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The Use of a Submerged Microfiltration System for Regeneration and Reuse of Wastewater in a Fresh-cut Vegetable Operation

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Abstract: Wash water from a fresh-cut vegetable processing plant was filtered using a submerged microfiltration module containing PVDF membranes. The unfiltered water and permeate were analyzed and the flux and fouling rate were monitored in an effort to find the ideal parameters for the system. The study found the system had a pure water rate of 24 L/hm^2 which was reduced to 19 L/hm^2 after 6 hours with cleaning, when run at 40–50 kPa. The ideal cleaning regime was found to be every 1 hour for a period of 120 seconds at 200 kPa.

Keywords: Filtration, submerged membranes, fresh-cut vegetable wastewater

INTRODUCTION

Food processors across the country must be proactive in facing and solving problems that might tend to counter the anticipated growth of their industry. One common problem in the food industry is the increasing levels of water use. The fresh-cut vegetable industry is a prime example of this.

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Examples of fresh-cut produce include shredded lettuce, raw vegetable salads, peeled baby carrots, and other vegetables that have been processed by slicing, peeling, shredding, chopping, coring, trimming, or mashing. The fresh-cut produce industry had $12 billion annually in sales over the last few years (1) and is continuing to grow. Another problem that is increasing in occurrence is the number of foodborne illnesses associated with the fresh produce and fresh-cut industry. Forty illness outbreaks were attributed to the consumption of fresh produce from 1998 to 2004, and 25 of these were related to fresh-cut produce (1). Fresh produce can become contaminated with pathogenic bacteria from water used in cleaning and irrigation as well as other numerous other paths. The risk increases with fresh-cut produce because the natural exterior or barrier of the product is broken and bacterial growth can occur in the presence of pathogens.

Clean water is used extensively in a cut vegetable operation to produce ready to eat vegetable salad mixes. Soil must be removed from the product as it is bought in from the farm. Water used for this purpose is treated in order to reduce disinfect, and chlorine is often used for this purpose to ensure that the pathogenic bacteria are removed from the vegetables. Wastewater recycling will ease the pressure on water usage and save the water and sewer costs in processing plants. The primary goal of the project was to prove the feasibility of using a low-cost polymeric microfiltration system for treating wastewater for recycling in order to reduce the in-plant water consumption and to determine the fouling rate and effective cleanup regimen for regenerating clean-membrane flux.

Membranes are generally rated by their nominal pore size, molecular weight cut-off (MWCO), and pure water permeability. The nominal pore size can have great variability. Molecular weight cut-off can be estimated from the nominal pore size. Research has found membranes with rate pore size of 0.2 μm have been shown to have pores up to 5 μm (4). The MWCO are usually described as the upper limit of the particle size and less than 10% of particles that size shall pass through (5). In fact, membrane companies advise that a MWCO of three to six times smaller than the particle of interest should be chosen (6). Many other factors need to be considered when choosing a membrane. The feed used and the permeate and retentate desired have a great impact on the flux rate and decline. In general, the tighter the MWCO the lower the flux rate.

The flux, the stability of flux with time, and any selectivity of a particular membrane together determine the viability and cost of a membrane process (7). Fouling of membranes causes the flux to decline in turn increasing cleaning needs or decreasing processing time, both of which increase costs. Fouling is due to hydrophilic-hydrophobic reactions between the membrane and the fluid being filtered (8).

MATERIALS AND METHODS

The feasibility of using the microfiltration system for recycling fresh-cut produce washing water was studied. The plant studied in this research discharges about 18.9 kL/h of wastewater, 454 kL of water per day. The microfiltration system was supplied by Sepro-Rochem (Santa Monica, CA). The membranes were polyvinylidine fluoride with a nominal pore size of 0.2 μm. These particular membranes were chosen based on the recommendation of the supplier for this particular waste stream. The membrane module was made up of 4 rows containing 92 membranes each for a total area of 14 m^2. The microfiltration module was submerged in a tank that was fitted with air sparging bars between each of the 4 rows of membranes, see Figs. 1 and 2. The used wash water from the plant was pumped into the tank containing the module and the permeate was pumped out through the membranes to be tested while the retentate remained and accumulated in the tank. The air sparging was run at all times in order to decrease accumulation of large particles on the membrane. The working cycle of the microfiltration module was monitored by measuring the operating pressure regularly, before and after back washing with permeate.

