Qualitative characteristics of sugar beet juices obtained in pilot extractor with pulsed electric field (PEF) pre-treatment.
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ABSTRACT
The conventional method of sugar extraction from sugar beets requires high temperatures (70–72 °C) and rather long duration (70 min). It results in high content of impurities (like pectins and melanoidins) in obtained juices and high water and energy consumption.
This work studies the sugar extraction from sugar beets preliminary pre-treated by pulsed electric field (PEF). The extraction was carried out in a countercurrent pilot extractor with 14 extraction sections. The cossettes were obtained by semi-industrial slicing machine. The extraction temperature varied from 70 to 30 °C, and draft (juice to cossettes ratio) changed from 120 to 90%. The PEF treatment was done with electric field intensity between 100 and 600 V/cm.
The quality of extracted juices was characterized by measuring the content of soluble solids (in °Brix), sucrose content (by polarimetry), juice purity \( P = \frac{\text{sucrose concentration}}{\text{total soluble solids}} \), concentration of colloidal substances (or alcohol in soluble solids), concentration of pectin (enzymatic determination) and proteins (Bradford method). UV-Vis absorption spectra of juices were also compared.
The sucrose content was measured in cossettes and in pulp for control of sugar losses and kinetics of cossette exhaustion during processing.
It was shown that juice obtained by mild thermal (50 °C) and cold (30 °C) extraction has higher purity, lower concentration of colloidal impurities (especially, pectins) and lower coloration. Diminishing of draft permitted better concentration of the extracted juice, but the cossettes were worse exhausted. The value of draft should be considered as a function of different factors like permissible sucrose loss in the pulp. The pulp obtained by cold extraction of PEF-treated cossettes had dryness noticeably higher than the dryness of the pulp obtained by conventional hot water extraction.
The obtained data confirm that “cold” sugar extraction assisted by PEF treatment may be a promising energy-saving method, permitting obtaining of high quality juices.

Keywords: sugar; extraction; pulsed electric field; juice quality; pilot extractor.

INTRODUCTION
The conventional technology of sugar extraction from beetroot includes thermal denaturation of sliced beetroot tissue followed by aqueous diffusion in hot water at 70–75 °C. The thermal treatment leads to the breakage of cellular membranes and tissue denaturation. However, thermal extraction results in a number of undesirable processes. Not only the cell membranes are destroyed, but the cell walls also change their inner chemical structure through reactions of hydrolytic degradation (molecular chain breakages and detachment of polysaccharide fragments [1]. Besides sucrose, other cell components (e. g. hydrosoluble pectins) penetrate through the cell wall and pass into the juice. These pectins and other impurities deteriorate the juice quality and complicate tremendously the subsequent process of juice purification. Moreover, thermal diffusion promotes formation of some colorants like melanins, which results in a brownish yellow near black colour of the extracted juice. The thermally induced degradation of beet tissue, extraction of non-sucrose cell components and formation of colorants decrease the juice purity and it requires further purification.
During the last decade, appreciable results were obtained in the development of non-thermal methods of cell damage based on the pulsed electric field (PEF) treatment. Under the effect of PEF (applied from several microseconds to several milliseconds), the membrane becomes permeable for small molecules and even some macromolecules. Recently, the PEF-assisted pressing and aqueous extraction from sugar beets were intensively studied. The alternative studies have shown the principal possibility of sugar extraction by cold or
moderately heated water [2], the thermal and cold diffusion kinetics were compared and diffusion coefficients $D_{eff}$ for untreated and PEF-treated sugar beet tissue were evaluated [3]. Also, it was reported that the purest juice was obtained after the cold diffusion.

Most of the published results on kinetics of sugar diffusion from PEF-treated sugar beets are limited by the small scale laboratory studies using a single tissue sample or a small quantity of sliced material in a batch extraction chamber. However, the industrial sugar extractors are continuous apparatus with sugar beet cossettes and hot water flowing in countercurrent. So, the confirmation of the encouraging results obtained with PEF-treatment in batch extraction chambers is still needed to predict the PEF efficiency on the industrial scale.

This work is aimed at approach of the study of sugar diffusion from sugar beets treated by PEF to the industrial conditions using special countercurrent extractor. The parametric study was carried out for investigation of the effect of electrical (intensity of PEF) and main extraction parameters (temperature, draft) on the sugar diffusion kinetics, as well as on the juice and pulp characteristics.

