

APPLICATION OF PULSED POWER TECHNOLOGY IN NON-THERMAL FOOD PROCESSING AND SYSTEM OPTIMIZATION

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Abstract

A pilot plant scale pulsed electric field (PEF) continuous processing system was integrated with an aseptic packaging machine to test and demonstrate the efficacy of PEF technology as a non-thermal food processing method. Major components includes a 40,000 V/17 MW_p high voltage pulse generator and a set of multiple stages co-field PEF treatment chambers. Fluid foods could be processed at 50 ~ 150 L/h flow rate and packed aseptically into 200 ml plastic cup containers. System design was discussed and the microbial inactivation effect of this integrated PEF system was validated by microbially-enhanced orange juice (MEOJ) tests. The studies on PEF treated, aseptically packaged fresh orange juice indicated that this technology has the potential to extend the product shelf life.

Introduction

High voltage pulsed electric field (PEF) technology is a promising innovation in non-thermal food processing. Many researchers have reported the microbicidal effectiveness of PEF^{1,2,3,4,5,6,7}. Application of intense high voltage pulsed electric field leads to irreversible cell membrane breakdown in microorganisms⁸ while causing little loss in food flavor and taste as compared to traditional heat pasteurization³. A minimum of 15 kV/cm average field strength is considered adequate to inactivate most vegetative cells. Other factors affecting PEF treatment are treatment temperature, stage of microbial growth⁹, field strength and total treatment time¹⁰. This paper reports the first integrated pilot plant scale PEF treatment system with continuous food flow and an examination of the factors to optimize PEF treatment. The study was undertaken to explore the feasibility of applying PEF technology in a commercial scale system.

System set-up

The integrated PEF treatment system consists of a fluid handling system, a 40,000 V / 17 MW_p pulse generator, a multiple stage co-field PEF treatment chamber system and an aseptic packaging machine which can package the treated fluid food aseptically with either a sterile air or nitrogen headspace. Designed system capacity is 200 L/h.

The whole system is designed to maintain sterile and hygienic environment during processing. Operational procedure includes a) sterilization-in-place (SIP) of processing components, the system is subjected to 121°C for 30 minutes to ensure sterility before each test. b) PEF treatment and aseptic packaging, PEF treatment is applied at the desired dosage. Immediately after treatment, liquid food was packaged aseptically into 200 ml thermally formed plastic containers, avoiding the possibility of post contamination. c) cleaning-in-place (CIP) of both processing and storage components.

1. *Pulse generator.* The circuit of the pulse generator is shown in Fig. 1. A 40 kV command charging power supply was used. The switching device was a 50kV/5kA hollow anode thyatron. This pulse generator operates at a maximum repetition rate of 1000 Hz. Different shapes of high voltage pulses could be applied to food by changing the pulse forming network (PFN). A high voltage probe (ratio 10,000: 1) and a 0.01 Ω current-viewing resistor monitored the discharge voltage and current signals, waveforms were displayed on a 100 MHz digital oscilloscope.

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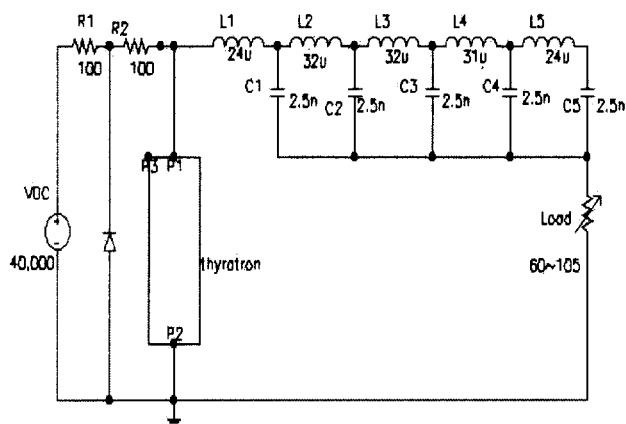


