

Laboratory Scale Extraction of Sugar Cane using High Electric Field Pulses

M.N. Eshtiaghi, N. Yoswathana

Abstract—The aim of this study was to extract sugar from sugarcane using high electric field pulse (HELP) as a non-thermal cell permeabilization method. The result of this study showed that it is possible to permeabilize sugar cane cells using HELP at very short times (less than 10 sec.) and at room temperature. Increasing the field strength (from 0.5kV/cm to 2kV/cm) and pulse number (1 to 12) led to increasing the permeabilization of sugar cane cells. The energy consumption during HELP treatment of sugar cane (2.4 kJ/kg) was about 100 times less compared to thermal cell disintegration at 85 °C (about 271.7 kJ/kg). In addition, it was possible to extract sugar cane at a moderate temperature (45 °C) using HELP pretreatment. With combination of HELP pretreatment followed by thermal extraction at 75 °C, extraction resulted in up to 3% more sugar (on the basis of total extractable sugar) compared to samples without HELP pretreatment.

Keywords—Cell permeabilization, High electric field pulses, Non-thermal processing, Sugar cane extraction.

I. INTRODUCTION

THE application of HELP in food processing was gained considerable attention in 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 extraction of intracellular compounds. It is noteworthy that an electroporation can be performed continuously and in a time scale of seconds, the treatment therefore can easily be integrated into existing processing lines.

Applying HELP to cellular tissue, an increase in mass transfer coefficients was observed due to cell membrane permeabilization [1]-[2]-[3]. Based on this effect a HELP application can replace or substitute conventional techniques in fruit and vegetable juice processing. First attempts to apply HELP technology for disintegration of cells were made by Krupp, Germany, in the 1960s, developing the ELCRACK process [4] based on experiments conducted elsewhere [5]-[6]. It is reported that [7] a 10-12 % increasing of juice yield could be achieved when applying electroporation to apple tissue. The energy input required to achieve a disintegration of plant cells is in the range of 10-20 kJ/kg, causing a temperature increase below 5 °C and indicating that product quality and fresh like character will be retained in contrast to thermal treatments.

M.N. Eshtiaghi is with the Mahidol University, Faculty of Engineering, Department of Chemical Engineering, Salaya, Thailand (corresponding author to provide phone: 0066-28892138-6101; fax: 0066-28892138-6129; e-mail: egmne@mahidol.ac.th).

N. Yoswathana is with the Mahidol University, Faculty of Engineering, Department of Chemical Engineering, Salaya, Thailand. (e-mail: egnyw@mahidol.ac.th).

Conventional procedures for production of sugar from cane and beets involve an extraction at elevated temperatures (≥ 75 °C). For disintegration and destruction of cell membranes a thermal treatment at temperatures in the range from 70 to 78 °C is applied. The membrane denaturation 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 requires a significant amount of energy, as high as 175 kJ/kg of treated beet [8]. It has been shown that mechanically pressed, raw juice has higher sugar concentration and contains less non-sugars, but juice yields remain unacceptable [9]. A HELP treatment of sugar beets prior to extraction could increase mass transfer rates and could allow to reduce extraction temperatures or to apply mechanical pressing. The applicability of a HELP pretreatment prior to sugar beet extraction at ambient temperature has been investigated elsewhere [10]. It was shown that after a HELP treatment at 2.4 kV/cm and a pulse number of 60, similar cell disintegration than after a thermal treatment at 75 °C for 15 min was obtained. A three-step pressing at a pressure of 5 MPa and intermediate addition of water was suggested to achieve a high sucrose content after a short processing time of 30 min in comparison to up to 90 min thermal extraction. The energy input required was 12 kJ/kg [11]. There is only one paper that reported about the application of high electric field pulses on sugar extraction from sugar cane [12]. This study has shown that it is possible to increase the yield of sugar from sugar cane using high electric field pulses at 5kV/cm and 20 pulses. The sugar yield after HELP treatment was at a very short process time (about 20 sec.) higher than thermally treated (15 min at 75 °C) sugar cane 74.5 and 71% respectively).

II. MATERIAL AND METHODS

A. Raw material

Sugar cane was purchased from Nakhorn Pathom district and stored until use (max. 2 days) in a refrigerator at +8 °C. For high electric field pulse treatment the sugar cane was cut in pieces of about 20 cm length.

