U. S. Food and Drug Administration
Center for Food Safety and Applied Nutrition
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Kinetics of Microbial Inactivation for Alternative Food Processing Technologies

High Voltage Arc Discharge

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Scope of Deliverables

This section covers early applications of electricity to pasteurize fluids. The use of arc discharge for liquid foods is unsuitable largely because electrolysis and the formation of highly reactive chemicals occur during the discharge. More recent designs show some promise for this technology, although this should be confirmed by independent researchers.

1. Definition, Description and Applications

High voltage arc discharge is a method to pasteurize liquid foods by applying rapid discharge voltages through an electrode gap below the surface of aqueous suspensions of microorganisms. Inactivation of microorganisms and enzymes contained in food products by electrical discharges began in the 1920s with the electropure process for milk. This process consisted of passing an electrical current through carbon electrodes and heating milk to 70 ° C to inactivate *Mycobacterium tuberculosis* and *Escherichia coli* (Barbosa-Cánovas and others 1999). It was one of the first electrical techniques used by the food industry to pasteurize milk (Palaniappan and others 1990). When rapid high voltages are discharged through liquids, a multitude of physical effects (intense waves) and chemical compounds (electrolysis) are generated, referred to as electrohydraulic shock, which inactivate the microorganisms (Edebo and Selin 1968). Enzymes are also inactivated by high voltage arc discharges. Inactivation is attributed to oxidation reactions mediated by free radicals and atomic oxygen. There is no significant temperature increase during treatment by arc discharge. The major drawbacks of this electrical method, however, are contamination of the treated food by chemical products of electrolysis and disintegration of food particles by shock waves (Barbosa-Cánovas and others 1999). The method based on continuous high voltage arc discharges was not considered suitable for use in the food industry (Dunn and Pearlman 1987; Jayaram and others 1991). More recent designs show some potential; however, chemical reaction products need to be identified and results validated.

2. Inactivation of Microorganisms

Allen (1969) disclosed an electrohydraulic process for producing microbial antigens. In this U.S. patent, he tested his electrohydraulic process with *E. coli* ATCC 11229 suspended in 0.01M phosphate buffer of pH 7.2. After 200 shocks of 182 J/discharge to a spark gap of 1.6 mm at 4.5 kV, a 6-log reduction was observed in a 1.2-liter volume of the static treatment chamber.

Another study provided critical operational conditions such as the stored electrical energy for each discharge in the range of 2500 to 22000 J; electric current of at least 1500 A; and time of discharge of less than 1 millisecond, preferably of 50 to 300 microseconds (Wesley 1971). The study did not provide microbial test data.

Gilliland and Speck (1967a) found electrohydraulic treatment to be effective in inactivating at least 95% of the vegetative cells of *E. coli*, *Enterococcus faecalis, Micrococcus radiodurans, Bacillus subtilis,* and its spores. High voltage electrical impulses were discharged at a rate of 1/s. *E. faecalis* and *E. coli* were less resistant, whereas *M. radiodurans* and *B. subtilis* were more resistant to electrohydraulic shock. Beattie and Lewis (1925) demonstrated a lethal effect of electrical discharges on microorganisms suspended in milk when applied voltage used to treat food was increased from 3000 V to 4000 V.

Gilliland and Speck (1967b) used a double tank system to study the mechanical and thermal effects of shock waves separately. The high voltage discharge occurred in the lower chamber and was separated from the bacterial suspension in the upper chamber by a rubber diaphragm. Both chambers were completely filled to obtain the full effect of pressure pulses. No significant inactivation or metabolic injury was observed, indicating that mechanical action alone was not responsible for the bactericidal action. No significant amount of cell breakage was observed by phase microscopy and cell wall stain preparations. Other studies by the same authors (Gilliland and Speck 1967a) suggest that there are no thermal effects, since more than 90% of the population was killed within 10 discharges, when the increase in temperature was only 0.5° C. Sytnik and Sytnik (1976) reported inactivation of the yeasts *Candida utilis, C. guilliermondii* and *Saccharomyces cerevisiae* in foods using a high voltage DC by employing 40 kV and 50 electrical discharges. They concluded that the chemical reactions were the major contributors to bacterial inactivation by electrohydraulic shock, and that thermal effects were insignificant, since the temperature rise reported in many studies was only a few degrees.

