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A New Method for Omitting Switch Circuit of PEF (Switchless PEF)

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ABSTRACT

Up to now, in Pulsed Electric Field (PEF) the switching circuit has been used to create pulse train for extracting effective material. These switches are expensive, and complicated in design. In this paper, a new idea has been presented based on omitting the switches. Instead of using switch, narrow plates with the constant voltage were employed which affect on food pieces floating in fluid environment. In this research, some foods have been treated. The PEF strength and pulse numbers were 0.6kV/cm and 1-50pulses, respectively. In these experiments two mentioned methods have been compared in energy consumption and amount of extracted effective material. This paper results indicate that the energy consumption of the new method(7.2J) is less than the traditional PEF system (14.4-138J) in the same results. So, it can be claimed that the fluid system is more effective in extracting materials and improving PEF efficiency.
KEYWORDS: Fluid, Food, Effective Materials, Energy Consumption, Pulse.
Running Title: A New Method for Omitting Switch of PEF

1. INTRODUCTION

High-voltage Pulsed Electric Field (PEF) is a capable technology in food processing such as extraction, pasteurization, and enhanced compression [1]. PEF processing involves treating liquid foods placed between electrodes by a strong pulse shaped electric field. The range of this field intensity is usually 0.5–50 kV/cm.

In comparison to the process of heating, Pulsed Electric Field works at low energy levels in short time. Therefore, this process can be considered as a non-thermal method. Pulsed Electric Field technology is based on penetrating biological membranes. This can be helpful, in producing fruit juices by improving yields of extractable ingredients. However, enzyme treatment can be avoided or reduced and the quality of the juice can be improved. Application of Pulsed electric Field to increase extraction properties is flourished as much as the inactivation of micro-organisms in fruit juice in recent years. The influence of PEF on solid–liquid expression from dissimilar plant tissues was demonstrated [2, 3].

A further function of PEF is pre-treatment before extraction e.g. the sugar from sugar beet slices [4]. The employment of PEF has been investigated and reported to be very promising in the recovery and production of commercially interesting and high value metabolites (natural pigments) from food [3], intensifying diffusion [5, 6] and acceleration of mass transport in drying procedure [7, 8]. PEF treatment on apple has been done by some scientists. For example, PEF with conventional high temperature-short time (HTST) effects on apple compared based on microbial inactivation and quality attributes[9]. He claimed PEF would have the potential to become a suitable replacement for traditional process if better designs are applied.

It was observed that phenolics content and volatile compounds concentration had statistical major differences between treatments of PEF and HTST in respect of minimal variability in pH and no important changes in acidity[10]. Pulsed electric Field technology has important parts such as generation of high electric field intensities, the design of chambers that impart uniform treatment to foods with minimum increase at temperature, and the design of electrodes that minimize the effect of electrolysis. One of the most important sections of PEF system is pulsegeneration. Generation of pulsed electric voltages requires a fast discharge of electrical energy during a short period of time. The PEF strength and pulse numbers were 0.6kV/cm and 1-100pulses, respectively. Experiments were done at 22-25°C. PEF chamber dimensions were 10×10cm^2 with the gap of 2cm. It was made from fiberglass insulation and PEF metal plates from stanless-steel-316. The common PEF consists of transformer, diode, capacitor and switch. The switch design and construction is more complicated and expensive than other parts.

In the traditional PEF system, a high voltage pulse has been applied to the fixed treating food but in the proposed method the fluid food is moving in a channel. DC high voltage causes a constant field between electrodes. If Narrow electrodes are used, moving food in this static field cause to sense a time variant field by

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the food. This time variant field is pulsed shape. By narrow electrodes the moving food is affected by different field intensities in each moment. In this method any pulse control part is not necessary. It is claimed that:

- this motion and using narrow plates causes the food sense pulsed shape field.
- Regarding the food speed (V) and the plates width(L), pulse width (T) can be calculated: T=L/V. For example, the narrow plates with 1cm width and the food speed of 1m/s, make a 10ms pulse width.
- The pulse numbers can be increased by adding plates.
- Different speeds lead to different delivered energy to the food.
- Switchless PEF (SPEF) machine construction cost is lower than a traditional PEF.
- Constructing industrial SPEF is much easier than a PEF machines.

