THE USE OF MEMBRANE FILTRATION AS AN ALTERNATIVE PRE-TREATMENT METHOD FOR POULTRY PROCESSING WASTEWATER

Ebenezer Abboah-Afari and Brian H. Kiepper

AUTHORS: Department of Bio and Ag Engineering, University of Georgia, Athens, GA 30602.
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Abstract. In 2009 Georgia's poultry industry, the nation's largest, processed 1.3 billion chickens utilizing 26L (7 gallons) of potable water per bird and generating >9 billion gallons of high-strength poultry processing wastewater (PPW). Many processing plants in Georgia are classified as 'indirect dischargers' in that the PPW they produce is pre-treated on-site prior to discharge to a local municipal sewerage collection system. As indirect dischargers, these poultry processors are subject to both regulatory permit limits as well as surcharge fees set by local environmental authorities to recover added costs associated with the treatment of higher strength waste streams. Currently, most poultry processors use a combination of mechanical screens followed by dissolved air flotation (DAF) to pre-treat their PPW. Although DAF is effective, the aggressive aeration of the fine PPW particulates causes excessive oxidative damage and bacterial degradation of fat and protein components of the recovered by-product. Research within the Biological & Agricultural Engineering Department at the University of Georgia is exploring the use of membrane filtration in the pre-treatment of PPW as an enhancement or replacement for DAF. Preliminary experiments utilizing membranes within the microfiltration (0.1-10µm) and ultrafiltration (0.01-0.1µm) ranges that use a semi-permeable surface under pressure to separate colloids and high molecular weight materials in solution have been tested on PPW. Three (3) membranes sizes/materials (0.30µm PVDF, 0.10µm Polysulfone, and 0.05µm Ultrafilic) that were tested at 2 operating pressures (50 psi, 80 psi) on PPW pre-sieved to 106µm. Results showed that the 0.30µm PVDF membrane was the most effective, producing a maximum permeate flux of 32.8 Gm^2h at 50 psi while achieving COD and TS removal rates of 90% and 35%, respectively.

INTRODUCTION

A crucial problem facing poultry processing plants today is high-strength wastewater generation, treatment and disposal (Kiepper, 2008). Regulations governing wastewater disposal have increased and become stricter on industrial and domestic wastewater treatment plants that discharge effluent directly into the environment. Therefore, the need for alternative, more effective means of pre-treatment is a constant challenge.

In the US more than 25 million chickens are processed everyday with an average of 26L (7 gallons) of potable water consumed per bird processed (Del Nery et al., 2007; Northcutt and Jones, 2004). Wastewater pre-treatment with potential water reuse provides the benefits of reducing potable water demand and energy consumption (Avula et al., 2009).

Membrane filtration can play a significant role in treatment of poultry processing wastewater (PPW) and potential water reuse because of its unique pressure driven process that uses a semi-permeable membrane to separate and concentrate colloids and high molecular weight materials in solution (Lo et al., 2005). The membrane serves as a barrier, allowing the passage of certain particulates and retention of others, implying the concentration of one or more components in the permeate (i.e., effluent passing through the membrane) and in the retentate (i.e., the concentrated stream that does not pass through the membrane). The nature of the membrane controls which components will permeate and which will be retained. Transfer of particulates through a membrane surface is predominately dependent on particle size; however several other factors also play crucial roles in membrane efficiency. The separation performance of a membrane is influenced by its chemical composition, temperature, pressure, feed flow and interactions between components in the feed flow and the membrane surface (Lin et al., 1997).

Membrane filtration has become a popular large-volume water and wastewater treatment method because of its ability to remove minute particles such as fats, protein and pathogens, and is now cost competitive with traditional treatment methods (Cheryan and Rajagopalan, 1998; Yushina and Hasegawa, 1994).

Current PPW treatment methods provide viable ways of reducing pollutants such as organic concentration, particulates and nutrients, but often neglect the fact that they can alter and adulterate potential valuable by-products for the rendering industry. Also, fat removal from wastewater using mechanical screens has traditionally been difficult due to fat's propensity to clog or blind over screen surfaces, thus requiring the use of backwash spray systems to keep screen surfaces open

(Zhang et al., 1997) and minute solid particle pass through the screens, thus making the process tedious and time consuming (Pankratz, 1995).

