Development of a New Cartridge Filter Management Procedure to Reduce Replacement Frequency and Reduce RO Fouling

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Abstract

The Groundwater Replenishment System (GWRS) is a 100 MGD indirect potable reuse project jointly sponsored by the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD). The GWRS purifies secondary treated wastewater through microfiltration (MF), reverse osmosis (RO) and ultraviolet advanced oxidation process (UV/AOP). Cartridge filters (CF) are included in the treatment process after MF to remove suspended solids that may be present in the RO feed water, thereby providing protection of the RO membrane elements. The treatment facility is equipped with 14 CF vessels, each rated for nominal 10 MGD and holding 296 filters. The filters have a nominal rating of 10 microns. CF fouling results in periodic replacement when the differential pressure (dP) reaches a predetermined limit not to exceed 15 psi (terminal pressure). Historically, CF replacement at the GWRS facility has occurred approximately two to three times per year. Each CF replacement incurs labor costs, material costs and results in loss of water production. To reduce these costs, staff has progressively developed new CF management procedures by investigating causes of CF fouling and ways to mitigate fouling before terminal pressure is reached. In this study, a rapid adenosine triphosphate (ATP) assay was used as a surrogate for total microbial biomass in the CF feed and CF effluent. Operationally, the goal is to minimize CF microbial shedding to the RO membranes during plant shutdowns and start-ups. Viable microbial shedding (measured by ATP) in the CF effluent was directly correlated to increased CF dP and RO fouling. As a result of these investigations, staff developed and implemented procedures to perform deadhead flushes of the CF system immediately prior to plant startups. The flushes moved loose filter material (bacteria) out of the system to waste before bringing the plant online, thus preventing the material from going to the RO membranes. The periodic dead head flushes also reduced CF replacement frequency, reducing overall operational costs.

Keywords: Cartridge filters; reverse osmosis; adenosine triphosphate (ATP)

Introduction

On January 10, 2008, Orange County Water District (OCWD) commissioned the 70 million gallons per day (MGD) Groundwater Replenishment System (GWRS). The Advanced Water Purification Facility (AWPF) is the main component of GWRS. In mid-2015 the GWRS initial expansion (GWRSIE) was completed and added an additional 30 MGD of production capacity to the AWPF for a total of 100 mgd. The AWPF purifies secondary treated wastewater for potable reuse, producing a highly treated water for direct injection into a seawater intrusion barrier and for groundwater recharge. Secondary treated wastewater is treated by microfiltration (MF) and reverse osmosis (RO) followed by ultraviolet advanced oxidation process (UV/AOP). Fourteen 10-mgd cartridge filter (CF) vessels are included in the treatment process, located between the MF and RO, to remove suspended solids that may be present in the RO feedwater. The purpose of cartridge filtration of MF-treated water, a common feature of advanced treatment facilities, is to protect RO membranes from debris that may have originated in the MF effluent equalization tank or from impurities associated with antiscalant and acid added prior to RO. The CFs have a nominal 10-micron rating and are replaced when the differential pressure reaches a predetermined limit not to exceed 15 psi (terminal pressure). The CFs were replaced three times during 2015 (April, June and November). Each CF replacement costs $28,000 for all 14 10-MGD vessels plus the loss of water production and labor costs. To reduce these costs, staff has progressively developed improved CF management procedures by investigating causes of CF fouling and ways to mitigate fouling before terminal pressure increase is reached.

In this study, a rapid adenosine triphosphate (ATP) assay (LuminUltra Technologies, Ltd) was used as an indirect measure of viable bacteria in the CF feed and CF effluent. ATP measurements provide results within minutes and are an acceptable approach for evaluating microbial water quality (Vang et al, 2014). ATP is a nucleotide found in all living cells, and is therefore useful as a surrogate measure of all active and unculturable microbial cells in a water sample. An ATP measurement provides a better estimate of the total microbial biomass than heterotrophic plate counts, where only a fraction of the total cells can be quantified (Maki et al., 1996; Siebel et al, 2008; Vang et al, 2014). In addition, ATP measurements have been used as a microbial tool for assessing regrowth in water systems (Siebel et al, 2008; Lautenschlager et al, 2010; Vital el al., 2012; Liu et al., 2013).