B. Equipments

High electric field pulse (HELP) treatment was carried out using a High electric field pulse equipment (SIB-Foodtech, Germany) with the following technical specification:

Max. Voltage	7 kV
Capacity of capacitors	4 μ F
Pulse frequency	1 to 10 Hz
Max. energy per pulses	98 J/pulse (at 7 kV)

The pulse energy during HELP pretreatment method was calculated using equation 1

$$Q = (V^2XC)/2 \quad (1)$$

Q is the energy per pulses (J), V is the Voltage (volt) and C is the capacity of capacitor (as Farad). For voltage of 7 kV and capacity of 4 μF the pulse energy is 98 J/pulse.

The HELP treatment chamber consisted of 2 parallel orientated stainless steel plates with a length of 25 cm and height of 9 cm. The gap between two plates was constant at 3.5 cm

C. Treatment methods

High electric field pulse treatment: 200 g sugar cane (2 pieces of sugar cane with the length of about 20 cm) were inserted into the treatment chamber containing about 200 g tap water (electrical conductivity about 0.2 mS/cm) so that the samples were covered with water.

Pressing: For pressing of sugar cane before or after HELP treatment was an on the market available sugar cane pressing machine with rotating cylinder rolling applied (Fig 4). The long pieces of sugar cane (about 20 cm length) were directed into the press machine and the extracted juice after pressing between two rolling press cylinder was measured after gravimetric method and calculated as % on the basis of fresh sugar cane weight (Fig. 1).

D. Extraction methods

The experiment for extraction of sugar cane was carried out using different methods.

1. To investigate the effect of temperature on sugar extraction in extraction brine during extraction on the sugar yield, 2.5 kg of untreated sugar cane pieces (20 cm length) were pressed using a rolling press. After that, the remaining pulp was immersed in 600g water at different temperatures (30, 45, 60 and 75 °C) for 5 min and pressed again (second press) using the rolling press. This pressing and immersion was repeated three times. The Juice weight and brix of juice for each pressing was measured separately (Fig. 2).

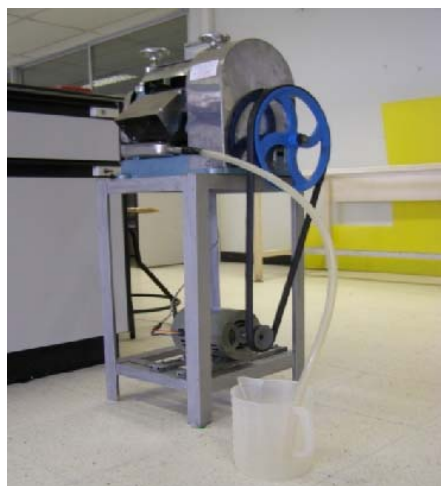


Fig. 1 sugar cane pressing machine with rolling press cylinders

2. To investigate the effect of process conditions during HELP treatment (Field strength and pulse number) on sugar extraction, 200g of the sample (sugar cane pieces of 20 cm length) was inserted in the HELP chamber (gap of chamber

3.5 cm) and treated at different voltages (3.5, 5.25, and 7 kV) and pulse numbers (2 to 16 pulses) as well as at constant voltage and electrode gap (7 kV and 3.5 cm respectively) and different pulse numbers (up to 30 pulses). The HELP pretreated sample was cut into small pieces with edge length of about 1 cm. 25 g of HELP pretreated sample was immersed in a beaker containing 100 ml distilled water and extract at room temperature (with slow agitation) for max. 120 min. During the extraction the brix of extraction brine in the beaker was measured after 15, 30, 60, 90 and 120 min extraction at room temperature. After that the beaker containing sample and solution was incubated in a water bath at 75 °C for additional 2 h and the final brix was measured (Fig. 3). The brix of extraction brine after 2h at 75 °C was considered as maximum achievable brix in extraction brine.

