

# Application of Short-Duration and High-Intensity Voltage Pulses for Food Processing and Storage Studies in Different Packaging Materials

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## ABSTRACT

**Introduction:** The focus of food scientists and engineers is towards non-thermal technologies for food processing and preservation for retaining the fresh attributes of the product without compromising safety and quality. In this research work, one of the non-thermal approaches called the pulsed electric field (PEF) method has been employed for shelf-life studies of raw milk processing and preservation.

**Objective:** The main aim of this study is to investigate the shelf life studies of raw milk processing based on intense electric pulses of short duration and its packaging using various materials viz., glass bottles, lacquered tins, polyethene pouches and retort pouches.

**Methods:** To analyze the shelf life studies of raw milk processing, a non-thermal approach called the pulsed electric field method, which uses high voltage electric pulses for food processing, has been employed.

**Results:** The raw milk procured from nearby villages was processed using a pulsed electric field system and its shelf life was investigated using four different packaging materials. A voltage level of 35 kV/cm and 600 square pulses of pulse width 2.5  $\mu$ sec enhanced the shelf-life to 28 days when stored in glass bottles.

**Conclusion:** The study suggests that the shelf life of processed milk samples is good in glass bottles followed by tins, retort pouches and polyethene pouches.

**Key Words:** Digital storage oscilloscope, Packaging materials, PEF processing, Raw cow milk, Shelf life

## INTRODUCTION

Recently, the non-thermal approach for processing and preservation of food is preferred in food industries. This technique employs short duration pulses, of width in the range of micro-seconds, applied to the raw food placed between a set of electrodes. There is no significant heating of the food subjected to the high voltage pulses. The applied high voltage causes an intense electric field thereby inactivating microbial organisms.<sup>1,2</sup> After the food processing, the packaging is important as it avoids post contamination. Certain foods are more sensitive to oxygen present in the air medium. The oxidation of fatty foods may produce off-flavours. Similarly, the loss of Vitamin C or discolouring of fruit juices may occur due to oxidation. The material used for packaging these kinds of foods that are exposed to oxygen should be able to prevent the transmission of oxygen into the food. The selection of pack-

aging material depends upon technical suitability, availability and cost. In this proposed research work, high voltage (HV) electrical pulses of short duration are used for processing raw cow milk placed in the space between a set of electrodes. The presented work explains how the raw milk is processed using HV electric pulses of short width and how it is effectively stored in packages of different materials. The raw milk samples were collected from six different villages in and around Koduvalli village near Redhills, Chennai. The raw milk was processed through the lab-scale HV electric pulse based processing parallel plate batch treatment chamber and the milk so processed was effectively preserved in packages made of different materials.

The remaining part of the paper is planned into various sections. Section 2 explains the concept of the Pulsed Electric Field (PEF) system employed for raw milk processing. Sec-

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tion 3 describes the packaging of PEF processed milk. The shelf-life studies of milk collected from different sources are described in section 4. Finally, the conclusions of the proposed work are given in section 5.

## MATERIALS AND METHODS

### Concept of food processing using Non-thermal method

The non-thermal method uses high voltage (HV) electric pulses for raw food processing. These HV electric pulses in turn produce a high-intensity electric field. This simple system of pulsed electric field (PEF) incorporates various essential components such as a scheme for producing an HV power supply, a bank of capacitors for energy storage, and HV resistor, a switch, processing chamber(s), voltage probes, current probes and temperature probes, and a cooling scheme. The overall PEF system is monitored by a control panel. The liquid food can be conducted through the processing equipment using a pump in the case of a continuous monitoring system.<sup>2</sup> The concept and application of PEF technology have been explained by many authors in the literature.<sup>3-9</sup>

In the system of HV electric pulses, a bank of capacitors is charged using the energy obtained from an HV power supply scheme. The charged capacitor bank is allowed to discharge through the food material to be processed for generating the required high-intensity electric field in the space (containing food) between the electrodes.<sup>4</sup>

Each energy storage capacitor in the capacitor bank has the capacitance  $C$  (F) as defined by equation (1):

$$C = \frac{\tau \sigma A}{d} \quad (1)$$

where  $\tau$  denotes the width of the HV electric pulse (s),  $\sigma$  represents the electrical conductivity of the food material to be processed ( $\text{Sm}^{-1}$ ),  $A$  represents the area of cross-section of each electrode surface ( $\text{m}^2$ ),  $d$  is the distance between the parallel electrodes (m). The following equation (2) is used to calculate the magnitude of electric field intensity ( $E$ ) in kV/m produced in the food material to be processed.<sup>10</sup>

$$E = \frac{\text{Charging Voltage (V)}}{\text{Distance (d) between the electrodes}} \quad (2)$$

