Preliminary Studies of Microfiltration for Food Processing Water Reuse

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ABSTRACT

Microfiltration of poultry scalder and chiller water and frankfurter chiller brine was examined in limited tests and found to produce permeates that may be recycled to the original systems. All permeates achieved turbidity readings of less than 50 NTU, with many less than 1 NTU, and all had plate counts of less than 10 microorganisms per ml. Except for brine, waters were filtered at the highest known plant operating temperatures. After 90 min of operation, flux rates as high as 110-440 L/m2h were achieved, depending on the water and filter conditions used. Flux rates were restored by as little as 15 min of in-line cleaning at 78-80°C with a detergent solution. Major advantages for the process are: (a) substantial energy savings through reuse of previously heated or cooled waters, (b) reduced disposal costs, especially through brine reuse, and (c) possible byproduct recovery of protein and fat concentrated in poultry retentate waters.

Meat and poultry processing plants consume large quantities of water, much of it either heated or cooled and/or chlorinated for microorganisms. For example, current regulations (7) require an overflow of 0.5 gal. of water per bird from a poultry chiller and require potable water for make-up. Make-up water must be cooled to maintain the chiller at 1-2°C. Reuse of process water would result in substantial cost savings from reduced energy requirements for heating and cooling, and from reduced make-up water requirements and waste-water discharges. Consequently, there is considerable interest in developing means for safe reuse of process waters. However, reuse of process water without treatment would inevitably result in a buildup of both organic matter and microbial population, and is prohibited by current regulations (7).

Rogers (6) screened various methods for removal of organic matter from poultry chiller water and concluded that filtration through diatomaceous earth (DE) was the most promising. Lillard (3-5) examined DE filtration in more detail and found that organic matter could be reduced so that effective bactericidal treatment was accomplished with 26-28 ppm chlorine gas and that filtered chiller water could safely be reused to flume broiler giblets. Unfortunately, the amount of DE needed for the large quantities of water involved would be costly and would generate problem amounts of used DE for disposal.

Microfiltration is a potential alternative means of reconditioning process water since it should be able to remove most microorganisms and suspended matter. Inert microfilters are now commercially available which may enable practical microfiltration of process waters. Technology to produce these filters is new and still evolving. Consequently, price of these filters may change substantially in the near future as production technology improves or economies of scale are realized.

The purpose of this study was to examine the efficacy of microfiltration as a treatment of selected process waters for reuse. Special goals were to determine if (a) effective flux rates could be achieved, (b) microbial count could be reduced such that permeate could be reused, and (c) chlorine demand would be reduced by removal of insoluble solids by the filter.

Work is currently underway examining plant scale filters. A future report is planned to report this work and to estimate filter costs needed for the process to be economically viable.

MATERIALS AND METHODS

Poultry chiller and scalded water and frankfurter chiller brine were chosen as representative process waters. Commercially, poultry waters are used in large amounts, carry substantial organic loads, incur large energy costs for heating or cooling and, as with chiller water, are often chlorinated. The volume of frankfurter chiller waters is very small compared to many other process waters but frankfurter chiller water is important because, as a brine, it represents a very difficult disposal problem.

As envisioned, process water would go to a microfiltration unit where it would be continuously circulated in a retentate loop across the filter membrane. Permeate, passing through the membrane, would be reused as processing water. Retentate would be greatly reduced in volume and have substantially increased solids content. This should enable retentate to be treated much more efficiently by waste treatment processes or may enable byproducts...
The filtration unit might be operated in either a batch or continuous mode depending on the process water and desired result. High-volume waters might be filtered in continuous mode, where a process water stream would flow from a unit, such as a poultry scaler or chiller, into the retentate loop of a filter. Permeate would return to the scaler or chiller. Retentate would be withdrawn from the retentate loop in a flow equal to that of scaler or chiller make up water. The filter unit would be sized to deliver whatever permeate flow might be needed to achieve desired process water quality. Low-volume waters, such as chilling brines, might be cleaned in a batch mode, following nightly shutdown of a chiller. In this instance, all the brine would go to the retentate loop over the course of a filtration trial. Permeate would be collected in a separate tank as cleaned brine for next day’s operation. No retentate would be removed during filtration. Filtration would be ended when most of the brine was cleaned. The small amount of brine remaining as retentate would then be removed.