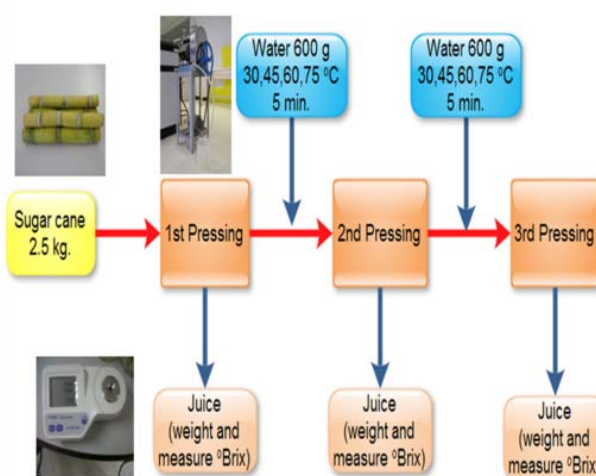


Fig. 2 Experimental for investigation the effect of extraction brine temperature on sugar extraction yield

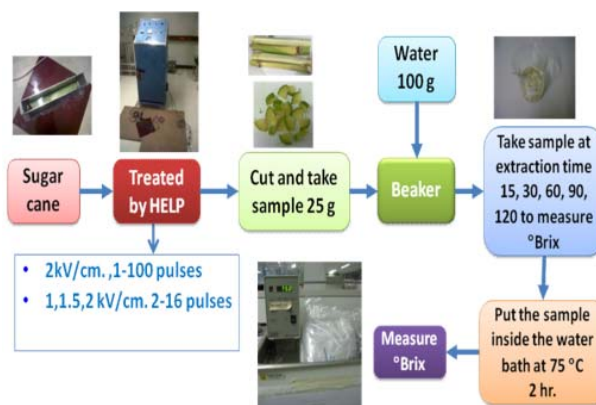


Fig. 3 experimental for investigation of HELP pretreatment on sugar extraction at room temperature

3. To compare the sugar extraction of HELP pretreated sample with untreated: 1 kg of HELP pre-treated (at 2kV/cm and 9 pulses) or untreated sugar cane (as sugar cane with 20 cm length) was used for this experiment. The samples were pressed (first press) using the rolling press and the juice was kept for measurement of weigh and brix-value. The

remaining pulp was immersed for 5 min in 200g of hot water (45 °C). The in the hot water immersed sample was again pressed (second press). After that the pulp was again soaked for 5 min in 200g hot water but at a higher temperature of 60 °C. The sample after second soaking was pressed using the rolling press and the juice was kept for analysis (weight and brix value). The remaining pulp after the third press was further immersed for 5 min in hot water (75 °C). After subsequent pressing (fourth press) of soaked pulp, the juice of the fourth press was kept for analysis and the remaining pulp was subjected to final soaking in 200 g water at very hot temperature (90 °C) for 5 min. Finally the sample soaked at 90 °C was pressed using the rolling press. The juice from each pressing step was kept for analysis and the weight of remaining pulp was determined (Fig. 4).

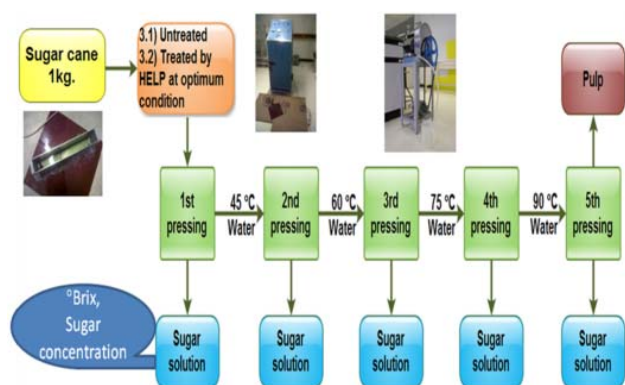


Fig. 4 Experiment for investigation of 5 times pressing and soaking (at different temperatures) on sugar extraction yield of untreated and HELP pretreated sugar cane

4. Similar to the described 5 step extractions in hot water, an additional experiment, but at fixed soaking temperature of 45 °C, was conducted to evaluate the possibility of effective sugar extraction using HELP pretreatment followed by extraction at a moderate temperature for energy saving reasons (Fig. 5).

