Development of pilot scale fluid handling system with energy recovery for pulsed electric field processing

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ABSTRACT

A fluid handling system with an energy recovery heat exchanger was developed for a portable pilot scale pulsed electric field (PEF) processing machine. The system was evaluated using apple cider. The results demonstrated energy recovery reduced utility cost and FDA 5 log-reduction requirement can be met.

INTRODUCTION

Consumers are increasingly becoming health-conscious, thus demanding for fresh-like quality foods, extended shelf life, and no artificial preservatives. Apple cider, for example, was traditionally made in a farmer from fresh apples and sold without any thermal pasteurization. However, due to outbreaks associated with pathogenic contamination from apples, the Food and Drug Administration (FDA) requires that all apple cider be pasteurized, and the process has to achieve a 5-log reduction to pathogens of concern. A processor or farmer has to use conventional thermal pasteurization or find alternative method to produce fresh like apple cider but still meet the FDA requirement.

PEF treatment is a promising nonthermal processing to inactivate microorganisms and meet consumer demands for foods with fresh-like quality. PEF-treatment of low viscous liquid foods such as apple juice, orange juice, cranberry juice cocktail, whole milk, 2% milk, skim milk, and chocolate milk is well documented in literature. However, there was no such a PEF processing system suitable for test on a farm. Addition to PEF processing, use of mild thermal treatments in combination with PEF has been suggested as a strategy to increase the effectiveness of microbial inactivation and extend longer shelf life without the compromise in food quality. Therefore, a portable 100 to 500 L/h PEF processing system with optional mild thermal treatment is needed.

The primary purpose of this project was to extend our PEF research in a farm scale and transfer the technology to marketplace. Specific objectives were to: 1) Design and construct a prototype PEF processing system (OSU-5C) that is suitable for test on a apple farm; 2) Evaluate the food safety performance of OSU-5C with a surrogate microorganism that is equivalent to *E. coli O157:H7* for a five-log reduction; and 3) evaluate the products produced by OSU-5C on an apple farm with quality and consumer acceptance tests. This presentation only focuses on the introduction of fluid handling system of OSU-5C and primary evaluation test.

MATERIALS AND SYSTEM DESIGN

The pilot scale fluid handling system consisted of a 80 L stainless steel product tank, a gear feed pump (Micropump, Inc.), four co-field continuous flow, tubular treatment chambers

(OSU), a backpressure control valve, hold-tubes, energy recovery plate heat exchanger EX-1 (Proflow series, AGC Engineering), and supplementary heat exchanger EX2 (Proflow series, AGC Engineering). Sanitary 0.5" (ID) stainless steel tubes were used for the connections between those components. RTD probes were used for monitoring temperatures. The system configuration is illustrated in Figure 1. The heat exchanger for energy recovery EX-1 was used to heat foods prior to PEF treatment and cool foods down after the holding tubes. The supplementary heat exchanger EX-2 could be used for heating the system during SIP (Sterilization in Place) and CIP (Cleaning in Place) cycles when connected to steam/hot water, or could be used for cooling the processed product when connected to cooling water. The hold tube section was optional to the system; it could be used when PEF plus mild thermal treatment was needed to increase extra shelf life of products, or it could be bypassed for PEF process only.

SYSTEM OPERATION

As shown in Figure 1, apple cider was pumped from product tank through the system with a feed pump. Apple cider passed heat-exchanger EX-1 and pre-heated, then passed through PEF treatment chambers for PEF processing. Apple cider was held in hold tubes before return into heat exchanger EX-1 for cooling. Heat-exchanger EX-2 further cooled the apple cider down before being filled into PET bottles. PEF process parameters were set or controlled by built in touch-screen panel (EZTouch Panel, Automation Direct, Cumming, GA). Voltage, pulse width, pulse repetition rate could be preset or inline adjusted. Peak pulse voltage, current, pulse width, and pulse repetition rate were monitored by oscilloscopes (TDS-210, Tektronix, Beaverton, Oregon).

