

# Impact of High Electric Field Pulses on Cell Disintegration and Oil Extraction from Palm Fruit Mesocarp

**K. Paoplook and M.N. Eshtiaghi**

Department of Chemical Engineering  
Mahidol University, Salaya, Nakhornpathom 73170 Thailand  
Email: egmne@mahidol.ac.th

**Abstract** – In this study the effect of high electric field pulses (HELP) as a non-thermal novel technique on cell disintegration and oil extraction of palm fruit mesocarp was investigated. The process parameters (pulse number 5 to 30 pulses, Field strength 1 to 5 kV/cm, capacity of capacitors 0.49 to 1.98 $\mu$ F) showed a direct effect on cell disintegration. Increasing the field strength increased the cell disintegration. Up to 97% cell disintegration was achieved after high electric field pulse treatment at 5 kV/cm and 30 pulses. In addition increasing the pulse number from 5 to 30 pulses (at constant field strength of 4kV/cm) increased the cell disintegration. Furthermore, the increasing the capacity of capacitors up to 1.98  $\mu$ F showed positive effect on cell disintegration of palm fruit mesocarp. The energy consumption and process time during cell disintegration using HELP was distinctly lower (about 12 kJ/kg, less than 30 sec.) compared to thermal treatment (at 80 °C, 2h, about 210 kJ/kg). Pressings of palm fruit mesocarp have indicated that the remaining pulp after pressing for high electric field pulse pretreated samples (at 4 and 6kV/cm) was distinctly lower (about 20 and 18.6% respectively) compared to thermally treated samples (21.5%). The measurement of oil yield showed positive effect of HELP pre-treatment. Increasing the field strength increased the oil yield. The peroxide value of crude oil pretreated with HELP was slightly higher compared to untreated or thermally treated samples.

**Keywords** – Palm Processing, High Electric Field Pulse, Cell Disintegration, Oil Yield, Peroxide Value.

## I. INTRODUCTION

Palm oil has become the world's leading vegetable oil in terms of consumption and production with 45.3 million tons produced worldwide in 2009 [1]. Palm oil is versatile in its uses in the food and chemical industries and increasingly as a feedstock for biofuels, which is another reason for the rising popularity of palm oil [2].

Palm oil is extracted from highly perishable oil palm fruit through wet processing. The essential steps for conventional palm oil processing are; Sterilization; Stripping; Digestion; Pressing; Clarification; Purification; Vacuum Drying; Nut Recovery. Conventional palm oil processing is a very energy intensive industry because of the sterilization and milling processes before pressing. The oil yield using conventional palm processing is low (17 to 18 % compared to 24% oil content in palm bunch). In addition, this industry produces huge amounts of waste water during the clarification step, containing high amount of organic substances that could negatively affect the

environment and need special treatment or complex biogas production.

The application of High Electric Field Pulses (HELP) in food processing has gained considerable attention within the last few 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.

Applying HELP to cellular tissue an increase in mass transfer coefficients was observed due to cell membrane permeabilization [3]-[4]-[5]. Based on this effect a HELP application can replace or substitute conventional techniques in fruit and vegetable juice processing. 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.

The application of electrical fields to biological cells in a medium (for example, water) causes buildup of electrical charges at the cell membrane [6]. Membrane disruption occurs when the induced membrane potential exceeds a critical value of 1 V in many cellular systems [7]. Several theories have been proposed to explain microbial inactivation by HELP. Among them, the most studied are electrical breakdown and electroporation or disruption of cell membranes [8]-[9]-[10]-[11]-[12].

It is noteworthy that electropermeabilization can be performed continuously and in a time scale of seconds. The treatment therefore can easily be incorporated into existing processing lines [13].

