Identification of Dominant Frequencies in Lightning Impulse Voltage Signal Applied to Microbial Inactivation in Liquid Foods

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Abstract:

A non-thermal Pulsed Electric Field technique is one of the non-lethal processing techniques to preserve liquid and solid foods. Pulsed Electric Field is the advancement of breaking up the microbes by applying a few hundred impulse voltage pulses in a very short time interval without any increase in temperature. Electrolytic derivatives, the breakdown of food particles is diminished through the application of short, high-intensity electric pulses. The effectiveness of microbial inactivation is influenced by several factors, including the intensity of the electric field stress, voltage wave shape, treatment time, total number of pulses, frequency of applied signal and the test chamber design. This research work was mainly intended to utilise the Marx lightning impulse voltage generator for the inactivation of microbes present in liquid foods and to identify the dominant frequency components contributing to the microbial inactivation by performing Frequency Response Analysis on the measured impulse signal. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency was verified by varying the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample was varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection was varied from 22 impulses per minute to 41 impulses per minute. Finally, the transfer function-based frequency response analysis was proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes.

Keywords: Pulsed Electric Field, Microbial Inactivation, Frequency Response Analysis, Impulse Injection.

Introduction

The Pulsed Electric Field (PEF) preservation method is a distinctive non-thermal food processing technology that serves as an alternative to traditional thermal techniques. PEF technology is widely used for food and biotechnology-related applications. Its effectiveness is shaped by a combination of factors, which can be broadly categorized into processing parameters, treatment medium characteristics, and biological attributes. A prior knowledge of these factors and their significance on inactivation rate is necessary in order to achieve a reliable outcome of the process. Dunn et al obtained U.S. patents to preserve liquid foods by electric pulse treatment. The patents outline two types of systems: a non-flow-through (batch) system and a continuous system, with experimental results primarily reported from the batch configuration [1–4]. Grahl et al. [5] observed that in the batch system, electric pulses reaching up to 26 kV/cm were delivered through the treatment chamber via a capacitor. According to Ayman H et al. [5], E. coli inactivation can be achieved at a minimum electric field stress of 0.43 kV/cm by increasing the number of impulses. Meanwhile, Shesha H. Jayaram et al. [6–10] have noted that in high-conductivity media, maintaining an optimal electric field exceeding 40 kV/cm necessitates the use of high-capacity generators. Several research studies have reported the treatment of water samples using a Marx lightning impulse generator with a high-energy impulse signal [11-16].

This study primarily aims to employ a Marx lightning impulse voltage generator for the inactivation of microbes in liquid food matrices. It also seeks to identify the dominant frequency components responsible for microbial inactivation through Frequency Response Analysis of the measured impulse signals. Typically, samples connected to the impulse generator exhibit varying impedance levels to the applied signal. Hence, this research proposes leveraging the data on dominant frequency components within the impulse signal. The outcome of this research work will pave the way to obtain maximum microbial inactivation efficiency in different liquid foods by designating specific frequency compositions for specific food items. This outcome will reduce the quantum of efforts taken to improve food quality.

1. Preliminary Investigations and Their Outcome

1.1 Water samples treated with impulse voltage.

The experimental investigations carried out in this research work use a Marx lightning impulse voltage generator, which is capable of generating short-duration lightning impulse voltage. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency is verified by varying the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample is varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection is varied from 22 impulses per minute to 41 impulses per minute. In addition, the effect of positive and negative polarity impulses on the inactivation efficiency is also analysed in this work. The results reveal that the treatment of water samples by injecting low-energy impulse voltage with varying impulse conditions is found to be effective in inactivating the microbes present in the water samples under consideration.

1.2 Description of experimental setup

Fig. 1 shows the experimental setup of the Marx Lightning Impulse Generator and the electroporation cuvette carrying a water sample. The impulse voltage is captured using a Yokogawa DLM 2022 Digital Storage Oscilloscope with a sampling rate of 1.25 GS/s and a bandwidth of 200 MHz. The generated impulse exhibits a front time of 1.2 µs and a fall time of 50 µs.