In construction of SPEF some pointes must be considered:

- DC high voltage generator
- Narrow Electrodes
- Food Carrier: Distilled water due to high resistance and therefore, less energy loss
- Food channel characteristic: Shape, material, dimensions, etc.

In this paper, the first section is introduction. The next section allocates to material and methods: design of PEF and SPEF (electrical and system parts), plant materials, and extraction procedure. In this section, Electrical design points have been described, carrier selection points are discussed, some mechanical aspects of moving the food in the carrier are surveyed, and at the end measurement methods and tools are presented. Result section claims that SPEF is more efficient than traditional PEF. In the last section which is conclusion, the various aspects of SPEF and PEF are compared.

2.MATERIALS AND METHODS

2.1 Design of PEF equipment

High voltage pulse generation needs to be discharged in a very short time. Accordingly, pulse width is much shorter than pulse interval. For this purpose, a capacitor as saving energy device is charged by high voltage AC resource. When the capacitor is charged completely, a high voltage switch can be closed. The saved energy delivered to the food material through the chamber. The switch must be fast and capable of letting a lot of energy pass; therefore, it is expensive and has high quality.

High Voltage source: high voltage is achieved by an incremental transformer that is used in neon lights. This source is able to provide current of about 1mA. The transformer can increase primary voltage from 220V to 15kV. In this paper, a field density of 600V/cm and the food container gap of 4cm have been defined. Therefore, output voltage of transformer was set 2400V. The variac adjusts the transformer input voltage around 35V.

High Voltage Capacitor: The capacitor saves energy for delivering output pulse to food material, whenever needed. Hence, each pulse's energy is directly proportional to its capacity. In the pulse generator circuit, a 7kV, 2μF capacitor was used.

High Voltage Diode: Based on configuration of figure 1, diodes must be able to tolerate voltage of more than 2400V in reversed mode. To create a diode with the mentioned capability, a series of 6 common 1kV diodes were used; 6A10 diodes.

High Voltage and Fast Switch: The switch is used for delivering energy from the capacitor to the food. This switch must be fast with low rise time. It must tolerate high voltage and high current. So it is an expensive part of the PEF circuit.

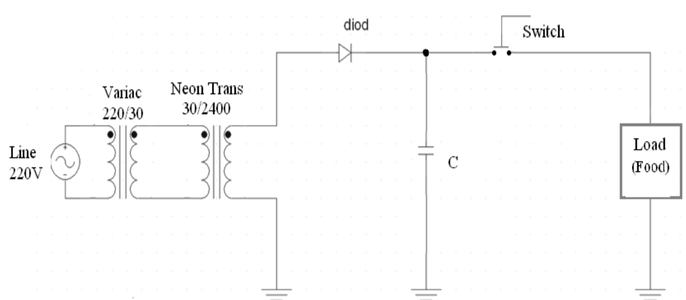


Figure1 high Voltage Pulse Generator Circuit

PEF chamber: A major component of a PEF unit is the treatment chamber for delivering electrical voltage pulses to food. It was chosen based on treatment conditions. The chamber characteristics are static chambers[11, 12], stainless steel electrodes [3, 4, 13], plexiglass insulator [4], and parallel plate electrodes [3, 14]. PEF chamber dimensions were 10×10cm with the gap of 1cm. Its cover was made from fiberglass insulation and its metal plates were made from stainless-steel-316.

2.2 Electrical Design of Switchless Pulsed Electric Field(SPEF) equipment

The idea was to use dc voltage with moving food in the fluid through narrow plates. Consequently, the first priority of the work was fabrication of a dc high voltage generator which must be able to load high current. Its electrical part configuration is shown in figure 2. To access a higher voltage, two rectifiers were used; one provides the positive voltage and the other the negative. For more safety, six 220V warning lights in series have been paralleled by the output.

