Electrical Treatment of Poultry Chiller Water to Destroy *Campylobacter jejuni*

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(MS# 95-68: Received 29 March 1995/Accepted 6 June 1995)

**ABSTRACT**

To control bacterial contamination in poultry processing, pulsed electricity in combination with a salt was evaluated as an electrical pasteurization method to kill *Campylobacter jejuni* in poultry chiller water. Chiller water from a poultry processing plant was mixed with either sodium chloride (NaCl) or trisodium phosphate (Na₃PO₄·12H₂O or TSP) at 0.1%, 0.2% or 0.3% concentration, and inoculated with *C. jejuni* at 1×10⁶ CFU/ml. The inoculated chiller water was treated at 4°C for 20 min using pulsed electrical signals at 10 mA/cm² current, 1 kHz frequency and 50% duty cycle. Samples taken at different intervals were serially diluted, pre-enriched in Brucella-FBP broth, plated on Campy-Cefex agar and incubated, and colony-forming units (CFU) were counted. The results showed that *C. jejuni* was reduced and that the bacterial death rate was dependent upon pH of the salt solution, salt concentration, and treatment time. In the electrical treatments, *C. jejuni* was reduced linearly on log scale in the chiller water mixed with TSP, but nonlinearly with NaCl. Bacterial destruction rate was accelerated by higher concentrations or higher pH of NaCl or TSP added to chiller water.

Key words: *Campylobacter jejuni*, poultry chiller water, electrical treatment

Electrical pasteurization methods have been studied for their applications in food processing. There are different methods, such as low electrical current, Ohmic heating, microwave and dielectric heating, and high-voltage electric fields, to destroy specific microorganisms in food products (11). The mechanisms of electrical pasteurization may be due to thermal, chemical, or mechanical effects, or combined effects transformed from the electricity applied. However, the poultry-chilling process does not allow high-temperature or high-voltage electrical field applications because of concerns for worker safety and product quality. Therefore, low-voltage electrical treatment is a more practical approach for poultry processing.

Low-voltage pulsed electricity was investigated to destroy *S. typhimurium* in saline solution, and electrical parameters such as current, frequency, and duty cycle were studied by Li et al. (6). It was also reported that *S. typhimurium* was killed using electrical stimulation with various salt solutions (7). Later, experimental results showed that *S. typhimurium* in poultry chiller water could be eliminated using electrical stimulation and food-grade salts (8). An electron microscopy study showed that low voltage electrical treatment caused morphological changes in *S. typhimurium* in various salt solutions (12). A flow-through electrical treatment system was investigated to eliminate *S. typhimurium* in poultry scalding water or chiller water (17). These studies suggested the possibility that pulsed electricity with food-grade salts may be an alternative method for treatment of poultry chiller water. However, no research has been done showing the effectiveness of electrical treatment on other bacteria present in poultry processing water. Therefore, the objective of this study was to investigate the bactericidal effect of pulsed electrical current with sodium chloride and trisodium phosphate at different concentrations on *C. jejuni* in poultry chiller water. This research would provide the poultry industry with more data on electrical pasteurization as a method for food safety and sanitation.

**MATERIALS AND METHODS**

**Chiller water**

Poultry chiller water was obtained from a local poultry-processing plant. The 19-L sample of chiller water was taken after 6 h of plant operation, which allowed the system to reach steady state and to achieve a dynamic equilibrium between solids lost in the overflow...
water and gained from incoming carcasses. The pH value of the chiller water for three replicates ranged from 6.8 to 7.5. Total aerobic plate count and C. jejuni in the chiller water were checked before the tests. The count of colony-forming units of C. jejuni was less than $1 \times 10^3$ CFU/ml, and the total aerobic bacterial count was less than $1 \times 10^5$ CFU/ml.

**Chemicals**

Since the conductivities of tap water and chiller water are in a range of 100 to 200 µS/cm, a salt at a low concentration is needed to add to chiller water to increase the conductivity for electrical treatments. Sodium chloride, NaCl, (Sigma Chemical Co., St Louis, MO) and trisodium phosphate, NaPO$_3$, T$_2$H$_2$O or TSP, (Rhone Poulenc Inc., Cranbury, NJ) at 0.1%, 0.2% and 0.3% concentrations were selected because of their good conductivity and acceptance as food-grade chemicals. The NaCl and TSP at these three concentrations have electric conductivities ranging from $1.0 \times 10^3$ to $5.1 \times 10^3$ µS/cm at 25°C (Table 1). Both of the salts can be used in food processing without negative effects on poultry products. The lower chemical concentrations were selected to reduce the cost of the operation and chemical residues on poultry products.