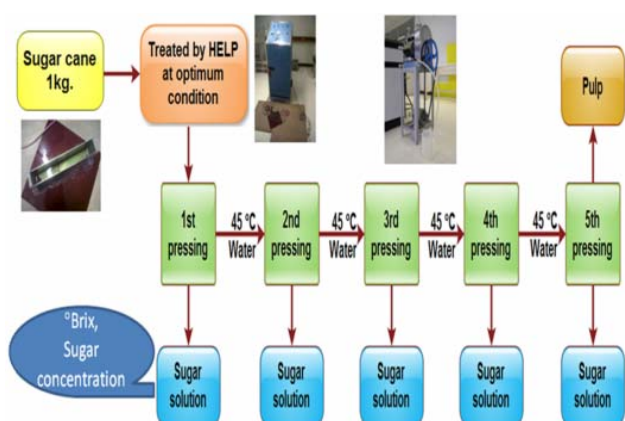


Fig. 5 Experimental for investigation of 5 times pressing and soaking (at constant temperature of 45 °C) on sugar extraction yield of untreated and HELP pretreated sugar cane

E. Analytical methods

The weight of juice during rolling pressing was determined using gravimetric method. Using a refractometer (Hanna refractometer, Germany) the sugar concentration in extracted juice or in extraction brine was determined and reported as brix-value (gram soluble solid in 100 g solution). The DNS method was applied to measure the exact amount of sugar (as sucrose, glucose and fructose) in the juice or extraction brine. Scanning Electron Microscopy (SEM) was applied to determine the structural deformation of the sugar cane cell wall during HELP treatment.

For calculation of extraction efficiency the relation between brix of extraction brine during extraction at room temperature and the maximum brix (after 2h extraction at 75° C) was calculated (equation 2).

$$\text{Extraction efficiency} = B_{\text{HELP}} / B_{\text{Therm}} \quad (2)$$

B_{HELP} = Brix of extraction brine at 15 to 120 min and extraction at room temperature

B_{Therm} = Maximum brix achievable after 2h extraction at 75 °C

The purity of extracted sugar solution calculated as relation between brix-value to measured sugar (equation 3):

$$P = (\text{Brix}/\text{DNS}) * 100 \quad (3)$$

P=Purity of juice, Brix=measured brix-value, DNS= measured sugar using DNS method

III. RESULTS AND DISCUSSIONS

Fig. 6 show the effect of extraction temperature on amounts of extracted sugar from untreated (fresh) sugar cane. Increasing the extraction temperature from 30 to 75 °C and constant extraction time of 10 min (3 times pressing and two times soaking each 5min) increased the sugar concentration in extraction brine.

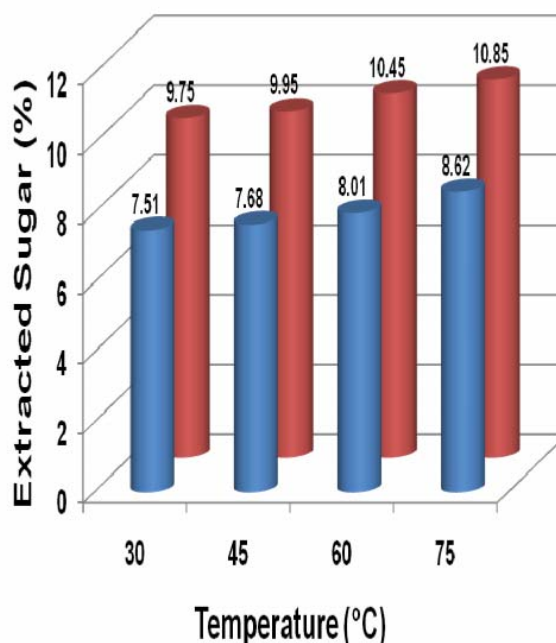


Fig. 6 Effect of extraction temperature on sugar yield

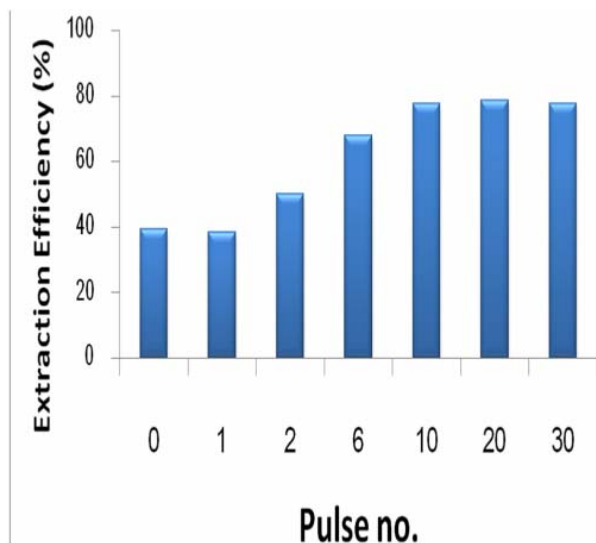


Fig. 7 Extraction efficiency of HELP (2 kV/cm, 4 μ F, 1-30 pulses) pretreated sample after 120 min. immersion in water at room temperature

