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Evaluation of ultrafiltration membranes for treating poultry processing wastewater

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ABSTRACT

The US poultry industry produces over 60 billion gallons of poultry processing wastewater (PPW) per year which requires treatment prior to discharge. In this work, nine different commercially available ultrafiltration membranes, having different nominal molecular weight cut-offs (10–300 kDa) and made of different polymeric materials (polyethersulfone and regenerated cellulose), were screened for treating PPW streams obtained from bird washer and chiller operations. Wastewater samples were treated for recycling and reuse purposes. Bird washer wastewater was found to cause more fouling as it contained higher biochemical oxygen demand (BOD), chemical oxygen demand (COD), fat, oil and grease (FOG) and total suspended solid (TSS) compared to the chiller wastewater.

The presence of suspended particles can lead to plugging of the membrane pores. Thus, it is important to select the most appropriate membrane (pore size, polymeric material, flux, etc.) that minimizes fouling and maximizes contaminate rejection. For the feed streams considered here, membranes with 30 kDa nominal molecular weight cut-off provided the most stable performance in laboratory scale tangential flow filtration. Larger pore size membranes displayed rapid flux decline most likely due to entrapment of smaller particulate matter within the membrane structure. These particles were excluded from the smaller pore size membrane by size exclusion. The particle size distribution of the feed stream affected the level of contaminate rejection. Significant removal of BOD (up to 93%), COD (up to 94%), TSS (up to 100%) and FOG (up to 100%) was obtained for both wastewater streams.

1. Introduction

The poultry industry is becoming one of the growing food industries as the demand for chicken products increases in the United States as well as the rest of the world [1]. Based on the National Agricultural Statistical survey by United States Department of Agriculture, the number of chickens slaughtered in 2016 was 8.9×10^9, an increase from 8.8×10^9 in 2015 [2]. During the various stages of processing, such as: scalding, bird washing, chilling, etc.; up to 26 L of water per bird are used [3,4]. Even for transport of inedible poultry by-products for further processing, water is required [5]. Due to the high levels of organics, biochemical oxygen demand (BOD), chemical oxygen demands (COD), total suspended solids (TSS), fat, oil and grease (FOG), nitrogen, phosphorus, etc.; these poultry processing wastewaters (PPW) require proper treatment before their disposal into the environment [6–8].

Fig. 1 is a schematic representation of the major operations in a poultry processing facility. After receiving the birds, they are passed through electric stunning and are slaughtered. Next, scalding is used to loosen the feathers in order to facilitate their removal. The next operation, known as picking, refers to feather removal. Following picking, evisceration involves the removal of the internal organs [9]. The wastewater collected from these unit operations forms the bird washer wastewater (BWW) stream. After the recovery of valuable by-products, the BWW is sent for treatment prior to discharge from the facility. The BWW contains high levels of protein, BOD, COD, FOG, etc. [10].

The chiller represents one of the last steps prior to cooking operations. The birds are chilled in water containing an antimicrobial agent in order to suppress bacterial growth [11]. Zhang et al. [12] and Avula et al. [4] indicated that the main contaminants of the chiller wastewater (CW) are blood, fat, oils and micro pollutants. They note TSS values of 600–800 mg L^{-1} in CW. About 30% of these suspended solids are large

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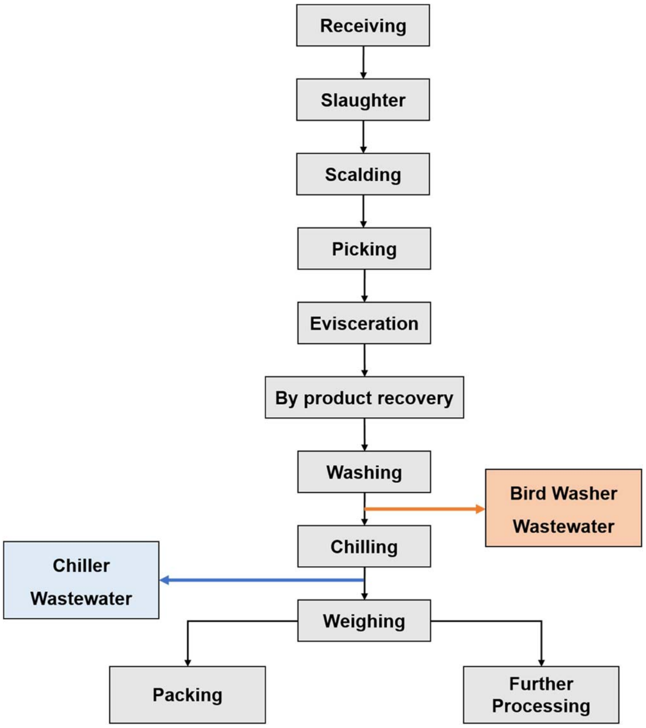

Fig. 1. Simplified schematic diagram for poultry processing.

floating particles of grease and fat. About 55% of the suspended solids are in the size range of 20–50 μm and consist of emulsified oils containing entrapped proteins and lipids. CW has lower BOD and COD than BWW. Here, we have investigated the feasibility of treating BWW and CW.