There is limited information in the literature about application of High Electric Field Pulses (HELP) for extraction of oil from oil rich fruits and seeds using HELP. Researchers [14]-[15] have studied the effect of HELP on cell permeabilization of coconut meat and juice yield. It was shown that that it is possible to permeabilize coconut meat at room temperature using HELP treatment at 2.5kV/cm and 20 pulses. The coconut milk yield increased up to 22% compared to untreated samples (Eshtiaghi, 2012). In addition, the HELP pretreated coconut meat showed up to 20 % shorter drying time compared to samples without pretreatment [14]. Ref. [15] examined the effect of HELP on oil extraction from maize and olives. They found that the HELP treatment of maize germ at 7.3 kV/cm and 91 kJ/km energy input increased the oil extraction from 23% (untreated sample) to 43%. The HELP treatment of olive at 1.3 kV/cm, 100 pulses resulted

in an increase of oil yield from 9.5 % (untreated sample) to 10.2 % after HELP treatment. Up to date no publication is available about application of HELP for processing of palm oil.

The aims of this study were to develop energy saving methods using high electric field pulses to reduce energy consumption during palm oil processing and to increase the oil yield.

## II. MATERIAL AND METHODS

### A. Raw materials

Fresh palm fruit (with or without bunch) from the south of Thailand was used for the experiments. For palm pressing experiments the fresh palm fruit was cleaned, packed in plastic bags and stored in a refrigerator (at about  $4 \pm 2$  °C) until use (about 2 weeks). For cell permeabilization ( $Z_p$ ) experiments the fresh palm fruit was subjected to  $Z_p$  measurement immediately after purchase.

### B. Equipments

The HELP treatment of palm fruits was conducted in an in our Department designed high electric field pulse equipment (max. voltage 7 kV, max. Power 1000 W) (Fig. 1).



Fig.1. High electric field pulse equipment

The treatment chamber for the HELP process was chamber consisting of 2 parallel stainless steel plates.

The energy per pulses ( $Q$ ) can be calculated using the following equation (Equation 1)

$$Q \text{ (Joule)} = \frac{(V)^2 * C}{2} \quad (1)$$

With  $V$ = voltage (V),  $C$ =Capacity of capacitor (F). The total energy input ( $Q [T]$ ) is the product of pulse energy and pulse number ( $n$ ) (Equation 2):

$$Q [T] = Q * n \quad (2)$$

The temperature increase during HELP treatment can be calculated as follows (Equation 3):

$$\Delta T (\text{°C}) = \frac{Q [T] (KJ)}{\rho * v * C_p} \quad (3)$$

Where  $C_p$  = specific heat of sample (kJ/kg.k),  $V$ = volume of sample (ml), and  $\rho$  = density of sample (kg/l)

For measurement of cell permeabilization an own-designed electrical circuit (figure 2) suitable for measurement of current passing through the sample was applied. The sample (palm fruit slices) was placed between two electrodes made of stainless steel rod (diameter =1.5 cm) and the current passing through the sample was measured (Fig. 2).

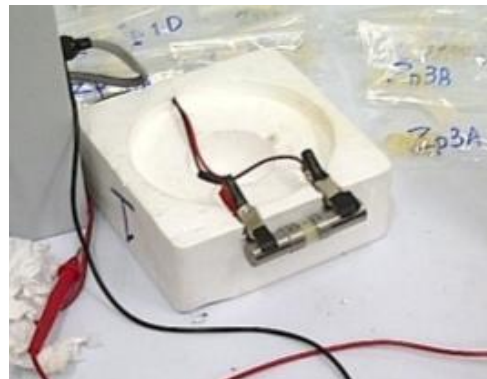
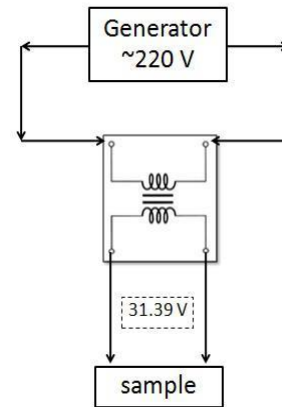


Fig.2. Circuit diagram (top) and the picture of  $Z_p$  measurement equipment.

