A Full Scale Evaluation of Ultra-fine Microfiber Cloth Medium to Achieve a 0.1 mg/L Total Phosphorus Limit

Terence K. Reid¹*, David Norton, Matthew C. Castillo¹

¹Aqua-Aerobic Systems, Inc, Loves Park, IL, 61111, USA
²Brockton Advance Water Reclamation Facility, Brockton, MA, 02401, USA
*Email: TReid@aqua-aerobic.com

ABSTRACT

A comparative evaluation was performed to determine if a newly developed ultra-fine microfiber cloth media (UF-CMF) is capable of enhancing particulate phosphorus removal and to attain a 0.10 mg/L effluent total phosphorus (TP) concentration. Two existing filtration systems were studied in parallel with one configured with the original polyester pile cloth medium (CMF) to serve as a control.

The UF-CMF achieved a 0.08 mg/L effluent TP level, representing a 27% reduction compared to the original CMF medium. Supporting evidence of improved particulate phosphorus reduction was corroborated by an additional 37% total suspended solids (TSS) reduction to 0.66 mg/L along with improved particle population reductions across all six measured channels ranging from 2 to >30 µm. Backwash rates for the UF-CMF remained low at about 1.3% of the applied flow but were slightly higher than rates observed for the CMF medium, further suggesting enhanced solids capture and TP removal.

KEYWORDS: Cloth media filtration, phosphorus, reclamation, ultra-fine microfiber, nutrient removal, particle size distribution, total suspended solids, eutrophication

INTRODUCTION

Urbanization has irreversibly changed the hydrologic properties of many of our nation’s rivers and streams. Decades of growing public interest in water quality issues has yielded pressures to restore these important water resources to their natural states. However, the characteristics of many urban rivers are dominated by or, in some cases, entirely dependent upon the anthropogenic activities associated with millions of people that live, work and recreate within the affected watersheds. With an average domestic per-capita wastewater production rate of 70 gallons/person/day (265 liters/person/day), (Tchobanoglous, G., et al 2003), the sheer volume and quality of the reclaimed water introduced into many of America’s urban rivers dictate the hydrologic characteristics more significantly than do natural inputs. As such, restoring these water systems to their natural state may be as difficult as removing the millions of people who influence them. Nevertheless, sustainable water quality management practices can promote a robust level of aquatic biodiversity and environmental aesthetics while supporting the intrinsic demographic trends that have defined the urban area.

The Clean Water Act (CWA) has been responsible for revitalizing countless lakes, rivers and streams through the National Pollution Discharge Elimination System (NPDES) since its
introduction in 1972. Despite the efforts derived from the CWA, the United States Environmental Protection Agency (U.S. EPA) has identified nutrients as the third leading cause of impaired and threatened waters in the US (U.S. EPA, 2013). In-situ total phosphorus (TP) levels as low as 24 micrograms per liter (0.024 mg/L) have been recommended as criterion for areas such as Ecoregion XIV (Eastern Coastal Plain) to prevent cultural eutrophication (U.S. EPA, 2000). In response, wastewater treatment plant administrators and operational personnel are tasked with balancing environmental, social and economic concerns to produce a sustainable solution to protect our waterways.

BACKGROUND

The Brockton Advanced Water Reclamation Facility serves a population of 100,000 which includes the City of Brockton, Massachusetts and the nearby towns of Abington and Whitman as well as about 20 industrial users. Located in the Matfield River subwatershed (Figure 1), the Brockton facility discharges into the Salisbury Plain River at segment MA62-06 and represents the largest of four municipalities permitted to discharge into the watershed by the U.S. EPA and enforced by the Massachusetts Department of Environmental Protection (MADEP, 2004) through permit MA0101010.

![Figure 1. Salisbury Plain River at Segment MA62-06 (MADEP, 2004)](image)

The Salisbury Plain River flows south-easterly through Brockton before joining the Matfield River (a tributary of the Taunton River) and ultimately joining the confluence of Mt. Hope Bay at the City of Fall River and Town of Somerset. Upstream of the plant’s outfall at segment MA62-06, the Salisbury Plain River is relatively small with a dry weather flow of 40 L/s (1.4 ft³/s) that fluctuates based upon the season and prevailing environmental conditions. The input of reclaimed water to the Salisbury Plain River by the Brockton Advanced Water Reclamation
facility is significant, as design conditions can increase the river’s flow by 900 L/s (31.7 ft³/s) under average conditions and by as much as 1,577 L/s (55.7 ft³/s) during peak hydraulic events. As such, downstream segments of the Salisbury Plain River are dependent upon the Brockton Advance Water Reclamation District to support the designated uses as a Class B inland water. In Massachusetts, such waters are classified as a habitat suitable for fish, sustaining aquatic life, maintaining aesthetics and supporting both primary and secondary recreational contact as well as being potentially suitable as a source of water supply (MADEP, 1996).

In order to attain a 24 µg/L in-stream TP concentration as previously mentioned, the Brockton facility would potentially need to target a lower discharge level to account for the phosphorus input from diffuse (non-point) sources. This target is well below a 0.10 mg/L suggested practical limit of technology (WERF, 2010), and discharging at in-stream threshold levels would present onerous technical, analytical and operational challenges to the Brockton facility as well as an economic burden on the local community.

