by J. Peter Clark

Pulsed Electric Field Processing

One of the more novel processes discussed at a recent workshop of IFT's Nonthermal Processing Division was pulsed electric field (PEF) processing. The workshop was held on September 14–16, 2005, at the Eastern Regional Research Center (ERRC) of the U.S. Dept. of Agriculture's Agricultural Research Service in Wyndmoor, Pa.

The PEF process and its status were described in detail by Howard Zhang (phone 215-233-6582), Research Leader at ERRC. Previously on the Food Science faculty at Ohio State University (OSU) and now Adjunct Professor there, Zhang said that PEF imposes a strong electric field on a flowing fluid for a very short time. Above a critical field strength of about 15,000 V/cm, vegetative cells are killed. In practice, higher field strengths are used, up to about 35,000 V/cm for disinfection (destruction of bacteria, fungi, and other microbes). Lower-strength fields are used for static PEF (not discussed here).

How PEF Works

When exposed to high electrical field pulses, cell membranes develop pores either by enlargement of existing pores or by creation of new ones. These pores may be permanent or temporary, depending on the condition of treatment. The pores increase membrane permeability, allowing loss of cell contents or intrusion of surrounding media, either of which can cause cell death.

***PEF imposes a strong electric field** on a flowing fluid for a very short time, [killing] vegetative cells [and] microbes.*

PEF has limited effects on spores and only appears to affect a few enzymes. Enzymes are important in juice processing because surviving enzymes can reduce pectin, which then can be less effective in keeping fruit particles suspended. Some sedimentation is common in fruit juices, but too much is unattractive. Some surviving enzymes may also enable discoloration and production of off-flavors.

PEF offers a 5-log reduction of most pathogens and is considered a pasteurization process, so products must be refrigerated. An important process consideration is prevention of post-process contamination, so filling is in an aseptic or clean room environment and containers must be cleaned and possibly sterilized.

The perforation of cell membranes caused by PEF also applies to fruit and vegetable cell walls, so a potentially beneficial side-effect of the process is improved extraction of juice from cells. This phenomenon is also applied in another promising use, concentration of sewage sludge, a suspension of live and dead cells and organic matter which can be very hard to filter and concentrate. PEF, by killing live cells and reducing their ability to retain water, greatly improves filtration. Extraction of sugar from beets and starches from potatoes may also be improved by PEF.

Process Variables

Zhang gave a good description of the process in one of the breakout sessions of the workshop.

Important process variables, he said, include the electric field, which can have various wave forms, strengths, and distribution in the treatment chamber; temperature; pressure; and time of exposure.

- **Electric Field.** The electric field is generated by equipment similar to that used in radar. This has some consequences for cost and availability. The most typical equipment generates a short square wave and reverses polarity, in part to avoid erosion of electrodes. However, a bipolar generator costs about twice as much as a monopolar one. Other wave forms include exponential decay and sinusoidal. The sinusoidal form is somewhat easier to generate, as it uses equipment similar to common radio equipment, but it reaches its peak power only for an instant and so delivers less energy per cycle above the critical field strength than does a square wave.
- **Temperature.** There is some temperature rise across the PEF treatment chambers due to the delivery of electrical energy, but the preservative effect is primarily nonthermal. A typical temperature change is about 30°C for orange juice and less for apple juice

Processes typically operate at 35–50°C because it has been found that microorganisms are more tolerant at low temperatures.

- **Pressure.** Pressure is applied to inhibit the formation of air bubbles in which electrical arcing could occur with fields above 20,000 V/cm.
- **Time of Exposure.** The field is cycled about 1,000 times/sec, and the fluid is exposed to multiple pulses by passing it through several treatment chambers.

Juices pasteurized by PEF *are being marketed by Genesis Juice Cooperative in the Portland, Ore., area. Labels state that the product is "Processed by Pulsed Electric Field."*

The treatment chambers are separated from each other by insulators, which may be ceramic or polymer. Each chamber has two electrodes, which are made from a conductor or semiconductor, according to Zhang. Ohio State holds patents on PEF treatment chamber and pulse generator designs.

Options for chamber design include parallel plates, co-axial, and co-field (the OSU approach). PEF may also be applied in a static (non-flowing) approach for foods such as meats. Electrical equipment components exposed to more than 35,000 V of potential must be immersed in oil for insulation and cooling. Issues in the equipment design include pulse coupling, switch design, high-voltage power supply, and over-current protection.

One supplier of the electrical equipment is Diversified Technologies, Inc. of Bedford, Mass. According to Mike Kempkes (phone 781-275-9444), Vice President of Marketing, DTI is primarily a defense contractor and acknowledges that designs for industrial food processing are only now emerging. So far, most of the PEF units that have been built are used in research and development, but one commercial application has received Food and Drug Administration approval and is currently on the market for processing of fresh juices (see below).

Available PEF Units

Zhang said that Ohio State has designed three PEF units that differ primarily in their fluid-handling capacity. The OSU-4, intended for laboratory use, has 1/8-in-diameter tubing (about 3 mm). The OSU-5, designed for pilot-plant use, has 1-cm-diameter tubing (10 mm); it is not commercially available, but OSU will build a laboratory unit for R&D purposes. The OSU-6, a 75-kW commercial unit built by DTI, has 1- to 1.2-cm-diameter tubing and can process orange juice at 500–2,000 L/hr and apple juice at up to 5,000 L/hr. DTI also offers several additional commercial units, as well as a smaller R&D unit and commercial-scale systems rated at up to 20,000 L/hr.

Current equipment costs are high, in part because of the relatively small market for the electrical equipment. Reliability can also be an issue, said Zhang, with electrodes now needing replacement about every 100 hr of operation. DTI, OSU, and others are investigating electrodes with longer lifetimes.

As fluid volumes increase, larger-diameter tubing implies larger gaps in the treatment chambers and thus higher voltages. Zhang believes a better approach to higher volume is to use parallel small tubes. Finally, temperature control is still a significant issue.

Being Applied Commercially

Genesis Juice Corp., Eugene, Ore., is selling PEF-treated juices and blends in the Portland market, according to Zhang. The products include apple, strawberry, and other flavors. The package is glass with a full label and is sold from a refrigerated case. Genesis is using an OSU-5 running at about 200 L/hr. Prices are higher than for other juice products, but Genesis promotes them as being from organic fruit and having almost-fresh flavor. The major motivation for PEF processing, he said, is to avoid the loss of flavor from normal thermal pasteurization. Shelf life is said to be 4 weeks.

Vegetable juices such as carrot need to be acidified and can pose challenges, said Zhang, because of particles having to pass through the small clearances of the treatment chambers. He also pointed out that *Listeria* in skim milk was among the more-resistant organisms.

Clearly, PEF is not the answer for every food, but it is intriguing for certain applications. There remain significant engineering challenges, which is why USDA, OSU, and the U.S. Army Soldier Systems Center in Natick, Mass., continue research in the area. **FT**

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