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APPLICATION OF HIGH ELECTRIC FIELD PULSES FOR SUGAR CANE PROCESSING

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ABSTRACT

The effect of high electric field pulses (HELP) on cell disintegration of sugar cane was investigated. The sugar cane was treated at different field strength (4 to 5 kV) and pulse number (10 to 80 pulses). The juice yield as well as mass transfer of HELP pre-treated sample was measured and compared with heated (20 min, 70º C) or untreated sample. The results showed that using HELP treatment at 4 to 5 kV the sugar cane cells could be effectively disintegrated. The mass transfers of HELP treated samples were comparable to heat treated samples. The juice yield of HELP pre-treated samples was higher (74.5% at 5kV, 20 pulses) than heat treated (73.2%) and untreated sugar cane (65.5%). The energy consumption for HELP disintegration of sugar cane (17 kJ/ kg at 5kV and 20 pulses) was 10 times less when compared to heat treatment (171 kJ/ kg). Additionally the cell disintegration using HELP occurred faster (less than 2 min with 1Hz pulses frequency and 80 pulses) than thermal disintegration (20 min at 70° C).

KEYWORDS: Sugar cane, high electric field pulses, juice yield

1. INTRODUCTION

Conventional procedures for production of sugar from sugar beets and sugar cane involve an extraction at elevated temperature (68-72 °C). The membrane denaturation due to heat treatment results in an acceleration of sugar release into the extraction media, but also cell wall components such as pectin may become soluble and can diminish juice purity and quality. In addition, the thermal denaturation as well as the hot water extraction require significant amount of energy, as high as 175 kJ/kg of treated sugar beet [1]. It has been shown that mechanically pressed, raw juice has a higher sugar concentration and contain less non sugars, but juice yield remains unacceptable [2].

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The possibility of using high intensity electric field to permeabilize the cell membrane of plant materials was discovered between the 60s and 70s [3, 4]. When an external electric field (E) is applied to a cell, a transmembrane potential is induced. Strong polarization of viable cells by an external electric field leads to an increase in cell membrane conductance and permeability [3].

The application of HELP in food processing gained considerable attention within the last decades, utilizing its impact on cell membranes. Apart from preservation the disintegration of biological tissue is often a key step in food processing prior to winning of intracellular compound. It is noteworthy that an electro permeabilization can be performed continuously and in a time-scale of seconds, the treatment therefore can be implemented into existing processing lines [5].

The extraction of juice from fruits and sugar beet by permeabilization of the cell membranes using high electric field pulse was studied by Bazhal and Vorobiev [6] and Flaumenbaum [7]. The preparation of carrot mash using HELP was investigated by Geulen [8] where juice extraction was shown to increase from 62% to 75%. Eshtiaghi and Knorr [9] found that HELP treatment increased the juice yield from grapes, apples and black currants. The concentration of quality indicators (i.e. acidity, soluble dry substance and colorant) was significantly higher in juices of HELP treated fruits as compared to those from untreated fruits. Bouzrara and Vorobiev [10] have studied the effect of pulsed electric field on beet juice extraction. The application of HELP pretreatment for cell disintegration during sugar beet extraction has been provided by Eshtiaghi and Knorr [11]. They have shown that the HELP treatment (20 pulses, ~2.5 kV/cm, 5 µF, 1 to 6 Hz pulse frequency) rapidly performed disintegration of sugar beet cell membranes in 20 sec or less. It was observed that in particular, field strength (1.2 to 2.5 kV/cm) and pulse number (1 to 200) had key influence on the disintegration. Apart from the conventional thermal cell disintegration (at 75 to 80°C) followed by extraction, it was possible to extract sugar beet after HELP pretreatment at ambient temperatures.

In addition the improvement of extraction and mass transport processes by HELP can be achieved with lower energy usage and shorter timescale than using heat or mechanically cell disintegration. The energy required for sugar beet cell integration at 60 pulses was about 12kJ/kg compare to thermal cell integration with 170 kJ/kg [12].

There is no available study about the application of HELP technology by the sugar cane processing for increasing the extractability of sugar during sugar cane extraction.

This study was aimed to investigate the effect of HEILP on sugar extraction from sugar cane and the effect of pulse number and field strength on juice yield and mass transfer.

2. MATERIALS AND METHODS

2.1 Raw material

Sugar cane from Salaya market (Nakhornpathom province, Thailand) was used as raw material. Sugar cane was cut into 10 to 15 cm cylinder length.