The system also included a 10 L tank for an alkaline cleaning solution as well as an additional pump to run a backflush. Membranes were fouled during the recycling operation, causing the membrane performance (flux) to drop. At this point the foulants were removed from the membrane using different membrane reconditioning methods; backflushing (permeate water) and chemical enhanced backflushing using an alkaline cleaner at different concentrations and time periods in order to return to the original flux rate. The backflushing was done at different time intervals during the recycling process. Studies on the frequency of cleaning, and the life of the membrane were done during reconditioning regimens.

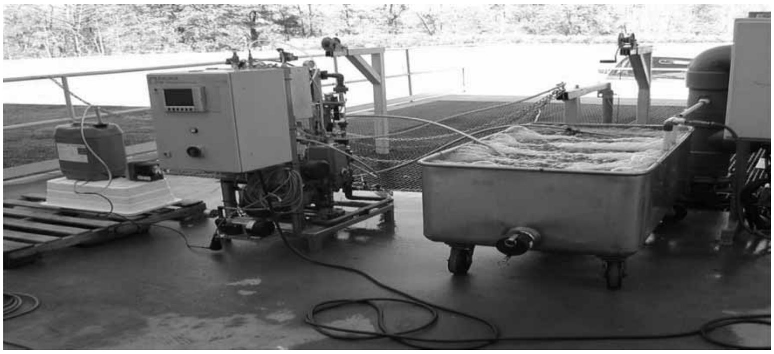


Figure 1. Microfiltation modules submerged in tank and necessary pumps and cleaners in place at plant.

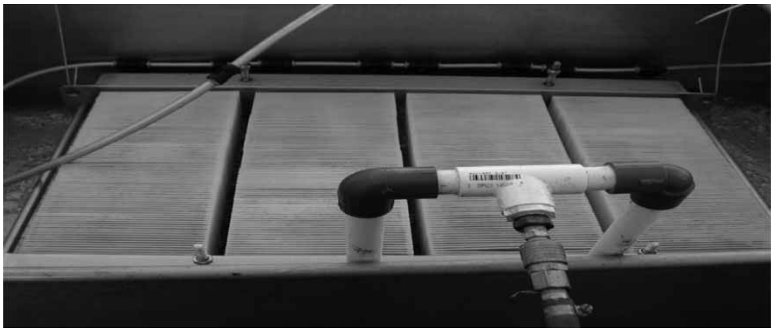


Figure 2. 14 m^2 PVDF membrane module submerged in fresh-cut wash water.

Water samples were drawn before and after the filter element. They were tested for total suspended solids, total plate count, pH, total and free chlorine content, and particle size diameter of the dissolved particles. Total solids were determined according to Standard Methods for the Examination of Water and Wastewater (2). Total aerobes were enumerated in duplicate using plate count agar (PCA; Difco Laboratories, Detroit, MI). Total coliform bacteria were enumerated by a 5-tube most probable number (MPN) technique using lauryl sulphate tryptose, brilliant green bile lactose an EC broths (BBL; MD). Gas positive EC tubes would be streaked on Levine's eosine methylene blue agar (BBL). Typical dark colonies with or without a metallic sheen would be streaked on PCA slants before confirmation using the IMViC classification (3). In the economic analysis, production costs of the proposed microfiltration systems were assessed and compared with current processes for break-even economic viability of each system. Water and energy use and associated costs were closely examined. The surface of the membranes both before and after fouling were studied with the use of scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

Water permeation in this module was started by the extraction pump of the permeate working under vacuum (average value; −90 kPa). The membrane module was submerged in the fresh-cut washed water and connected to a hydraulic pump. The microfiltation membranes were chemically washed when hydraulic performance worsened (usually after 1 h of working). The flat membranes contained in the module were back flushed with permeate, and permeate mixed with cleaner after every 1 hour for a period of 120 seconds, at the maximum pressure of 200 kPa. Alkaline chemical was used; Rochem cleaner A. The average flow of the microfiltration permeate was 0.189 L/hm^2kPa.

Testing of flat microfiltation membranes working under vacuum was of special interest, because this membrane system has a different conception compared to traditional spiral-wound membrane processes. The feasibility of using a low-cost microfiltration system for recycling wastewater in a vegetable processing plant was demonstrated. Pump size and power requirement are low because water enters the system through the membrane at the suction side of the pump and pressure inside the membrane module is 90 kPa. The plant discharged 18.9 kL/h of wastewater that contains 600 mg/L soluble solids and 50 mg/L suspended solids. The water can be recovered by microfiltration and reused in the plant to remove soil from the incoming vegetables. The polymeric membrane microfiltration system eliminated microorganisms and suspended solids from the wastewater producing a clear permeate from a green-colored wastewater.