During the GWRSIE, full plant shutdowns were necessary to accommodate construction and equipment installations. The shutdowns varied from hours to several days. Staff noticed that each shutdown resulted in CF dP increases. Increased RO fouling (decrease in membrane specific flux) was also observed and appeared to coincide with the plant shutdowns. After each plant shutdown followed by plant (and CF) start-up, ATP analysis indicated that the CF effluent contained significantly higher concentrations of microbial activity than before the shutdown. The microbial biomass in the CF effluent will be directly deposited onto RO membranes during normal operations because RO acts as a complete barrier to bacteria. This would be expected to cause and/or increase biofilm formation and biofouling of RO. Biofouling is defined as the accumulation of microorganisms accompanied with agglomeration of extracellular materials on the membrane surface (Hori, H., Matsumoto, S., 2010; Al-Juboori, A. R., Yusaf, T., 2012). When the microorganisms adhere to the membrane surface, they aggregate forming a biofilm (Flemming, H.C et al, 2011). Thus, reducing microbial loading in the RO feed (CF effluent) to RO membranes reduces the potential of biofilm formation and subsequent biofouling.

The overall aim of this study was to quantitatively investigate AWPF shutdown effects on total microbial biomass in the CF effluent using a rapid ATP assay and to develop new CF management procedures.

Materials and Methods

Total ATP occurs as microbial ATP fractions, where total ATP = cellular ATP + free ATP (Hammes et al., 2010). The free ATP fraction is thought to originate from cells in the die-off phase (Stanley, 1986). LuminUltra Quench-GoneTM Aqueous Test Kit was used to measure cellular ATP (cATP) in CF feedwater and effluent. This test kit utilizes a 5-minute filtrationbased analysis to measure cATP. cATP is a direct indication of the planktonic populations because cATP represents ATP in living microorganisms and not free ATP in the sample fluid (www.lumiultra.com).

Total chlorine was measured using Hach DPD method 1485 (Hach DR4000U spectrophotometer).

Scanning electron microscopy (SEM) analysis was performed using a Philips XL-30 FEG SEM at the MC2 facility at University of California Irvine.

Results and Discussion

The difference in appearance between a new and old (fouled) CF is dramatic (Figure 1). New CFs are bright white and fouled filters are a brown/tan color. The filter discoloration is likely due to a combination of bacterial deposition from the MF effluent break tank, bacterial growth and exopolysaccharide production inside the CF vessels, debris sloughed off from the break tank, and debris introduced by acid and threshold inhibitor (antiscalant) addition. SEM of a new filter shows smooth clean fibers with open spaces; the used filter fibers are covered with bacteria and the spaces are filled with bacterial mats which make water flow more difficult hence increasing the CF dP (Figure 2).