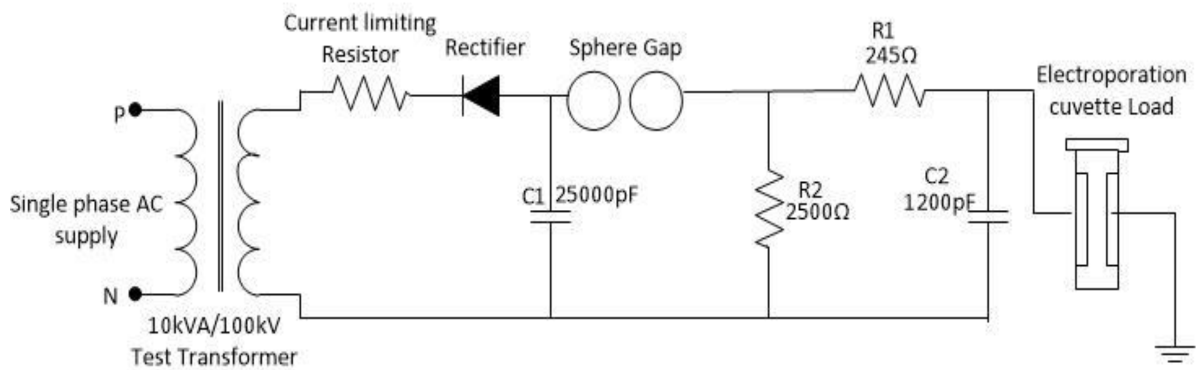

Fig.1 – Marx Lightning Impulse Voltage Generator setup for the injection of impulse voltage to the water sample

Fig. 2 shows the impulse wave shape under negative polarity and positive polarity. The magnitude of electric field strength at no load is maintained at 43 kV/mm, and at loaded conditions, it is maintained at 11.2 kV/mm for the Raw Groundwater sample and is maintained at 19.2 kV/mm for the chlorinated water sample.

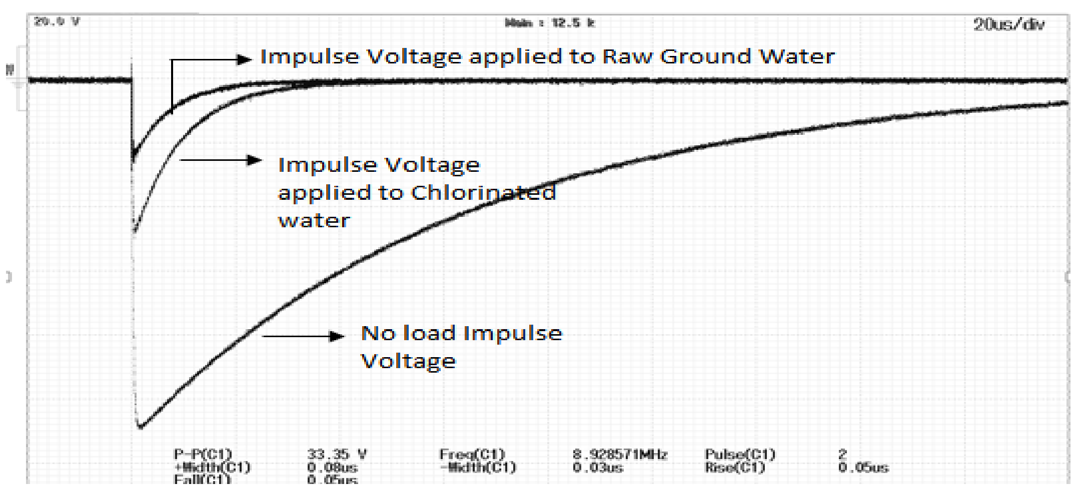

Fig. 2 - Negative polarity Impulse voltage wave under no load & loaded conditions

3.3 Results and Observations

3.3.1 Effect of varying number of Impulses on Raw Ground Water Sample and on Chlorinated Water Sample

Four different numbers of impulses [25, 50, 75, and 100] are used with negative polarity to inactivate naturally grown coliform bacteria E. coli. The electric field strength is maintained constant at 11.2 kV/mm for the raw groundwater sample and is maintained constant at 19.2 kV/mm for the chlorinated water sample. Table 1 shows the results of colony-forming units/mL for different numbers of impulses on the raw groundwater sample.

