal drying.

Aujourd’hui, avec les développements technologiques dans le domaine du traitement et de la manutention des déchets, les résidus de production de l’industrie alimentaire ont une valeur ajoutée et sont maintenant réutilisés comme engrais ou aliments pour animaux. La réutilisation des déchets est amenée par l’augmentation des restrictions environnementales. Ceci amène la nécessité de séparer les fractions solides/liquides de la masse de déchets pour réutilisation potentielle des deux fractions. La présente étude examine une méthode d’extraction associant électro-osmose et pression mécanique. Plusieurs essais ont été entrepris à différents niveaux de pression et de courants électriques pour trois types de déchets. Les résultats obtenus indiquent que l’association de l’électro-osmose à une pression mécanique, peut augmenter le taux de solide du déchet à plus de 50%, et ce, avec une fraction de la consommation d’énergie qu’il en coûterait si les déchets étaient traditionnellement séchés à l’air chaud. En effet, nos essais ont augmenté le taux de solide de 30 à 49% pour la drèche de brasserie, de 23 à 53% pour le marc de pomme de même qu’une augmentation de 11 à 67% pour des déchets maraîchers.

INTRODUCTION

In the industrial food processing field, there is a large variety of wastes due to the vast selection of raw food materials being processed. Although many of these food wastes have sufficient nutritional value as feed, these waste materials have little economic value because of their low dry-matter content resulting in high transportation and drying costs per unit of nutrient (Francis 1980). These costs can be minimized by reducing the materials’ moisture content through dewatering.

Common dewatering processes use a variety of mechanical apparatuses such as screw presses, belt presses, vacuum filters, etc. Separations involving other mechanical forces such as ultrasonic and non mechanical forces such as electric or magnetic fields have been used in a few specialized sectors (Muralidhara 1990). There are definite potential benefits in combining multiple dewatering fields.

In a dewatering process, there is no phase change, which means that the energy requirement is lower than for a conventional drying process. The energy requirement for dewatering increases very rapidly as the moisture content decreases. Dewatering is mostly a pre-drying process which reduces the moisture content, however not enough to ensure safe storage. Dewatering must be followed by a conventional drying process to attain a safe moisture level. Thus dewatering represents a way of reducing the cost of the drying process by reducing the overall energy requirement (Lightfoot and Raghavan 1995).

Electro-osmosis is the phenomenon of liquid moving through a porous solid as the result of a voltage applied across the mixture. Electro-osmosis is caused by the electrical double layer which exists at the interface of suspended colloidal particles (Lockhart 1983; Muralidhara 1990). In slurries, most solids have a slight electric charge compared to the water medium; this is referred to as the zeta potential. When exposed to an electric field, the electric double layer causes the motion of the particles (electro-phoresis) and the liquid (electro-osmosis). The solids are attracted to one electrode while the water migrates towards the other electrode. The product’s zeta potential rules the position of the positive and negative electrodes. For optimal process during electro-osmotic dewatering, the water content in the sludge bed moves from the top to the bottom electrode, hence the water content in the sludge bed decreases in the sludge portion near the top electrode where the electrical resistance is locally increased (Yoshida and Yasuda 1992). This increase in electrical resistance hinders the efficiency of dewatering, since the electric field strength is not uniform throughout the sludge bed. Therefore, it is considered that the sludge bed should be compressed forcefully to reduce the distance between the electrodes as the water is removed. This pressurized electro-osmotic dewatering can suppress or limit the formation of the unsaturated sludge layer (Yoshida and Yasuda 1992).

Combined fields dewatering cannot produce completely dry solids, but it can remove water in an economically bene-
ficial way (Muralidhara 1988). Indeed, when comparing thermal and electro-osmotic energy requirements for water removal from a clay slurry, it was found by Sunderland (1988) that the energy requirements were, respectively, 2400 MJ/m³ and 225 MJ/m³.

The purpose of this research was to study the possibility, for the food processing industry, of economically reducing the moisture content of waste with a dewatering process combining mechanical pressure with electro-osmosis, prior to a finishing conventional drying process.

MATERIALS AND METHODS

Waste material
Fresh apple pomace was obtained from a local apple juice producer. It contained pulp, peels, and cores and 1% rice hulls. Between 250 and 350 kg wet pomace is produced from each metric tonne of apples pressed for juice. Apple pomace may be used for vinegar or other by-product production as well as for livestock feed (NRC 1983). Apple pomace is palatable to cattle and sheep. The average digestion coefficients of wet apple pomace for ruminants are 37% protein, 46% fat, 65% fibre, and 85% NFE (NRC 1983). Fresh apple pomace (75-78% moisture) spoils rapidly and must be used quickly or be preserved through dehydration.

Fresh brewer’s spent grain (BSG) was obtained from a local brewery (69-71% moisture). BSG is an inexpensive source of essential food fibre and protein. It has more protein (25-30%) and dietary fibre (15-20%) than regular flour (Hanigan 1978). The BSG can be milled and added to commercial recipes to produce inexpensive and nutritious cookies, breads, and muffins for human consumption. BSG is presently used primarily as an animal feed; it may, however, be more profitable as an ingredient in human food products.