The energy stored per unit volume ( $w$ ) in  $\text{J/m}^3$  of the capacitor is denoted as equation (3), where  $\epsilon$  denotes the permittivity of food material placed between the electrodes (F/m).

$$w = \frac{1}{2} \epsilon E^2 \quad (3)$$

The HV switch is closed in response to a trigger signal. The charged capacitors discharge at a very fast rate through the

food material placed in between a pair of electrodes kept in a processing chamber where the food is treated.<sup>11</sup>

### PEF system

A pulsed electric field (PEF) supply unit also called a pulse power source is designed for 40 kV using high dielectric constant capacitors. It is made to charge in parallel and discharged in series through a very low inductance. The heart of the unit is the Pulse Forming Network (PFN) which has a HV power supply unit, a pulse forming unit, a filtering network and a main spark gap switch. The control unit is designed to have a trigger generator that generates a trigger pulse in response to a +5V command which initiates the spark gap discharge automatically. The system is designed to have a minimum load of 50  $\Omega$ . The 50  $\Omega$  resistor is selected to avoid loading problems when high concentration juices or salt solutions are processed. A kilovolt meter (analogue) is inbuilt to record the voltage and a digital storage oscilloscope is used to record the pulse shape. An energy meter is also incorporated into the system to record the energy consumed after each trial. The schematic arrangement of the PEF system is shown in figure 1.

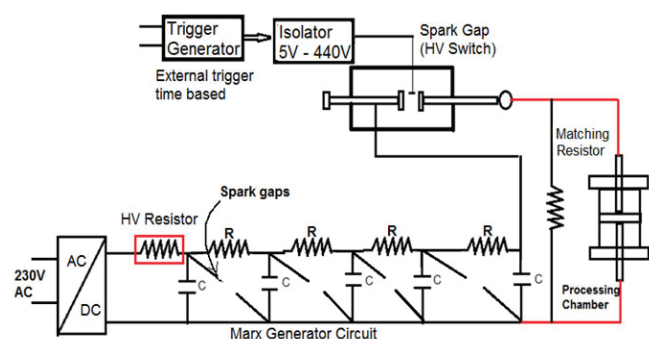


Figure 1: Schematic of PEF method of milk processing.

### PEF chamber

A lab-scale PEF chamber is designed using an acrylic sheet embedded with two circular food-grade stainless steel electrodes. The PEF chamber consists of a fill valve, drain valve and adjustable electrodes. The active PEF region can be varied by adjusting the distance between the electrodes. The diameter of the electrodes is designed as 9.5 cm. The PEF chamber is designed for batch processing which can hold approximately 100 ml of liquid food.

The raw milk is treated at different pulse rates and different voltage levels. The parameters (voltage, distance between electrodes, and the number of pulses) are standardized by conducting many trials and by undergoing platform tests, chemical analysis, microbial analysis and nutrient analysis. The raw milk is treated with standardized parameters and packed using different packaging materials.

## Packaging materials

Food packaging plays an important role in extending the period during which the processed food will remain safe. The shelf-life of the PEF processed food product can be extended using packaging materials that are less sensitive to oxygen exposure. Some authors have reported that the headspace has higher oxygen concentration with more diminished Vitamin C levels.<sup>12</sup> A technique called Modified Atmosphere Packaging (MAP) is used to regulate oxygen concentration in the headspace.

The factors which influence the degradation of flavour compounds are (i). oxidation, (ii). susceptibility of materials used for packaging to permeate through and absorb flavour compounds. The rate of absorption is more if both the flavour compound and the materials used for packaging have similar chemical structural configuration or similar polarity.<sup>13</sup> For example, the volatile flavour compounds such as d-limonene and  $\alpha$ -pinene of orange juice are more easily absorbed by low-density polyethylene (LDPE) due to the strong affinity of the non-polar hydrocarbon of LDPE to the non-polar terpene hydrocarbons present in the juice.<sup>14</sup> However, the packaging materials can be so designed with low diffusivity and solubility to reduce the absorption of the fresh volatile flavour compounds of HV electric pulses treated food. The other polymer elements like polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), and ethylene vinyl alcohol (EVOH) do not easily absorb the volatile flavour compounds. The EVOH is commonly used in food packaging to help keep the air out and the flavour compounds in. However, the period during which the processed orange juice will remain safe is reduced due to the presence of oxygen in the package headspace.<sup>15</sup> The oxygen concentration can be limited in headspace using the Modified Atmosphere Packaging technique for extending the shelf-life of foods treated by short-duration HV electric pulses.