**MATERIALS & METHODS**

The field-grown sugar beet roots (Beta vulgaris) were provided by sugar plant in Chevrières, TEREOS, France. The sugar beet roots were cut in the cossettes using pilot slicing machine (British Sugar, England). The industrial knife blocks were provided by MAGUIN (France). The quality of sliced sugar beet cossettes was characterized by two main parameters: Silin number and mush content [1].

Extraction was carried out in a specially developed pilot countercurrent extractor with a double envelope to maintain the desired temperature of extraction. It consists of 14 rectangular communicating sections separated by a double wall allowing the water flow from section to section. The perforated plastic baskets filled with 500 g of cossettes were moved manually between the neighbouring sections each 5 min in the direction opposite to water flow. Construction and detailed principle of this extractor were reported [4].

The total time of extraction was 70 min. The temperature of diffusion varied in different experiments from 30 to 70 °C. In some experiments the draft value (diffusion juice to cossettes ratio) varied between 120 and 90%, but typically it was fixed at 120%. Exhausted cossettes (pulp) after extraction were pressed during 30 min under the pressure of 6 bars, using a laboratory press with elastic diaphragm.

The portions of extracted juice were regularly sampled for measuring of the soluble solids (°Brix) and sucrose content. The portions of pulp were sampled for measuring of the insoluble solids, °Brix and sucrose content. Soluble solids measurements (°Brix) were done by means of digital refractometer. Sucrose content in juice and cossettes was determined by polarimetry method. And juice purity was calculated as: $P = \frac{\text{Sucrose content}}{\text{Soluble solids content}} \times 100\%$. The total concentration of colloids and polymers in extracted juice was measured by means of precipitation in ethanol. The concentration of proteins was determined by means of Bradford method. The concentration of pectins was measured by enzymatic method using Pectin identification procedure.

UV-Vis absorption spectra of the juices and filtrate samples were measured by means of UV-spectrophotometer. The wavelength range was within 220–900 nm (with the precision of ±1 nm). The path length of the quartz cuvettes was 10 mm. The coloration and turbidity of juices and filtrates were measured and calculated according to recommendations of ICUMSA. The juice turbidity was expressed as the difference between the absorbance measured at 720 nm before and after the sample filtration through the 0.45 μm membrane. The coloration of juices (pre-filtered through the 0.45 μm membrane) was calculated as: $\text{Coloration} = \frac{\text{Absorbance at 420 nm}}{\text{Brix}} \times 100\%$.

The pilot PEF generator (Hazemeyer, 5000 V, 1000 A, France) was used in this study. The PEF generator provided the monopolar pulses of a near-rectangular shape. The intensity of electric field typically was fixed at $E = 600$ V/cm. One train of pulses was used for PEF treatment. The train consisted of $n$ pulses ($n = 500$) with pulse duration $t_i = 100\ \mu$s and pulse repetition time $\Delta t = 5$ ms. The total time of PEF treatment was $t_{PEF} = 50$ ms (that corresponds to 5.4 kW·h/t of energy input). Such parameters of PEF treatment protocol were selected according to the previously reported data [5], [6]. In some experiments with higher diffusion temperature (60 °C), the value of $E$ was varied between 600 and 100 V/cm.

**RESULTS & DISCUSSION**

*Influence of extraction temperature on juice quality.*

Fig. 1 presents the sucrose content and the purity of final juices obtained by diffusion of untreated and PEF-treated cossettes. For the untreated cossettes, the sucrose content in a cold diffusion juice was very low (< 6%
at 30 °C) and the purity of a cold juice was < 80%. This result confirms once more the necessity of thermal diffusion, which permits the sucrose content of about 14% and the juice purity of more than 90% at 70 °C (Fig. 1). For the PEF-treated cossettes, the sucrose content in a cold diffusion juice (30 °C) was slightly lower (about of 13%) than in a hot diffusion juice (70 °C). However, the purity of a cold diffusion juice obtained from the PEF-treated cossettes was not lower than the purity of a hot juice. The general tendency is that the extraction of sucrose from PEF-treated cossettes decreases slightly with decrease of diffusion temperature from 70 to 30 °C. However, the juice purity does not decrease and remains approximately the same in the total range of studied temperatures (between 30 and 70 °C). Concerning the juice purity, more detailed study is needed to analyse the cold juice characteristics after the standard juice purification. This work is limited by evaluation of the purity of diffusion juice (before purification). Nevertheless, the high values of diffusion juice purity after the PEF treatment indicate the selectivity of sucrose extraction.