Cell disintegration degree ( $Z_p$ ) was calculated using measurement of electrical conductivity of sample before and after treatment (Equation 4).

$$Z_p = \frac{I_t - I_0}{I_f - I_0} \times 100 \quad (4)$$

Where  $I_t$  is electrical conductivity of sample after treatment,  $I_0$  is electrical conductivity of untreated sample, and  $I_f$  is electrical conductivity of sample after freezing.

### C. Methodology

**Thermal method:** For thermal cell permeabilization ( $Z_p$ ) palm fruit mesocarp was cut in to thin slices of  $2 \pm 0.5$  mm thick using a sharp knife. After that the samples were packed in Polyethylene (PE) bags and sealed air free. The bag was immersed in a water bath at a constant temperature (80 °C) and different treatment times (2 to 15 min), followed by immediately cooling the samples in cold water (25 °C). The thermally pre-treated samples were then subjected to  $Z_p$  measurement.

For thermal treatment of palm fruit for pressing about 190 g of palm fruit mesocarp (pieces of  $2 \pm 0.5$  mm) was put in a PE bag. The air inside the bag was removed as much as possible and sealed. The bag was then immersed in a water bath at about  $95 \pm 2$  °C for 60 min. After that the bag was removed from the water bath and cooled in a water bath at about 50 °C. Finally the warm sample (at 50 °C) was pressed using a hydraulic press.

High electric field pulse (HELP) treatment method: About 10 g of palm mesocarp slices (thickness of about  $2 \pm 0.5$  mm) was placed in a HELP chamber with a fixed gap (1.0 cm) and electrode surface of  $7.5 * 8.1$  cm. After that 30 ml tap water (conductivity 0.3 mS/cm) was added inside the chamber to cover the sample with water. The HELP treatment was carried out at different voltages (1 to 5kV) and pulse numbers (5 to 30 pulses) and capacity of capacitors (0.49 to 1.96  $\mu$ F). Immediately after HELP treatment the sample was removed from the HELP chamber and the  $Z_p$  measurements carried out.

For HELP treatment of palm fruit for pressing about 70 g of palm mesocarp slices (thickness of about  $2 \pm 0.5$  mm) was placed in a HELP chamber with a fixed gap (1.0 cm) and large electrode surface of  $16.5 * 11$  cm. After that 140 ml tap water (conductivity 0.3 mS/cm) was added inside the chamber to cover the sample with water. The HELP treatment was carried out at different voltages (2, 4, and 6kV) and a constant pulse number (30 pulses) and capacity of capacitors (0.49  $\mu$ F). After that the HELP treated samples were removed from the HELP chamber and pressed.

Freezing method: For measurement of  $Z_p$ , the palm mesocarp slices (thickness of about  $2 \pm 0.5$  mm) were packed in a PE bag and stored in a freezer at about -20 °C for 24 h. After that the sample was thawed at room temperature and  $Z_p$  was measured or subjected to pressing.

Pressing methods: The mesocarp of palm fruit (as slices) with different pretreatments (untreated, HELP treated and heat treated or freezing) was incubated for about 30 min in an oven at 50 °C to increase the sample temperature prior pressing at about 45 °C. 30 g of warm sample was placed on 2 layers of cheese cloth and pressed in a laboratory scale hydraulic press at a constant pressure of 68 bar for 5 min. After that the weight of remaining pulp was measured. The pressed liquid phase (mixture of fat and water) was collected and stored in a freezer (-20 °C) for analyzing the oil properties (refractive index, and peroxide number). The measurement of water content in the remaining pulp was conducted at 105 °C in an oven until constant weight of sample (about 8h) and the % water content was calculated. The dried pulp was stored in a PE bag at room temperature for measurement of remaining fat in pressed pulp.