The wastewater typically contained 0.1 to 0.3 mg/L free chlorine and 3.0 to 6.0 mg/L bound chlorine. Most of the bound chlorine was in the suspended solids because the treated water contained only 0.16 mg/L bound chlorine and free chlorine. Recycling of this water will not accumulate bound chlorine because the retentate that contained most of the bound chlorine is discharged from the system.

Untreated Water

- Total solids = 218.0 mg/L
- pH = 7.3−7.4
- Free chlorine = 0.1−0.3 mg/L
- Total chlorine = 6.9 mg/L

Permeate

- Total solids = 100.0 mg/L
- pH = 7.1−7.2
- Free chlorine = 0.00 mg/L
- Total chlorine = 0.16 mg/L

Water flux rates through the membrane were dependent on the suspended solids content and the temperature. Pure water permeability through the polyvinyldine fluoride polymeric membrane was 0.267 L/hm^{2}kPa flux rate with wastewater started at 0.267 L/hm^{2}kPa and dropped to 0.211 L/hm^{2}kPa after 6 hours of operation. It was possible to operate the system with only one cleanup over an 8 hour shift and regain the original flux. Cleanup consisted of draining the tank that held the membrane module, replacing the wastewater with clean tap water, and applying a mild alkaline detergent (pH 10). With the pump stopped, air was sparged over the membrane for about 300 seconds followed by draining the wash water and refilling the tank with wastewater. It was necessary to continuously sparge the outside surfaces of the membrane with air to prevent complete fouling. When the system was run without air sparing, the foulant penetrated the membrane pores resulting in sharply reduced flux over a 0.33 hour period. Cleaning the foulant that penetrated the membrane pores required very aggressive scouring of the membrane to restore flux. The cleanup regimen has to be carefully done in order to ensure longevity of the membrane operating life. The large increase in resistance of the microfiltration membrane after filtration of fresh-cut washed water is caused by the formation of a relatively thick deposit on the outer surface of the membrane as seen in SEM images in Figs. 3 and 4. Figure 3 is the PVDF membrane before use and the pores are very visible and open but in Fig. 4 the pores are covered with a thick deposit of particles resulting in the decreased flux and increased pressure.

Figures 5 and 6 show that a decrease in flow was observed because of fouling, but chemical washing was effective in restoring the initial flow values of microfiltation permeates. The experiment demonstrated that back-flushing is effective in cleaning the flat membrane contained in the microfiltation module. As Fig. 6 shows, periodic back-washing permitted restoration of the low value of the microfiltration operating pressure, and, therefore, the low energy consumption. Backwash has proved to be an effective physical method for flux recovery of membranes. An absorbed layer of particulate and colloidal matter accounts for the major part of deterioration of the membrane performance. The success of backwash in flux recovery in microfiltation indicates that absorptive fouling could be reversed by flow reversal.

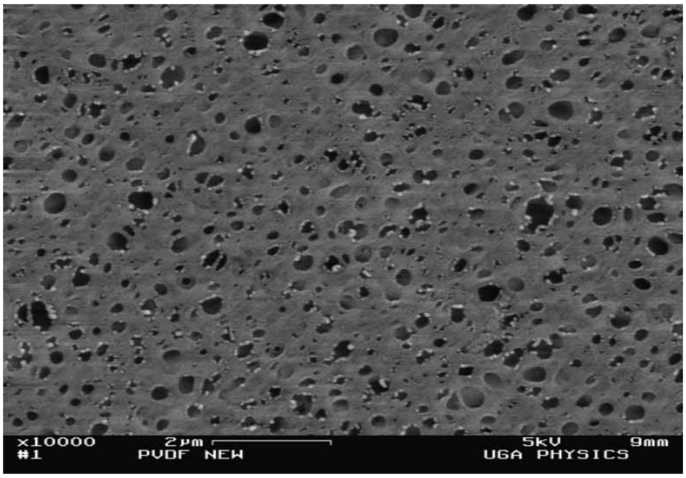


Figure 3. SEM image of PVDF membrane before use in fresh-cut wash water. Nominal pore size of 0.2 μm, with 10,000 times magnification.