Table 1 - Colony Forming Unit/mL for different numbers of impulses with negative polarity impulse voltage on the raw groundwater sample

	Number of colonies counted				
Dilution level for serial dilution method	Before Treatment	After Treatment			
		25 impulses	50 impulses	75 impulses	100 impulses
10^{-3}	210	160	120	45	19

The findings reveal that increasing the number of impulses enhances the degree of microorganism inactivation. Table 2 shows the inactivation level of naturally grown coliform bacteria.

Table 2 - Inactivation level of naturally grown coliform bacteria E. coli in raw ground water sample exposed to different numbers of impulses

Number of impulses	Percentage viability	Log Reduction	Inactivation Efficiency
25	76.19	5.6	19.05
50	57.14	5.95	42.8
75	21.43	6.217	78.57
100	9.05	6.28	90.95

Table 3 shows the results of colony-forming units/mL for different numbers of impulses on a chlorinated water sample, and Table 4 shows the inactivation level of naturally grown coliform bacteria.

Table 3 - Colony Forming Unit/mL for different numbers of impulses for negative polarity impulse voltage on the chlorinated water sample

	Number of colonies counted				
Dilution level for serial dilution method	Before Treatment	After Treatment			
		25 impulses	50 impulses	75 impulses	100 impulses
10^{-3}	250	200	100	1	1

Table 4 - Inactivation level of naturally grown coliform bacteria E.coli in chlorinated water samples exposed to different numbers of impulses

Number of impulses	% viability	Log Reduction	Inactivation Efficiency
25	80	5.7	20
50	40	6.17	60
75	0.4	6.4	99.6
100	0.4	6.4	99.6

It is evident from the results that the viability of coliform bacteria decreases with a higher number of impulses in both the Raw Groundwater sample and the Chlorinated water sample. Also, the log reduction and inactivation efficiency increase for a higher number of impulses for both water samples.

2. Frequency Response Analysis on the injected impulse signal

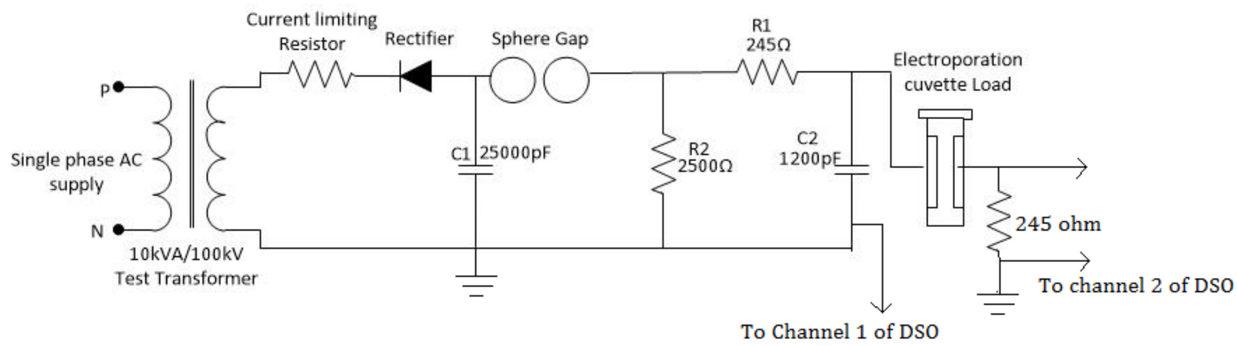

Fig. 3 – Experimental setup for impulse injection and measurement of impulse voltage and current signal

In general, frequency response analysis is used to identify faults and physical displacements in transformer windings [17-18]. In this research work, a similar kind of transfer function-based frequency response analysis is proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes. Fig. 3 shows the experimental setup for impulse injection and measurement of the impulse voltage and current signal. The injected impulse voltage is captured in channel 1 of the oscilloscope, and the impulse current flowing through the sample is captured in channel 2 of the oscilloscope and the wave shape of the input-to-output ratio is obtained by dividing the voltage signal and current signal. The resultant impedance wave is subjected to FFT analysis, and the FFT wave representing the dB magnitude versus frequency is obtained to identify the dominant frequency components. This analysis is repeated for different samples, including water samples and different juice samples. It is also proposed to correlate the relationship between frequency compositions and inactivation efficiency. The outcome of this analysis can be used to treat specific food items with a specific range of frequency instead of applying different frequency test signals.

