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Research article

Impact of operations and cleaning on membrane fouling at a wastewater reclamation facility

Murthy Kasi [a,*], Halis Simsek [b], Steve Ahlschlager [a], Kent Ritterman [a], Jim Hausauer [c], Jeff Hoff [c], Eakalak Khan [d]

[a] *Moore Engineering, Inc., West Fargo, ND 58078, USA*
[b] *Department of Agricultural and Biosystems Engineering, North Dakota State University, Fargo, ND 58108, USA*
[c] *City of Fargo Wastewater Treatment Plant, Fargo, ND 58102, USA*
[d] *Department of Civil and Environmental Engineering, North Dakota State University, Fargo, ND 58108, USA*

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ABSTRACT

Effects of operational changes on membrane fouling were evaluated for a wastewater reclamation facility. The focuses were on addition of a coagulant (ferric chloride) versus no addition and an accidental high chlorine (sodium hypochlorite) dose. Two membrane modules with different service ages, 3 years versus 9 months, were compared. Fouling rates ranged between 2 and 3 times higher during no ferric chloride addition. Chemical cleaning frequency was reduced by approximately 5 times during ferric chloride addition for older membranes, while it did not change for newer membranes. High chlorine dose had slightly improved membrane permeability for newer membrane, and reduced the transmembrane pressure (TMP) for both older and newer membranes. Chemical wash with enzymatic detergents substantially improved membrane permeability and reduced TMP for both older and newer membranes. Fouling index values indicated that coagulant addition had greater impact on performance recovery for older membranes than newer membranes. Successful and economical operation of membranes depends on fouling rate, which in this study was found to be a function of flux, membrane age, pretreatment, and cleaning type and frequency.

1. Introduction

Increasing demand for fresh water due to population growth and industrialization has created a need for alternative sources of water. Recent advances in water treatment technology, such as membrane treatment, have enhanced the reuse of treated municipal wastewater effluent for non-potable purposes. Fouling of the membrane is a major operational challenge in treating secondary effluent. Various operational and cleaning practices have been developed to control the fouling mechanism and meet the requirements of quality and quantity of the produced water (Ahn and Song, 2000; Kang and Choo, 2006; Porcelli and Judd, 2010; Raffin et al., 2011). Typical cleaning practices involve physical or chemical methods. Hydraulic back-washing is one of the most common physical methods, while chemical cleaning methods can be done with acids, alkalis, detergents, enzymes, complexing agents or disinfectants. Typically, physical methods are shown to be effective in controlling reversible fouling while chemical methods can protect membranes from irreversible fouling. However, chemical treatments are relatively expensive, can damage membranes, and produce toxic by-products.

Coagulation has been identified as a successful pretreatment process for micro/ultrafiltration (Baek and Chang, 2009; Konieczny et al., 2009; Hey et al., 2017). Konieczny et al. (2009) have shown that the application of an in-line coagulant as a pretreatment to membranes contributes to the improvement of the water quality as a result of improved removal of organic matter. In the same study, Konieczny et al. (2009) have shown that coagulation restricted the fouling of the membranes, so that contaminants deposited on the membrane can easily be removed. Particle size distribution measurements by Baek and Chang (2009) indicated that soluble and colloidal foulants present in secondary effluents were entrapped in coagulated floc, which reduces the amount of foulants entering into membrane pores thereby reducing the membrane fouling through

* Corresponding author. Current address: HDR, 412 E Parkcenter Blvd, Suite 100, Boise, ID 83703, USA.
E-mail address: murthy.kasi@hdrinc.com (M. Kasi).

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pore restriction. Pore restriction is one of the fouling mechanisms (others being pore blocking and cake layer formation), which is considered to be relatively difficult to remove from the membranes.

Important parameters of concern in operating a treatment plant are the rate of fouling and the response of membrane restoration after various cleaning practices. Most fouling studies are bench/laboratory based and do not provide the membrane behavior/response to various cleaning practices including type of cleaning chemicals and cleaning frequency that characterizes the response in full scale systems. Furthermore, scale-up effects, differences in membrane materials, and the feed water quality could lead to the differences between the bench-scale and the full-scale systems.

The City of Fargo, North Dakota, USA operates an effluent reuse facility (ERF) treating its secondary effluent from a two-stage trickling filter wastewater treatment plant and supplies the produced water to an ethanol production plant. Ultrafiltration followed by reverse osmosis is employed to meet the water quality and quantity requirements as per a memorandum of understanding between the ethanol plant owner and the City of Fargo. Since the commissioning of ERF, several changes have taken place in terms of operation and cleaning of the microfiltration units to meet the desired quantity and quality of supplied water while maintaining the transmembrane pressure (TMP) below the maximum design value for each membrane unit.