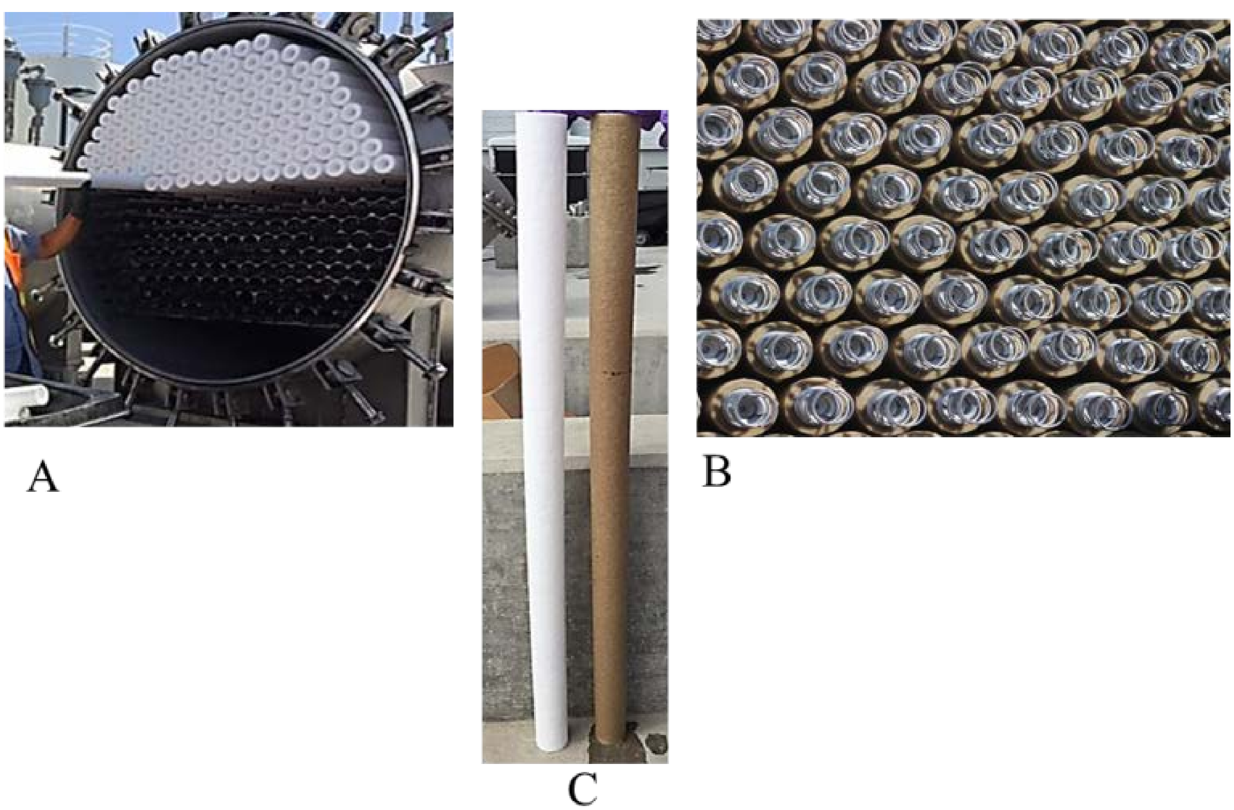

Figure 1. CF replacement: A) new CFs, B) used CFs ready for replacement, and c) comparison of new (white) CF and fouled (brown) CF.