While the traditional pre-treatment method of dissolved air flotation (DAF) is effective, residual fat can still range from 50-60 mg/L in PPW effluent discharges (Dyrset et al., 1998). Previous research on tertiary physical screening of PPW has shown retained particulate matter had mean fat, protein, crude fiber and ash levels of 63.5%, 17.5%, 4.8% and 1.5%, respectively (Kiepper et al., 2008).

Microfiltration (MF) and Ultrafiltration (UF) are membrane-based pressure driven processes that has been widely used to simultaneously purify, separate, and concentrate colloids and high molecular weight materials in solution (Lo et al., 2005). They have been shown to remove particulates, bacteria and pathogens, as well as in recovering protein (Cheryan and Rajagopalan, 1998). Microfiltration (MF) uses an applied pressure of <0.2 MPa and is used primarily in the particulate size range of 0.1 - 1.0 µm. Ultrafiltration uses applied pressures up to 1 MPa and separates particles of in the range of 0.01 – 0.1µm (Nakao, 1994).

To test the potential of membrane filtration as a pre-treatment for PPW, an experiment was conducted using membranes in the micro- and ultra-membrane filtration ranges with permeate volume (i.e., flux), and concentration of chemical oxygen demand (COD) and total solid (TS) measured and analyzed.

MEMBRANE FILTRATION EXPERIMENT

Grab samples of PPW were collected after the primary (1,500µm) and secondary (500µm) physical mechanical screens at a Georgia broiler processing plant during normal slaughter operations and transported immediately to the University of Georgia. 4L subsamples of PPW were poured through a 500µm sieve and designated as "raw PPW". The 4L of raw PPW were then pre-sieved through a 106µm sieve to prepare the samples for membrane filtration. Pre-sieved subsamples ranged in temperature from 26-30^{o}C (79-86^{o}F) and pH ranged from 6.0-6.2 S.U.

The experiment was carried out using Spintek STC bench-scale membrane filtration system (Spintek, 2008). This system simulates a full-scale membrane filtration system by circulating raw wastewater from a feed tank, past a sample of test membrane in a cross-current configuration under pressure. A variable speed pump and back pressure control valve maintain constant pressure on the membrane. The wastewater stream circulates back through the feed tank as a concentrate, while the treated water passes through the membrane as permeate (Figure 1).

The experiment was designed in a 3 x 2 configuration with 3 membrane sizes/materials (i.e., 0.05µm Ultrafilic, 0.10µm Polysulfone and 0.30µm PVDF) operated at 2 pressure levels (50 and 80 psi) for a total of 6 treatments. The six treatments were conducted once per week for 3 weeks for a total of 18 randomly completed trials. Each test membrane had a surface area of 0.005m^2.

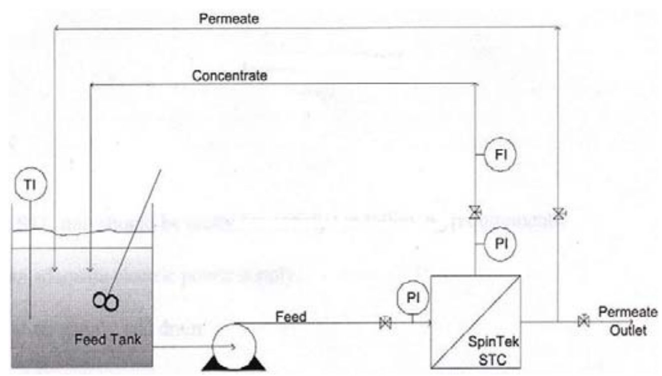

Figure 1: Spintek Static Test Cell (STC) Membrane Filtration System **(Source: http://www.spintek.com/stc.htm)**

Each trial consisted of a 4L pre-sieved subsample of PPW being placed into the feed tank of the STC Membrane Filtration System fitted with one of the 3 membranes and operated for 2 hours at one of the pressure levels. A total of 16 wastewater samples were collected in 1L glass jars during each trial. Representative raw PPW (i.e., 500µm) and pre-sieve (106µm) PPW samples were collected prior to each membrane filtration trial. During each trial, membrane filtration permeate samples were collected every 10 minutes (i.e., 12 effluent samples) with the volume of effluent noted for subsequent permeate flux calculations.