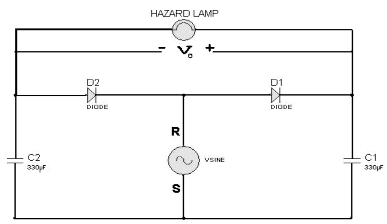


Figure2 rectified fixed voltage generator circuit

High Voltage Source with a Low Drop in High Current: Because of using negative and positive part of the output voltage, DC output equals $Vout_{DC}=2Vm=2\sqrt{2}Vac$. Therefore, there are two options for producing DC: A) Using the line voltage of 220V which yields DC output of 622V:$Vout_{DC}= 2\sqrt{2}Vac=2\sqrt{2}\times 220=622V$. B) Using the 380 volt three phases yields DC output of 1074V.$Vout_{DC}= 2\sqrt{2}Vac=2\sqrt{2}\times 380=1074V$. In this experiment, the option B was used.

High Voltage Diode: The most important device in rectifying is diode. Considering the configuration in figure 2, each diode bears around 600V reversed voltage. Therefore, 6A10 diodes are used in circuit and can support a 6A current in the direct bias mode. This diode has the capability of tolerating up to 1kV in the reversed bias mode.

High Capacitance, High Voltage Capacitors: The appropriate accessible capacitors were 330 microfarad with 400V. However, the necessary voltage is more than 1200V.According to the rules of circuit theory, the capacitors must be arranged in series mode to make a higher voltage capacitor. To increase the capacity of the capacitors, they must be parallel. To acquire a capacitor with higher capacity and voltage tolerance more than existing capacitors, several capacitors were used in parallel and series (figure 3). The result capacitor was a 165 microfarad and 1600 volt which was sufficient for our project.

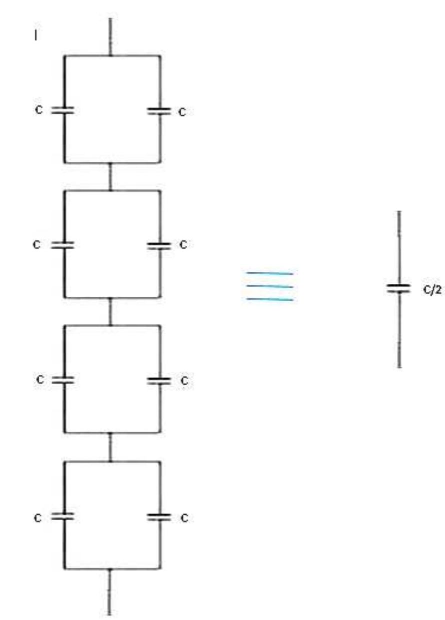


Figure3 Equivalent of parallel and series capacitor

Electrodes with Narrow Width: passing food through a flat field (DC voltage source) will sense a pulsed shape field, provided that plates would have narrow width. Each pair of electrode makes one pulse; therefore, n pair of electrodes produce n pulses (figure 4).