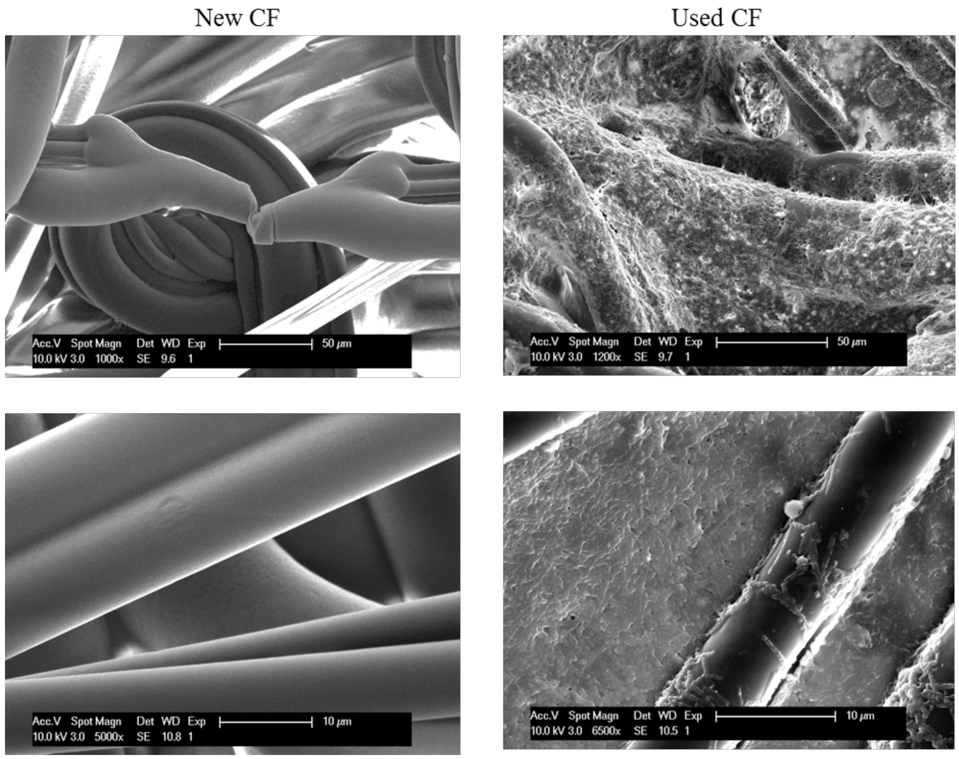

Figure 2. SEM of a new and used cartridge filters.

During normal operation conditions, increased RO fouling (as indicated by decrease in normalized specific flux, gfd/psi) was correlated with the increased CF dP (Figure 3) and CF effluent cATP (Figure 4). This indicates that as the CFs fouled and microbial shedding increased, RO performance decreased.

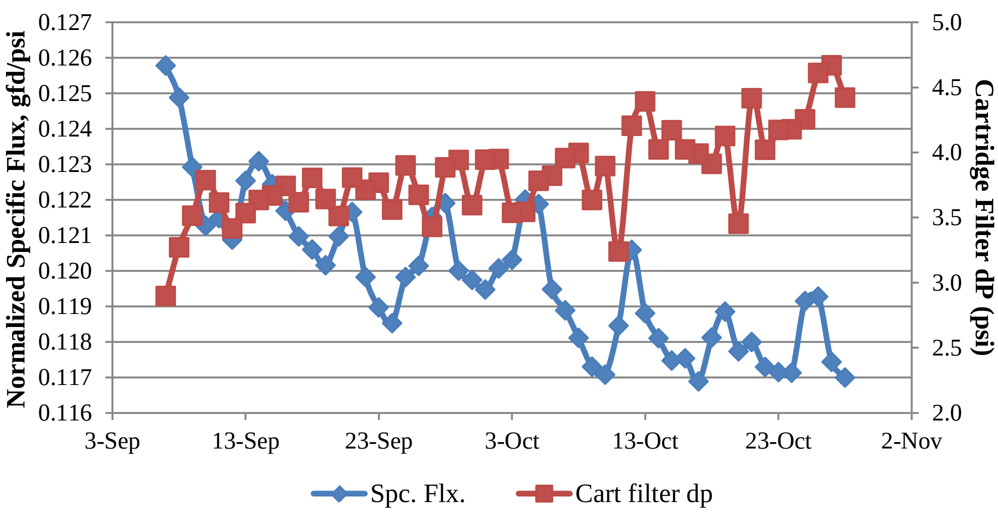

Figure 3. CF differential pressure and RO membrane performance as indicated by normalized specific flux (dP = differential pressure; gfd = gallons per square foot per day; psi = pounds per square inch),