Analytical methods: The oil content in fresh palm fruit as well as pressed pulp was measured using Soxhlet method. 10 g of sample was dried in an oven at 105 °C for 8 h and after that the dried sample was placed in a Soxhlet apparatus. The extraction of oil from the sample was carried out using 250 ml hexane at the boiling temperature of hexane (about 60° C) for 8h. Using a rotary vacuum

evaporator (Buchü, Switzerland) the hexane was removed and the remaining oil was measured gravimetrically and calculated as % on the basis of fresh or pressed sample (see equation 5).

$$\text{Oil yield (\%)} = \frac{\text{extracted oil (g)}}{\text{sample (g)}} \quad (5)$$

The peroxide value (PV) of crude oil was determined using AOAC official method 965.33. Pressed oil was centrifuged at 4000 rpm, for 15 min and at 50 °C. 2 g of clear phase of centrifuge was mixed with 30 ml of  $\text{CH}_3\text{COOH}-\text{CHCl}_3$  (3:2 volume ratios) and 0.5 ml of saturated KI was added. The mixture was titrated using 0.01M  $\text{Na}_2\text{S}_2\text{O}_3$ . The Peroxide value was calculated using equation 6:

$$\text{PV (mequ.)} = S * M * \frac{1000}{\text{sample (g)}} \quad (6)$$

Where S= ml  $\text{Na}_2\text{S}_2\text{O}_3$  and M=molarity of  $\text{Na}_2\text{S}_2\text{O}_3$

The refractive index of palm oil extracted using different pretreatments (heating, freeze thaw, enzymatic and HELP treatment) was determined using a refractometer (ATAGO CO., LTD., Japan).

### III. RESULTS AND DISCUSSIONS

#### D. Thermal cell permeabilization of palm fruit mesocarp

In figure 3 the effect of time during heat treatment (80 °C) on cell permeabilization of palm fruit demonstrated. Increasing the treatment time from 2 to 25 min increased the degree of cell permeabilization ( $Z_p$ ) continuously. Up to 80 % cell permeabilization could be achieved after 15 min heat treatment at 80 °C.

#### E. Cell permeabilization using high electric field pulses

Interestingly increasing the field strength from 1 to 5 kV/cm increased the cell permeabilization (Fig. 4). At field strength of 4 kV/cm and higher cell permeabilization higher than 80% could be achieved. This indicated that the HELP process is an effective method for cell permeabilization of palm fruit. Up to about  $Z_p=95\%$  could be observed at 5kV/cm and 30 pulse number. The process duration for cell permeabilization using HELP was distinctly shorter (30 sec. at pulse frequency of 1Hz) comparing to thermal processing (15 min, at 80 °C).

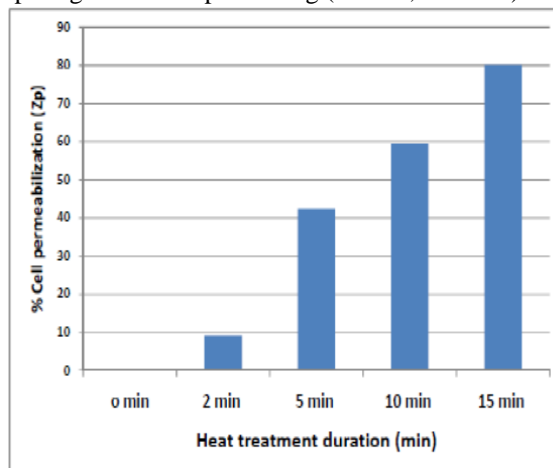


Fig. 3. Effect of heat treatment time at constant temperature of 80 °C on cell permeabilization degree ( $Z_p$ )

A continuous increasing of the  $Z_p$  with increasing of pulse number during HELP (4kV/cm and 0.49  $\mu$ F) treatment from 5 to 30 pulses was observed as shown in figure 5. Up to 75 % cell permeabilization was observed after 30 pulses. The energy consumption for 30 pulses at 4kV/cm and 0.49  $\mu$ F was about 12kJ/kg and distinctly lower compared to thermal (80 °C) treatment (about 210 kJ/kg). This indicated the energy saving advantage of this new technology compared to thermal processing. To find out if, with further increasing the pulse number, the  $Z_p$  will be increased, need additional experiments.