4.1 Preliminary Results of Frequency Response Analysis applied to the water sample and the Mosambi Juice Sample

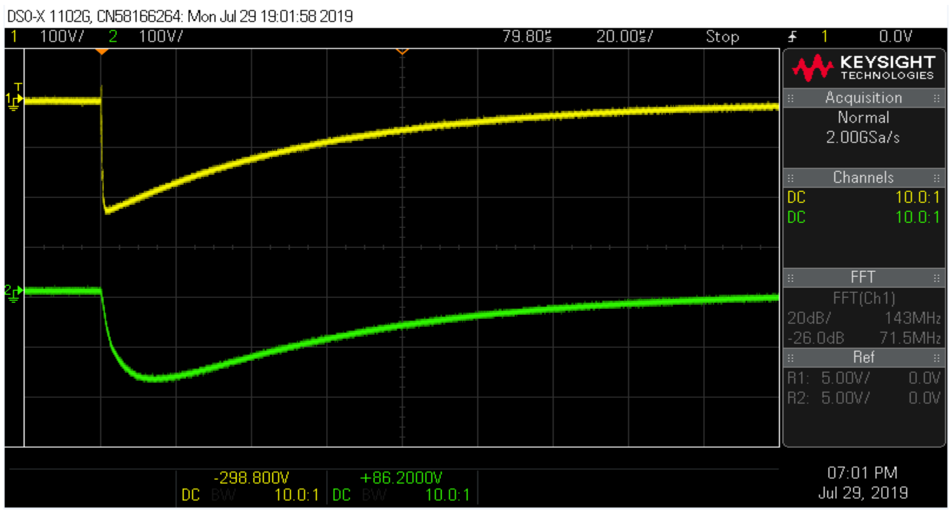

Fig. 4 - Lightning impulse voltage and impulse current measurement in a raw groundwater sample