Permeate flux is the permeate (i.e., membrane effluent) flow per unit area per unit time and is the most common calculation used to determine membrane efficiency (Cheryan and Rajagopalan, 1998). In this experiment, permeate flux was calculated and expressed as gallons per square meter of membrane surface per hour (Gm^{2}h).

The pH of all samples was adjusted to < 2.0 S.U. using H^2SO^4 as a preservative and stored at 4^{o}C prior to analysis.

ANALYTICAL AND STATISTICAL ANALYSIS

All wastewater samples were analyzed for COD (chemical oxygen demand method 5220D) and TS (total solids method 2540B) (APHA, 1998). COD was used to determine the concentration of organic materials in each PPW sample, while the TS test was used to determine the concentration of solids present in each PPW sample.

Data were subjected to statistical analysis by the SAS JMP 8.0.2 program (SAS Institute, 2009). Data from the 3 x 2 treatments with 3 replications were analyzed by 1-way

ANOVA procedures for a completely randomized design with membranes and pressure as the main effects. Means were separated using the Tukey-HSD procedure (SAS Institute, 2009).

RESULTS AND DISCUSSION

Permeate Flux. Permeate flux (Gm^{2}h) values calculated at 10 minute intervals and averaged for the 3 repetitions at each membrane size over the course of the 2 hour STC membrane filtration system trials at 50 and 80 psi are graphically shown in Figures 2 and 3, respectively. These permeate flux values were in the expected range and are relatively similar to the results reported by Lo et al. (2005). Visual inspection of Figures 2 and 3 show that while the 0.05µm Ultrafilic and 0.30µm PVDF membranes flux values produced a flux curve (downward sweeping) similar to Lo et al. (2005), the 0.10µm Polysulfone membrane did not. At both pressures, the 0.10µm Polysulfone membrane produced flux values that were relatively flat with only slight increases over the 2-hour time period.

Figures 2 and 3 also show that the differences between the 3 membranes in flux curves seen over time at the 50 psi level were negated at the 80 psi level. Finally, all trials showed a steady state permeate flux after 2 hours with no visible trend towards blinding of any of the membranes indicated.

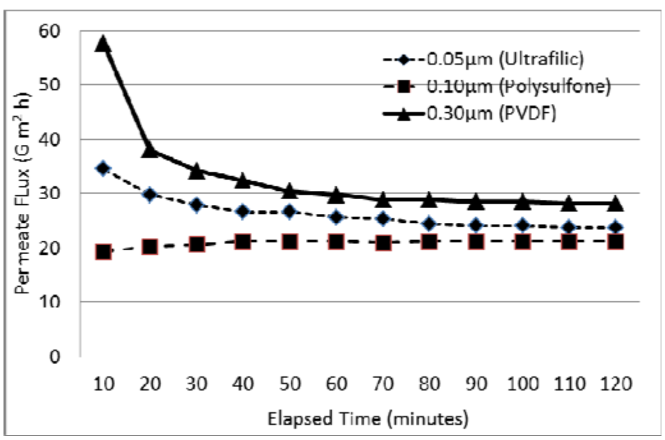

Figure 2. Poultry processing wastewater permeate flux (G m^2 h) values at 10 minute intervals for 3 membrane filters at 50 psi operating pressure

A total mean permeate flux value was calculated for each membrane by averaging the twelve (12) 10-minute interval flux values during each trial. The total mean permeate values for the 3 membrane sizes at the 2 pressure settings are summarized in Table 1. Results showed that at 50 psi operating pressure, the 0.30µm PVDF (32.8 Gm^{2}h) and 0.05µm Ultrafilic (26.4 Gm^{2}h) membranes were not significantly different (P<0.05), however the mean permeate flux of the 0.10µm Polysulfone (20.9 Gm^{2}h) was significantly lower.

At 80 psi operating pressure, the 0.30µm PVDF (32.4 Gm^{2}h) and 0.05µm Ultrafilic (30.9 Gm^{2}h) membranes were not significantly different, nor were the 0.05µm Ultrafilic and 0.10µm Polysulfone (27.7 Gm^{2}h) membranes significantly different. However, the flux of the 0.30µm PVDF membrane was significantly higher than the 0.10µm Polysulfone membrane.