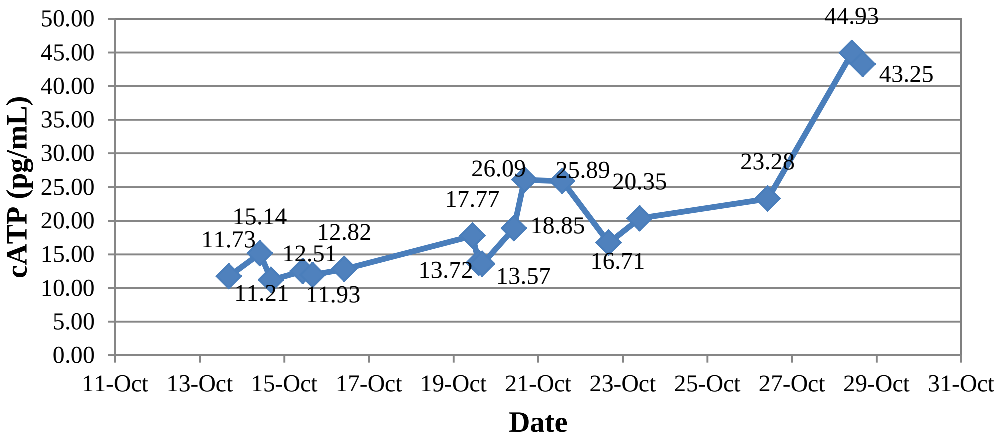

Figure 4. CF effluent cATP measurements coinciding with Figure 3.

During a standard plant startup, after a 7.5-hr shutdown, cATP was measured in CF effluent as plant flows increased from 0 to 50 mgd (Figure 5). Before the shutdown, cATP concentration in CF effluent was at 67.6 pg/mL. After 7.5 hours, as the plant came online, the cATP in the CF effluent peaked to 77,800 pg/mL, suggesting a microbial shedding/sloughing of biomass that had grown in the CFs while the plant/CFs were offline. The temperature and pH inside the CF vessels, during the shutdown, was probably within optimal bacterial growth range since the outside temperature was 32°C and the CF influent pH was 6.9. The optimum temperature for most bacteria to survive and grow is between 25°C and 40°C, and the optimum pH ranges from 6 to 8 (Ratkowsky, D.A. et al, 1982). It is likely that on warmer days the stainless steel CF vessels act as bacterial incubators providing optimal conditions for growth. As the plant flow increased (Figure 5), cATP concentration decreased to 85.6 pg/mL at 50 mgd, suggesting a gradual microbial flushing of the CFs. During this process, the viable bacteria in the CF effluent moved from the CFs to the downstream RO membranes, potentially increasing the RO biofouling potential. Given this observation, staff modified their CF protocol to implement deadhead flushes of the CF system (to waste) immediately prior to plant startups after a shutdown in order to prevent discharging shutdown-associated CF biogrowth to the RO process.

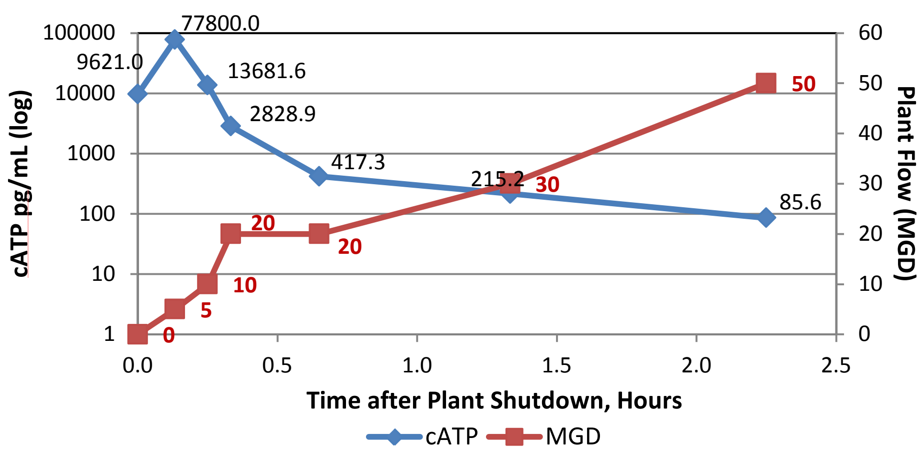

Figure 5. CF effluent cATP concentrations after a 7.5-hr. shutdown. cATP was measured at intervals during the plant start up, 0 – 50 mgd.