Increasing the capacity of capacitors from 0.49 to 1.98  $\mu$ F increased the cell permeabilization degree ( $Z_p$ ) for palm fruit treated at 2 or 4 kV/cm and constant pulse number. On the one hand, increasing the capacity increased the  $Z_p$ , on the other hand, increasing the capacity of capacitors means increasing the energy consumption during HELP treatment. From the data in Fig. 6 a 4-fold increase in the capacity of capacitors led to about 2-fold increasing of  $Z_p$ . It is also important for process optimization to find out the highest  $Z_p$  with lowest energy consumption.

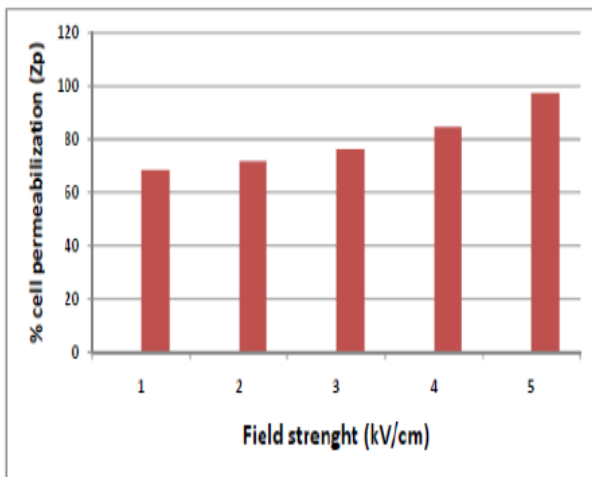


Fig.4. Effect of field strength during High electric field pulse treatment on cell permeabilization degree ( $Z_p$ )

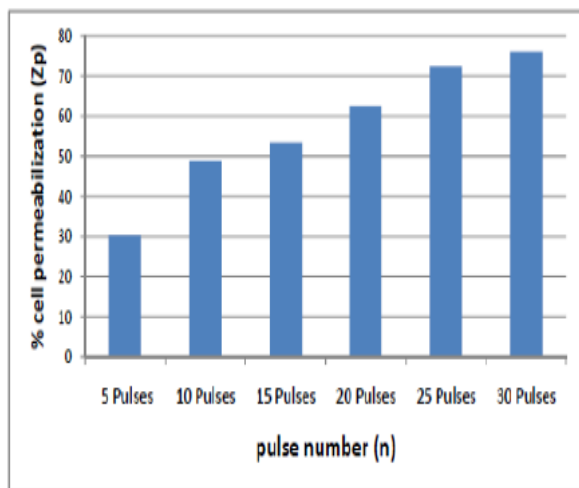


Fig.5. Effect of pulse number during High electric field pulse treatment at constant field strength of 4 kV/cm, 0.49  $\mu$ F on cell permeabilization degree ( $Z_p$ )

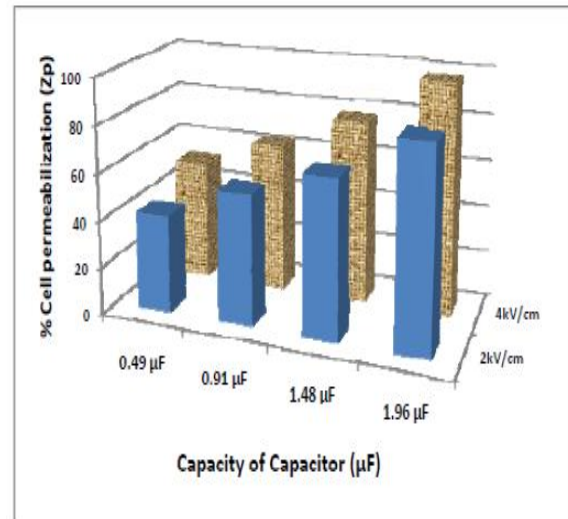


Fig.6. Effect of capacity of capacitors during High electric field pulse treatment at two different field strength of 2 and 4 kV/cm on cell permeabilization degree ( $Z_p$ )

#### F. Effect of high electric field pulses on palm processing

As it shown in figure 7, with increasing of field strength from 2 kV/cm to 6 kV/cm, the amount of pressed pulp decreased. This was distinctly obvious at field strength of 6 kV/cm. Comparison between thermal (boiling for 1 h) and freeze thaw methods, with high electric field pulse method showed clearly the advantages of this new technology for pressing of fresh palm mesocarp. In addition the HELP process is a very fast method (less than 1 min treatment time (at 6kV and 30 pulses with pulse frequency of 1Hz) compare to thermal (1h) and freeze thaw methods (24h). Furthermore the energy consumption of HELP treatment for cell permeabilization (less than 20 kJ/kg) in this study was distinctly lower compared to boiling (at 95 °C, about 280 kJ/kg) method.