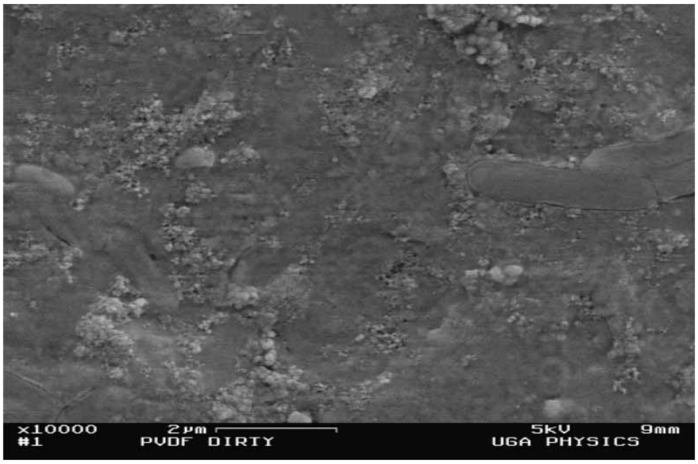


Figure 4. SEM image of PVDF membrane after use in fresh-cut wash water and before washing. Nominal pore size of 0.2 μm, with 10,000 times magnification.

Particle size distribution was completed using a particle size analyzer. The wash water had an average particle diameter of 137.18 μm. The permeate was found to have an average particle diameter of 3.08 μm, see Figs. 7 and 8. This shows that the membranes were removing particles on average larger than 3.08 μm. Figure 7 shows the range of particle size from 0.1–1000 μm and this is decreased after filtration to 0.1–10 μm, showing the removal of the larger particles.

Researchers believe the results of this study will have a tremendous impact on the food industry. Operations which generate relatively clean

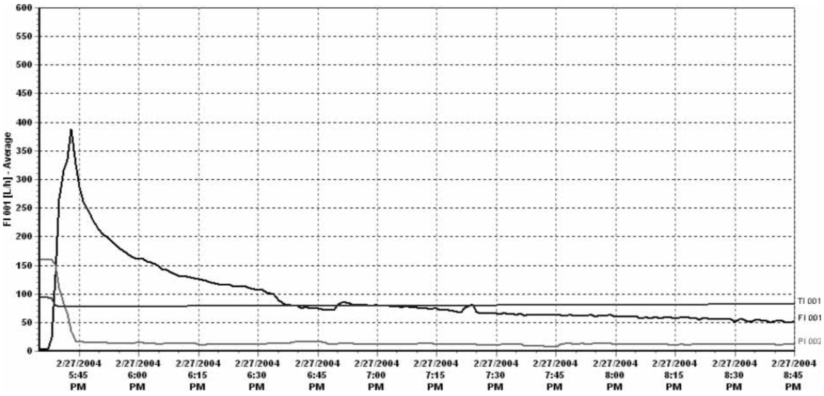


Figure 5. Flux rate of fresh-cut wash water without air bubbling/backflushing.

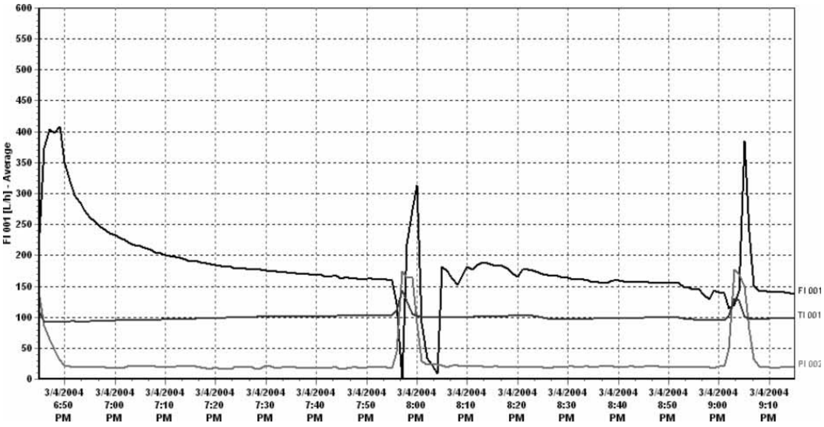
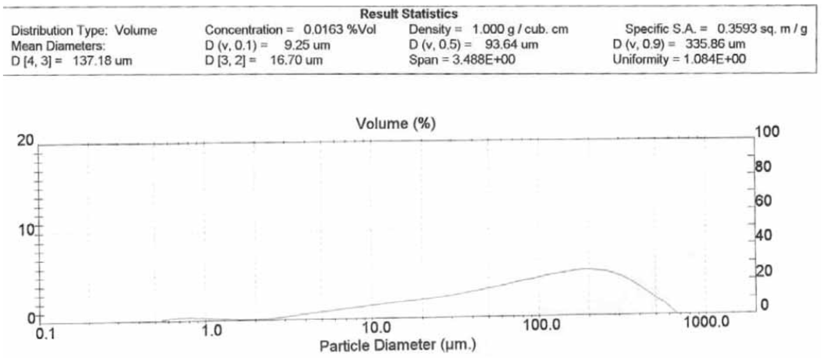


