Pulsed Electric Field Treatment of Sugar Beet

N. Nakthong¹ and M N Eshtiaghi²

1 Postdoctoral researcher at Mahidol University, Thailand
2 Prof. at Mahidol University, Thailand
E-mail: mohammad.esh@mahidol.ac.th

Abstract. The effect of high electric filed pulses on sugar extraction from sugar beet strip during continuous pilot scale extraction was investigated. The results have shown that sugar beet strip could be extracted at moderate temperature (35-50°C) using PEF pre-treatment. The sugar extraction yield of PEF pre-treated samples was about 98.5 to 99.8 % (for extraction times of 30 an 70 min at 50 °C respectively). In contrast, the sugar extraction yield for untreated samples was distinct lower (92.5 % at 50 °C, 30 min and 94 % at 50 °C and 70 min extraction time. In additions, the pressing of PEF pre-treated extracted pulp was more effective than thermal extracted (at 70 °C) sample. Furthermore, the drying of PEF pre-treated extracted pulp was faster than drying of pulp from thermal extracted sample. The results of this study confirmed that the PEF technique is an energy and time saving method for continuous sugar beet processing.

1. Introduction
The application of PEF in food processing gained considerable attention within the last decades, utilizing its impact on cell membranes permeabilization. Apart from preservation the disintegration of biological tissue is often a key step in food processing prior to extraction of intracellular compounds. It is noteworthy that an electro-permeabilization can be performed continuously and in a time scale of seconds. The PEF treatment therefore can easily be implemented into existing processing lines. Conventional procedures for production of sugar from beets involve an extraction at elevated temperature (68-72 °C) after carving the beets into cossettes. The thermal denaturation as well as the hot water extraction requires a significant amount of energy, as high as 175 kJ/kg of treated beet [1]. PEF treatment of sugar beets prior to extraction could increase mass transfer rates and could allow to reduce extraction temperatures. The applicability of a PEF pretreatment prior to an extraction at ambient temperature has been investigated by researchers [2], [3]. It was shown that after a PEF treatment at 2.4 kV/cm and a pulse number of 60 with a energy consumption of about 10 kJ/kg, similar cell disintegration was acheived compare to a thermal treatment at 75 °C for 15 min. A three-step pressing at a pressure of 5 MPa and intermediate addition of water was suggested to achieve a high sucrose content juice after a short processing time of 30 min in comparison to up to 90 min for thermal extraction[2,3,4]. Bouzraraand Vorebiev [5] reported a juice yield of 78 % sugar extraction after application of 1000 pulses with a peak voltage of 1.2 kV. Schultheiss et al. [1] reported an increase of juice yield by factor of 2.1 after a PEF treatment with 2-3 kJ/kg energy input in comparison to an untreated sample. Raw sugar beet juice quality was maintained or improved even when using low quality beet as raw material. El-Belghiti et al. [6]developed a two–exponential kinetic model to describe diffusion during extraction of sugar from sugar beet. Optimum PEF processing parameters have been identified as 0.67kV/cm and a pulse number of 250. The aim of this study was to design and implement a continuous working pilot scale PEF chamber suitable for cell disintegration of sugar.
beet strip. In addition, the effectiveness of this PEF chamber for cell permeabilization and sugar extraction was studied and compared with conventional thermal processing.

2. Materials and methodology

2.1 Raw material
The fresh sugar beet was washed and cut into strips with about 5 to 6 mm thickness and 50 to 80 cm length using a household grinding machine.

2.2 Pulsed electric field treatment
The Pulsed electric field treatment was carried out using a high voltage DC generator (max. 10 kV). The capacity of applied capacitors was 4 µF. The applied high electric pulses were exponential shape with pulse duration of about 0.5 ms/pulse.
The continuous operating treatment chamber consisted of 2 parallel, half circle, acrylic plate (gap 10 cm) with a radius of about 40 cm and a volume of about 14 liters (Fig. 1 and 2). Two electrodes with a surface area of 200 cm² were oriented parallel inside the treatment chamber (Fig. 3). The sample was manually directed into the treatment chamber with a flow rate of about 12 kg/h. The relation between sample and treatment media inside the continuous PEF chamber was about 1:1. The PEF treatment carried out at constant voltage and pulse frequency (9kV, 10 Hz respectively).
The energy consumption per kg of sample during PEF treatment was calculated using the following equation:

\[ Q = \frac{V^2 \cdot C}{2 \cdot n} \]

Where V (in volt) is the peak value of the decaying voltage in the sample, C is the capacity of condenser (in Farad), m is the mass of sample (kg), and n is the pulse number per kg of sample.
The energy input per kg of sample was about 10kJ/kg and the temperature increase due to PEF treatment was about 2.5 °C.

