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Generation of High Voltage Rectangular Pulses for Juice Processing

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Abstract— *High voltage Rectangular pulses of short duration are often used in Microwave Radars, high power electromagnetic pulse measurement, Lasers, civilian ,defense and food processing applications. In the present work, a prototype high voltage pulse generator and food processing chamber are designed and developed. A high voltage rectangular pulse of output voltage of 12.5 kV and duration 2µs is achieved experimentally and the pulse is discharged into a matched load. The voltage and current are measured across the load to validate the designed load impedance. The pulses are applied to food processing chamber consisting of raw cabbage juice.*

Keywords— *High voltage rectangular pulses, pulse forming network, stainless steel food grade chamber, liquid food, characteristic impedance.*

I. INTRODUCTION

Pulsed electric field (PEF) is an advanced non thermal method employed for food preservation where high voltage pulses of short duration are applied for microbial inactivation. PEF technology is most preferred as it causes very least change in its physical characteristics. PEF technology has been regarded as advantageous in comparison to other means of microbial inactivation. PEF technology was developed to produce high quality foods. For food quality attributes, PEF method avoids or greatly reduces detrimental changes in the sensory and physical properties like maintaining the original aroma, flavor, texture and other important nutrients. The PEF method provides consumers with microbiologically safe, minimal processed fresh like products.

Academic Institutions in India like Indian Institute of Technology, Kharagpur, Anand Agricultural University, Gujarat, Anna University, Chennai, Amity University of Food Technology, Noida are carrying out some research work in this field. Laboratory research work on liquid and solid foods are carried out at the premier Research institutes like Central Food Technological Research Institute, Mysore and Mumbai, National Institute of Food Technology Entrepreneurship and Management, Haryana, national Agriculture and Food Analysis and research Institute, Pune and Indian Institute of Crop Processing Technology (IICPT), Thanjavur.

Globally, many academic/research institutes like Ohio State University (USA), Stark food and Dairy systems Netherlands, Berlin University of Technology, Germany, Minoufiya University, Egypt, Yangzhou University, China and King Faisal University, Kingdom of Saudi Arabia are carrying out research work in liquid food processing. Most of the research work is confined to the laboratory models and there are lots of gaps between the commercialization of liquid food processing by an application of pulsed electric fields and conventional food processing (thermal methods). Considering the above, there is great need for studies/research using PEF in commercial and Industrial processing of liquid foods.

High voltage Electric pulses of short duration find more importance in increasing the shelf life and maintaining the food quality with low processing cost. These Electric pulses can be applied for milk, fruits, raw vegetable juices, eggs and other applications like extracting oil from the plant sources, drying enhancement and modification in enzyme activity. Inactivation of microbial count depends on the number of pulses applied and pulse duration [1]. For efficient inactivation of microbial count, the electric field usually 20-100 kV/cm in the food chamber to be uniformly distributed [2], [3]. The combined application of PEF and thermal treatment can result in faster inactivation of microbial count [4]. J R Grenier et al. conducted experiments to inactivate the cells in E. coli by subjecting it to 3 kV pulses. The effect on the number of transformants was observed by changing the pulse width [5].

II. PULSE FORMING NETWORK

A Chaney et al. developed a 400V, 75ns pulse generator using Schmitt trigger and MOSFET driver control [6]. J Rao et al. developed a high voltage rectangular pulse generator delivering 12.5 kV, rise time of 46.5ns and pulse width of 220ns into a 50Ω load using a combination of 24 stage Marx, Pulse forming line and Magnetic switch [7]. J Rao et al. proposed different topologies to obtain nanosecond pulses with fast rise time. The topologies include Marx generator with magnetic switch in series, Marx generator with peaking circuit, Marx generator with pulse forming line and Marx generator with Blumlein transmission line. Rectangular pulses of different rise time and fall time were obtained for each topology [8].