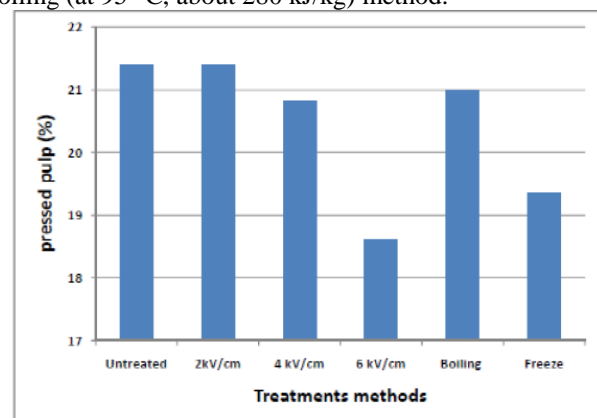


Fig.7. Effect of high electric field pulse treatment at different field strength ( 2 to 6 kV/cm) on amount of pressed pulp of palm

#### G. Effect of high electric field pulse on oil yield

The positive effect of High Electric Field Pulse technique for oil extraction from palm fruit is demonstrated in figure 8. Increasing field strength increased the oil yield drastically. Whereas the oil yield at

2kV/cm was about 51%, the oil yield increased up to 64% at 6kV/cm. The highest oil yield was observed for thermally treated (Boiling) and freeze thawed samples (71.63 and 73.04 respectively). High electric field pulse is an energy saving process and very fast method compared to thermal and freezing methods. The thermal method consume huge amount of energy that is about 20 times higher than HELP processing and is time consuming. Freeze thawing process could not applied in palm oil processing because of the very slow process (up to 1 day) and very expensive technique (high energy cost and expensive machinery). In contrast, the HELP technique is a very fast method (less than 1 min processing time) and an energy saving method. In addition, the waste water amount using HELP treatment technique is lower than the conventional thermal method. However, the process parameters during HELP treatment should be further optimized to increase the oil yield and to achieve similar oil yields as the conventional thermal process. Additional experiments are going on in our laboratory to optimize the process parameters, such as field strength and capacity of capacitors. Furthermore, the design of a continuous operating chamber for palm fruit treatment is planned.

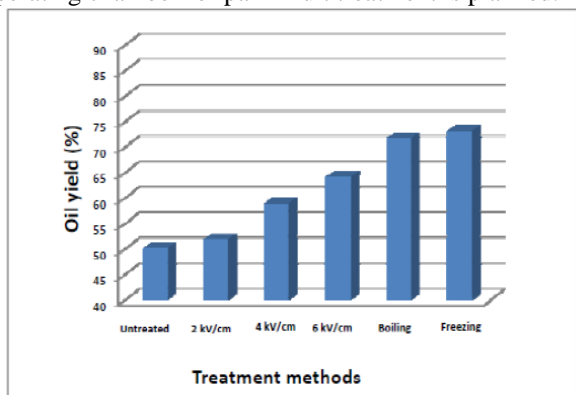


Fig.8. Effect of different treatment methods on % oil yield on the basis on total oil content in fresh palm mesocarp)

#### H. Effect of high electric field pulse on Refractive index of oil

In general the refractive index of crude palm oil prepared in this study, was slightly lower compared to the refractive index of refined oil from the market (Fig.9). The refractive index of oil from untreated and freeze-treated was nearly similar (1.4525) and slightly higher than heat treated (boiling) samples (1.4516). The refractive index of HELP pretreated samples showed a decrease in refractive index with increasing applied field strength.