2.2 Analytical methods

Total soluble solids (°Brix value= °B-value): measurement of the dissolved dry substance followed the IFU No. 8 method (°Brix = total soluble solid in 100 g liquid sample). The sugar content in juice as well as in treatment medium (leached sugar in treatment medium during heat and HELP treatment) and the measurement of sugar leaching during mass transfer experiment carried out by refractometer (ATAGO, Japan).

For calculation of total sugar extracted during pressing the following equations was applied:

$$S_{juice} = °B_{juice} \times \text{juice yield} \qquad \text{equation (1)}$$

S_{juice} = sugar extracted during pressing (g/ 100 g juice)

°B_{juice} = refractometer value for total soluble solids (as g/100 g liquid)

The leaching of sugar during treatment (heat or HELP treatment) was taken in to account to calculate total sugar (as soluble solid matter) extraction (equation 2):

$S_T = S_{juice} + S_{leach}$ equation (2)

S_T = total sugar extraction

S_{leach} = sugar in treatment medium (g/100 g treatment medium)

2.3 High electric field pulse treatment

For high electric field pulse treatment a laboratory scale high voltage equipment built up in Mahidol University was used (Figure 1). The specification of equipment was as follows:

High voltage transformer: 15 kV, 400 W (LECIP NEON Transformer, Model EX230A 15 N, Japan),
High voltage capacitance: 6 kV, 28 µF (MAXWELL, Maxwell Laboratories Inc, California)
High voltage spark gap: Adjustable spark gap (built up in Mahidol University)
Treatment chamber: 375 ml (L*H*B = 15*2.5*10 cm)
The pulse form applied in this study had exponential decay shape.

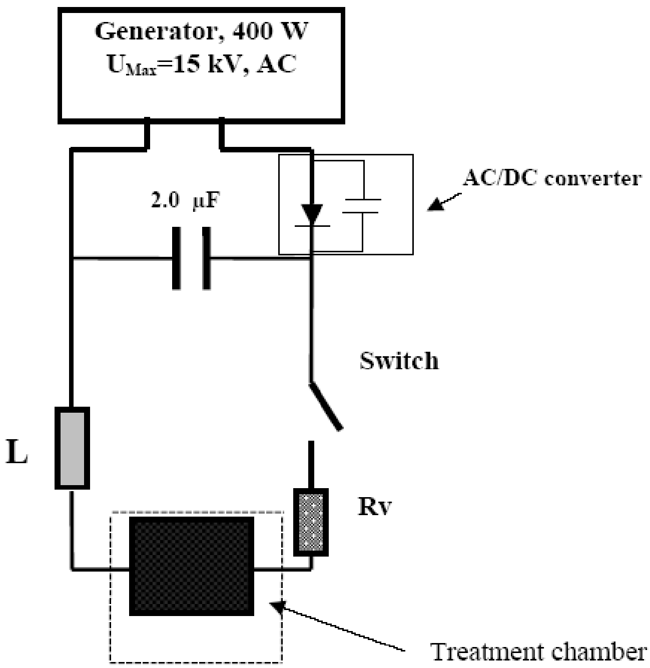

Figure 1 Scheme diagram of HELP equipment

The experiment was performed in stainless steel electrodes (with space of 2.5 cm apart) placed within Plexiglas treatment chamber. The stainless steel electrodes had a total area of 150 cm^2. Voltage at the treatment chamber was registered with a 75 MHz high voltage probe (Tektronix, P6015A, USA) connected to a digital voltmeter (ITT Measurement, metrix, France). Pulses for the HELP treatment had exponential decay.

Sugar cane was cut into 10 to 15 cm length. Sugar cane pieces (approx. 140 g) were then placed in treatment chamber containing tap water (conductivity ≈ 0.63 mS/cm) and treated at different conditions of HELP (4 to 5 kV and 10 to 80 pulses). After treatment the HELP treated samples were take out of the treatment chamber and the volume and Brix (total soluble solids) of treatment media were measured. The treated samples were used immediately for pressing.