Fresh vegetable (81-82% moisture) waste was obtained from a wholesaler. At the fresh fruits and vegetables market level, a great deal of wastage occurs since only perfectly shaped, bruiseless, just ripe products appeal to the consumer. The dry matter values of vegetables from the Brassica family (cabbage, cauliflower, broccoli, etc.) show 29% crude protein, 11.63% crude fibre, 2.6% ether extract, 11.3% total ash, 45.8% NFE, 0.69% calcium, and 0.56% phosphorous (Francis 1980).

Each waste was divided into 1 kg samples and kept frozen in sealed containers throughout the testing period. Samples were taken out of the freezer, one at a time when needed. They were kept in a refrigerator to prevent spoilage before use, within 2-3 days, in the dewatering trials. Each test sample was left to reach room temperature before use.

Dewatering test apparatus (lab scale)
The experimentation of combined mechanical and electro-osmotic dewatering was performed with a simple lab-scale apparatus. The dewatering apparatus is shown in Fig. 1. It consists of a chamber made from a PVC pipe in which a carbon graphite electrode is positioned at the bottom of the cylinder. This electrode is held in place by an O-ring and a screw-in drain plug having a plenum with a hole for the passage of the electrode wire and for the exiting of the accumulated water. The lower electrode is perforated with 20 holes of 5.0 mm diameter to allow the drainage of both the water and the produced gases out of the waste material. A filter cloth is placed between the lower electrode and the waste material to prevent the material from clogging the perforations. Both lower and upper electrodes are made of carbon graphite disks of 12.7 mm thickness. An applied pressure supplied by a gas piston on the upper electrode and placed on top of the waste material completes the dewatering process by mechanical means. The polarity of both electrodes is chosen according to the polarity of the zeta potential of the waste particles. In the case studied here, a negative potential was found for all types of materials tested. With this negative potential, the signs of the two electrodes were set for optimal efficiency of the combined fields dewatering, i.e., the cathode was chosen as the bottom electrode, whereas, the anode was chosen as the top electrode. This choice favours the migration of the water out of the produce with gravity. Thus the suspended particles migrate toward the positively charged anode (top electrode) and the liquid phase moves toward the cathode filter (bottom electrode).

Combined fields dewatering tests were conducted by applying both pressure and an electric field supplied by a d.c. power source assuring constant applied voltage of 30 volts in the case of BSG with current intensity varying from 0.35 to 0.1 amps and constant current intensity of 0.15 and 0.30 amps with voltage varying from 30 to 5 volts for both the apple pomace and the vegetable sludge. The variations in current intensity and applied voltage were monitored during each test to estimate the electrical energy consumption. The choice of applied electric field was governed by equipment limitations. Indeed, in the case of BSG the power source could maintain a constant voltage, whereas in the case of apple pomace and vegetable waste, the power source could only be operated under constant current intensity.

Experimental design (lab-scale)
BSG In total, sixty 1-hour dewatering trials were conducted.
Economic considerations

For mechanical dewatering, the energy consumption is expressed as the compression energy:

\[ CE = PAD \]  

where:
- \( CE \) = compression energy (J/test period),
- \( P \) = pressure (Pa),
- \( A \) = area (m\(^2\)), and
- \( D \) = displacement (m/test period).

The displacement was measured using an IDU25E digital gauge with resolution of 0.01 mm (Mitutoyo Corporation, Japan). The displacement gauge was positioned on the piston arm which compressed the sludge bed.

Moisture content

The moisture content of each sample was determined by the air oven method (AOAC 1990). The decrease in moisture content due to the combined field dewatering was compared to the decrease in moisture content due to mechanical dewatering alone.

The filtrate extracted from the press cakes was collected for solids content determination using the air oven method. The solids content of the liquid fraction was used in material balance calculations.

RESULTS AND DISCUSSION

Effects of pressure and electrical current (lab-scale)

Liquid fraction Filtrate solids varied from 2-4.8% for apple pomace, from 3-4% for BSG, and from 4-5% for vegetable waste. No significant trend was found relating pressure and electric field to filtrate solids content (\( \alpha = 0.05 \)).

Solid fraction The percent solids of the press cakes are presented in Figs. 2, 3, and 4 for BSG, apple pomace, and vegetable waste, respectively. Only the results concerning the medium sample size are presented here. Similar results were obtained for the small and large sample sizes. The graphs clearly show the increase in percent solids from initial, to mechanical pressing, to combined pressing with an electric field.