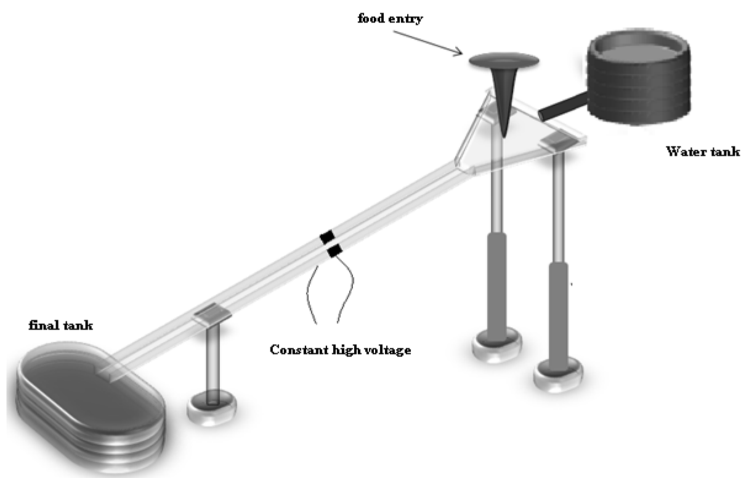


Figure4 Schematic of SPEF system

2.3 System Design of Switchless Pulse Electric Field equipment

As mentioned in previous sections, food must move in order to sense electrical pulses. For this purpose different methods can be used, one of them is using pump. Another way for making movement is employing a channel with a specified slope. The food has been put in upper tank. By opening a 1.2 inch valve the food moves downward based on its weight and the Earth's gravity. In these experiments the second method is being used. The fluid is distilled water which has a high electrical resistance and therefore is suitable for our experiments. For implementing the mechanical part, one channel made of fiber glass material with the length of 1m, width and height of 2cm is constructed. After that one pair of blades with the width of one centimeter is installed on the wall of the channel (figure 2). According to calculations and experiments, for having 1 meter per second velocity for the fluid containing food, slope of the channel must be approximately 20 degrees. As it was possible to have different velocities for food and fluid containing it, the velocity of the food was measured independently. For exact measurement of food speed, a canon camcorder was used. As the number of frames per second was 25FPS, the interval between two frames was 40ms. By measuring the relocation in two sequential frames (4cm) the speed of food was concluded (v=x/t) which resulted 1m/s. While foodless fluid was passing through the duct, electrical current was almost 2.5 milliamps. This amount reached 200 milliamps when fluid was containing small pieces of apple.

2.4 Plant material

By analyzing various kinds of foods, apple with soft tissue was chosen.

The golden apple was purchased from a local supplier and stored in a dark place at 4ºC.

2.5 Extraction procedure

In every experiment 20 grams of chopped apple was immersed in water. This mixed material was treated by the high voltage. Three samples were used every time to make sure of repeatability of results. Then it was mixed with an electrical mixer for 10 minutes. At the end syrup was filtered and three parameters of absorption coefficient, refraction index, and electrical conductivity were measured. Then this suspension was filtered through a Whatman filter (0.7µm). Devices used for comparing the results and having an appropriate benchmark for comparison between PEF and SPEF systems are as follow:

- Conductometer: A device for measuring specific conductance(in Siemens per centimeter).
- Refractometer: A device for measuring refraction index of the fluid(Refraction) and the absorption coefficient of light (Brix).

In this paper, Brix is presented in 100th of percent, refraction index is the last two digits of the number 1.333--, and syrup conduct is according to µS/cm.

In this article electrical field with approximate intensity of 600V/cm was applied to both PEF and SPEF systems. Electrical conditions were as fallow:

a) PEF system:
Voltage: 2.4kV

Capacitance: 2μF;
distance between Plates: 4cm,
plate width: 10cm
height of Plates: 10cm

b) SPEF pulse system:
Voltage: 1.2kV
distance between electrodes: 2cm
Electrodes width: 1cm
channel height: 2cm
channel slope: 20°
fluid speed: 1m/s
length of the duct: 1 m.

3. RESULTS AND DISCUSSION

3.1 Consumption energy comparison between PEF and SPEF systems

In PEF pulsed system, 2 microfarad capacitor is filled up to 2400 volts, therefore discharge energy of the capacitor is equal to:

One Pulse Energy in PEF=.5 × CV^2=.5 × 2 × 2.4^2=5.76J (1)

In Switchless PEF, moving food with 1m/s velocity stands between the pair of high voltage electrodes for 0.03s. Applied voltage equals to 1200V and measured current equals to 200mA:

Dissipated Energy in SPEF= V × I × t=1.2 × 200 × .03= 7.2J (2)

Therefore, switchless system energy is close to one pulse energy in PEF system.