Another effective technology used for the preservation of high voltage treated foods in the liquid state is Aseptic food packaging which can extend the shelf-life of HV treated foods compared to that of the conventionally processed food products.<sup>16,17</sup> The aseptic food packaging technique employs plastics and laminated paper as packaging materials. However, the extension of the initial high quality of flavour, colour, and nutrients of HV electric pulses treated food products depends on the proper selection of packaging materials. Some authors have proposed Polyethylene as a packaging material that can provide a low barrier to oxygen.<sup>18-20</sup> But this low barrier property of polyethylene may cause instability of vitamins and the flavour compounds in the processed food products.<sup>18</sup>

Some authors reported that vitamin C, colour, and flavour compounds of HV treated food can be effectively maintained at 4°C for 112 days if the HV treated food is preserved in glass bottles and polyethylene terephthalate (PET) bottles in

which the concentrations of vitamins are higher than that in high-density polyethylene (HDPE) or LDPE bottles.<sup>12</sup>

## Packaging materials used for the study

The packaging materials used for the study are glass bottles, metal tins, Poly Ethylene pouches and Retort pouches respectively. The glass bottles of 200 ml capacity are sterilized in a hot air oven at 160°C for half an hour. The processed samples are aseptically collected in sterile glass bottles, corked and stored in 4°C cold rooms as shown in figure 2(i).

The lacquered tins (pull open type) of 80 mm diameter and 70 mm height are kept in a hot air oven for half an hour and the processed samples are filled aseptically and sealed using a canning machine and stored in a 4°C cold room as shown in figure 2(ii). The LDPE plastic is the first grade of polyethylene produced using a high-pressure process. Polyethylene pouches of 200 ml capacity with 50-micron thickness are sterilized in ultraviolet (UV) light and the processed milk samples are collected aseptically and sealed using a band sealer and stored in 4°C cold room as shown in figure 2(iii). Another type of food packaging called reportable pouch is made from a pre-fabricated multilayer laminate of flexible plastic and Aluminum metal foil. Here in this work, the dimension of the retort pouch consisting of Aluminium metal foil is 15 cm × 20 cm. Retort pouches of 200 ml capacity are sterilized under UV light and the processed milk samples are collected aseptically and sealed using a band sealer and stored in a 4°C cold room as shown in figure 2(iv). The processed food products placed in retort packaging are sterile and shelf-stable.

## Quality control tests conducted for PEF processed milk preserved in different packages

The temperature was recorded after each trial using a high sensitive thermocouple to check the rise in temperature after processing. The colour and odour were determined using 9 points Hedonic scale rating by 10 selected untrained panelists. A sample volume of 100 ml of processed milk sample was given to the panellists to give their ratings in comparison with the control. In five minutes of exposure of 5 ml of the processed milk sample in a test tube to a boiling water environment, the flakes/clots appeared on the inside of the test tube and they indicated positive for the test. A digital pH meter standardized using a pH buffer of 4.0, 7.0 and 9.2 was used to determine the pH value of the processed food at room temperature. The acidity in the milk was estimated by titration method using 0.1N NaOH solution. The titratable acidity which is the sum of natural acidity and developed acidity can be expressed in terms of percentage of lactic acid and was calculated using the values of ml 0.1 NaOH used, normality of 0.1N NaOH and ml milk solution used in this work.

A 10 ml of milk was pipetted out using a sterile pipette into a sterile Methylene Blue Dye Reduction Test (MBRT) test



tube to which 1ml of methylene blue was added and closed with a sterile rubber cork. The test tubes were kept in the water bath at a temperature of  $37 \pm 0.5^\circ\text{C}$ . Time taken for the reduction of methylene blue dye was observed. The time at which the blue colour disappeared was noted as MBR time. Total plate count was assessed for the processed and control samples of milk in different packaging materials during storage daily for 30 days. The samples were analyzed in triplicate following the methods of ISO 4833 for total plate count. Coliform was assessed for the processed and control samples of milk in different packaging materials during 30 days period of storage. The analysis of the milk samples was carried out in triplicate following the methods of ISO 16649 – 2 for coliform. The nutrients such as fat, protein, Solids-not-fat (SNF) contents and lactose were assessed in the PEF processed milk during its storage period using a milco scanner.