For statistical analysis of the results, the parameters under study were arranged to study the effect of the different applied pressures, the three sample sizes, and the combined pressures and electrical fields.
electric fields. For all wastes, the results indicated a significant difference in solids content for the different applied pressures \((p=0.0001)\). For any pressure, the results indicated a significant difference in solids content between sample size \((p=0.01)\). This supports Schwerin’s (1902) comment that there is a maximum thickness for effective electro-osmotic dewatering. However, this study did not allow us to estimate that maximum electro-osmotic thickness. For any combination of pressure with an electric field, the results showed a significant increase in solids content when the electric current was increased from 0.15 to 0.3 amps \((p=0.0001)\) and finally for both apple and vegetable waste, the statistical analysis results showed a significant increase in solids content when the electric current was increased from pressure alone.

**Electric fields and energy consumption**

The voltage and current intensity drop data obtained during the monitoring of the combined fields dewatering trials were plotted versus time and curves were fitted to all graphs, and equations were derived. Each equation was significant at a 99% level of confidence (Steel and Torrie 1980). These equations were used in Eq. 2 to calculate the electrical energy consumption. Table I presents the combined electrical and mechanical energy consumption. The energy consumption is expressed in joules per kilogram of water removed. From Table I, the results of the BSG trials show that the applied electric field has an increased dewatering efficiency with an increase in applied pressure with electrical energy use of 1420 kJ/kg H₂O at 86 kPa brought down to 716 kJ/kg H₂O at 431 kPa. This supports the work of Yoshida and Yasuda (1992) in which it was stated that the dewatered bed should be compressed forcefully to limit the increase in electrical resistance which decreases the dewatering efficiency.

Such evidence of pressure benefit to electro-osmosis is not seen from the other two types of waste which have a relatively constant electrical energy consumption regardless of applied pressure.

The energy used by the combined electro-osmosis and mechanical dewatering is considerably higher than for mechanical dewatering alone. However, combining the processes results in an increase in solids content by a few percentage points prior to thermal drying which requires approximately 3.5 to 5 MJ/kg of water removed (Morey et al. 1976).

**CONCLUSIONS**

This study has proven the potential of combined fields dewatering as a pre-drying process to reduce moisture content, with an energy consumption although considerably higher than mechanical dewatering still representing an energy saving compared to thermal drying. The dewatering results have shown that the percent solids can be increased from 30 to 49% for BSG, from 23 to 53% for apple pomace, and from 11 to 67% for vegetable waste.

The best dewatering results were obtained in all cases when combining high pressure with high electric current. The addition of electro-osmosis considerably increases the energy requirement of the dewatering process, but it allows the increase of solids content by a few percentage points prior to the even more energy intensive finishing thermal drying process required to reach safe moisture content.

Mechanical dewatering is presently used in many industries as a pre-drying treatment. Simple, low cost modifications to equipment in order to benefit from combined fields have a lot of potential and warrant investigation as this dewatering technology will help to reduce the cost of by-product recovery.
Table 1: Electrical and mechanical energy requirements for different pressure-current combinations
(data is the average of two replicates for medium sized samples).

<table>
<thead>
<tr>
<th>Current / Voltage (amps/volts)</th>
<th>Pressure (kPa)</th>
<th>Electrical energy (kJ/kg H₂O removed)</th>
<th>Mechanical energy (kJ/kg H₂O removed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSG waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.35-0.08 / 30</td>
<td>86.2</td>
<td>1424</td>
<td>0.261</td>
</tr>
<tr>
<td>0.3-0.07 / 30</td>
<td>172.4</td>
<td>948</td>
<td>0.500</td>
</tr>
<tr>
<td>0.27-0.055 / 30</td>
<td>258.6</td>
<td>732</td>
<td>0.655</td>
</tr>
<tr>
<td>0.32-0.058 / 30</td>
<td>344.7</td>
<td>723</td>
<td>0.602</td>
</tr>
<tr>
<td>0.35-0.06 / 30</td>
<td>431.0</td>
<td>716</td>
<td>1.028</td>
</tr>
<tr>
<td>Vegetable waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3 / 8-13.5</td>
<td>172.4</td>
<td>173.7</td>
<td>0.126</td>
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<tr>
<td>0.3 / 6-16.5</td>
<td>301.7</td>
<td>187.5</td>
<td>0.161</td>
</tr>
<tr>
<td>0.3 / 6-15</td>
<td>431.0</td>
<td>172.5</td>
<td>0.241</td>
</tr>
<tr>
<td>0.15 / 5-9</td>
<td>172.4</td>
<td>48.0</td>
<td>0.094</td>
</tr>
<tr>
<td>0.15 / 5-10</td>
<td>301.7</td>
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</tr>
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<td>0.15 / 4-8</td>
<td>431.0</td>
<td>48.8</td>
<td>0.213</td>
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<tr>
<td>Apple waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3 / 23-27</td>
<td>172.4</td>
<td>1076.9</td>
<td>0.240</td>
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<td>0.3 / 24-30</td>
<td>301.7</td>
<td>1182.9</td>
<td>0.330</td>
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<td>0.15 / 10-13</td>
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<td>269.4</td>
<td>0.604</td>
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REFERENCE