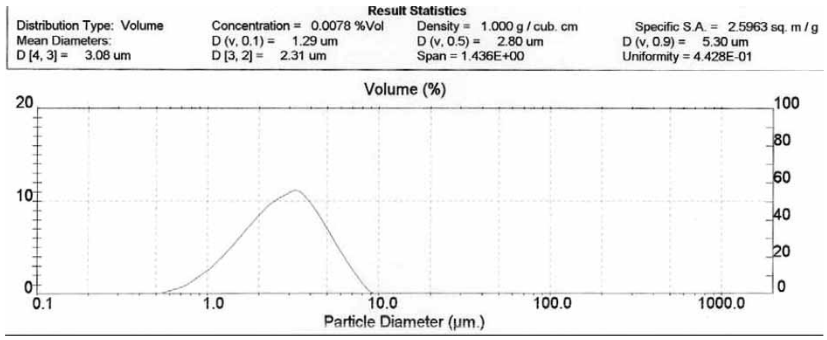
Figure 6. Flux rate of vegetable wash water with air bubbling and backflushing (0.5 % Rochem Cleaner A (for 2 min after every 1 hr interval).

wastewater (free from pathogenic microorganisms or dangerous chemical constituents) can benefit from this study. The results demonstrated that a system can be operated for one whole shift without having to be cleaned in the middle of a shift. The results also found that the required flux rates to make the recycling operation effective can be obtained with a relatively small system that is cost effective. Economic analysis was completed on the system to show that for a plant this size(18.9 kL per day) savings of around $200,000 per year can be obtained. This number was calculated using costs for maintenance, equipment, labor, cleaners, installation, and energy as well as money saved from reduced water costs and discharge savings. Since many plants treat water on site or send it to a municipal treatment plant this


Result Statistics

Distribution Type: Volume
Concentration = 0.0163 %Vol
Density = 1.000 g / cub. cm
Specific S.A. = 0.3593 sq. m / g
Mean Diameters:
D (v, 0.1) = 9.25 um
D (v, 0.5) = 93.64 um
D (v, 0.9) = 335.86 um
D [4, 3] = 137.18 um
D [3, 2] = 16.70 um
Span = 3.488E+00
Uniformity = 1.084E+00

Figure 7. Particle size analysis of wash water before filtration.



Result Statistics

Distribution Type: Volume
Concentration = 0.0078 %Vol
Density = 1.000 g / cub. cm
Specific S.A. = 2.5963 sq. m / g
Mean Diameters:
D (v, 0.1) = 1.29 um
D (v, 0.5) = 2.80 um
D (v, 0.9) = 5.30 um
D [4, 3] = 3.08 um
D [3, 2] = 2.31 um
Span = 1.436E+00
Uniformity = 4.428E-01

Figure 8. Particle size analysis of fresh-cut wash water permeate.

savings can vary. Membrane life is estimated at 5 years. It is recommended that the integrity of the membranes be tested on a regular basis by monitoring particle size in the permeate. The dividends will be more when water use is restricted because of drought.

REFERENCES

1. Center for Food Safety and Applied Nutrition—Food and Drug Administration. (2006). *Guide to Minimize Microbial Food Safety Hazards of Fresh-cut Fruits and Vegetables, Draft Guidance*; Rockville, MD.
2. American Public Health Association, American Waterworks Association and Water Pollution Control Federation. (1980) *Standard Methods for the Examination of Water and Wastewater*, 15th ed.; Am. Public Health Assoc.Inc.: Washington, DC.
3. American Public Health Association. (1976) *Compendium of Methods for Microbiological Examination of Foods*; Am. Public Health Assoc.: Washington, DC.
4. Kachalsky, L.A. (1994) Experiences with microfiltration in the New York City watershed management program, *Proceedings NWRI Microfiltration Water Treatment Symposium*; NWRI: Ottawa.
5. Cooper, A.R. and Van Derveer, D.S. (1979) Characterization of ultrafiltration membranes by polymer transport measurements. *Separation Science Technology*, 14–6: 551–556.
6. Pall Corporation. (2006) Select the Proper Separation Product for Your Application, www.pall.com/laboratory_7046.asp accessed 11/28/2006.
7. Genne, I., Doyen, W., Adriansens, W., and Leysen, R. (1997) Organo-mineral ultrafiltration membranes. *Filtration and Separtions,* 964–966.
8. Cornelissen, E.R., Boomgaard, T.V.D., and Strathmann, H. (1998) Physiochemical aspects of polymer selection for ultrafiltration and microfiltration membranes. *Journal of Membrane Science*, 138: 283–289.