The energy of pulses for exponential decay pulses is approximated as where V (volt) is the peak value of the decaying voltage in the sample, C is the capacitance of capacitor (F)(equation 3).

$$Q = \frac{1}{2} \times V^2 \times C \text{ (Joule)} \qquad \text{equation (3)}$$

The total energy (Q_T) during HELP treatment per volume of sample is a product of number of applied pulses and energy of each pulses (equation 4):

$$Q_T = \frac{Q \times n}{\nu} \text{ (Joule)} \qquad \text{equation (4)}$$

Q_T = specific energy (J/liter)
n = number of pulses
ν = volume of treatment chamber (ml)

The temperature increases during HELP treatment because of electrical energy dissipation in treatment chamber could be calculated using following equation (assumption: adiabatic conditions):

$$\Delta T = \frac{Q_T}{\rho \times C} \text{ (°C)} \qquad \text{equation (5)}$$

Δ**T**= temperature increase (°C), $\mathbf{Q_T}$ = specific energy (kJ/litre), ρ = specific density of sample (kg/liter) and **C** = specific heat capacity of sample (kJ/kg.K) (approx. 3.8 kJ/kg)
The temperature increase due to HELP treatment (4 kV, 28 µF, 30 pulses) at 20 °C was ~ 4 °C.

2.4 Heat treatment

Sugar cane pieces (approx. 200 g) were put in polyethylene (PE) bag together with 200 ml tap water. Polyethylene bags were immersed in warm water (71°C±1°C) for 20 min. After heat treatment the bags were immediately cooled in cold water (30 ºC) for 30 min. The sugar cane pieces were taken out of the PE bag and the weight and Brix of treatment medium in bag were measured. The treated samples were used immediately for pressing.

2.5 Pressing

The untreated, heat treated and HELP treated sugar cane pieces were cut into small pieces of approx. 3*3 mm length and 1 mm thickness using kitchen knife. Fifty grams of sugar cane pieces were inserted in a cotton cloth and pressed in a uniaxial hydraulic press (pressing area = 50 cm^2; press-cake thicken ≈ 0.3 to 0.7 cm) at 30 bar for 5 min. After pressing the weight and Brix of juice and the weight of pressed sample (pulp) were measured.

2.6 Mass transfer measurement (sugar leaching)

Fifty grams of untreated, heat or HELP treated sugar cane pieces (3 mm length) were put in a 200 ml beaker and 100 ml of tap water was added to wash off free sugar on the surface of sugar cane pieces. After 1 min the water phase was withdrawn and the "washed" samples were mixed with 100 ml tap water. The samples were agitated occasionally for 1 min at each interval (10 min). The sugar leaching was determined and °B value during 15 to 180 min at room temperature was measured.

3. RESULTS

3.1 Juice yield

The effects of pulse number at different voltages on juice yield and sugar extraction were shown in Table 1, Figures 2 and 3. HELP pre-treatment led to higher degree of juice yield and sugar extraction compared to untreated sample. HELP treatment at 4 kV and 30 pulses or at 5 kV and 20 pulses resulted in similar juice yield compare to heat treated (20 min, 70 °C) sample. Calculation of total sugar extracted after different pre-treatment methods have showed that the total sugar extracted using HELP pre-treatment is similar or higher (16.6 to 17.2%) than heat treated (16.6%) sample (Table 1) and higher than untreated sample (14.5 %). We have observed that HELP treatment after 10 pulses rapidly increased the juice yield as well as the total sugar extraction of sugar cane. Additional pulses (more than 10 pulses) have only slight effect on increasing the juice yield and total extracted sugar. Bouzrara and Vorobiev (10) found that sugar beet extraction using HELP gave similar dependence of juice yield and pulse number. They have concluded that there is a threshold for pulse number and quasi-totality of cell destruction. Further pulsing leads to inefficiency of energy input and cell destruction.

Table 1 Effect of different pre-treatment on juice yield, total sugar extracted, pulp weight and energy consumption

Treatment	Pulse No.	Brix of juice (g/100g)	Juice yield (g/100 g sample)	Total sugar extracted (g/100 g sample)	Pulp weight (g/100 sample)	Energy consumption (kJ/kg sample)
untreated		22.20 ±0.57	65.50±2.13	14.54±0.43	34.50±2.13	0
Heat treated (20 min, 70 °C)		20.93±2.40	73.24±2.71	16.81±0.60	26.77±2.71	171
HELP (4kV, 28 μF)	10	21.55±0.07	72.11±1.91	16.64±0.36	27.89±1.91	5.43
	30	20,85±0,92	73.20±4.53	16.78±1.62	26.80±4.53	16.29
	50	19,15±0.07	73.85±2.62	16.30±0.20	26.15±2.62	27.15
	80	19.05±0.07	74.30±1.58	17.05±0.50	25.70±1.58	43.44
HELP (5kV, 28 μF)	10	21.25±0.64	74.04±2.88	16.82±0.14	25.96±2.88	8.48
	20	20,75±0.07	74.50±0.35	16.76±0.09	25.50±0.71	16.97
	40	20.80±0.05	74.75±0.35	16.95±0.07	25.25±0.35	33.94
	80	20.80±0.28	74.98±0.04	17.19±0.2	25.03±0.04	67.88