The actual composition of PPW depends on the type of system used, the method of operation and the processing loads. Several investigators [13–15] have considered treatment of slaughterhouse wastewaters with very high BOD (over 2000 mg L^{-1}) and COD (up to 9000 mg L^{-1}). Here, the focus is on PPW streams with much lower BOD (~390 mg L^{-1}) and COD (460 mg L^{-1}) values. To reduce plant water consumption (crucial in arid areas) as well as wastewater volume to municipal treatment plants, there is significant interest in recycling and reuse of these wastewater streams [4,7,16–18].

Several unit operations have been reported in the literature for the treatment of poultry slaughterhouse wastewater including biological treatment involving aerobic and anaerobic systems [1,7,8,19,20]. Although these biological treatments are effective and economical, the need for long retention times and consequently, large land area, often limits the practicality of these processes [21–26]. Compared to conventional separation procedures, such as conventional filtration (e.g. diatomaceous earth filtration), decantation, centrifugation, chromatography, etc.; membrane based separation processes were found to be advantageous as they provides simple, miniaturized, cost-effective unit operations [27–29]. Furthermore, an ultrafiltration membrane can provide an absolute barrier to pathogens. This could be a major advantage as validation of pathogen removal will be essential if PPW are to be recycled and reused.

Here, we focus on the use of ultrafiltration membranes. In particular, by choosing an appropriate pore size ultrafiltration membrane, it may be used to validate clearance of virus and bacteria [30–37]. In the poultry industry, ultrafiltration has been used to separate fat and protein. Lo et al. [30] reported the retention of almost all crude protein in poultry processing water and reduction of COD to less than 200 mg L^{-1} by polysulphone ultrafiltration membranes. Bayar et al. [25] investigated the effect of pH on the treatment of poultry slaughterhouse wastewater by electrocoagulation using aluminum electrodes. Their process was optimized for higher COD removal rate (~ 85% in 20 min). Mohammad et al. [27] reviewed the application of ultrafiltration not only in the poultry industry, but also in the entire food processing industry [33]. Though ultrafiltration could find numerous applications in the food industry, membrane fouling is reported to be one of the major issues limiting its practical application [38–41].

The main aim of the present investigation was to evaluate the overall performance of nine different commercially available membranes with different nominal molecular cut-offs, membrane barrier and inert support materials for processing different streams from PPW, i.e. BWW and CW. Their performance was evaluated in terms of water recovery potential as well as removal efficiency of BOD, COD, TSS, FOG, proteins, TKN (total Kjeldahl nitrogen) and TDS (total dissolved solids). Since practical application of ultrafiltration will involve effective membrane regeneration, a membrane cleaning procedure was also developed.

2. Experimental

2.1. Wastewater

BWW and CW samples were obtained from Tyson Foods Inc. (Springdale, AR). The BWW sample was collected after the de-feathering process prior to evisceration. CW was collected from the chiller wastewater stream. All water samples were analyzed at the Food Safety and Research Laboratory, Tyson Foods Inc. The following water parameters were measured: BOD, COD, TSS, FOG, TDS, proteins, TKN and pH. In addition, the size distribution of the particles in the wastewater samples was determined using a laser diffraction particle size analyzer (Beckman Coulter, LS 13 320, Brea, CA).

2.2. Ultrafiltration membranes

Commercially available ultrafiltration membranes, four polyethersulfone (PES) and five regenerated cellulose (RC), were tested. Membrane properties are summarized in Table 1. These membranes were kindly provided by MilliporeSigma (Billerica, MA) and Pall Corporation (New York, NY).

Table 1
The characteristics of the ultrafiltration membranes used in the present investigation. UHMW stands for ultra-high molecular weight.

Membrane	Nominal Molecular Weight Cut-off	Material	Support	Provider
PES 30	30 kDa	Polyethersulfone	Polyolefin Nonwoven	Millipore Sigma
PES 50	50 kDa	Polyethersulfone	Polyolefin Nonwoven	Millipore Sigma
PES 100	100 kDa	Polyethersulfone	Polyolefin Nonwoven	Millipore Sigma
PES 300	300 kDa	Polyethersulfone	Polyolefin Nonwoven	Millipore Sigma
RC 30	30 kDa	Regenerated Cellulose	UHMW Polyethylene	Millipore Sigma
RC 100	100 kDa	Regenerated Cellulose	UHMW Polyethylene	Millipore Sigma
RC 300	300 kDa	Regenerated Cellulose	UHMW Polyethylene	Millipore Sigma
P-RC 10	10 kDa	Regenerated Cellulose	Polypropylene	Pall Corporation
P-RC 30	30 kDa	Regenerated Cellulose	Polypropylene	Pall Corporation