J Rao et al. proposed a 12.5 kV high voltage rectangular pulse generator with a repetitive frequency of 5 kHz. Experiments were conducted under single shot and the results are compared with simulation results [9]. High voltage rectangular Pulse of 2 kV, rise time less than 1ns is produced by fully charging the coaxial cable and discharging into a matched load [10]. Most often Type-B pulse forming network is used to generate rectangular pulses [11-14]. The equivalent circuit of Type-B pulse forming network is shown in fig 1.

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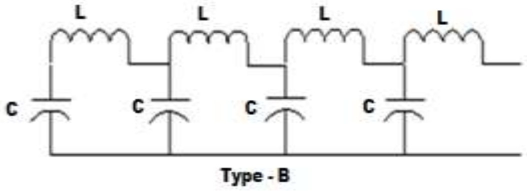

Fig. 1. PFN network.

A ten stage PFN was developed in the present work with each capacitor of rating 10 nF, 20 kV and stage inductor of 1μH. Simulation is carried out in PSPICETM and the pulse width obtained is in close agreement with the calculated value (1.8μs) [14]. The fabricated prototype model of the pulse forming network is shown in fig. 2.

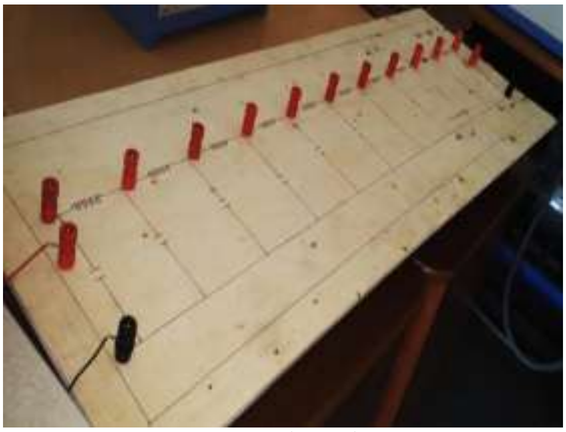
Fig. 2. Prototype model of pulse forming network.

III. Design and Fabrication of Food Grade Chamber

An effective PEF treatment for microbial inactivation is possible with uniform electric field in the food processing chamber. Non-uniform electric fields lead to some volume of liquid over treated and remaining volume under treated. To maintain uniform field inside the chamber, circular shape electrodes are used in the present work and the materials used are Teflon and 304 type stainless food grade steel.


Fig. 3. Type-1 prototype food processing chamber.

In the first design (type-1) both the cup and lid are made up of Teflon with LV and HV electrodes inserted in middle of the cup and lid. The prototype model of the food processing chamber made of Teflon is shown in fig. 3. In the second design (type-2) bottom cup is made up of food grade steel and the lid is made up of Teflon and is shown in fig. 4. In the third design (type-3) bottom cup acts as LV electrode. The lid is also made of stainless steel with bushing surrounding the HV electrode and is shown in fig. 5.


Fig. 4. Type-2 prototype food processing chamber.


Fig. 5. Type-3 prototype food processing chamber.

The designed chambers can produce constant electric fields at 90% of the region between the electrodes. Hence we can use these chambers to treat liquid foods and obtain accurate results. The third prototype model is best suitable to get a uniform electric field in the chamber.

IV. Experimental Setup and Discussion on Liquid Food Processing

The experimental set up with type-3 prototype food processing chamber is shown in fig. 6. The chamber is filled with 20ml of cabbage juice. The distance between the electrodes is set to 4.3mm in order to get matching impedance of 10Ω (source impedance). Each stage capacitor is charged to 12.5 kV and discharged into the food processing chamber. The voltage and current waveforms are shown in fig. 7 and fig. 8 respectively. High voltage Probe P6015 which is having a multiplication factor of 1000 is used to measure the voltage.

Fig. 6. Experimental setup of PFN, food chamber & DSO.