MICROBIAL INACTIVATION TEST

Apple cider were used for this test. Fresh apple cider was made by FMC juicer (Lakeland, FL). The cider was incubated at 22ºC for 3 days, or inoculated with *Lactobacillus planetarium* prior to PEF treatments. *L. plantarium* was selected fir this test because of its high resistance to PEF treatment, and it is a non pathogenic surrogate to E.coli O157:H7. Microbial growth in the treated and control incubated samples during storage was measured through total plate count (TPC) and total mold and yeast counts by plating samples onto plate count agar (PCA) for TPC and onto potato dextrose agar (PDA) acidified with 10% tartaric acid for mold and yeast counts. *L. plantarum* in the treated inoculated samples was plated onto MRS (Man, Rogosa and Sharpe). PEF plus mild thermal treatment was used for this test. The treatment conditions are listed in Table 1.

RESULTS AND DISCUSSION

Figure 2 and Figure 3 show the temperature profiles of the PEF processing for incubated and inoculated apple cider, respectively. The energy recovery heat exchanger efficiently heat the apple ciders prior to PEF treatment and cool the apple cider after holding without external heat or cool supply source. The temperature difference between product in (T1) and 1st PEF (T2) was equal to that between holdout (T6) and 1st EX-out (T7). To achieve the same temperature profile without the energy recovery heat exchanger, a system had to use extra electricity for preheating and city water for cooling. Therefore the energy recovery system saved 28 kW electricity for heating and 1500 L city water for cooling per one-hour operation. Addition to utility cost reduction, the system was integrated with pulser and the whole unit was portable and only required for plug-in of electricity, product line, and a filler with optional cooling water connection. However, the system required extra attention to initial temperature of apple juice. The hold temperature was dependent on electrical conductivity and initial temperature of juice and PEF treatment conditions. When a product was selected and PEF parameters were determined, the hold temperature solely depended on the initial temperature of apple juice, which would affect the effectiveness of microbial inactivation of juice.

Microbial reductions of both incubated and inoculated ciders were function of PEF field strengths and hold temperature. Table 2 shows aerobic microbial counts of incubated apple cider samples treated by PEF+HTST and stored at room temperature and refrigerated temperature for 7 days. The treatment of 32 kV/cm obtained 5 log-reductions and no recovery was observed during 7-day-storage at room temperature or refrigerated temperature. The treatment of 26 kV/cm had 4 log-reductions and no growth was found in both storage temperatures. Table 3 shows that both treatments of 32 kV/cm and 26 kV/cm effectively inactivated mold & yeast. For *L. plantarum* inoculated juice samples (Table 4), 5 log-reductions were achieved by 32 kV/cm or 26 kV/cm PEF treatment, and no recovery was observed at refrigerated temperature. However, *L. plantarum* gained recovery during room temperature storage. The reasons for *L. plantarum* recovery at room temperature may be (1) as a surrogate, *L. plantarum* was recognized as higher resistance to PEF or thermal treatment than natural flora or mold & yeast in juices; (2) lower hold temperature corresponding to same PEF treatment for incubated juice samples. The incubated juice had 77ºC hold temperature (32kV/cm) and 66ºC hold temperature (26 kV/cm). In comparison, the inoculated juice only had 72ºC hold temperature (32kV/cm) and 56ºC hold temperature (26 kV/cm). Inlet temperature of raw material affected holding temperature, consequently affected effectiveness of microbial inactivation and cell recovery.

CONCLUSIONS

The fluid handling system provided high efficiency of microbial inactivation in apple ciders and significantly increased energy efficiency thus reduced the operational cost. The system also had advantaged of easier operation and better temperature control than an old system. The system combined with OSU-5C pilot scale pulse generator meets the FDA 5 log reduction requirement and could be used in a farm for apple cider pasteurization. Future modification on this system would be automatically adjustment or control of the inlet temperature of raw materials so that the holding temperature wouldn't be affected by the inlet temperature of raw materials. Effectiveness of microbial inactivation of juices by PEF treatment only would be further evaluated.