Figure 1. Schematic diagram of the pulse generator

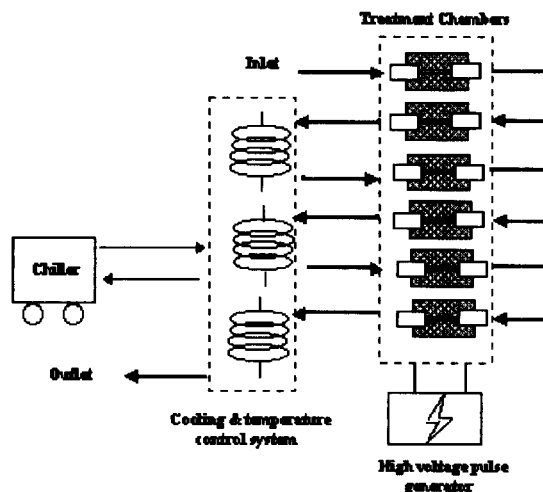


Figure2. PEF Treatment chamber system

2. *Multiple stages co-field PEF treatment chamber system.* A novel design of the PEF treatment system was used in the integrated pilot plant processing system. It consisted of a set of co-field tubular treatment chambers and a temperature regulating subsystem as shown in Fig. 2. Each PEF treatment chamber consists of two stainless steel tubular electrodes and a tubular insulator body made of Delrin®, both materials are FDA approved for the food industry. The diameter of the cylindrical treatment zone was 0.48 cm and the distance between the electrodes was also 0.48 cm. These parameters guaranteed an adequate average field strength inside the treatment zone and a quasi-uniform dynamic fluid flow profile. Electric field distribution within the PEF treatment chamber was simulated by finite element method assuming dc field. The electric field strength along the axis of the PEF treatment chamber is illustrated in Fig. 3. The treatment temperature was regulated at 30°C to provide optimum inactivation effect⁹. In this study, 12 PEF treatment chambers were connected to provide sufficient treatment. Fluid food flowed sequentially through all 12 chambers. By adjusting the repetition rate (800 Hz) and the system flow rate (75 L/h), an average of 3.3 pulses were delivered to the food in each chamber within the 4.16 ms resident time. Overall resistance of orange juice in all 12 chambers was approximately 60~70 Ω, regardless of the flow rate.

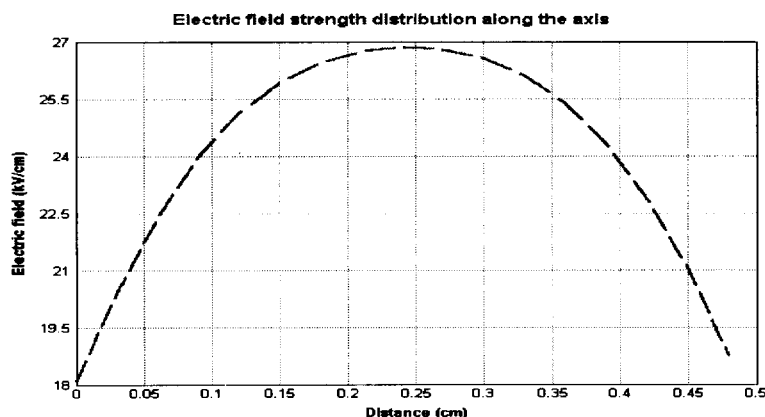


Figure3. Field distribution along the center axis of the cylindrical treatment zone

Experiments

Two types of fluid food were used. One type of food used was microbially-enhanced orange juice (MEOJ) which was used to determine the optimum processing parameters for the pilot plant system. The juice was prepared by reconstituting commercially available, pulp-free frozen orange juice concentrate and allowing it to incubate at 25°C

for 72 hours, letting the initial microbial load to reach 10^8 CFU(colony forming unit) /ml. The MEOJ was then treated with high voltage pulsed electric field at various dosages. Treated juice was aseptically collected at a sampling port immediately after treatment. A sample of the untreated MEOJ was also taken. Microbial inactivation effect of all samples was microbiologically examined using total aerobic plate counts and yeast and mold counts. Samples were diluted in 0.1%(w/v) sterile peptone water and plated onto tryptose agar (Difco) for total aerobic plate counts and onto potato dextrose agar (Difco) for yeast and mold counts. Tryptose agar plates were incubated at 30°C for 48 hours and potato dextrose agar plates were incubated at 22°C (room temperature) for 5 days before counting.

The other type of food used was freshly reconstituted, pulp-free orange juice from frozen concentrate. This juice was used to test the pasteurization effect of the integrated pilot plant PEF system using aseptic packaging and demonstrate the applicability of the system for commercial use. After processing, juice was packaged aseptically into 200 ml containers. These containers were stored at 4°C, 22°C and 37°C for refrigerated, room temperature (normal) and accelerated shelf life studies. Samples were periodically taken after selected storage times and microbially analyzed as previously described.

Three different types of high voltage pulses were tested for their effectiveness in microbial inactivation, namely square wave, exponential decay waveform, and an under-damped RLC waveform. In all experiments, the system was charged up to 33 kV at 800 Hz.

Square wave was generated using the circuit outlined in Fig. 1. The typical pulse waveforms are shown in Fig. 4 . Peak electric field strength E_p was 35 kV/cm and the critical pulse width τ_c (the portion having over and above 15 kV/cm average field strength) was 1.46 μ s, rendering a total average treatment time of 60 μ s. Rise time of the pulses waveform was 60 ns.