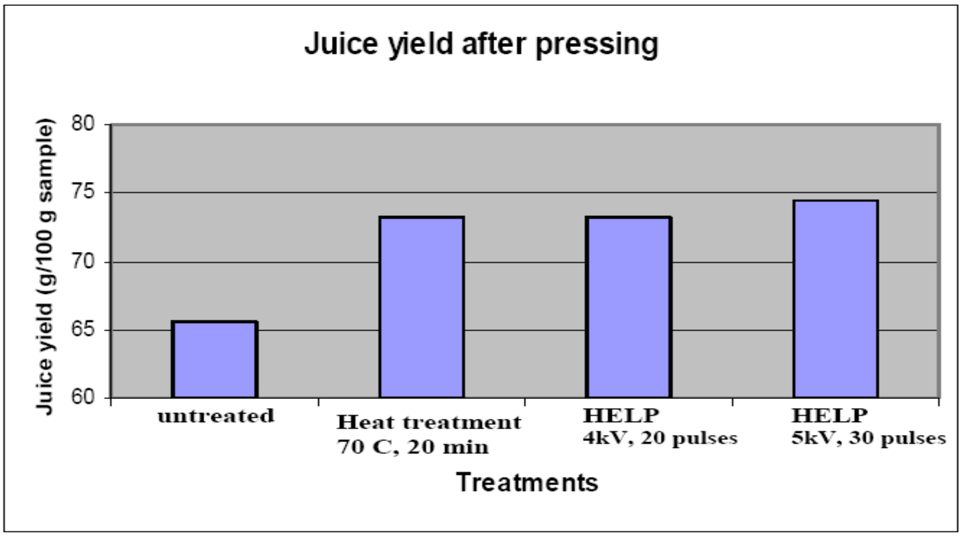

Figure 2 Effect of different treatment (heat treatment and HELP treatment) on juice yield of sugar cane

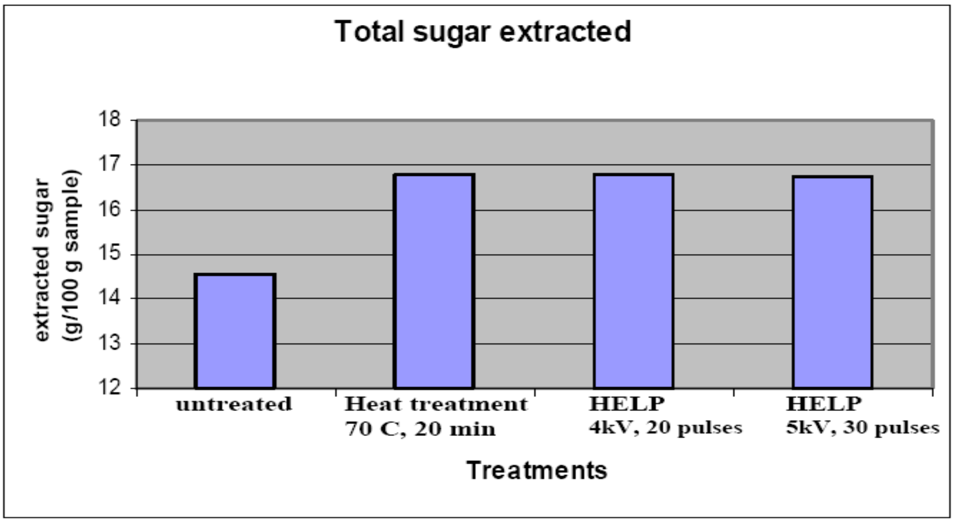

Figure 3 Effect of different treatment (heat treatment and HELP treatment) on total sugar extraction from sugar cane