3.2 Effects of SPEF on extraction of some fruits effective component and comparison with PEF

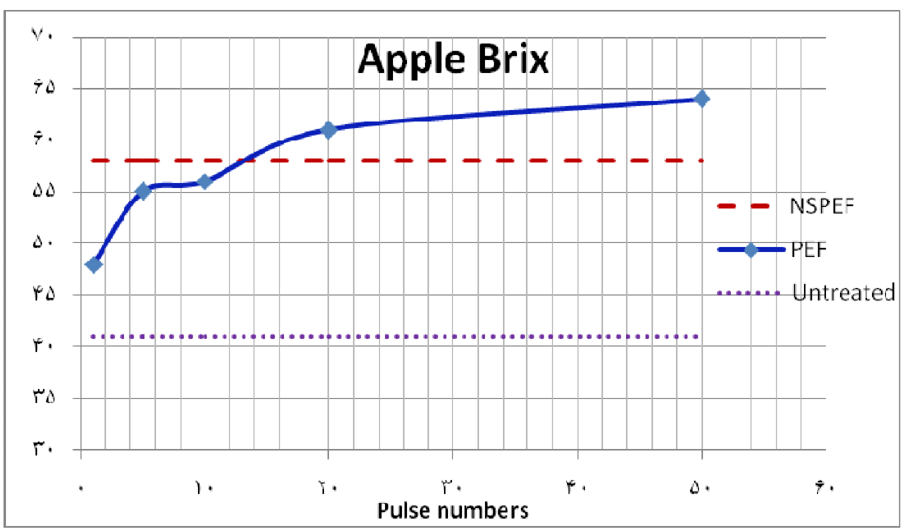
In this article, effects of SPEF process on three kind of fruits were studied. These fruits are apple, red cabbage, and sugar beet. For surveying these effects, three parameter of Brix, Refraction, and Conductance were measured. Experiments showed:

a) SPEF is impressive on extraction of effective material of fruits, considerably.
b) SPEF result is much better than untreated sample.

After that different experiments of SPEF and common PEF (with 1, 5, 10, 20, and 50 pulses) were done on mentioned three kinds of fruits.

3.3 Brix results

In this stage, Brix of apple and red cabbage syrup was measured by the refractometer. Figure 5 show the results of this measurement.



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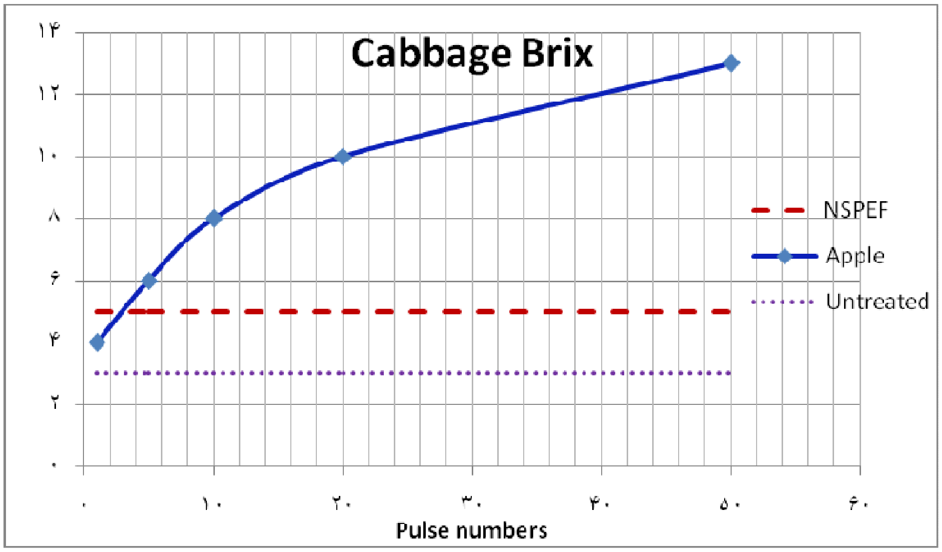


b

Figure 5 Brix comparison between PEF and SPEF a) apple b) red cabbage.
Untreated (dotted line ….), PEF (Solid line ——) , and SPEF (dash line ----)