Exponential decay pulses were generated by removing all the inductors in Fig. 1 circuit. Typical output pulses are shown in Fig. 5, E_p was 62.5 kV/cm and τ_c was 0.85 μ s, providing 35 μ s of total treatment with a rise time of 40 ns. The exponential decay pulses are capable of providing a relatively high peak electric field, but the pulse fall time is long and the magnitude of the electric field drops below 15 kV/cm rapidly.

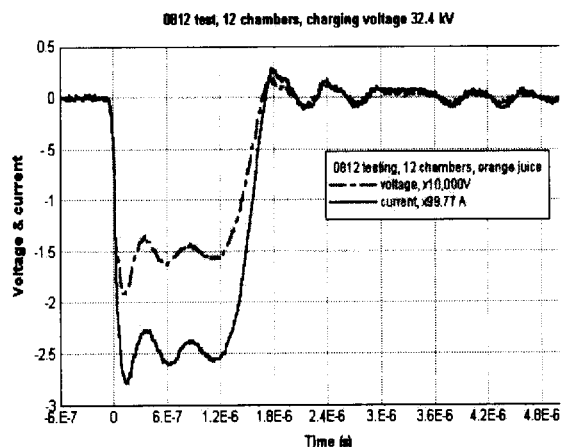


Figure 4. Typical Square wave pulses

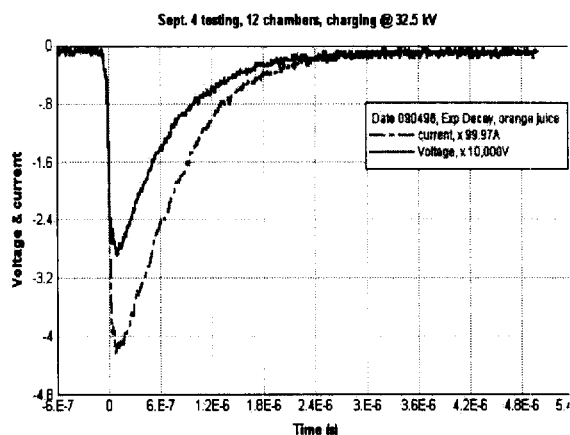


Figure5. Typical Exponential decay pulses

The under damped RLC pulses were produced using the circuit illustrated in Fig. 6. Typical waveforms are shown in Fig. 7, having 37 kV/cm of E_p , 1.64 μ s of critical pulse width and 67 μ s of total treatment. Rise time of this type of pulses was 400 ns. A relatively long pulse duration could be achieved when using this type of pulses, and it is easy to obtain a polarity reversal in the applied pulses, which is considered helpful in inactivating micro-organisms⁵.

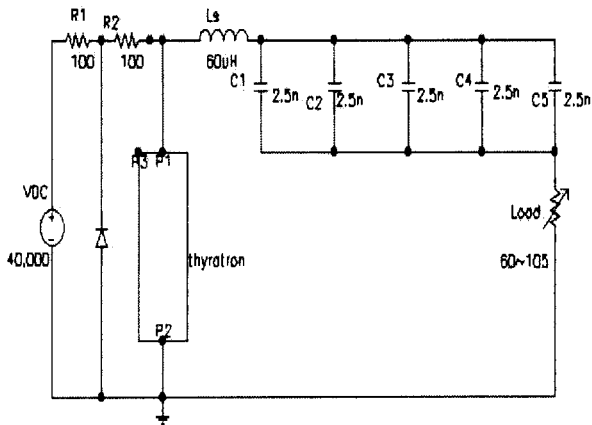


Figure 6. Schematic diagram of the under-damped RLC circuit

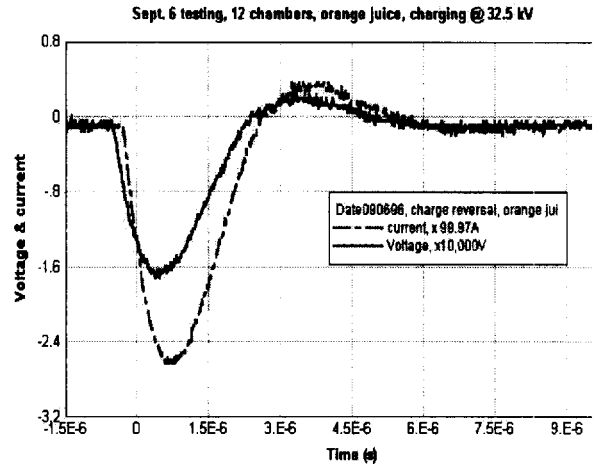


Figure 7. Typical under-damped RLC pulses

Results and Discussions

The test results on the microbially-enhanced orange juice indicated that after PEF treatment there is a minimum of 3.6 log cycles of reduction in microbial count, as determined by total aerobic plate counts, regardless of the pulse wave shapes (Table I). This corresponds to a 99.9% reduction in the microbial population in the MEOJ. The above results have been verified by repeated tests, suggesting that the pilot plant scale PEF treatment system is capable of inactivating microbes in a large volume of fluid food product.