The effect of pulse numbers at constant field strength of 2kV/cm on sugar leaching is demonstrated in Fig. 7. Increasing the pulse number from 1 to 10 increased the extraction efficiency from 40 to 80 %. Further increasing the pulse number higher than 10 pulses showed nearly no effect on extraction efficiency. From this data it is clear that only 10 pulses is sufficient to permeabilize the cells in sugar cane. Considering the energy consumption (10 pulses for 200 g sugar cane), the total electrical energy consumption for cell permeabilization using HELP is less than 2.5 kJ/kg sugar cane.

The investigation of the effect of field strength at different pulse numbers on cell permeabilization has shown that with increasing the field strength from 1 kV/cm to 1.5 kV/cm the extraction efficiency increased (Fig. 8). Further increasing the field strength (up to 2 kV/cm) indicated only a slight positive effect of sugar extraction. From this data the field strength of 2 kV/cm and pulse number of about 9 was sufficient to achieve the highest extraction efficiency during extraction at room temperature. Interestingly, it was possible to extract sugar cane at room temperature without any heating after only 9 pulses (at 2kV/cm field strength) with an extraction efficiency of up to 80 %. This indicated that HELP technique is a fast and non-thermal cell permeabilization suitable for sugar cane extraction with energy consumption up to 80 to 100 times less compare to conventional thermal cell permeabilization (at about 80 to 85 °C).

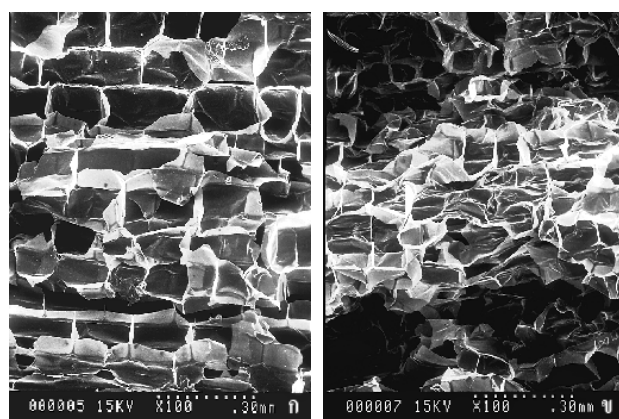


Fig. 9 Sugar cane cell wall, left) Untreated, right) Treated by HELP at 2 kV/cm., 9 pulses

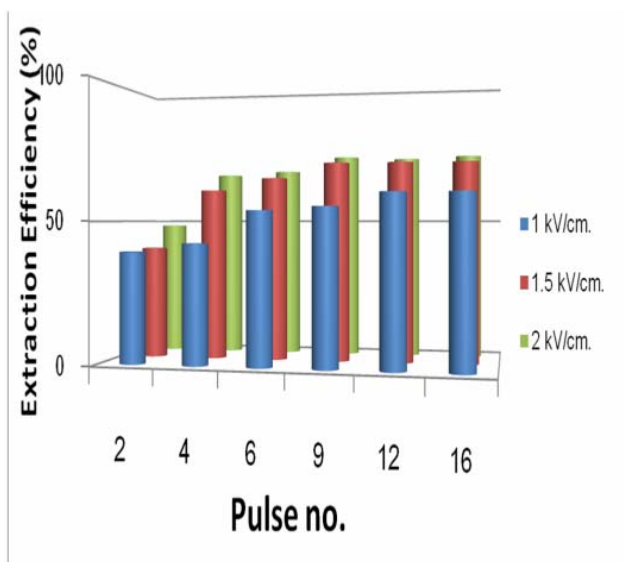


Fig. 8 Effect of HELP treatment conditions (Field strength and pulse number) on extraction efficiency of HELP pretreated sugar cane after 120 min extraction at room temperature

The observation of cell wall structure using SEM has indicated that the cell wall structure of HELP pretreated sample (treatment at 2kV/cm, 9 pulses) only slightly changed compare to untreated (fresh) sugar cane (Fig. 9). The cell wall structure was clearly visible after HELP treatment.