#### I. Effect of high electric field pulse on Peroxide value of oil

The peroxide value of all investigated samples was lower than 13. The lowest peroxide value was observed for thermally pretreated samples (boiling sample (3.67) followed by refined oil from market (6.06) Fig. 10). The peroxide value of untreated and freeze pretreated samples was similar (9.63 and 9.67 respectively). In contrast, the peroxide value of HELP treated samples at 2kV/cm was distinctly higher (14.83) compared to untreated samples. Increasing the applied field strength, decreased the

peroxide value rapidly and was nearly similar (10.67) compared to untreated samples.

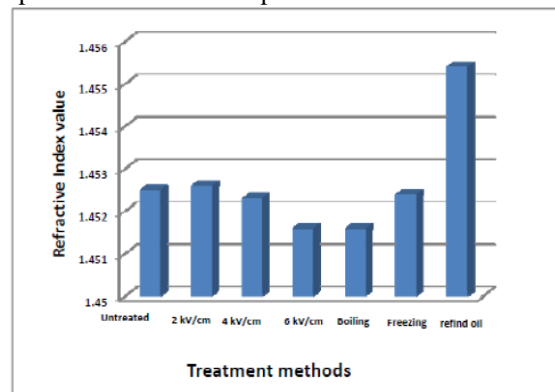


Fig.9. Effect of treatment methods on refractive index of crude palm oil

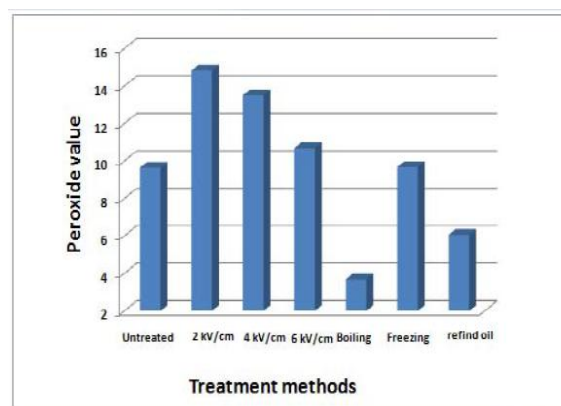


Fig.10. Effect of treatment methods on Peroxide value of crude palm oil

## IV. CONCLUSION

The application of high electric field pulse technique has indicated that it is possible to permeabilize palm fruit at room temperature. The extent of cell permeabilization was dependent on process parameters (field strength, pulse number, and capacity of capacitors). The energy consumption for cell permeabilization using HELP was distinctly lower ( $\approx 12$  kJ/kg) compared to the thermal method (about 210 kJ/kg). In addition, HELP treatment could increase the oil yield compared to untreated samples. Increasing the field strength showed a positive effect on oil yield. However the oil yield of HELP pretreated samples was lower than thermally pretreated samples. Further investigation is necessary to optimize the HELP process parameters and to increase the oil yield.

## ACKNOWLEDGMENT

This research project is partially supported by NSTDA, Thailand and Mahidol University of Thailand.