Table I Microbial inactivation and shelf life study data

Waveform	Square wave	Exp. Decay	Under-damped RLC
E_p (kV/cm)	35	62.5	37
τ_c (μ s)	1.46	0.85	1.64
E_{avg} (kV/cm)	29.5	21.24	23.52
Inactivation (Logs)	4.2	3.6	\
Accelerated shelf life (37 °C)	8 days	4 days	5 days
Normal shelf life (22 °C)	34 days	7 days	26 days
Refrigerated shelf life (4°C)	>7 months	>7 months	>7 months

When comparing the microbial inactivation data, it was shown that approximately more than a half log cycle reduction could be obtained by using square wave pulses as compared to that achieved with exponential decay pulses (Table I). These data suggested that the square waveform is effective in inactivating at least 50% more microorganisms than the exponential decay at any specific treatment condition.

PEF-treated, aseptically packaged orange juice had an extended shelf-life at 4°C (Fig. 8) compared to the untreated orange juice, which spoiled after 30 days, with a total plate count of more than 10^6 CFU/ml. A minimum shelf-life of 7 months at 4°C has been achieved with the PEF-treated, aseptically packaged orange juice. These data suggest that the pilot plant PEF treatment system is a viable choice for treatment of fluid food products. Moreover, normal and accelerated shelf life study data also implied that square wave pulses had the best pasteurization effect (Table I).

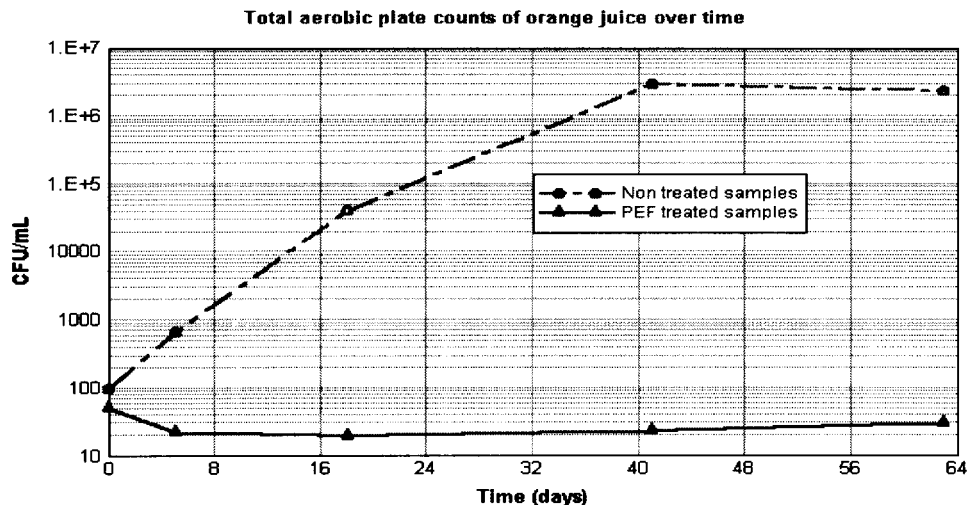


Figure 8. Total aerobic plate counts of PEF-treated and untreated orange juice over time

It is obvious from the data in Table I that neither E_p nor pulse duration time alone should be considered as the determining factor for microbial inactivation. In order to reveal the most substantial factor, the average field strength was calculated using the following formula

$$E_{avg} = \frac{1}{\tau} \int_0^{\tau} E(t) \cdot dt$$

where τ is the pulse duration.

A comparison of this parameter E_{avg} strongly suggested that a higher average field strength results in a better treatment effect. Exponential decay and under-damped RLC waveform are not capable of providing an effective electric field strength (15 kV/cm) for a relatively long time, due to their long tail time and a rapid drop in field intensity during that period. Therefore these two types of pulses can not provide a satisfactory pasteurization effect as compared to square waveform.

Conclusions

It was concluded that PEF processing was effective in eliminating 99.9% of the natural microflora in liquid food at a pilot plant scale, irrespective of the applied pulse waveforms. The square wave pulses was most effective. A higher average field strength results in a better pasteurization result.

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