The combination of HELP pretreatment (2kV/cm, 9 pulses) and thermal extraction (at 75 °C, 5 time pressing) is much more effective than only conventional thermal extraction. Whereas the thermal extraction resulted in 12.99% extracted sugar, the combination of HELP pretreatment and conventional extraction resulted in up to 13.39% sugar extraction (Fig. 10). This shows the extractability increase gives up to 3.08 % more sugar yield in the case of HELP pretreated sample compared to untreated. Interestingly, it was possible to extract the HELP pretreated sugar cane at a distinctly lower extraction temperature (45 °C) compared to the thermal process (at 75 °C) with nearly the same sugar yield. This demonstrates that it is possible to decrease drastically the energy consumption during sugar extraction without any compromising of the sugar yield.

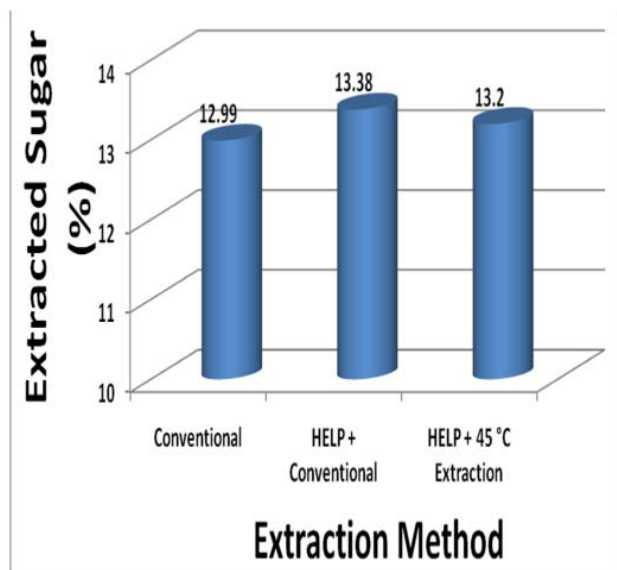


Fig. 10 Effect of HELP pretreatment combined with extraction at moderate or high temperature on sugar extraction

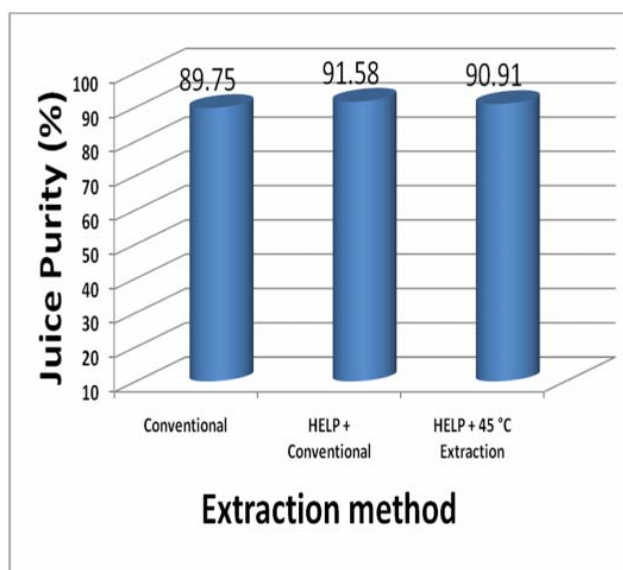


Fig. 12 Purity of extracted sugar solution using HELP treatment compare to untreated sample