Figure 1. Schematic of experimental equipment with continuous PEF treatment chamber
2.3 Cell disintegration experiment
Sugar beet was sliced in thin strips (3 to 4 mm thickness and about 3 to 5 cm long). Untreated, PEF pre-treated (0.9 kV/cm, 10 pulses), and thermal treated (during diffuser transportation at different retention times) were subjected to determination of cell disintegration. The cell disintegration index ($Z_p$) was determined as described by Angersbach and Knorr [7, 8]. $Z_p=0$ implies total intact cells and $Z_p=1$ indicates complete cell disintegration.

2.4 Sugar extraction
The sugar beet strip with or without PEF treatment was extracted in a pilot scale counter current diffuser using top water (35 °C). The effective volume of diffuser was about 80 liter and length was 2 m (figure 3). The diffuser temperature was about 70 °C (untreated), or 50 °C and 35 °C (for PEF pre-treated) at inlet section and about 35 °C at outlet section. The temperature inside the diffuser was measured in 5 different positions along the diffuser and recorded. The relation between flow rate of sugar beet and extraction water (deduction) was about 1: 1.1. The retention time of sample in the diffuser was adjusted to 70 and 30 min. by mean of adjusting the transport speed of screw inside the diffuser. The flow rate of sugar beet strips in the diffuser was adjusted for 30 ± 4 kg and 80 ± 10 kg for experiments with extraction time of 70 min. and 30 min. respectively. The sugar beet juice was taken after 2 times of running time of diffuser (after 60 min continuous extraction of experiment with 30 min retention time in diffuser and after 140 min for extraction experiment with retention time in diffuser of 70 min. respectively) to assure homogeneity sampling.
2.5 pressing
The extracted sugar beet was pressed in a batchpilot scale (uniaxial press, press-cake thickness ≈ 0.5-1 cm, 5 kg sample weight) hydraulic press (Siefertcompant, Germany) at constant time and pressure (10 min and 50 bar respectively).

2.6 Drying
The pressed pulp was dried in a fluid bed dryer (ATP-Berlin, Germany) at 70 °C until constant weight.

2.7 Analytical methods
Dissolved dry substances (°Brix value): measurement of the dissolved dry substances followed the IFU No. 8 method (°Brix= total soluble solid content [g/100g]).
Sucrose content (°S): polarimetry method as described by Werner [9]: Warm water digestion: 26 g of sample or 60 g of extracted strips were mixed in a beaker containing 177 ml 2.5% lead acetate solution. The suspension was filtered and the optical rotation was analyzed by polarimeter (°S= Sucrose content [g/100g]).
Dry matter (gravimetric method): 2-5 g of sample or extracted sugar beet strips were rubbed (sea sand) and placed in the oven dryer (103±2 °C) until constant weight was achieved.

Purity: Juice/ press water purity was calculated as

$$\text{Purity} (%) = \frac{°S}{°\text{Brix (juice)}} \times 100$$

Acidity: the sample was titrated using 0.1 n NaOH up to pH=7.0 and the acidity was reported as mg CaO.

3. Results and discussions
The thermal disintegration of untreated sugar beet strips within diffuser increased with increasing extraction time (figure 4). For sample with extraction time (retention time in diffuser) of 30 min and extraction temperature of 70°C was total cell disintegration after 15 min. obvious. In contrast, thermal extraction of untreated sample at 50 °C resulted less than 50 % cell disintegration after 30 min extraction time and about 70 % cell disintegration after 70 min. This indicates that for thermal sugar beet permeabilization an extraction temperature higher than 50 °C in diffuser is necessary (figure 5). Interestingly, using PEF pre-treatment at room temperature instantaneously up to 90 % cell disintegration after 125 pulses at field strength of 0.9 kV/cm was achieved. In general PEF pre-treatment could increase sugar extraction compare to conventional extraction and at constant temperature. Whereas sugar yield of untreated sugar beet at 50 °C and extraction time of 30 and 70 min was less than 94%, was the sugar yield of PEFpre-treated sample at the same extraction temperature and time as untreated sample distinct higher (up to 99.6%) and comparable to thermal extracted (70°C, 70 min) sugar beet (99.4%) (figure 6). This indicates that it is possible to extract effectively sugar beet at moderate or low temperature using PEFpre-treatment. Because of very low energy consumption during PEFpre-treatment (about 10kJ/kg) and drastic reducing of energy consumption during extraction of sugar cane the PEF technique could be a suitable method to reduce the energy consumption during sugar extraction from sugar beet.
Figure 4. Measurement of cell disintegration during extraction in diffuser at 70 °C

Figure 5. Measurement of cell disintegration during extraction in diffuser at 30 and 50 °C