A 9 point Hedonic scale rating was used to measure the food acceptability. For sensory evaluation, colour, odour, and overall acceptability were assessed by selecting 10 untrained panellists. The 100 ml samples of all the processed milk samples were presented to the panellists. The preferred samples in comparison with untreated samples were rated by the panellists. The data were analyzed by a nonparametric test called Mann – Whitney U test for comparing the median of two populations that come from the same population. The test statistic is given by equation (4):

$$U = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - \sum_{i=n_1+1}^{n_2} R_i \quad (4)$$

Where,  $U$  = Mann – Whitney U test statistic

$n_2$  = first sample size;  $n_2$  = second sample size

$R_i$  = Rank for the observation from  $i^{\text{th}}$  sample size

### Packaging of PEF processed milk

The PEF processed milk is stored at  $4^\circ\text{C}$  in packages of different materials as shown in figure 2. The stored samples were subjected to sensory, chemical and microbial analysis at regular intervals. As glass bottles are impervious to microorganisms, pests, moisture, oxygen and odours, they did not migrate and react with milk. Sensory attributes, chemical and microbial analysis revealed a shelf life of 27 days. The tins used were double seam with push-on lids which are used to make canned foods. As the tins are impermeable to moisture, odours, light and microorganisms, the shelf life extended to 25 days. A retort pouch is made from a laminate of flexible plastic and metal foils.<sup>19</sup> The pouches were kept under UV light before packing. Its shelf life extended to 22 days. Polyethylene pouches were relatively permeable to oxygen and the shelf life of the PEF processed milk stored in polyethylene pouches extended to 22 days.<sup>20-21</sup>

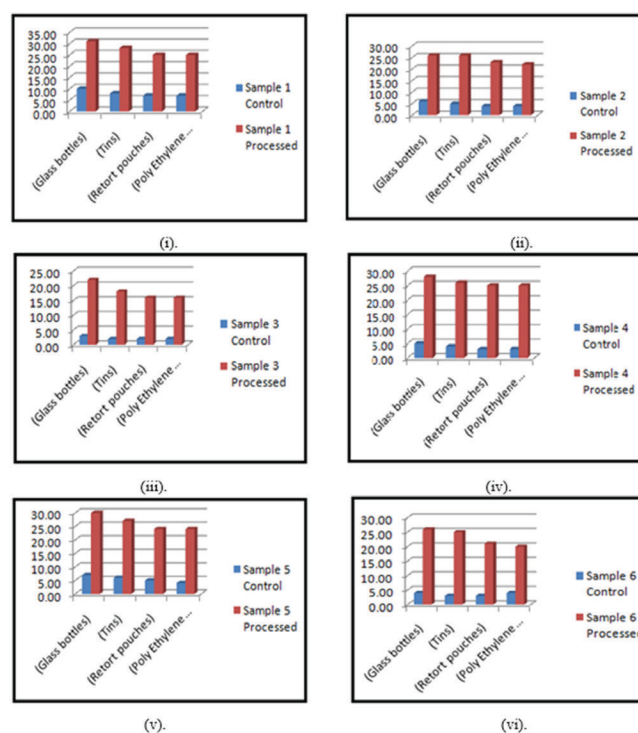


**Figure 2:** PEF processed milk stored in (i). Glass bottles, (ii). Tins, (iii). Polyethylene pouches, (iv). Retort pouches.

## RESULTS AND DISCUSSION

### Shelf-life studies of milk collected from different sources and stored in different packages

The following figure 3 shows the comparison between different packaging materials for milk samples collected from six different places around Alamathy Redhills village. The horizontal axis represents packaging materials and the vertical axis represents the storage period in days. The processed milk samples are compared with untreated milk samples.



**Figure 3:** Comparison of packaging materials concerning storage period for (i). sample 1, (ii). sample 2, (iii). sample 3, (iv). sample 4, (v). sample 5, and (vi). sample 6.

### Statistical analysis

In the statistical analysis of the milk sample, the distance between the electrodes, the voltage level, the number of pulses, and pulse frequency are taken as independent variables. The microbial load and shelf-life of milk samples are considered as dependent variables. The impact of

packaging materials during shelf life studies is analyzed using a Two-way Analysis of variance (ANOVA) that tests the effect of two independent variables (control and processed samples) on a dependent variable (days). **Table I** shows the comparison of different packaging materials concerning the storage period for untreated and processed milk samples. **Table II** gives the data generated by the ANOVA test. **Table III** shows the comparison between the packaging materials based on the Tukey HSD test. **Table IV** illustrates the homogeneous subsets 'a' and 'b' for different packaging materials based on Tukey HSD and Duncan's multiple range test with a 5% level of significance.