**REFERENCES**

- [1] United States Department of Agriculture, "Our Commitment to Sustainable Palm Oil." [http://www.adm.com/en-US/responsibility/supply\\_chain/Documents/Palm%20Sustainability%20Brochure.pdf](http://www.adm.com/en-US/responsibility/supply_chain/Documents/Palm%20Sustainability%20Brochure.pdf), 2005.
- [2] K. Sundram, R. Sambanthamurthi, Y-A Tan "Palm fruit chemistry and nutrition." *Asia Pacific J Clin Nutr.*, 2003, 12(3), 355-362.
- [3] D. Knorr, M. Geulen, T. Grahl, and W. Sitzmann Food "Application of high electric field pulses." *Trends Food Sci Technol.* 1994, 5, 71-75.
- [4] M. Bazhal, and E. Vorobiev "Electrical treatment of apple cossettes for intensifying juice processing." *J. Sci. Food Agric.* 2000, 80, 1668-1674.
- [5] M. Fincan, F. DeVito, and P. Dejmeck "Pulsed electric field treatment for solid-liquid extraction of red beetroot pigment." *J. Food Eng.*, 2004, 64, 381-388.
- [6] K. H. Schoenbach, F. E. Peterkin, R. W. Alden, and S. J. Beebe "The effect of pulsed electric fields on biological cells: Experiments and applications." *IEEE Trans Plasma Sci.* 1997, 25(2), 284-292.
- [7] A. J. Castro, G. V. Barbosa-Cánovas, and B. G. Swanson "Microbial inactivation of foods by pulsed electric fields." *J Food Process Pres.* 1993, 17, 47-73.
- [8] U. Zimmermann, and R. Benz "Dependence of the electrical breakdown voltage on the charging time in *Valonia utricularis*." *J Membrane Biol.*, 1980, 53:33-43.
- [9] U. Zimmermann "Electrical breakdown, electroporation and electrofusion." *Rev Physiol Biochem Pharmacol.*, 1986, 105, 175-256.
- [10] A. J. H. Sale, and W. A. Hamilton "Effects of high electric fields on microorganisms I. Killing of bacteria and yeast." *Biochim Biophys Acta.*, 1967, 148, 781-788.
- [11] H. Vega-Mercado, O. Martin-Belloso, F.-J. Chang, G. V. Barbosa-Cánovas, and B. G. Swanson 1996a. Inactivation of *Escherichia coli* and *Bacillus subtilis* suspended in pea soup using pulsed electric fields. *J Food Process Preserv.* 1996, 20(6), 501-510.
- [12] H. Vega-Mercado, U. R. Pothakamury, F.-J. Chang, G. V. Barbosa-Cánovas, and B. G. Swanson "Inactivation of *Escherichia coli* by combining pH, ionic strength and pulsed electric fields hurdles." *Food Res Int.*, 1996, 29(2), 117-121.
- [13] E. Puertolas, E. Luengo, I. Alvarez, and J. Raso "Improving Mass Transfer to Soften Tissues by Pulsed Electric Fields: Fundamentals and Applications." *Annu. Rev. Food Sci. Technol.*, 2012, 3, 263-282.
- [14] B.I.O. Ade-Omowaye, A. Angersbach, K.A. Taiwo, D. Knorr "Use of pulsed electric field pre-treatment to improve dehydration characteristics of plant based foods." *Trends Food Sci. Technol.*, 2001, 12, 285-95
- [15] M.N. Eshtiaghi "Coconut fruit processing using advanced technology." Bachelor thesis, Mahidol University, Thailand, 2012.
- [16] M. Guderjan, S. Toepfl, A. Angersbach, D. Knorr "Impact of pulsed electric field treatment on the recovery and quality of plant oils." *J. Food Eng.*, 2005, 67, 281-87.

**AUTHOR'S PROFILE**
**Kamonwan Paoplook**

Was born in 1993, Thailand. She is Master degree candidate in Mahidol University, Faculty of Engineering, Department of Chemical Engineering. She has 2 international presentation and 3 accepted papers for publication in international journals.


**Mohammad Naghi Eshtiaghi**

Was born in Teheran, IRAN He received his Bachelor degree in Nutrition Science in Institute of food and nutrition science in IRAN. After that he received his Master degree in Food and Biotechnology in Berlin University of Technology in Germany. In addition, he has received his PhD degree in Food and Biotechnology in the same

University in Germany followed by Post doctoral degree (Novel Technology in Food Processing) and Professor Degree in Food and Biotechnology Processing in Germany.

He was many years as Assistant Prof. in Berlin University of Technology in Germany. He is now as visiting Prof. in Mahidol University, Department of Chemical Engineering Thailand.

His research interests are Nano technology, Novel technology for food production and preservation, Biofuel, Non-thermal food processing, active substances from foods.

He is author and co-author of more than 100 international presentation and publications in the field of food processing, nano-technology, bio-ethanol and biodiesel, active substance extraction from plant waste using subcritical water.