During one CF replacement event in 2015, cATP was monitored in the CF effluent. The CF effluent cATP concentration after CF replacement ranged 12.5 to 29.7 pg/mL over approximately 40 days after replacement (Figure 6). A 5-hr plant shut-down event then occurred 8 weeks later, and the CF effluent cATP concentrations were measured during a CF effluent flush (flushed effluent went to waste) after the plant shutdown (Figure 7). Directly before the shutdown CF cATP was 25.4 pg/mL. After the 5-hr shutdown, CF effluent cATP peaked at 999.9 pg/mL. Thirty minutes of CF flushing removed the majority of the viable biomass decreasing cATP to 70.9 pg/mL; this concentration of cATP was still higher than the 12-30 pg/mL range observed after a CF replacement (Figure 6). The flush prevented the viable biomass from reaching the RO membranes and thus potentially decreased the RO membrane biofouling potential.

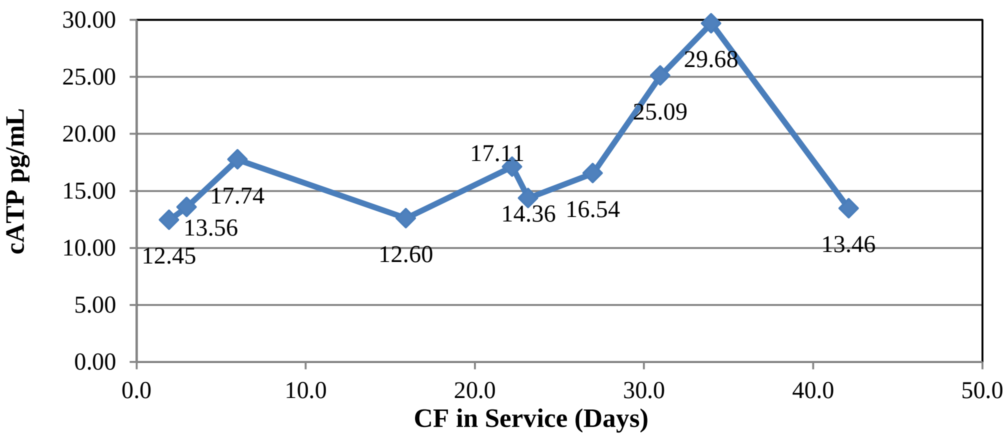

Figure 6. Typical profile of CF effluent cATP concentrations after CF replacement at Day 0.

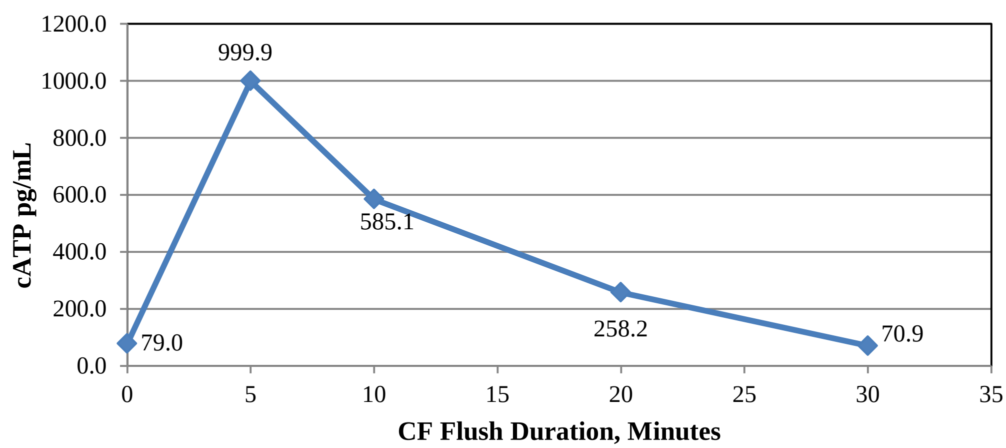

Figure 7. CF effluent cATP concentrations collected during flush to waste procedure after a 5-hr. plant shutdown.