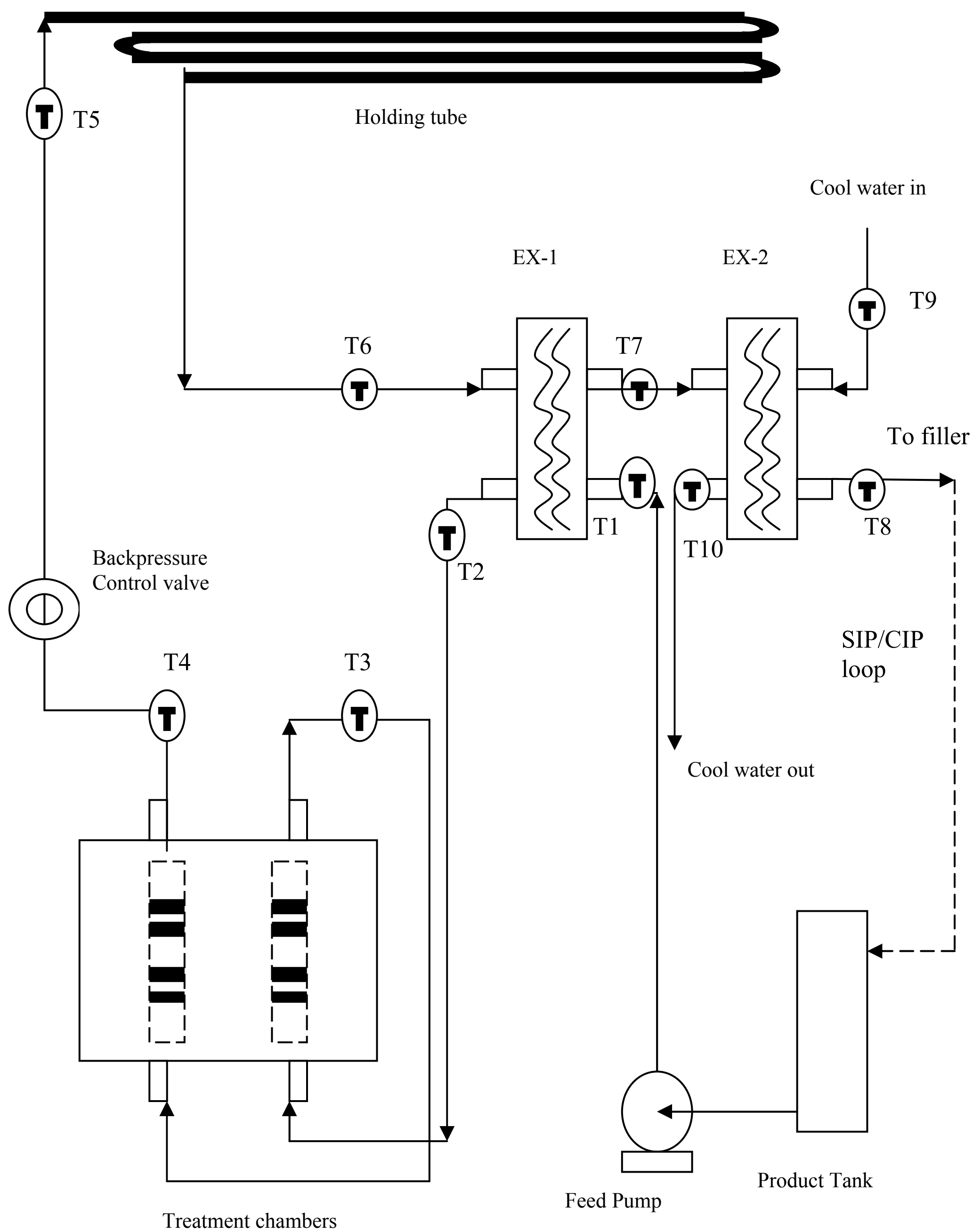

Figure 1 System Configuration

Table 1 Processing conditions for microbial inactivation test

PEF field strength (kV/cm)	32, 26, 20
PEF pulse repetition rate (pulse per second)	600
Pulse duration time (μs)	2
Total PEF treatment time (μs)	44
Hold-temperature (C)	dependent on PEF field strength
Hold-time (s)	15
Flow rate (L/h)	125
Backpressure (psi)	40