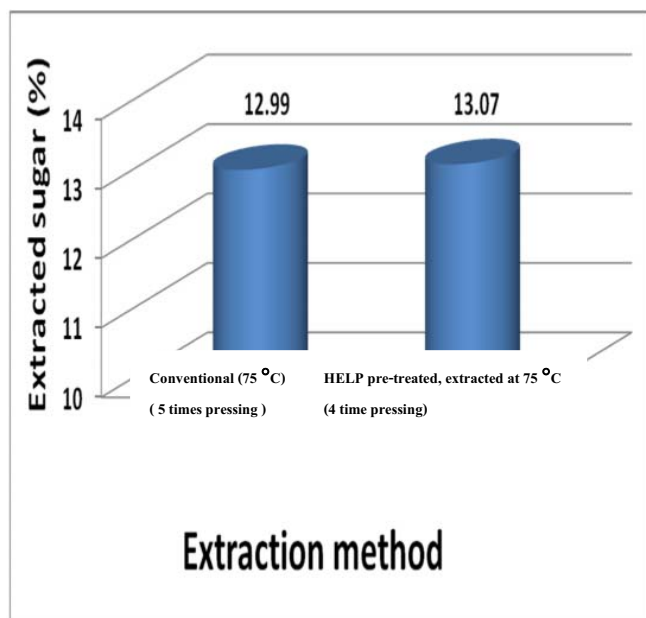


Fig. 11 Effect of HELP pretreatment on extraction time of sugar cane

The effect of HELP pretreatment on extractability of sugar during thermal processing has showed that using HELP pretreatment the extraction time will be shorter (fig. 11). The extracted sugar was in the case of HELP pretreated sugar cane after 4 times pressing nearly similar to the untreated sample. This means about 20 % shorter extraction time in the case of HELP pre-treated samples compared to untreated. The decreasing of extraction time could increase the throughput in sugar industry drastically. The measurement of purity of extracted juice showed that the HELP pretreated resulted comparable or slightly higher purity than thermally extracted samples (fig. 12).

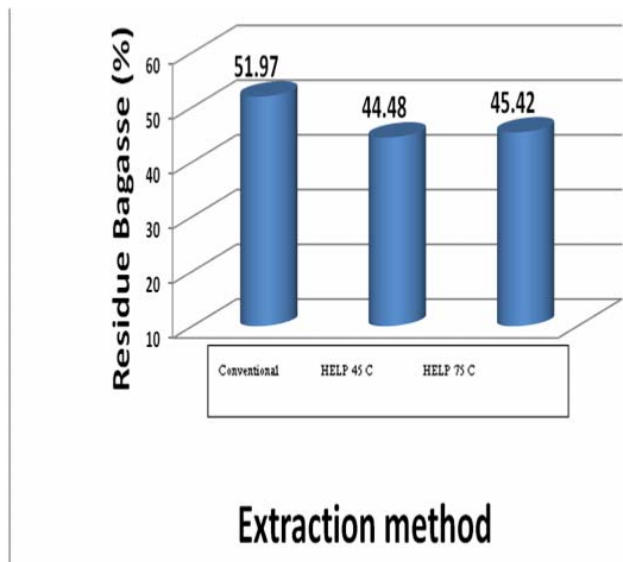


Fig. 13 the residual bagasse after final pressing of HELP pretreated and untreated sugar cane bagasse

In addition to increasing the sugar yield in the case of HELP pretreated samples a decreasing of the residual bagasse of final pressed pulp was observed. In general, the HELP pretreated samples showed up to 12 to 14 % less residual bagasse compare to untreated samples (Fig 13). During conventional thermal extraction at very high temperature (≥ 75 °C) the cell wall compounds such as pectin and cellulose undergoes thermal degradation and gel formation (water uptake) in the cell wall region. The bonded water in gel could not be removed during final pressing and remained inside the pulp causing higher pulp weight. Lower water content in pulp means less energy consumption for evaporation of water before burning the pulp for electricity production in the sugar industry.

IV. CONCLUSION

HELP technique is a suitable method for fast permeabilization of sugar cane. Relatively low field strength of about 2 kV/cm and pulse number about 10 pulses was sufficient to permeabilize sugar cane sufficiently. The energy consumption for sugar cane cell permeabilization using HELP was about 80 to 100 times less compared to thermal cell permeabilization (≥ 75 °C). In addition, it was possible to extract HELP pretreated sugar cane at a moderate temperature (45 °C) with nearly similar sugar yield compared to high temperature (about 80 to 90 °C) extraction of untreated samples. Combination of HELP pretreatment and conventional thermal processes led to about 3% more sugar extraction compared to only conventional thermal extraction. This indicated the increasing of profit during sugar extraction using HELP pretreatment method. In addition, using HELP pretreatment the extraction time could be decreased up to 20 %. Interestingly, the weight of final pressed pulp was about 12 to 14 % lower in the case of HELP pretreated samples compared to untreated samples. This could have additional advantages for energy saving during the sugar cane extraction process.

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