Apparatus and definitions

The apparatus used for this investigation is shown in Fig. 1. Process water was pumped through a heat exchanger, where it was heated to filtration temperature then passed to a Ceraflow microfiltration module (Norton Co., Worchester, MA). The module was a shell-and-tube design consisting of a stainless steel sanitary housing enclosing a filter bundle of porous ceramic (Al₂O₃) tubes. Filters consisted of 28 tubes with a 0.091-m² (1 ft²) surface area or 8 tubes with a 0.026-m² (0.3 ft²) surface area. Filter pore size was either 0.2 μm or 0.45 μm. Inside diameter of the tubes was 2.8 mm. Retentate was recirculated. Filter pressure was adjusted by a valve on the water return line. Permeate was either discharged in batch operation or recombined with retentate in continuous operation. At times, some permeate was also collected in a small reservoir and backflushed through the filter membrane for cleaning.

Inlet and outlet pressure was measured by pressure transducers, inlet temperature by a thermocouple, and inlet flow rate by a paddle wheel flowmeter (Model FP-5205, Omega Engineering, Inc., Stanford, CT). Data were collected by a CR-7 data logger (Campbell Scientific, Inc., Logan, UT).

A sanitary design, positive displacement pump (Model D025, Waukesha Foundry Co., Inc., Waukesha, WI) with 1.5 Hp adjustable drive was used to pump liquid to the module. Flow rate to the module was varied between 10-42 L/min.

In this report transfilter flow refers to the linear velocity of retentate over the membrane surface (retentate velocity through a filter tube). Transmembrane pressure was the difference between the retentate and permeate sides of the membrane. The permeate side was maintained at atmospheric pressure for all experiments. Transfilter pressure was the difference between retentate pressures at the filter inlet and outlet. Flux was permeation rate per unit area of membrane.

Material

Process waters were obtained from nearby commercial plants. Poultry chiller water was obtained from the first stage exit of a two-stage chiller and had floating ice when collected. Overflow from a poultry scaler was collected at 52°C from a second processor and frankfurter chiller brine was collected at -10.5°C from a third processor. Each sample was transported under ambient conditions to the Western Regional Research Center (WRRC) on the same day as the filtration trial.
collection. Upon arrival at WRRC, poultry waters were passed through 40- and 325-mesh sieves to remove trace amounts of large particles. Brine was relatively clean and was not sieved. Poultry scald water samples, used within 24 h of collection, were stored at ambient temperature. All other samples were stored at 1°C until used.

Analyses

Total solids, ash, ether extractables (fat), and Kjeldahl nitrogen were determined by AOAC methods (1). Viscosity was determined at filtration temperature by a falling ball viscometer (Fish Schubman Corp., New York, N.Y.). Turbidity was determined by a Model DRT turbidity meter (HF Instruments, Fredonia, N.Y.). Chlorine demand was calculated as the difference between added chlorine and total residual chlorine 60 min after addition. Chlorine was added to samples at levels of 400, 200, and 100 ppm and then total residual chlorine was determined according to Method 330.1 (2). Permeate microorganism count was determined by first sterilizing all equipment contacting the permeate with 50 ppm chlorine followed by thorough flushing with sterile water. Process water was sampled at the start of a trial and permeate samples were collected at various times during midtrial and at the end of a trial. Samples were plated on non-selective plate count agar, incubated aerobically at 25°C (77°F), and observed daily for 4 d and plate counts noted. Frankfurter chiller brine samples were additionally plated on a selective medium containing 7.5% NaCl. The selective medium, Staphylococcus 110, is designed to test for Staphylococcus when used at 35°C, but was used at 25°C to check for organisms that would stand the salt concentration of the brine.