**Microbiological analyses**

Campylobacter jejuni (ATCC 33291) was cultured in Brucella-FBP broth with oxyrase (Oxyrase, Inc., Mansfield, OH) at 42°C for 18 to 24 h before being added to poultry chiller water. The culture method of Nirooomand and Fung (10) was used for isolation of C. jejuni from the chiller water samples. Samples were diluted with Brucella-FBP broth with oxyrase and pre-enriched at 42°C for 6 h. The samples were then plated on Campy-Cefex agar (14), placed in plastic zipper bags, and degassed. The bags were then filled with a mixture of 5% O$_2$, 10% CO$_2$ and 85% N$_2$ gases to provide a microaerobic atmosphere and incubated at 42°C for 24 to 48 h. The Petrifilm aerobic count plate (3M Microbiological Products, St. Paul, MN) was used to enumerate total aerobic bacterial populations in chiller water.

**Electrical apparatus**

The electrical equipment described by Li et al. (8) was used to generate and control pulsed electrical current for treatment of poultry chiller water. Two electrodes (anode and cathode) were made of 6.8 by 5.0 cm rectangular platinum foil (99.99% purity) with a thickness of 0.025 mm. A rectangular glass jar with 300-ml volume was used as a treatment container. The anode and cathode were placed vertically at the two opposite ends inside the glass container. The distance between the two electrodes was 9 cm. The electrode area submerged in the solution was 34 cm$^2$. A digital storage oscilloscope was used to monitor the waveform, voltage, current, frequency, and duty cycle.

**RESULTS AND DISCUSSION**

**Effect of salt concentrations**

Three different concentrations were tested for both sodium chloride and trisodium phosphate to determine the effect of salt concentration on reduction of C. jejuni in chiller water treated with pulsed electrical current. The bacterial reductions discussed are the means of three replicates. At 10 min of electrical treatment time, the number of C. jejuni was reduced by 0.5 log unit in 0.1% NaCl (Fig. 2a), 1.2 log units in 0.2% NaCl (Fig. 2b), and 1.4 log units in 0.3% NaCl (Fig. 2c). Similarly, in the electrical treatments with TSP, the number of C. jejuni was reduced by 1.2 log units in 0.1% TSP (Fig. 3a) and 2.3 log units in 0.2% TSP (Fig. 3b) in 10 min. For 0.3% TSP treatment, the reduction rate could not be estimated because all cells of C. jejuni in both the control and treatment were destroyed in 5 min (Fig. 3c). The data showed that the reduction rate of C. jejuni in the electrical treatments was increased as the salt concentration increased. Table 2 shows in detail the bacterial destruction rate in log CFU/ml per min and the D value in min for different chemicals and concentrations. The bacterial destruction rate was calculated using the data collected at the 10 min.

**Electrical treatment**

Six trials were conducted in the experiment: 0.1%, 0.2%, and 0.3% of both NaCl and TSP (Table 1). In each trial, a treatment (with electricity applied) and a control (without electricity) were set up. Each trial was replicated three times.

For each trial, one liter of the chiller water at 2 to 5°C was mixed with a calculated amount of appropriate salt to get the desired salt concentration. The pH and salt concentration of the chiller water were measured using a pH meter and a conductivity meter. The mixed chiller water was inoculated with C. jejuni to obtain an initial microbial population of $1 \times 10^6$ to $1 \times 10^7$ CFU/ml. Three hundred milliliters of the chiller water mixed with a salt and inoculated with C. jejuni was put into the treatment container, and another 300 ml in the control container. Both treatment and control containers were placed in an ice bath to keep the temperature between 2 and 5°C during the test. Electrical signals at 10 mA/cm$^2$ current, 1 kHz frequency and 50% duty cycle were applied for 20 min through the two electrodes in the treatment container. The electrical parameters were selected on the basis of the study of Li et al. (8). The pH and temperature of the chiller water were monitored during the tests using pH papers and thermometers. Samples (5ml) were taken from the areas 10 mm away from the anode and cathode in the treatment container at 0, 5, 10, 15, and 20 min intervals for microbiological analyses. At the same intervals, samples were also taken from the center area of the control containers. A flow chart in Figure 1 shows the whole process of the experiments conducted in this study.