Figure 8 demonstrates the visual difference between CF influent and CF effluent after a 2.5-hr plant shutdown. CF effluent was collected at 1, 5, 7 and 11 minutes during a CF flush to waste procedure after the plant shutdown and shows the impact these flushes have on water quality going to the RO membranes.

In addition to pre-startup deadhead flushes of the CF filters after a plant shutdown, staff has implemented a preventative maintenance CF procedure to perform deadhead flushes when CF dP starts to rise during normal operation. The preventative flushes have reduced CF dPs and potentially decreased CF change outs and therefore overall operational costs. This is evidenced by the fact that four complete CF change outs, every 3 – 6 months, were performed in both 2014 and 2015 prior to changes to the CF operational procedures. In 2016, pre-startup CF deadhead flushes and preventative maintenance flushes were routinely practiced, and only two complete CF replacements were performed.

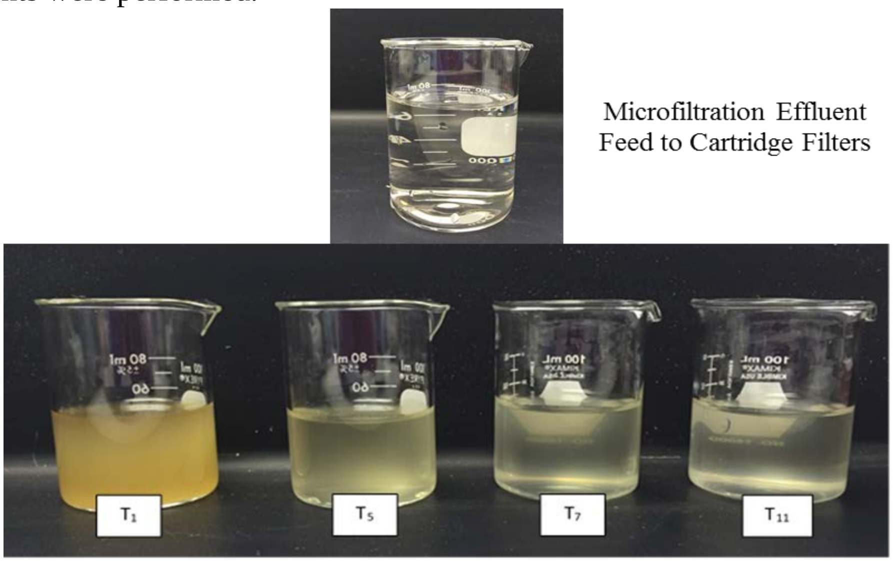

Figure 8. Visual difference between CF influent and CF effluent after 2.5-hr plant shutdown. CF effluent samples were collected at 1, 5, 7 and 11 minutes during CF flush to waste procedure.

Conclusions

Cartridge filters are included in the treatment process after MF to remove suspended solids that may be present in the RO feed water, thereby providing protection of the RO membrane elements. In this study, microbial water quality of CF effluent was investigated. Conclusions of this study were:

- The rapid ATP LuminUltra assay was able to detect increased microbial biomass in CF effluent. This assay is a reliable tool to be used in monitoring CF performance and fouling.
- Quantifying microbial ATP in CF effluent provided the necessary information for staff to evaluate changes to CF procedures to prevent bacterial biomass from reaching the RO membranes.
- As a result of the investigation of CF effluent cATP after plant shutdowns and associated RO performance, staff developed and implemented new operational procedures to perform deadhead flushes of the CF system after plant shutdowns immediately prior to plant startups.
- The flushes move loose filter material (bacteria) out of the system to waste before bringing the plant online, preventing the material from reaching the RO membranes.

- In addition to pre-startup deadhead flushes of the CF filters after a plant shutdown, staff has implemented a preventative maintenance CF procedure to perform periodic deadhead flushes when CF dP starts to rise during normal operation.
- The periodic deadhead flushes during normal operations help to reduce CF dPs and decreased CF replacements, reducing overall operational costs.

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