Experimental

Process water was filtered in a series of trials according to the flow sheet in Fig. 1. Two modes of operation were used, batch and continuous. In batch operation, permeate was discarded. Batch operation was used to concentrate insoluble solids in the retentate (a concentration trial) and to test the ability of a short membrane backflushing to restore the flux of the fouled membrane. All concentration trials were at least 4 h in duration. Backflushing, when used, was begun 4 h after starting a trial and repeated hourly thereafter. During backflushing, recirculation was stopped and about 1 L of permeate at filter temperature was pumped back through the filter membrane at pressures up to about 1100 kPa. Backflushing took less than 1 min to complete.

In continuous operation, permeate was recombined with retentate and recirculated, thus maintaining a constant insoluble solids concentration in the retentate. Continuous operation was used to observe the effect on flux of increasing transmembrane pressure (a pressure scan) or increasing transfilter flow (a flow scan).

A pressure scan was made by holding transfilter flow (retentate velocity through the filter tubes) constant and making a series of trials at differing transmembrane pressures (pressure drop across the membrane). Pressure on the permeate side of the membrane was kept at atmospheric for all trials in this report. In similar manner, a flow scan was made by holding transmembrane pressure constant and making a series of trials at different transfilter flows. All pressure and flow scans were at least 90 min in duration, sufficient to establish flux decay. Filtration temperatures were chosen for poultry chiller and scald water to reflect normal operating criteria. Poultry chiller water was filtered at 15°C, a chiller exit water temperature at the high end of commercial practice, and scald water was filtered at 50-52°C. It was thought that at -10°C, the collection temperature of frankfurter chiller brine, flux might be unacceptably low; so a filtration temperature of 20°C was arbitrarily chosen to see if an acceptable flux could be achieved. If flux was acceptable and the resultant permeate was essentially free of microorganisms, then 20°C filtration might be used to clean brine of microorganisms and suspended solids but probably would not achieve any energy savings. Acceptable flux would also indicate the possibility of acceptable filtration at lower temperatures where energy savings would be expected.

For poultry chiller or scald water, a different plant water collection was used for each concentration trial, pressure scan or flow scan. But all trials within each scan were made from the same collection. All frankfurter chiller water trials were made from a single plant collection.

The filter was cleaned in place after each trial using a recycling technique. Permeate and backflush shutoff valves were closed and three cleaning solutions were successively recirculated through the filter. The first solution contained 19.5 ml of Micro brand detergent/L of distilled water. The second cleaning solution was 0.1 N KOH, and the third was 0.1 N HNO₃. Each solution was recirculated for 30 min at a transfilter velocity of 4 m/s and 50°C. The system was then thoroughly flushed with room temperature distilled water. A few spot tests were made substituting a single 15-min cleaning with the Micro solution at about 75-80°C followed by a thorough flushing with room temperature distilled water.

Thoroughness of the cleaning was tested by filtering room temperature distilled water at a transfilter velocity of 3.4 m/s and a transmembrane pressure of 75 kPa. Permeate rate was noted 1 min after filtration was begun and compared to that recorded when the filter was clean.

RESULTS AND DISCUSSION

Flux values

Figure 2 shows some representative flux decay curves for concentration (batch) trials using a 0.45-μm filter. Starting with a clean filter, both continuous and concentration trials typically exhibited similar curves to those in Fig. 2, with rapid flux decay from initial values. After about 1 h flux stabilized to a rather slow rate of decay.

A number of factors influence flux, including such variables as the nature and starting concentration of dissolved and suspended solids, temperature, pressure, flow, and pore size, but only the latter three were specifically examined. As illustrated in Fig. 2, poultry scald water flux was always substantially higher than that obtained for either of the other process waters at the filtration temperatures used. Since the different process waters would ideally be filtered at or near their normal temperature, they were not tested at the same temperature. The greater flux of poultry scald water was probably due to a number of factors but higher temperature must have been a major influence because of its effect in reducing viscosity. The nature and starting concentration of solids in the waters may also have influenced the differences in flux but these influences were beyond the scope of this study.