![Figure 1](image1.png)

**Figure 1.** Sucrose content and purity of juices extracted from non-treated and PEF treated cossettes versus diffusion temperature.

However increase of the extraction temperature can result in decomposition of the cell walls and substantially accelerates extraction of different oligo- and polymolecular compounds, which are the main constituents of the cellular walls and membranes. The temperature increase also accelerates various chemical reactions between extracted components of the cellular juice (e.g., colour development due to Maillard reaction). The temperature enhanced extraction of high molecular weight compounds and formation of undesirable products of chemical reactions results in decrease of extracted juice quality. This may be detected by more sensitive methods of analysis.

The results of more detailed analysis of the juice quality (total colloidal compounds, proteins, pectins, coloration and turbidity of extracted juices) are presented in Fig. 2 and Fig. 3. The concentration of colloidal impurities is significantly higher in a “hot” juice than in a “cold” juice (Fig. 2). The total concentration of colloidal compounds almost corresponds to the sum of concentrations of the proteins and pectins and it may be assumed that pectins and proteins are the main high molecular weight impurities present in the extracted juice.

The measured concentrations of proteins in the extracted juices were low (0.055 ± 0.002%) and did not depend on the temperature of extraction. Such behavior may be explained by assumption that the proteins pass into the juice from the cells that were damaged during cutting of the sugar beet cossettes. Thermal disintegration of the sugar beet cells at 70 °C did not result in additional extraction of proteins, probably, due to their coagulation in cells.

From the other side, the temperature increase above 50 °C resulted in solubilization of pectins. At high temperature pectins passed into the juice (Fig. 2) and decreased its purity. Increase of pectin concentration in the sugar beet juice during the “hot” extraction may significantly deteriorate its technological properties.
Presence of polymers increases juice viscosity, decreases crystallization rate, decreases juice filterability and recovery of valuable compounds (e.g., sucrose) [1].

The coloration and turbidity of extracted juices versus the temperature of extraction are presented in Fig. 3. Increase of extraction temperature from 30 to 70 °C resulted in increase of turbidity by 10% (± 5%) and juice coloration by 27% (± 5%). It is known that colour development during the sugar beet juice extraction may have different mechanisms: enzymatic browning (formation of melanins), Maillard reaction between amino compounds and reducing sugars (formation of melanoidins), thermal degradation of sucrose and hexoses (formation of caramels and HADP) [1], [7], [8]. The kinetics of color formation reactions (except for enzymatic browning) and yield of colored compounds (melanoidins, HADP, caramels) was enhancing with the temperature increase [7], [8]. Therefore, decrease of extraction temperature from 70 to 30 °C may prevent or retard formation of melanoidins during extraction of sugar beet and results in lower coloration and better quality of juices (Fig. 3).

**Influence of extraction temperature on pulp pressing.**
Pressing of exhausted sugar beet pulp is a very important operation facilitating its transportation and storage [1]. Mechanical dewatering of pulp is less energy consuming than thermal drying. Therefore, many efforts were done in the sugar industry for increasing dry matter of pulp by pressing. Actually, the modern screw presses permit increasing of dry matter in a pulp to 28–32% [1]. Up to now, the influence of PEF treatment on the pressing efficiency of exhausted sugar beet pulp was not investigated.