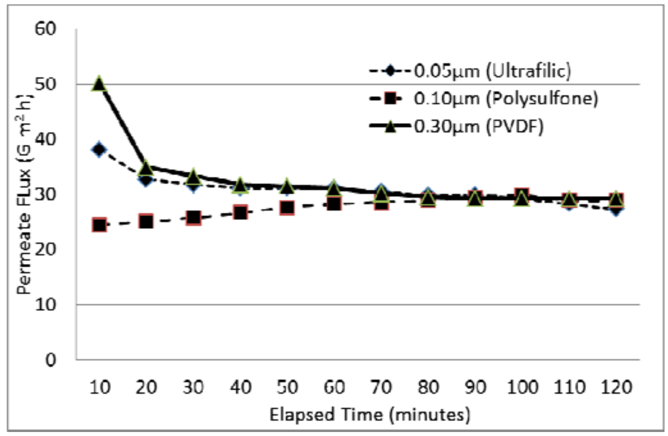

Figure 3. Poultry processing wastewater permeate flux (G m2 h) values at 10 minute intervals for 3 membrane filters at 80 psi operating pressure

As expected the membrane filter with the largest nominal gap openings (i.e., 0.30µm PVDF) had the largest total mean flux values, however it was unexpected that the membrane with the next largest nominal gap openings (i.e., 0.10µm Polysulfone) would have the lowest mean flux values. These results would indicate that the membrane material (i.e., Polysulfone) played a significant role in reducing the separation efficiency of the 0.10µm membrane.

Table 1. Poultry processing wastewater mean permeate flux (Gm^{2}h) values for 3 filtration membranes at 50 and 80 psi

	50 psi (Gm^{2}h) (P=0.0010)	**80 psi** (Gm^{2}h) (P=0.0231)
0.30µm PVDF	32.8^{a}	32.4^{a}
0.05µm Ultrafilic	26.4^{a}	30.9^{ab}
0.10µm Polysulfone	20.9^{b}	27.7^{b}

^{a,b} - differing superscripts within a column indicates statistically significant differences (P<0.05)

Statistical analysis comparing the mean permeate flux values of each membrane at the 2 operating pressures as shown in Figure 4. While there was no significant difference in the mean flux values for the 0.30µm PVDF membrane (32.8 Gm^{2}h @ 50 psi, 32.4 Gm^{2}h @ 80 psi) at the 2 operating pressures, both the 0.05μm Ultrafilic (26.4 Gm^2h @ 50 psi, 30.9 Gm^2h @ 80 psi) and 0.10μm Polysulfone (20.9 Gm^2h @ 50 psi, 27.7 Gm^2h @ 80 psi) membranes showed significant differences.

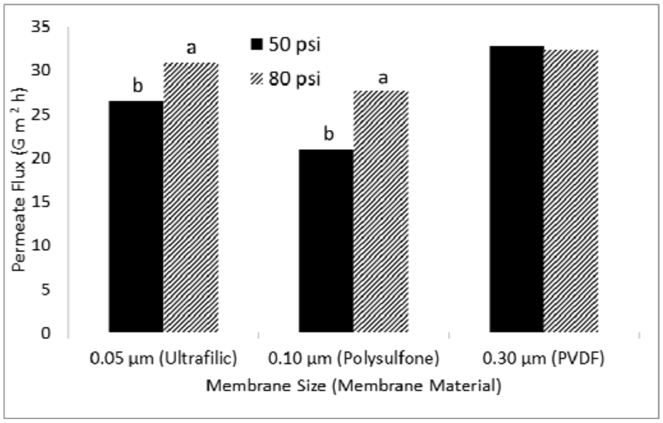

Figure 4. Poultry processing wastewater mean permeate flux values (Gm^2h) for 3 filtration membranes at 50 and 80 psi

COD Concentration. The concentration of organic matter in each PPW sample was measured using COD. COD concentration data were also used to calculate a COD removal efficiency value for pre-sieved (i.e., 106μm) and membrane permeate PPW samples. The membrane producing the lowest mean COD concentrations and highest COD removal percentages was deemed the most effective.

The mean COD concentrations (mg/L) for raw PPW and pre-sieved PPW samples for the 18 membrane filtration trials were 5,429 and 4,432 mg/L, respectively. Thus the 106μm pre-sieving reduced the COD concentration on average by 18.4%.