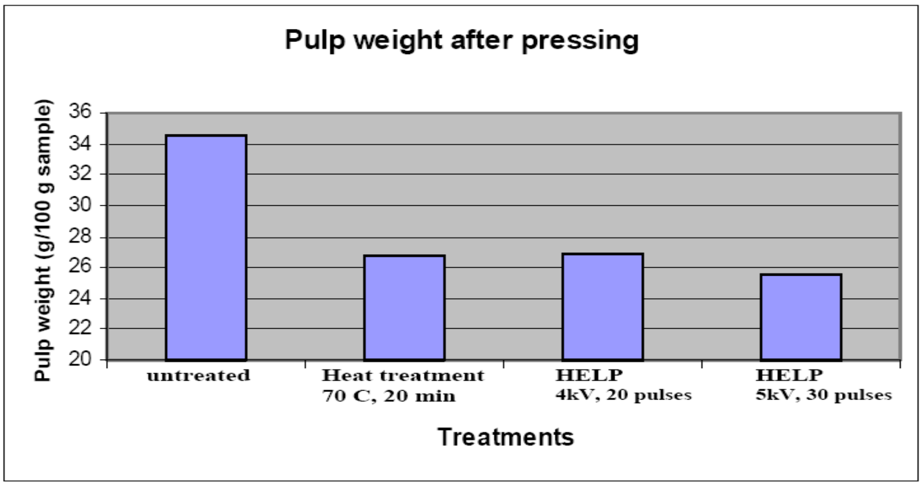

Figure 4 Effect of different treatment (heat treatment and HELP treatment) on pulp weight after pressing of sugar cane

3.2 Brix of juice

The Brix value of juice in the case of HELP treated well as heat treated sample was lower (approx. °B=20%) than untreated (°B=22%) pressed juice. This may be because of "sugar leaching" during pre-treatment. The sugar release during pre-treatment was approx. °B=2 in the case of heat treatment and 1 to °B=1.6 in the case of HELP treatment (data not shown).

3.3 Sugar leaching

The sugar leaching (mass transfer as index for cell disintegration) during 3h at room temperature (30 ºC) was shown in Figure 5. Higher sugar leaching (higher Brix value) indicates effective cell disintegration of sugar cane during HELP treatment after 10 pulses and 4 kV. Increasing the pulse number had only negligible effect on mass transfer. The mass transfer of HELP treated sample was similar or higher compare to heat treated (70 ºC, 20 min) sample and higher than untreated sample.

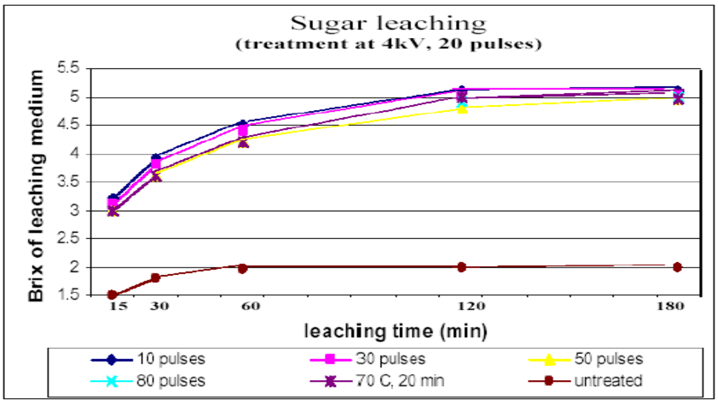

Figure 5 Effect of different pre-treatment on sugar leaching during immersion in water

3.4 Energy consumption

The energy consumption for HELP treatment (at 4 kV and 30 pulses or at 5 kV and 20 pulses) was approximately 17 kJ/kg sample which was much lower than heat treatment (171 kJ/kg). In fact increasing the pulse number as well as voltage increased the total energy consumption during HELP treatment but the overall energy consumption in the case of HELP treatment at 20 to 30 pulses was up to 10 times less than heat treatment method (Table 1).

In addition the treatment time for HELP treatment at pulse frequency of 1 Hz was extremely shorter (less than 1 min for 30 pulses) than heat treatment (20 min). This indicates that HELP treatment can reduce the energy and time required for extraction.

4. CONCLUSIONS

HELP treatment at room temperature and very short time is suitable method to permeable plant cells such as sugar cane. HELP pre-treated sugar cane showed nearly the same juice yield as heat treated sample and higher than untreated sample. The pulp weight of HELP pre-treated sample was obviously less compare to untreated sample. The energy consumption for cell disintegration using HELP method was nearly 10 times less compare to conventional heat treatment at 70 ºC, 20 min.

The advantage of HELP treatment such as shorter processing time and lower energy consumption, made HELP treatment as interesting alternative to conventional cell disintegration methods for increasing the juice yield and sugar extraction of sugar cane.

5. ACKNOWLEDGEMENT

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