**TABLE 1. Means and standard deviations of conductivity, pH, and temperature change of poultry chiller water with food-grade salts at different concentrations for destruction of Campylobacter jejuni using electrical treatment**

<table>
<thead>
<tr>
<th>Salt added</th>
<th>Concentration (%)</th>
<th>Conductivity (µS/cm)</th>
<th>pH</th>
<th>Temperature change (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0.1</td>
<td>$3.16 \times 10^3 \pm 0.23 \times 10^3$</td>
<td>$7.3 \pm 0.1$</td>
<td>$2.3 \pm 0.5$</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.2</td>
<td>$4.01 \times 10^3 \pm 0.17 \times 10^3$</td>
<td>$7.1 \pm 0.2$</td>
<td>$1.2 \pm 0.3$</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.3</td>
<td>$5.07 \times 10^3 \pm 0.31 \times 10^3$</td>
<td>$7.1 \pm 0.1$</td>
<td>$0.0 \pm 0.0$</td>
</tr>
<tr>
<td>TSP</td>
<td>0.1</td>
<td>$0.99 \times 10^3 \pm 0.10 \times 10^3$</td>
<td>$11.2 \pm 0.2$</td>
<td>$3.6 \pm 0.3$</td>
</tr>
<tr>
<td>TSP</td>
<td>0.2</td>
<td>$1.97 \times 103 \pm 0.20 \times 10^3$</td>
<td>$11.5 \pm 0.4$</td>
<td>$1.8 \pm 0.1$</td>
</tr>
<tr>
<td>TSP</td>
<td>0.3</td>
<td>$2.66 \times 10^3 \pm 0.14 \times 10^3$</td>
<td>$12.1 \pm 0.1$</td>
<td>$0.4 \pm 0.1$</td>
</tr>
</tbody>
</table>

* The original chiller water was 4 to 6°C, pH 6.8 to 7.5, and 137 to 183 µS/cm.

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sampling after the electricity was applied, which gives the change in *C. jejuni* numbers in log CFU/ml per min. The D value was also presented to show the time required to destroy 90%, or 1 log unit, of *C. jejuni* (5). Because not all data showed a linear relationship between the number of *C. jejuni* and time on a semi-log plot, the D values shown in Table 2 are only estimated on the basis of the data for the first log unit reduction of *C. jejuni*.

![Flow chart of the experiments conducted for electrical treatment of poultry chiller water to destroy Campylobacter jejuni.](image)

**Figure 1.** Flow chart of the experiments conducted for electrical treatment of poultry chiller water to destroy Campylobacter jejuni.

**Effect of salt solution pH**

In the NaCl trials, the number of *C. jejuni* in all control groups remained almost constant in the neutral pH of the NaCl solution (Figs. 2a, b, c). However, *C. jejuni* in the TSP controls was reduced by different levels in different concentrations of TSP (Figs. 3a, b, c). The high pH of the TSP solution, which was around 12, was bactericidal to *C. jejuni*. The survival pH range for *C. jejuni* is from 4 to 9 (5). It should be noted that the pH of chiller water with added TSP was lower than the pH of pure TSP solution. The TSP solution could eliminate all *C. jejuni* cells in a very short time when its concentration was higher than 0.3% (Fig. 3c). Slavik et al. (13) reported that 10% TSP dipping could reduce *C. jejuni* on chicken carcasses. During electrical treatments, the pH of chiller water with TSP remained between 11 and 12, but the pH of chiller water with NaCl changed to 6 around the anode and 8 around the cathode. The number of *C. jejuni* was reduced linearly on a log scale in all TSP treatments, but nonlinearly in all NaCl treatments. The nonlinear reduction of *C. jejuni* in the chiller water with NaCl might be due to chlorine generated during electrical treatment, which was discussed in a study by Li et al. (7).