As it is shown

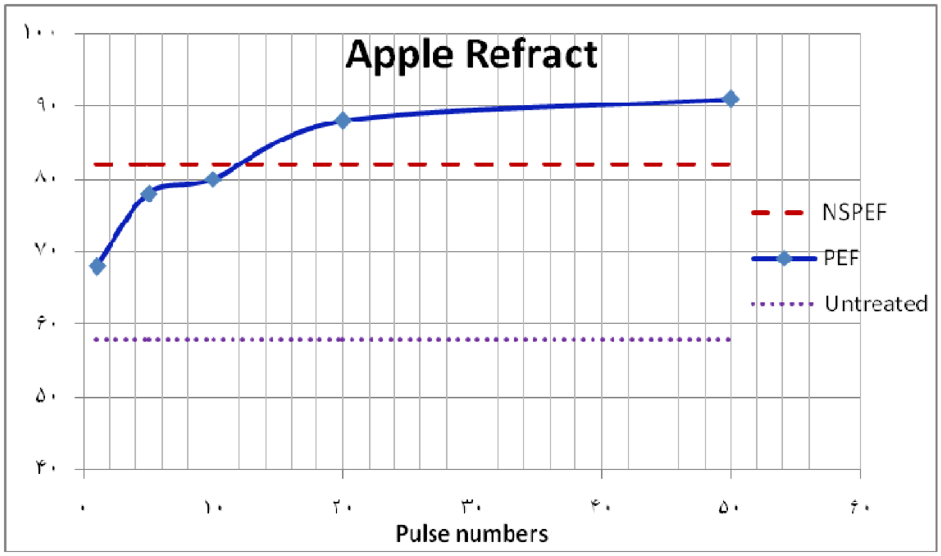
a) obtain Brix of SPEF is more than PEF in equal applied energies (Energy consumption of SPEF equals to one pulse of PEF):

apple: 58 for SPEF in comparison with 48 for PEF.
Red cabbage: 5 for SPEF in comparison with 3 for PEF.

b) By intercepting the curves it can be find out that for equal Brix it is needed to apply more than one pulse in PEF:

apple: 13 pulses
red cabbage: 3 pulses
It is obvious that making this number of pulses needs much more energy than a SPEF system.

3.4 Refraction results
In this step, refraction index of apple and red cabbage syrup was assessed by the refractometer. Figure 6 show the results of this measurement



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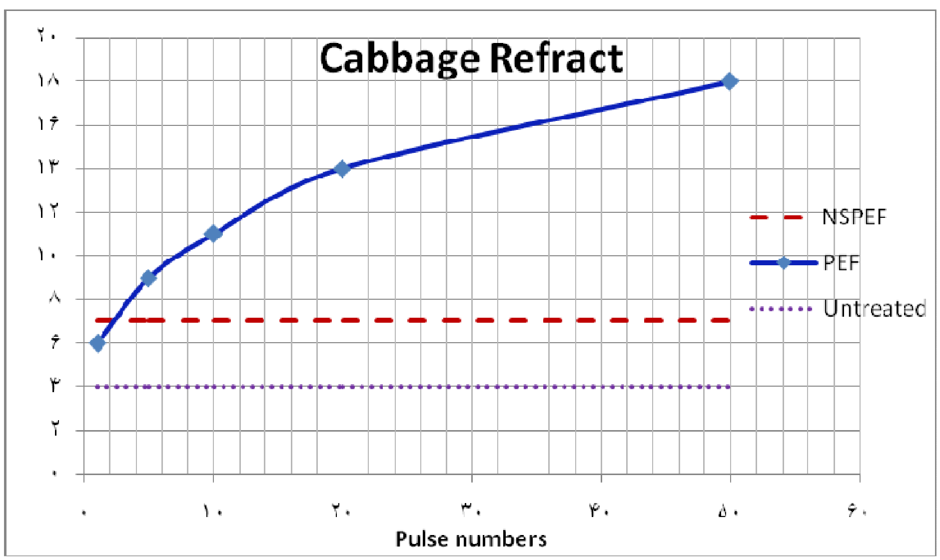