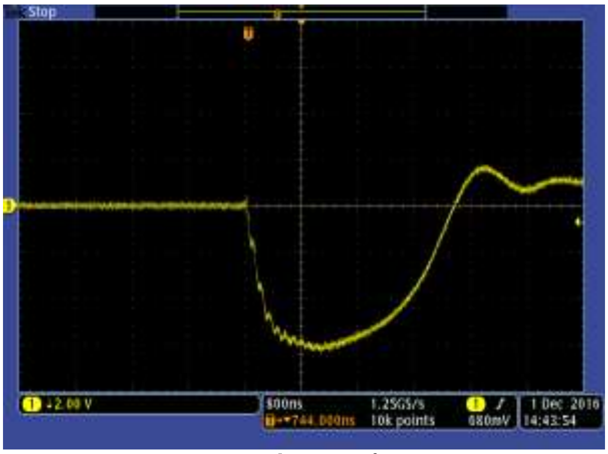

Fig. 7. Voltage waveform.

From fig. 7 the voltage magnitude from the waveform is 6 kV (3 divisions x 2V/division x 1000). Pearson current monitor model 101 which is having sensitivity of 0.01V/A is used to measure the current. From fig. 8 current is 680A (3.4 divisions x 2 V/division x 0.01V/A). Load impedance is given by

$$Z = \frac{V}{I} = \frac{6000}{680} = 8.9\Omega \qquad (1)$$

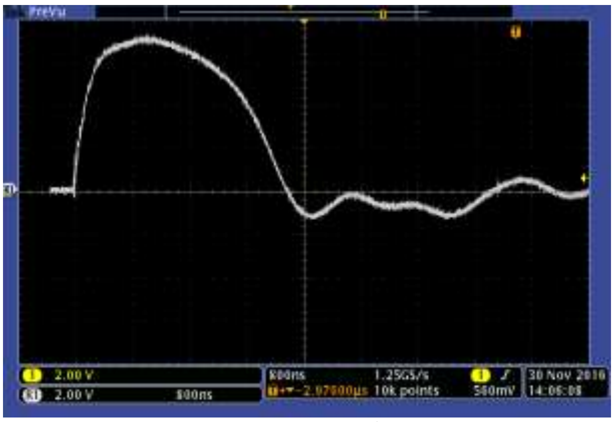

Fig. 8. Current waveform.

The designed load impedance is 10Ω and experimentally obtained value is 8.9Ω and the error is 11%, which can be due to small variation in the gap distance between the LV and HV electrodes. In this work treatment of cabbage juice was chosen because of its health benefits like weight loss, healing skin diseases, increasing immunity power etc. The pulse width of the waveform is 2µs (70% of magnitude). Raw cabbage juice was subjected to 100 pulses and it was tested for sensory properties like color, smell and taste. It has been observed that there was no change in the sensory properties before treatment and after treatment. The untreated and treated sample is shown in fig. 9.

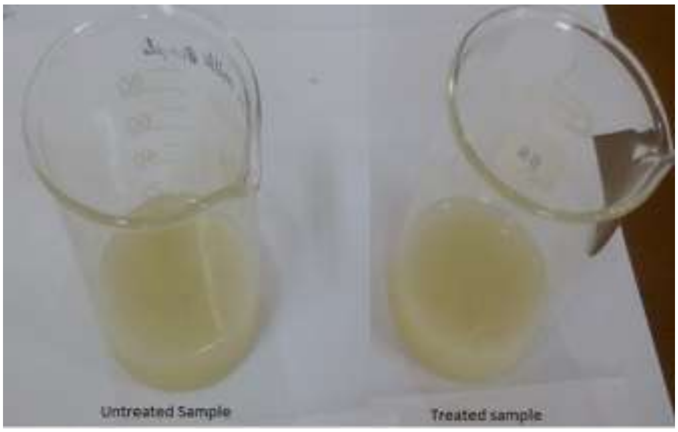

Fig. 9. Untreated and treated cabbage juice.

V. Conclusion

In the present work, high voltage pulse generator and the food processing chamber was designed and developed. High voltage pulses of 12.5 kV with pulse width of 2 µs were generated. The load impedance was determined from the obtained voltage and current waveforms. The experimental results are in agreement with the estimated values. The generated pulses were applied to raw cabbage juice to test only the sensory properties. The work can be carried further to test the inactivation of microbial organisms and increase the shelf life of the liquid food and any kind of raw juices.

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