This paper presents a study that attempts to understand the effects of operational changes and cleaning practices on membrane fouling. The study had two objectives. The first objective was to understand the effects of following parameters on fouling behavior of ultrafiltration membranes: membrane age, pretreatment (ferric chloride addition), and cleaning frequency and methods. To obtain a relationship between membrane fouling and various cleaning practices using membrane fouling index (MFI) was the second objective.

Historical data was used to calculate permeability based on permeate flow, temperature, TMP and membrane surface area. Slopes from linear relationships between normalized permeability and cumulative permeate volume per unit membrane area among various cleaning practices were used as the MFI (Huang et al., 2007). Individual MFI values (after each type of cleaning, i.e. hydraulic and acid/chlorine maintenance wash) and overall MFI values (includes several hydraulic and acid/chlorine maintenance washes) were estimated for the membrane units. Operational data for ultrafiltration membrane units with 3 years of operation and 9 months of operation (at the time of data collection) was used for this purpose.

Table 1
Water quality summary.

Water quality parameters	Fargo WWTP secondary effluent	Ethanol plant requirement
pH	7.5	7 to 8.5
BOD_5	10 to 30 mg/L	<2 mg/L
Hardness	300 to 500 mg/L as $CaCO_3$	<10 mg/L as $CaCO_3$
Calcium	<89.6 mg/L	<10 mg/L
Chloride	<178.2 mg/L	<10 mg/L
Silica	5 to 8 mg/L	<3 mg/L

2. Materials and methods

2.1. Descriptions of flow scheme and effluent reuse facility

The Tharaldson ethanol plant near Casselton, ND, required process water, boiler feed water and cooling tower makeup water during ethanol production. Average water demands of the ethanol plant were 0.96 MGD in summer (>12 °C) and 0.79 MGD in winter (<12 °C). The peak day demand was 1.4 MGD. Reuse of treated wastewater was considered as a source through an engineering assessment and secondary effluent from the City of Fargo Wastewater Treatment Plant (WWTP) was selected. Water quality characteristics of the secondary effluent are summarized in Table 1. An ERF was built to supply treated wastewater meeting the quantity and quality requirements. The quantity requirements were to meet the water demands while the water quality requirements are listed in Table 1. Two 26-mile pipelines were constructed, one to supply the treated water to the ethanol plant and the other to return the used water back to the wastewater treatment plant. An overview of the flow scheme is illustrated in Fig. 1.

Major unit operations at the ERF were an inline static mixer, three Memcor® CP ultrafiltration units, three horizontal cartridge filters, and four reverse osmosis (RO) units. A process flow diagram of the ERF is shown in Fig. 2. Each CP unit consisted of 120 modules with a membrane pore size of 0.04 µm. The membranes were made of polyvinylidene fluoride (PVDF) polymer material. Each RO was a two stage system consisting of 10 pressure vessels in the first stage and 5 in the second stage. The focus of the present study was on ultrafiltration; hence, further details on RO system are not included.

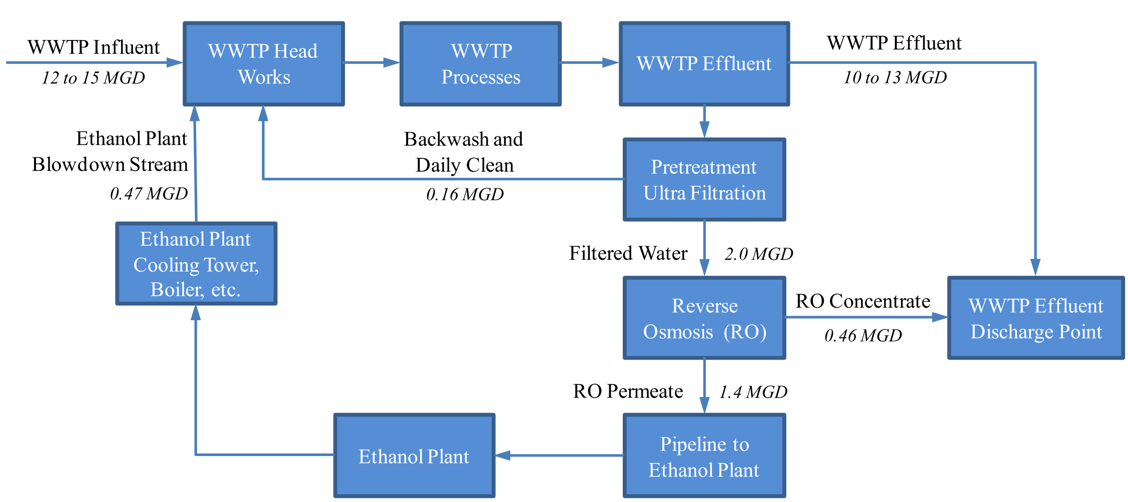

Fig. 1. Fargo effluent treatment facility (major flows during peak production of ethanol).