**Table I: Comparison of different packaging materials concerning storage period for untreated and processed milk samples**

Glass bottle		Tins	
Control (untreated)	Processed	Control (untreated)	Processed
5.83±2.48	27.17 <sup>a</sup> ±3.25	4.667±2.160	25 <sup>ab</sup> ±3.578
Retort pouches		Poly Ethylene sachets	
Control (untreated)	Processed	Control (untreated)	Processed
4±1.789	22.33±3.44	4±1.67	22 <sup>b</sup> ±3.52

**Table II: Data generated by ANOVA test**

Source	Type III Sum of squares	df	Mean square	Fitness value	Sig.
Corrected Model	4682.917 <sup>a</sup>	7	668.988	83.018	.000
Intercept	9918.750	1	9918.750	1230.869	.000
Packaging	96.917	3	32.306	4.009	.014
processed	4563.000	1	4563.000	566.246	.000
Packaging * processed	23.000	3	7.667	.951	.425
Error	322.333	40	8.058	---	---
Total	14924.000	48	---	---	---
Corrected Total	5005.250	47	---	---	---

<sup>a</sup>- Correlation coefficient = 0.936 (Adjusted value of Correlation coefficient = 0.924).

<sup>df</sup>- degrees of freedom, 'Sig.'- Significance

The error in Mean Square is calculated as 8.058 based on observed means.

**Table III: Comparison between the different packaging materials based on Tukey HSD test**

Dependent variable: days				
Test	Packaging	Packaging with other materials	95% confident interval	
			Lower bound	Upper bound
Tukey HSD	Glass bottle	2	-1.4397	4.7730
		3	0.2270	6.4397
		4	0.3937	6.6063
	Tins	1	-4.7730	1.4397
		3	-1.4397	4.7730
		4	-1.2730	4.9397
	Retort pouches	1	-6.4397	-.2270
		2	-4.7730	1.4397
		4	-2.9397	3.2730
	Polyethylene sachets	1	-6.6063	-.3937
		2	-4.9397	1.2730
		3	-3.2730	2.9397

**Table IV: Homogeneous subsets for different packaging materials**

Test	Packaging	No. of trials N	Subset	
			B	a
Tukey HSD <sup>b</sup>	Poly Ethylene pouches	12	13.0000	---
	Retort pouches	12	13.1667	---
	Tins	12	14.8333	14.8333
	Glass bottle	12	---	16.5000
	Sig.	---	0.400	0.484
Duncan <sup>b</sup>	Poly Ethylene pouches	12	13.0000	---
	Retort pouches	12	13.1667	---
	Tins	12	14.8333	14.8333
	Glass bottle	12	---	16.5000
	Sig.	---	0.143	0.158

Statistical analysis was carried through average and percent-age analysis. Two way ANOVA test was carried out by keeping the days as dependent variables and all the other facts as independent variables. Duncan's multiple range test was conducted to find the homogenous subsets.

Statistical analysis demonstrates that the packaging materials differ significantly between them. The shelf-life of milk in glass bottles showed a significant difference when compared to tins, polyethylene sachets and retort pouches. But, the retort and polyethylene sachets do not differ significantly. Glass bottles attained a maximum shelf-life followed by tins. The fitness of the model is reflected through the 'F' value which is significant at the 1% level. The independent variable (control sample and processed samples) also show significant variations across the four different groups which are also reflected through the 'F' values at a 1% level of significance. From homogenous subsets, Polyethylene, Retort and tins do not differ significantly at a 5% level of significance. Group 1 (Glass bottles) has a significant difference when compared to the other packaging materials such as Polyethylene, Retort and Tin.

## CONCLUSION

The raw milk procured from nearby villages was processed using a pulsed electric field system and its shelf life was investigated using four different packaging materials. A voltage level of 35 kV/cm and 600 square pulses of pulse width 2.5  $\mu$ sec enhanced the shelf-life to 28 days when stored in glass bottles. During the shelf-life studies in different packaging materials, it was observed that there was a significant difference between glass bottles and the other packaging materials. Among the four packaging materials, glass bottles exhibited a greater shelf-life followed by tins, retort pouches and polyethylene sachets.

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