Increasing suspended solids in the retentate during a concentration trial would be expected to have some effect on flux. However, if so, it was relatively minor in the range tested since flux typically exhibited the slow decrease illustrated in Fig. 2. Even though retentate volume was reduced as much
as 8.5-fold in some trials (ratio of starting volume to ending volume), total solids level was never more than 0.54%. If solids content were taken to higher levels flux might reasonably be expected to show an increasingly sharp reduction.

Ninety-minute flux values were well into the region of relatively stable flux decay, so they were used to compare effects of pressure and flow. Figure 3 shows the effect of increasing pressure at constant flow rate. Over the range tested, both poultry chiller water and frankfurter chiller brine showed relatively small changes in flux. Poultry scalder water also showed an essentially flat response to increasing pressure. There may have been an improvement in the region of 150-200 kPa but more tests would be needed for confirmation. In contrast, increased flow at constant pressure showed a clear and consistent increase in flux, especially for scalder water, as shown in Figure 4. Although based on limited tests, it appears that flow has a much larger effect than pressure. This is probably due to the nature of the suspended solids coating the membrane. Many of these are probably bits of tissue and fat which would be expected to deform under increasing pressure and form a more compact layer counteracting the increased driving force of the pressure. In contrast, increased flow would tend to flush more of these particles from the membrane surface, reducing the thickness of the layer and thus increasing flux. Increased flow would also result in increased pressure, so more extensive testing would probably identify an optimum balance between the benefits of increased flow versus increased pumping costs and the possible negative influence on flux of increased pressure.

Figure 5 shows the effect of pore size on flux for poultry scalder water using the same water sample. Although both curves were obtained under the same filter conditions, the smaller pore size had a larger flux. However, in trials using distilled water, the 0.45-μm pore size produced a substantially larger flux than the 0.20-μm pore size. Scalder water tends to plug the 0.45-μm filter more than the 0.20-μm filter and this probably indicates the presence of more particles in scalder water near the pore size on the 0.45-μm filter. Other waters were not tested in this manner.

No attempt was made to optimize conditions in these tests. It is possible that higher flux could be achieved for any or all of these process waters. In these limited tests, 90-min flux as high as 440 L/m²h achieved for poultry scalder water (continuous operation at 50°C, 130 kPa and 6.0 m/s using a 0.20-μm filter). Best results for poultry chiller water and frankfurter chiller brine were lower but still high enough to encourage further investigation. Ninety-minute flux as high as 120 L/m²h was obtained for frankfurter chiller brine (continuous operation at 20°C, 207 kPa and 4.0 m/s using a 0.45-μm filter) and as high as 110 L/m²h for poultry chiller water (batch operation at 15°C, 138 kPa and 3.4 m/s using a 0.45-μm filter).

Flux was completely restored to original values by the post-trial, in-line cleaning technique employing successive washings with detergent, alkaline and acid solutions, all at 50°C. This severe cleaning technique was normally used since emphasis was on other areas of experimentation. However, in spot test, 15-min cleaning with detergent at 75-80°C also completely restored flux rates, indicating less
MICROFILTRATION OF PROCESS WASTES

Figure 4. Change in flux with transfilter flow. Flux measured after 90 min running time. Scaler water filtered using a 0.2-µm filter at 50°C and 130 kPa, chiller brine using a 0.45-µm filter at 20°C and 207 kPa, and chiller water using a 0.45-µm filter at 15°C and 103 kPa.

Figure 5. Change in flux with time during concentration of poultry scaler water using different pore size filters. Both trials filtered at 50°C, 3.4 m/s and 124 kPa.

vigorouss backflush.

Flux data, before backflushing, gave a linear plot on log-log paper. This was used to extrapolate the permeate volume without backflushing, which is plotted in Fig. 6. Actual permeate volume with backflushing was calculated from experimental data and shows flux decreased too fast to compensate for the loss of permeate used for backflushing. Thus the net volume of permeate slowly fell behind that extrapolated without backflushing.