Figure 6. Effect of thermal and PEF treatment on sugar yield

Table 1. Effect of PEF treatment and subsequent extraction at different temperature on pH-value, acidity and juice purity compare to thermal extraction
The comparison between the chemical compositions (pH, acidity, purity) of juice extracted from untreated and PEF pre-treated is shown in table 1. The pH value of PEF pre-treated and subsequent extracted at 35°C was distinct lower (5.26 to 5.49) compared to PEF pre-treated or untreated samples extracted at elevated (50 °C) or high temperature (70°C). The lower pH value and higher acidity of samples extracted at 35 °C is probably because of microorganism activity in the sample during long extraction time. Lactobacillus bacteria could grow fast at temperature about 35 °C and convert sugar to lactic acid followed by decreasing of pH and increasing of acidity in extracted juice. Further investigations are necessary to confirm this hypothesis. Adding Ca(OH) during sugar beet extraction could increase the pH in extraction juice and prevent the microorganism growth during extraction in diffuser.

The purity of extracted juice was in the case of PEF pre-treated and subsequent extracted samples similar to the untreated extracted samples (table 1). Interestingly, the pressing of extracted sugar beet (pulp) was much more effective in the case of PEF pre-treated samples compared to thermal extracted. The weight of pressed pulp was in the case of thermal extracted sample about 26 to 27%. In contrast the weight of pressed pulp of PEF pre-treated samples was about 21 to 24% (figure 7). The higher amount of remaining water in thermal extracted sample is maybe because of binding of water molecules with cell wall polymers (specially pectin) and gel formation at high extraction temperature (≥70 °C). The weight reduction during pressing of pulp is important because of economical aspect. Generally water removing using mechanical method (pressing) is cheaper than thermal water removing.

The measurement of press water (liquid phase after pressing of extracted pulp) showed clearly the advantage of PEF pre-treatment for sugar beet extraction (table 2). Whereas the brix value of press water in the case of untreated sample extracted at 50 °C was higher than 6 %, was the brix value of press water for PEF pre-treated and subsequent at 50 °C extracted samples less than 1.5%. Additionally, the purity of press water of PEF pre-treated samples comparable or slightly lower compare to press water of untreated samples.
**Figure 7.** Effect of thermal and PEF treatment on pulp weight after pressing

**Table 2.** Effect of PEF pre-treatment on quality of press water from extracted pulp and sugar free dry mater of dried pressed pulp

| treatment          | Brix of press water (%) | Purity of press water (%) | Sucrose free dry mater of dried pulp (%) |
|--------------------|-------------------------|---------------------------|-----------------------------------------|
| Ub75 °C, 70 min    | 1.13±0.11               | 0.57                      | 6.5                                     |
| Ub65 °C, 30 min    | 1.75±0.11               | 0.46                      | 7.4                                     |
| Ub50 °C, 70 min    | 6.5±0.19                | 0.91                      | 6.7                                     |
| Ub50 °C, 30 min    | 7.28±0.11               | 0.95                      | 6.3                                     |
| PEF50 °C, 70 min   | 1.07±0.05               | 0.84                      | 8.0                                     |
| PEF50 °C, 30 min   | 1.48±0.08               | 0.88                      | 6.8                                     |
| PEF35 °C, 75 min   | 2.15±0.05               | 0.74                      | 7.5                                     |
| PEF35 °C, 30 min   | 2.15±0.09               | 0.79                      | 6.9                                     |

Drying of pressed pulp have shown that the PEFpre-treated and subsequent extracted samples at 50°C could be dried faster (20 min) compare to thermal extracted (at 70 °C) samples without PEFpre-treatment (30 min)(figure 3). This made the energy and time saving advantages of PEFpre-treatment during drying of pulp obvious. The increased drying rate of PEF pre-treated pressed pulp is maybe because of lower temperature during extraction and less thermal degradation of cell wall materials (pectin, cellulose). At high extraction temperature above 70 °C, the pectin substances in cell wall perhaps absorb water and induced gel formation. The bonded water molecule in the pectin network is difficult to remove during pressing and drying. In contrast, PEF pre-treated samples could be extracted at moderate temperature (about 50 °C) without or only with slight thermal degradation of cell wall biopolymer and less gel formation of cell wall materials. This could explain the effective dewatering of pulp during pressing and faster drying during fluid bed drying.
4. Conclusion
Using PEF pre-treatment it was possible to extract sugar beet at moderate (50 °C) or even at room temperature (35 °C) compare to conventional thermal extraction at 70 °C. This indicates the advantage of PEF technique for energy saving during sugar extraction from sugar beet. In addition, the remaining sugar in pressed pulp of PEF pre-treated sample was distinct lower compare to untreated extracted sample. Drying of PEF pre-treated pulp was effective and faster than thermal (at 70 °C) extracted samples. Faster drying time during drying process offers additional energy saving possibility in energy intensive sugar beet processing.

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