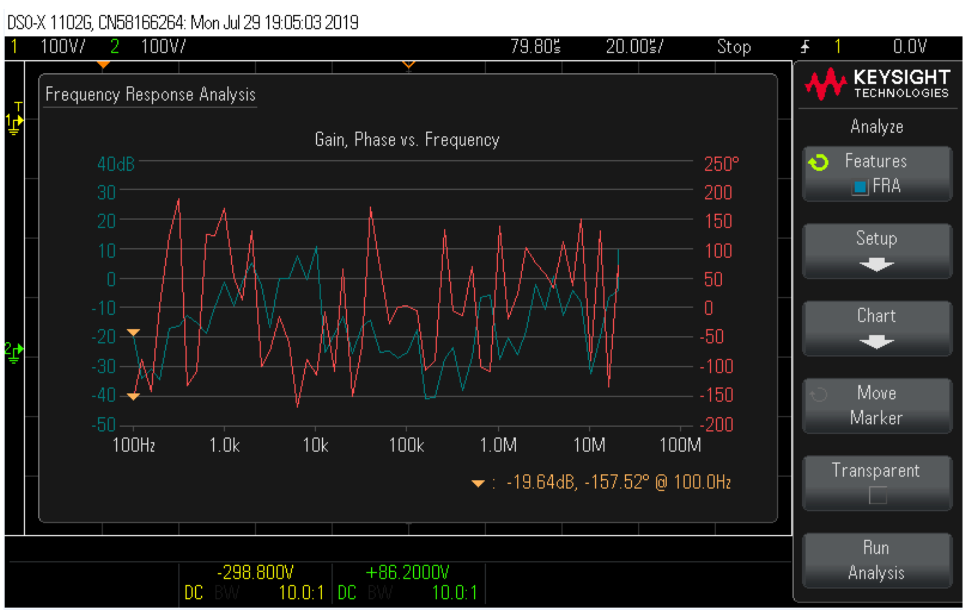

Fig. 5 - FRA on the measured impulse signals in the raw groundwater sample

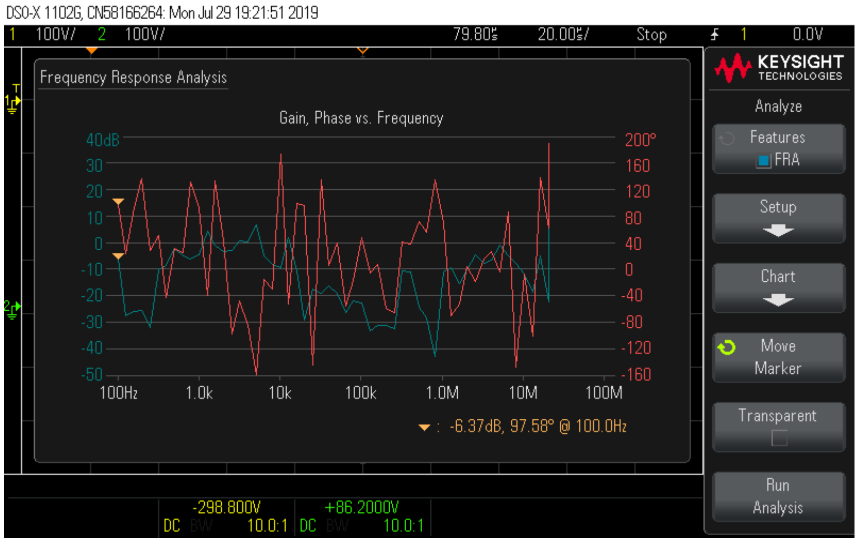

Fig. 6 – FRA on the measured impulse signals in the Mosambi juice sample

Fig. 3 shows the lightning impulse voltage wave applied to the water sample placed in a cuvette and the current flowing through the sample. Fig. 5 shows the Frequency Response Analysis on the measured impulse signal.

The FRA plot is obtained using the built-in function in the Keysight digital storage oscilloscope. Similarly, Fig. 6 shows the FRA plot for the mosambi juice sample. From the observation, it is clear that the impedance offered to the impulse signal by the water sample and the juice sample is different. Fig. 7 clearly shows the dB versus frequency plot for both samples. It is evident that there is an appreciable difference in frequency response in the juice sample when compared to the water sample.

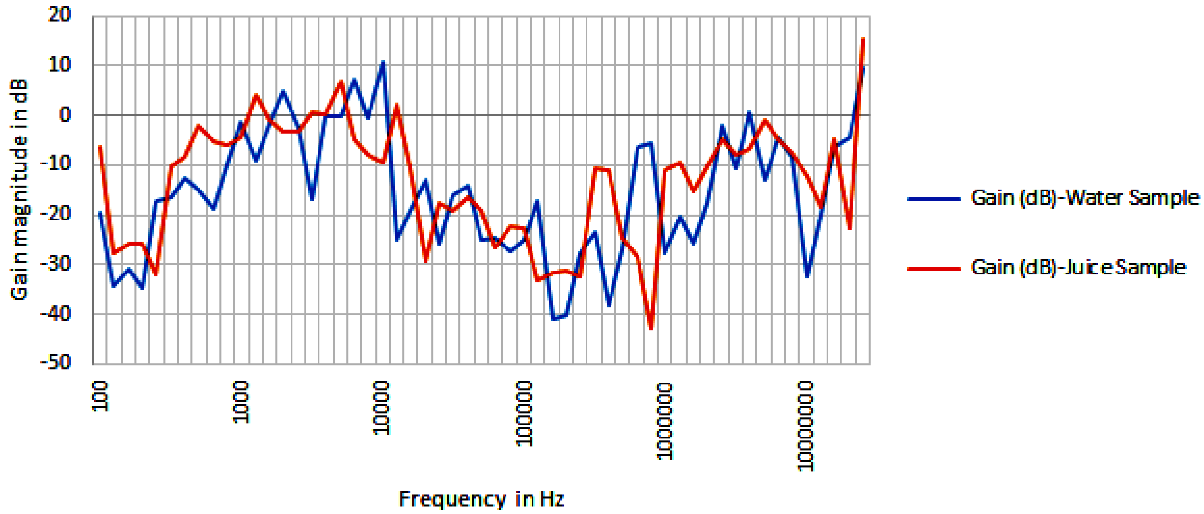

Fig. 7 – Comparison of dB magnitude for both water and juice samples

5. Conclusion

This research work is mainly intended to utilise the Marx lightning impulse voltage generator for the inactivation of microbes present in liquid foods and to identify the dominant frequency components contributing to the microbial inactivation by performing Frequency Response Analysis on the measured impulse signal. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency is verified by varying the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample was varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection was varied from 22 impulses per minute to 41 impulses per minute. Finally, the transfer function-based frequency response analysis was proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes. The outcome of this analysis can be used to treat specific food items with a specific range of frequency instead of applying different frequency test signals.

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