According to FABCO Technologies (FABCO Technologies 1998), submerged electrical-arc technology may be an alternative to heat pasteurization of liquid foods, but these claims need to be validated independently. Recent experiments were reported to achieve a 5- to 7-log reduction of pathogenic bacteria in inoculated orange juice without affecting taste or color (FABCO Technologies 1998). This company reported that their arc discharge commercial-scale system reduced total microbial plate counts in fresh-squeezed grapefruit juice by more than 50 percent, boosting refrigeration shelf-life and fresh flavor to more than 100 d. Endotoxins and target microorganisms such as *Listeria monocytogenes*, *Clostridium sporogenes, Salmonella* Typhimurium*, Lactobacillus lactis, E. coli* O157:H7, *Aspergillus niger*, and *Penicillum digitatum* were tested in citrus juices using the electric pulsed power, reportedly achieving 5- to 7-log microbial and endotoxin reductions (FABCO Technologies 1998). The process was also reported to achieved 6- to 7-log reductions of pathogenic bacteria in milk. Their process consumes little energy compared to thermal pasteurization of juices and was reportedly to be more energy efficient than other non-thermal processes (that is, high pressure and pulse electrical fields) with juice-processing potential. The process was reported to have the potential to disinfect process water. It must be noted that there has been no other publication on the effectiveness of this process. Results reported by FABCO Technologies should be independently validated by other researchers.

3. Mechanism of Microbial Inactivation

In the early literature (Allen 1969; Wesley 1971; Sytnik and Sytnik 1976) the inactivation of microorganisms by high voltage arc discharge was reported to be related to the hydraulic shock wave generated by an electrical arc. More recent literature concluded that arc discharge prompted the formation of highly reactive free radicals from chemical species in foods, such as oxygen (Gilland and Speck 1967b; Vega-Mercado and others 1999). These free radicals are toxic compounds that serve to inactivate certain intracellular components required for cellular metabolism. Gilliland and Speck (1967b) found that lactic dehydrogenase, trypsin, and proteinases of *B. subtilis* were inactivated by electrohydraulic shock. They concluded that the enzyme inactivation was due to free radical oxidation reactions.

Palaniappan and Sastry (1990) presented an extensive literature review on the effect of electrohydraulic shock on the inactivation of microorganisms. They reported that bacterial inactivation was not due to heating, but mainly to irreversible loss of membrane function as a semipermeable barrier between the bacterial cell and the environment and to the formation of toxic compounds (oxygen radicals and other oxidizing compounds). In their review, it was concluded that chemical action is a complex effect and depends not only on the voltage applied but also on the type of microorganism, initial concentration of cells, volume of the medium used, distribution of chemical radicals, and electrode material (Palaniappan and Sastry 1990). Membrane damage was demonstrated by the lysis of protoplasts, leakage of intracellular contents, the loss of the ability of *E. coli* to plasmolyze in a hypertonic medium, and the release of galactosidase activity in a permease-negative mutant of *E. coli* (Sale and Hamilton 1967). Along with this, the number of cells of *Staphylococcus aureus* destroyed by high voltage discharges correlated with the numbers that could not be converted to spheroplasts. This result led to the conclusion that cell death was due to membrane damage.

4. Validation/Critical Process Factors

There is not enough information in the literature to determine critical process factors and to devise ways to handle deviations. In this regard, the following is a list of process variables that should be considered:

- Discharge field should be higher than 25 kV/cm to initiate breakdown of the gas phase.

- Discharge energy should be high enough to generate a sufficient quantity of ozone and/or UV irradiation for microbial inactivation to occur.
- Discharge repetition rate should be high enough to maintain a continuous ionization in the gas phase.
- Product should be sufficiently aerated to maintain a continuous gas bubble phase and ionization.

5. Research Needs

Early literature attempted to explain the phenomenon of microbial inactivation, and it was concluded that the hydraulic wave, that is, pressure, did not contribute to the bactericidal effect. A more recent development (FABCO Technologies 1998) focuses on the delivery of the treatment to the product while flowing through an arc plasma chamber. Oxygenation is a critical part of the process since the submerged arc discharge actually takes place within the gas bubbles. This partial breakdown of gas causes ionization, resulting in reactive ozone and UV radiation. In this regard, some research needs include:

- Understanding how delivery of highly reactive ozone and UV radiation by electric arc discharge inactivates microorganisms.

- Quantifying the inactivation kinetics and mechanisms.

- Identifying reaction process products generated during the submerged arc discharge process due to the highly reactive nature of ozone and UV radiation.
- Defining maximum allowable dose, in a manner similar to food irradiation.

Glossary

Electrohydraulic treatment. A rapid discharge of high voltage electricity across an electrode gap below the surface of aqueous suspensions.

High voltage electrical impulse. Application of high voltage discharges to a liquid medium in a very short time.

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