Mean permeate COD concentrations produced by the 3 membranes at the 2 operating pressures are shown in Table 2. Expectantly, the 0.05μm Ultrafilic membrane produced the permeate with the lowest ($P<0.05$) COD concentrations (518 mg/L @ 50 psi, 412 mg/L @ 80 psi). The resulting mean permeate COD concentrations represent 50 psi and 80 psi removal levels of 88% and 91%, respectively by the 0.05μm Ultrafilic membrane.

Unexpectantly, the 0.10μm Polysulfone membrane produced the highest COD concentrations (944 mg/L @ 50 psi = 79% removal, 793 mg/L @ 80 psi = 82% removal), which were significantly higher than the 0.30μm PVDF membrane (585 mg/L @ 50 psi = 87% removal, 475 mg/L @ 80 psi = 89% removal). Like the permeate flux results, the COD concentration results showed that the 0.10μm Polysulfone membrane was the least efficient producing the lowest mean flux and highest mean COD values.

Table 2. Poultry processing wastewater mean permeate chemical oxygen demand (COD) concentrations (mg/L) for 3 filtration membranes at 50 and 80 psi

	50 psi (mg/L) (*P<0.0001*)	**80 psi** (mg/L) (*P<0.0001*)
0.10μm Polysulfone	944[a]	793[a]
0.30μm PVDF	585[b]	475[b]
0.05μm Ultrafilic	518[c]	412[b]

[a,b,c] - differing superscripts within a column indicates statistically significant differences (P<0.05)

TS Concentration. The concentration of solids in each PPW sample was measured using TS. TS concentration data were also used to calculate a TS removal efficiency value for pre-sieved (i.e., 106μm) and membrane permeate PPW samples. The membrane producing the lowest mean TS concentrations and highest TS removal percentages was deemed the most effective.

The mean TS concentrations (mg/L) for raw PPW and pre-sieved PPW samples for the 18 membrane filtration trials were 3,355 and 2,991 mg/L, respectively. Thus the 106μm pre-sieve reduced the TS concentration on average by 10.8%.

Mean permeate TS concentrations produced by the 3 membranes at the 2 operating pressures are shown in Table 3. Surprisingly, the 0.30μm PVDF membrane (the membrane with the largest nominal gap openings) produced the permeate with the significantly lowest TS concentrations (1953 mg/L @ 50 psi, 2004 mg/L @ 80 psi). These resulting mean permeate TS concentrations represent 50 psi and 80 psi removal levels of 35% and 33%, respectively by the 0.30μm PVDF membrane.

As with COD, the 0.10μm Polysulfone membrane produced the highest TS concentrations (2871 mg/L @ 50 psi = 4% removal, 2500 mg/L @ 80 psi = 16% removal), which were significantly higher than the 0.05μm Ultrafilic membrane (2322 mg/L = 22% removal) at 50 psi, but not at 80 psi (2327 mg/L = 22% removal).

Table 3. Poultry processing wastewater mean permeate total solids (TS) concentrations (mg/L) for 3 filtration membranes at 50 and 80 psi

	50 psi (mg/L) (*P<0.0001*)	**80 psi** (mg/L) (*P*=0.0012)
0.10μm Polysulfone	2871[a]	2500[a]
0.05μm Ultrafilic	2322[b]	2327[a]
0.30μm PVDF	1953[c]	2004[b]

[a,b,c] - differing superscripts within a column indicates statistically significant differences (P<0.05)

CONCLUSIONS

In this experiment the most effective membrane was the 0.30µm PVDF (the membrane with the largest nominal gap openings) which produced the highest permeate flux values while producing the second lowest COD and lowest TS concentrations. The 0.05µm Ultrafilic membrane (the membrane with the smallest nominal gap openings) was also effective in producing high flux values (not significantly different from the 0.30µm PVDF membrane) while producing the lowest COD and second lowest TS concentrations. The 0.10µm Polysulfone membrane was the least effective having the lowest flux and highest COD and TS concentration in effluent permeate.

This experiment shows the viability of membrane filtration as a pre-treatment method for PPW. All trials ended with permeate flux in a steady state indicating good resistance to blinding by the membranes. Permeate flux values of over 32 Gm^2h were obtained while achieving over 90% COD and 35% TS removal levels.

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