While these are projections and may be somewhat in error, they indicate that backflushing, as tried in these experiments, is probably of little or no value for poultry chiller water and frankfurter chiller brine.

Permeate properties

Table 1 lists the turbidity values of various waters. Visually, all permeates were completely clear, with brine permeate colorless, poultry chiller permeate pink and poultry scaler permeate yellow in color. Turbidity of poultry starting waters was high, ranging from 170 to 680 NTU. Retentate from these waters increased in turbidity with increasing concentration. Then, in some instances, retentate turbidity began to drop, perhaps due to precipitation or agglomeration of light-scattering particles. Permeate turbidities from a 0.45-µm filter were very low, less than 8 NTU for chiller permeate and less than 43 NTU for scaler permeate. Scaler permeate from a 0.2-µm filter was substantially lower at less than 1 NTU. Starting frankfurter chiller brine was reasonably clear at about 10 NTU, with its associated permeate less than
TABLE 1. Change in turbidity of various process waters with reduction in retentate volume.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Filter pore size, μm</th>
<th>V₀</th>
<th>V</th>
<th>Tubidity, NTU</th>
<th>Retentate</th>
<th>Permeate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry chiller water</td>
<td>0.45</td>
<td>1.0</td>
<td></td>
<td>170</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.9</td>
<td></td>
<td>245</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.6</td>
<td></td>
<td>500</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2</td>
<td></td>
<td>620</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.9</td>
<td></td>
<td>660</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Poultry scalder water</td>
<td>0.45</td>
<td>1.0</td>
<td></td>
<td>680</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
<td>740</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7</td>
<td></td>
<td>680</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.2</td>
<td></td>
<td>580</td>
<td>42.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.6</td>
<td></td>
<td>470</td>
<td>38.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>1.0</td>
<td></td>
<td>320</td>
<td>--</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>2.3</td>
<td></td>
<td>680</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.6</td>
<td></td>
<td>720</td>
<td>0.64</td>
<td></td>
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<td></td>
<td></td>
<td>5.9</td>
<td></td>
<td>520</td>
<td>0.61</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>8.4</td>
<td></td>
<td>240</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Frankfurter chiller brine</td>
<td>0.45</td>
<td>1.0</td>
<td></td>
<td>9.5</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.2)</td>
<td></td>
<td>&lt;10</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.4)</td>
<td></td>
<td>&lt;10</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

aRatio of starting water volume to retentate volume at time of sampling. Parenthesis indicates estimate.
bOperating conditions were 15°C, 138 kPa and 3.4 m/s.
cOperating conditions were 50°C, 124 kPa and 3.4 m/s.
dOperating conditions were 20°C, 207 kPa and 4.0 m/s.

Table 2 lists the microorganism counts in starting process waters and associated permeates. In each instance, microorganisms in the permeate were less than 10 per ml. The 0.45-μm filter effectively retained most microorganisms in the retentate. Based on size concentrations, a smaller pore size, such as 0.20 μm, should be equally effective. However, permeate from 0.20-μm pore size filters was not tested for microorganisms. Of course, any organisms present, smaller than the pore size, would be expected to pass through the filter.

Permeate was essentially composed of soluble solids and its composition remained relatively constant throughout each trial. Any changes relative to starting water reflected removal of insoluble particles larger than filter pore size.

Table 3 shows final composition for several trials at the indicated retentate volume reduction. All values reflected some experimental variation. For example, composition of poultry scalder water and permeate were close enough to cause some crossover of ash and nitrogen results; permeate values should be slightly lower than starting water. Frankfurter retentate total solids and ash should be slightly higher than starting brine. Fat analysis showed the largest variation, enough to indicate its results should be considered only approximate. Although some components, such as fat, may be at saturation in the permeate, others may increase with continued reuse of the permeate.