b

Figure 6 Refraction index comparison between PEF and SPEF a) apple b) red cabbage. Untreated (dotted line ….), PEF (Solid line ──) , and SPEF (dash line ----)

As it is shown

a) Taken refraction index of SPEF is more than PEF in equal applied energies (Energy consumption of SPEF equals to one pulse of PEF):

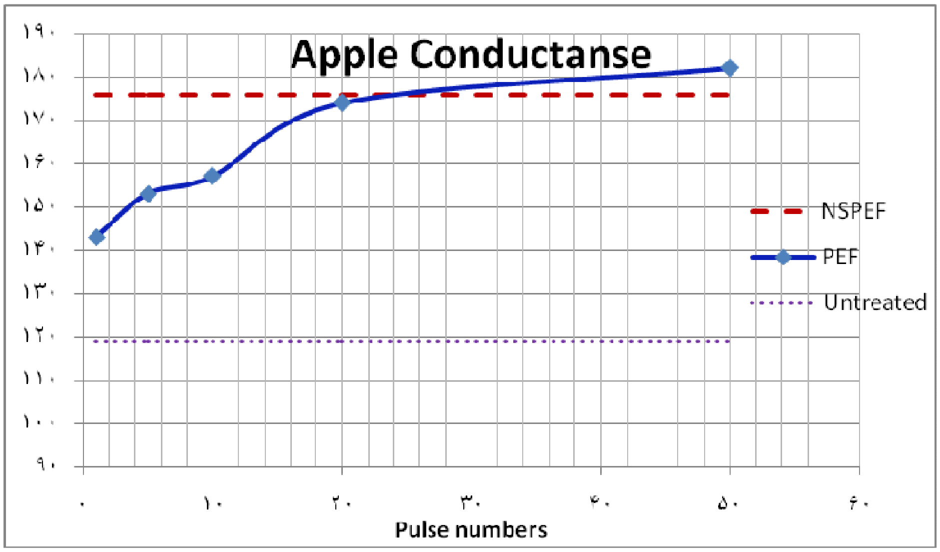
apple: 382 for SPEF in comparison with 368 for PEF.
Red cabbage: 7 for SPEF in comparison with 4 for PEF.

b) By intercepting the curves it can be realized that for the same refraction index more than one pulse must be applied in PEF:

apple: 12 pulses
red cabbage: 2.5 pulses

3.5 Conductivity results

In this step, conductivity of apple, red cabbage, and sugar beet syrup was measured by the conductometer. Figure7 show the results of this measurement



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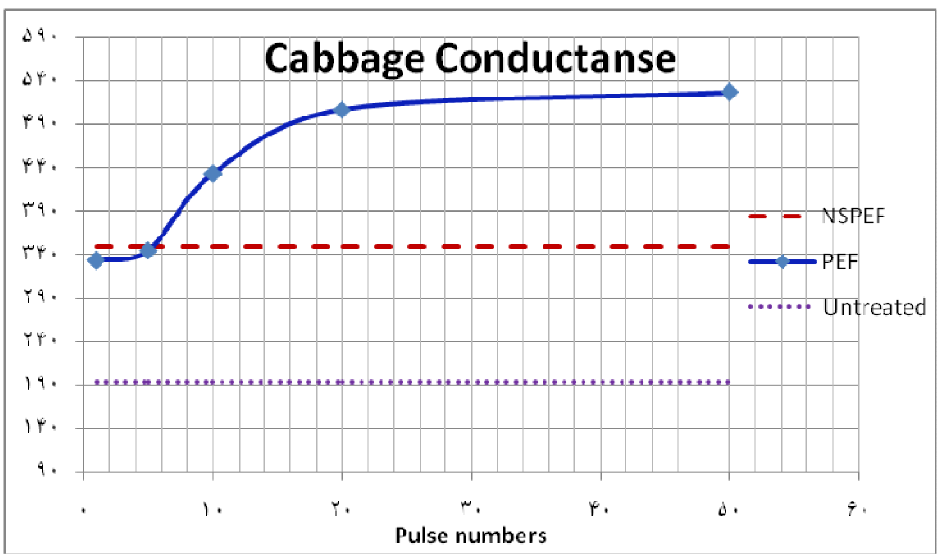