**Effect of treatment time**

The cell number of *C. jejuni* in chiller water was reduced as the electrical treatment time increased. However, the bacterial reduction curves were different due to the effects of salts, their pH and concentrations as discussed in the previous sections. For 1 log unit reduction of *C. jejuni* in the chiller water by using electrical treatment, it took 16 min with 0.1% NaCl (Fig. 2a), 10 min with 0.2% NaCl (Fig. 2b), 8 min with 0.3% NaCl (Fig. 2c), 13 min with 0.1% TSP (Fig. 3a), 7 min with 0.2% TSP (Fig. 3b) and 1 min with 0.3% TSP (Fig. 3c).

If a shorter treatment time is desired, a higher salt concentration or a higher pH salt solution may be selected. Electrical current can be increased to get higher bacterial destruction rates, according to studies by Li et al. (6, 7). More data are needed to develop a mathematical relationship between bacterial destruction rate and electrical parameters including current, frequency, and duty cycle. In a poultry processing plant, this electrical pasteurization method may be applied to treatment of chiller water using a flow-through system as described by Wolfe et al. (17).

![Changes in the number of Campylobacter jejuni in poultry chiller water mixed with sodium chloride at 4°C and pH 7 and treated with 10 mA/cm² and 1 kHz pulsed electrical current](image)

**Figure 2.** Changes in the number of Campylobacter jejuni in poultry chiller water mixed with sodium chloride at 4°C and pH 7 and treated with 10 mA/cm² and 1 kHz pulsed electrical current. Open symbols represent three replicates of the control without electricity applied, and closed symbols represent three replicates of the electrical treatment.
ELECTRICAL DESTRUCTION OF CAMPYLOBACTER JEJUNI 1333

In conclusion, *C. jejuni* was effectively destroyed in poultry chiller water by the use of pulsed electrical current with either sodium chloride or trisodium phosphate at concentrations from 0.1% to 0.3%. The bacteria were destroyed more quickly in higher pH solutions. The higher salt concentrations accelerated the bacterial destruction. The death rate of *C. jejuni* was dependent on salt concentration, pH, and treatment time. When the pulsed electricity was set at 10 mA/cm² current, 1 kHz frequency, and 50% duty cycle, 1 to 16 min were required to get 1 log unit reduction of *C. jejuni* in poultry chiller water mixed with 0.1% to 0.3% sodium chloride or trisodium phosphate. The reduction of *C. jejuni* in chiller water was linear on a log scale with TSP, but nonlinear with NaCl.

ACKNOWLEDGMENTS

This research was funded by the Food Safety Consortium sponsored by U. S. Department of Agriculture.

REFERENCES


FIGURE 3. Changes in the number of *Campylobacter jejuni* in poultry chiller water mixed with trisodium phosphate at 4°C and pH 11 to 12 and treated with 10 mA/cm² and 1 kHz pulsed electrical current. Open symbols represent three replicates of the control without electricity applied, and closed symbols represent three replicates of the electrical treatment.

TABLE 2. Destruction rate of Campylobacter jejuni in the poultry chiller water with salts using electrical treatment at 10 mA/cm² current density, 1 kHz frequency and 50% duty cycle

<table>
<thead>
<tr>
<th>Salt added</th>
<th>Concentration (%)</th>
<th>Destruction rate (log CFU/ml/min)</th>
<th>D value (min)</th>
<th>Linear curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0.1</td>
<td>0.05 ± 0.01</td>
<td>16.0 ± 4.3</td>
<td>no</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.2</td>
<td>0.12 ± 0.03</td>
<td>10.1 ± 1.2</td>
<td>no</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.3</td>
<td>0.14 ± 0.03</td>
<td>8.5 ± 0.7</td>
<td>no</td>
</tr>
<tr>
<td>TSP</td>
<td>0.1</td>
<td>0.12 ± 0.05</td>
<td>13.2 ± 0.9</td>
<td>yes</td>
</tr>
<tr>
<td>TSP</td>
<td>0.2</td>
<td>0.23 ± 0.07</td>
<td>7.2 ± 0.4</td>
<td>yes</td>
</tr>
<tr>
<td>TSP</td>
<td>0.3</td>
<td>1.20 ± 0.15</td>
<td>0.9 ± 0.1a</td>
<td>yes</td>
</tr>
</tbody>
</table>

* C. jejuni was destroyed in both the treatments and controls.

JOURNAL OF FOOD PROTECTION, VOL. 58, DECEMBER 1995