There was no clear reduction in chlorine demand of permeate from poultry chiller water. At 400 ppm added chlorine, the chlorine demand of permeate was 195 ppm.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Vob Total</th>
<th>Solids (%)</th>
<th>Ash (%)</th>
<th>Nitrogen (%)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Poultry chiller water</strong> d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starting water</td>
<td></td>
<td>0.14</td>
<td>0.05</td>
<td>0.009</td>
<td>0.05</td>
</tr>
<tr>
<td>Permeate</td>
<td>4.5</td>
<td>0.07</td>
<td>0.04</td>
<td>0.003</td>
<td>0.025</td>
</tr>
<tr>
<td>Retentate</td>
<td>4.5</td>
<td>0.44</td>
<td>0.05</td>
<td>0.015</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Poultry scalder water</strong> d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starting water</td>
<td></td>
<td>.141</td>
<td>0.048</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>Permeate</td>
<td>8.4</td>
<td>0.084</td>
<td>0.053</td>
<td>0.021</td>
<td>0.014</td>
</tr>
<tr>
<td>Retentate</td>
<td>8.4</td>
<td>0.539</td>
<td>0.084</td>
<td>0.071</td>
<td>0.060</td>
</tr>
<tr>
<td><strong>Frankfurter chiller brine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starting water</td>
<td></td>
<td>15.72</td>
<td>14.07</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>Permeate</td>
<td>(1.4)</td>
<td>14.75</td>
<td>13.96</td>
<td>0.025</td>
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<tr>
<td>Retentate</td>
<td>(1.4)</td>
<td>15.05</td>
<td>14.06</td>
<td>0.026</td>
<td></td>
</tr>
</tbody>
</table>

*As received basis.

Operating conditions were 15°C, 138 kPa and 3.4 m/s using 0.45-μm filter.
Operating conditions were 50°C, 124 kPa and 3.4 m/s using 0.20-μm filter.
Operating conditions were 20°C, 207 kPa and 4.0 m/s using 0.45-μm filter.

Waste treatment/byproduct recovery

Retentate, with its reduced volume and increased solids, could go to waste treatment or possibly to byproduct recovery. Volume was reduced as much as 8.4-fold in these tests, and the indications were that substantially greater concentration could be obtained for any of the process waters tested. Reduced volume would be highly desirable from the standpoint of waste treatment cost.

Further concentration may be necessary for economical byproduct recovery, but both poultry chiller and scalder retentates appear to have potential based on their composition. As shown in Table 3, crude protein comprised over 80% and fat about 11% of total solids in the poultry scalder retentate. In the poultry chiller retentate, crude protein comprised about 20-30% and fat about 30-36% of total solids. Further concentration should raise both crude protein and fat content since ash appears to be mostly soluble material and is not held back by the filter membrane. Frankfurter chiller brine total solids are mostly soluble salts. Although insoluble organic solids could be concentrated in the brine, their low initial level and the fact that crude protein is only a small part of these solids indicates there is little potential for byproduct recovery.

CONCLUSIONS

These limited tests have indicated microfiltration is a promising method of reconditioning process water for reuse. An important advantage for microfiltration of poultry chiller and scalder waters would seem to be in the area of energy savings. Because of the large volumes of water involved in poultry operations, substantial energy loss occurs when these waters are discarded. A substantial portion of this energy would be saved by reuse of the permeate. Flux, especially for scalder water, seems high enough to justify optimism that overall process economics for microfiltration would be favorable. The virtual absence of microorganisms in the permeate, along with possible increased waste treatment efficiency, or byproduct recovery from the concentrate, should all help the process economics.

Brine flux is also high enough to justify further investigation. In addition to the energy savings, substantial waste treatment cost savings might result from the reduced need to discard high-concentration salt solutions.

Scaleup of data should be relatively easy since commercial-scale filters have the same filter tube dimensions as the laboratory-scale filters. Commercial-scale filters incorporate more tubes per filter module. Future in-plant studies are planned, with commercial-scale equipment. Longer term operation is needed to develop suitable data to optimize operation and make an economic analysis.

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by diatomaceous earth filtration and chlorination. J. Food Sci. 43:1528-1531.