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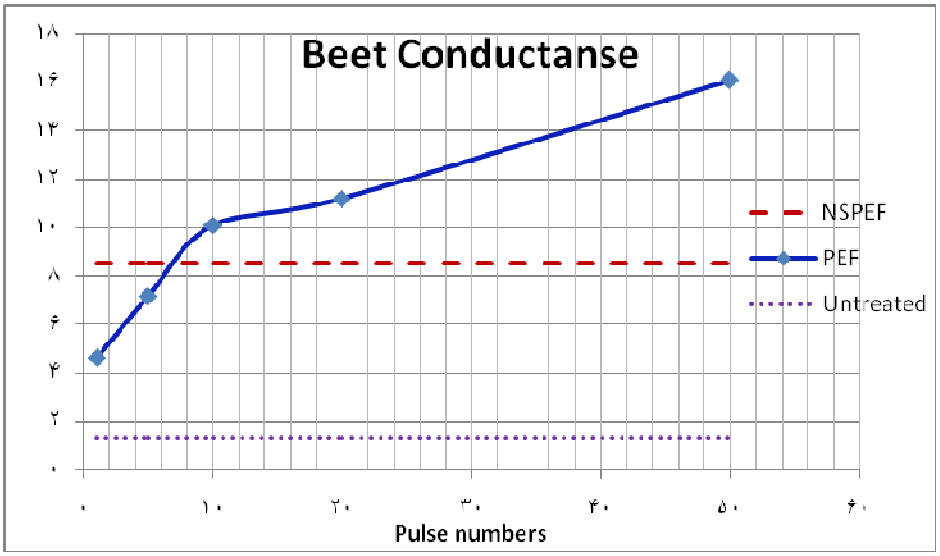

c

Figure7 Conductance comparison between PEF and SPEF a) apple b) red cabbage c) sugar beet. Untreated (dotted line ….), PEF (Solid line──) , and SPEF (dash line ----)

As it is shown

a) Achieved conductivity of SPEF is more than PEF in equal energies (Energy consumption of SPEF equals to one pulse of PEF):

apple: 176 for SPEF in comparison with 143 for PEF.
Red cabbage: 350 for SPEF in comparison with 193 for PEF.
Sugar beet: 8.52 for SPEF in comparison with 1.32 for PEF.

b) By intercepting the curves it can be realize that for the same refraction index more than one pulse in PEF must be apply:

apple: 24 pulses
red cabbage: 5 pulses
Sugar beet: 7 pulses

4- Conclusion

In this article, a new idea has been introduced that the switching circuits can be eliminated. It applies electrical pulse on food by using the movement of the food and extracts more effective material from it. Results of the experiments on different foods and measuring Brix, refraction index, and conductance show that this method is more efficient than PEF. According to switching circuit elimination, pulse generator system will have less cost and easier maintenance. It can be claimed that SPEF needs less energy in comparison with conventional PEF, in other words applying the same amount of energy SPEF gives better results.

As the number of plates used in the innovated system is one pair therefore one pulse will be applied to food. If more than one applied pulse is needed more plates can be used. In order to change the pulse width variation in food velocity or plate width can be used.

5- Acknowledgement

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