Fig. 4 presents the dryness of pulp obtained at different extraction temperatures before and after the pressing. All the pulp samples were well exhausted (the losses of sucrose in a pulp were less than the optimum value of 0.4% on beet). The dryness of the pulp before pressing (5–6.4%) was nearly independent of diffusion temperature (Fig. 4). On the contrary, the pressing efficiency depended very significantly on conditions of diffusion of the PEF treated cossettes. After PEF treatment of cossettes and subsequent cold diffusion (at 30 °C), the pulp dryness was high (> 30%). The pulp dryness was lower after exhausting of cossettes at higher temperatures. For instance, the pulp dryness was respectively 26 and 21% for the cossettes treated by PEF and exhausted at 50 and 60 °C. The dryness of the pulps obtained from PEF treated and untreated cossettes was nearly the same (16–17%) after their exhaustion by hot water (70 °C). It is well known that pectic substances presented in a beet tissue swell at higher diffusion temperatures [1]. Swollen polymers can obstruct pressing. The obtained pressing results are very promising. However, more studies will be needed for their confirmation and scale up.
Draft is a factor that defines water consumption in diffusion process. In industrial conditions the draft is usually equal to 120% [1]. Such value of draft was generally accepted in order to assure sufficient exhausting of cossettes. Diminution of draft leads to the increase of sugar loss in a pulp, while increase of draft causes additional water consumption and additional energy consumption for juice evaporation [1]. Implementation of diffusion technology with PEF treatment may change the optimal value of water used in extraction process and the optimal value of draft. Therefore, the influence of draft on the extraction kinetics was also investigated in this study. The draft was varied in the range of 120–90% for the diffusion of PEF treated cossettes at 70 °C and at 30 °C. Fig. 5 shows the influence of draft and diffusion temperature on the sucrose content in a final diffusion juice. Evidently, the sucrose content in diffusion juice increases with draft decrease for both studied temperatures. However, for better estimation of the advantages of draft decreasing, the sucrose loss in a pulp should also be evaluated. For example, the loss of sucrose in a pulp after the treatment of cossettes by PEF and their exhaustion in water at 30 °C, was 0.29 °S for the 100% draft and 0.77 °S for the 90% draft. On the other hand, some additional quantity of sucrose remaining in a pulp raises its nutritive value and can be desirable in some of its applications for animal feed.

**Figure 4.** Dryness of the pulp (before and after pressing) versus diffusion temperature.

**Figure 5.** Influence of draft and extraction temperature on sucrose content in the diffusion juice

**Figure 6.** Influence of applied electric field strength on sucrose concentration in diffusion juice obtained at 60 °C.
Influence of voltage

It was shown previously [3], [9] that preheating of the plant tissue decreases membrane electroporation threshold and makes the PEF treatment efficient at lower electric fields. Therefore, in the present study some experiments were conducted with low PEF treatment of cossettes under the diffusion temperature of 60 °C. In these experiments, the PEF intensity \( E \) varied from 0 to 600 V/cm and the value of draft was fixed (120%). Fig. 6 presents the sucrose content after the thermal diffusion of juices treated by PEF of different intensities \( E \). It can be seen from Fig. 6 that increase of \( E \) value from 257 V/cm to 600 V/cm does not enhance the sucrose extraction and is unnecessary for diffusion at 60 °C. From the other hand, lower values of \( E \) (100–150 V/cm), decrease sucrose concentration in a juice. In such case, diffusion at 60 °C is less effective. Evidently, the optimal value of \( E \) was 257 V/cm for diffusion at 60 °C. The PEF treatment of mildly heated cossettes can be an interesting alternative solution when very high throughputs of sugar beets should be treated and high intensity PEF treatment is difficult to implement.

CONCLUSION

The principal possibility of cold and mild thermal extraction of sucrose from sugar beet cossettes treated by PEF is confirmed by experiments with a pilot countercurrent extractor. Diffusion juice obtained by cold extraction (at 30 °C) has purity that is not lower than the purity of a juice obtained by conventional hot water diffusion at 70 °C, lower concentration of colloidal impurities (especially pectins) and lower coloration. Sugar beet pulp can be well exhausted by cold or mild thermal extraction of cossettes treated by PEF. Decreasing of draft permits better concentration of the extracting juice, but the cossettes are worse exhausted. The value of draft in a case of cold extraction of the PEF treated cossettes should be considered as a function of different factors like permissible sucrose loss in the pulp. Increase of the temperature of the extracting liquid up to 50 or 60 °C permits better concentration of diffusion juice, decrease of the time of diffusion and treatment of cossettes by PEF with lower intensity. The dryness of pulp obtained by cold extraction of PEF treated cossettes is noticeably higher than the dryness of pulp obtained by conventional hot water extraction.

For cold and mild heat extraction (30–60 °C) the optimal parameters of PEF protocol were between \( E = 600 \) V/cm (at 30 °C) and \( E = 260 \) V/cm (at 60 °C). The value of draft can be decreased from 120% to 100% or even to 90% for the extraction duration of 70 min if the PEF treatment is associated with mild heating. The obtained results are very promising but should be confirmed in the future studies on semi-industrial scale.

REFERENCES