Table 2 PCA (log cfu/mL) -- Incubated Apple Cider

	Control		32kV/cm		26kV/cm		20kV/cm	
Time (days)	Room Temp	Ref. Temp	Room Temp	Ref. Temp	Room Temp	Ref. Temp	Room Temp	Ref. Temp
0	6.45	6.45	1.31	1.31	2.43	2.43	6.15	6.15
3	Miss	6.90	<1	1.22	<1	2.28	Miss	6.04
7	7.20	6.20	1.23	1.17	1.43	2.04	5.79	5.89

Table 3 PDA (log cfu/mL) -- Incubated Apple Cider

	Control		32kV/cm		26kV/cm		20kV/cm	
Time (days)	Room Temp	Ref. Temp	Room Temp	Ref. Temp	Room Temp	Ref. Temp	Room Temp	Ref. Temp
0	6.04	6.04	<1	<1	<1	<1	5.69	5.69
3	6.68	6.11	<1	<1	<1	<1	5.49	5.98
7	6.41	6.04	<1	<1	<1	<1	5.92	5.99

Table 4 *L. plantarum* (log cfu/ml) – Inoculated Apple Cider

	Control		32kV/cm		26kV/cm		20kV/cm	
Time (days)	**Room Temp**	**Ref. Temp**	**Room Temp**	**Ref. Temp**	**Room Temp**	**Ref. Temp**	**Room Temp**	**Ref. Temp**
0	**6.49**	**6.49**	**1.36**	**1.36**	**1.88**	**1.88**	**5.76**	**5.76**
3	**7.52**	**6.46**	**4.97**	**<1**	**Miss**	**<1**	**7.08**	**5.40**
7	**7.18**	**6.20**	**6.52**	**<1**	**7.15**	**<1**	**7.26**	**5.11**

Fig.2.Temperature Profile (Incubated Apple Cider)

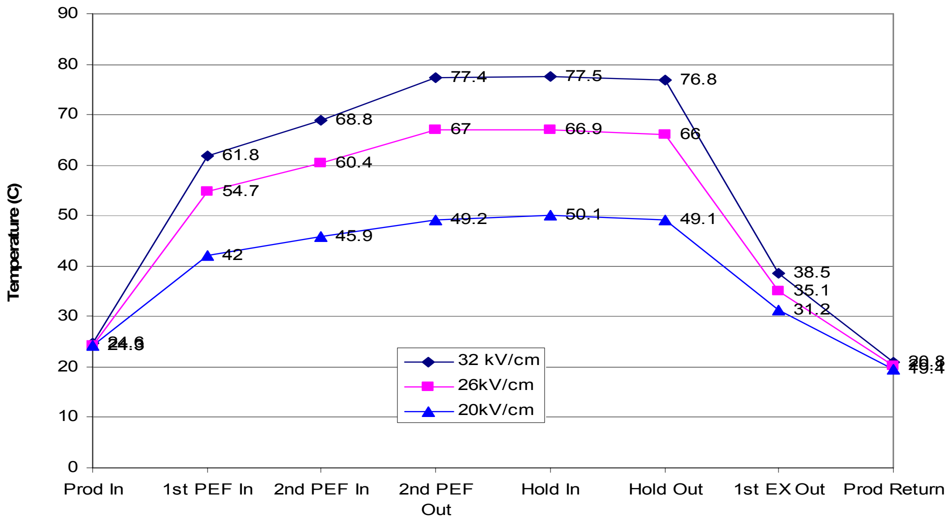

Fig. 3. Temperature Profile (Apple Cider Inoculated with L. plantarum)