**Reuse as an Alternative**

One potentially viable economic consideration is for the Brockton Advanced Water Reclamation District to repurpose the reclaimed wastewater for non-potable uses such as landscaping, agriculture, industrial processes, cooling tower make-up and toilet flushing. Such a strategy could effectively reduce the phosphorus loading to the Salisbury Plain River at MA62-06 while also reducing the need for high-level nutrient removal at the Brockton facility. While this approach is consistent with growing interest and initiatives for water reuse in Massachusetts (MAPC, 2005), the spatial transference of the reclaimed wastewater to a different location (demand) could pose detrimental effects on current downstream withdrawals and aquatic habitats. This alternative may not be sustainable considering the potential environmental and social consequences despite its possible economic attractiveness.

**The Brockton Advanced Wastewater Reclamation Facility**

The Brockton treatment facility was issued an NPDES permit in May 2005 that includes a 0.2 mg/L effluent TP limit based on a 60-day rolling average from two 24-hour composite samples each week. The permit does not include a discharge requirement for nitrogen removal, but the plant is required to monitor and report effluent nitrate and nitrite concentrations.

In response to a 2006 consent decree, the city completed the final phase of an $83 million plant upgrade in 2008 to replace aging equipment and upgrade the process to comply with current and anticipated future permit requirements (Norton and Mead, 2013). The modifications included an increase in capacity to treat a 3,234 m³/hr (20.5 mgd) annual average daily flow with a 5,682 m³/hr (36 MGD) peak flow. The process was designed to achieve 5.5 mg/L effluent total nitrogen (TN) along with the 0.2 mg/L TP permit limit. The City of Brockton and their engineer/consultant planned the expansion considering more stringent future effluent objectives in preparation for a potential Total Maximum Daily Loading (TMDL) that could occur during the plant’s 20-year effective design life.
Purpose
The City of Brockton sought to investigate methods to reduce their current TP discharge by an additional 50% in an effort to further protect the Salisbury Plain River and Taunton River Watershed. A primary goal of the study was to determine if significant TP reductions could be attained with minimal impact to current equipment, processes and operational costs.

METHODOLOGY

Brockton elected to replace the four existing automatic backwashing (ABW) sand filters that were installed in the 1980s (Figure 3) by evaluating alternatives as part of the plant upgrade. Each of the 33.5 m (110 ft) by 4.9 m (16 ft) sand filters were rated for a 1,420 m$^3$/hr (9 mgd) nominal capacity, but were able to actively filter only 70-83% of this flow. Further, the units had become maintenance intensive, requiring extensive repair and replacement of the underdrains and sand media (McConnell, Firmin and Norton, 2009).
AquaDiamond® Filtration System
The first of ultimately four model ADIFC 1680 AquaDiamond® cloth media filtration systems was installed in Phase 2 of the construction. Developed by Aqua-Aerobic Systems, Inc. (Loves Park, IL), the AquaDiamond concept was designed to be easily retrofitted into existing ABW filter beds and provide an increase in hydraulic capacity without adversely affecting the hydraulic profile. Each AquaDiamond provides 238 m² (2,560 ft²) of filtration area and is rated for a 1,900 m³/hour (12 MGD) nominal average daily flow and a 3,800 m³/hr (24 MGD) maximum flow.

Filtration Media Development
Although the solid / liquid separation process is accomplished with a variety of mechanical filtration devices, the most critical component is filtration medium. Until the early 1990s, granular media filters had been used almost exclusively for tertiary treatment in wastewater plants. In 1991, Aqua-Aerobic Systems, Inc. (AASI) introduced a needle felt cloth medium to the United States, engineered to meet low turbidity and TSS levels as needed to comply with wastewater recycling criteria. In 2001, AASI introduced a new, more robust pile cloth design, which became the new quality standard for cloth media filtration. Through continued research and product development, seemingly small modifications to the medium’s construction were shown to offer significant impacts on performance. By the completion of the Phase 3 expansion at Brockton, the AquaDiamond filters employed the latest development in polyester, woven, pile-cloth media filtration (Figure 4) that was proven effective in allowing Brockton to comply with the 0.2 mg/L TP limit.
Ultra-fine Cloth Media Filtration

With a desire to investigate whether further TP reductions were possible, the City of Brockton administrative staff approached AASI in order to be the first municipality to evaluate a newly developed ultra-fine microfiber medium on their existing AquaDiamond filters. This medium supports an array of densely packed polyester microfibers that promote the particle removal mechanisms associated with depth filtration. The newly developed UF-CMF filaments are constructed of a specially designed microfiber which is described as an ultra-fine fiber of less than 0.1 tex per filament (100 mg of material per 1 kilometer of filament). By employing ultra-fine fiber in media construction, the ratio of media depth to fiber diameter (L/d) is increased by 200-300% over the existing standard-fine CMF medium (Figure 5), and filtration performance characteristics are enhanced. An example of a public-private partnership, both parties agreed to share costs and install the new medium on each lateral of one of the two existing filtration systems (Figure 6).
Protocol

In the fall of 2012, a testing protocol was jointly drafted to outline the test’s objectives, flow conditions, chemical dosing, sampling schedule, analytical methods and daily monitoring requirements. The two primary objectives were:

1. To assess the ability of the UF-CMF medium to remove particulate phosphorus and satisfy a 0.1 mg/L TP proposed numeric limit.
2. To validate the hydraulic and solids loading rates used to design future model 1680 AquaDiamond cloth media filters using the new UF-CMF medium.

Secondary goals of the study included recording and quantifying:

- Individual and combined backwash volumes
- Relative TSS, turbidity and particle population reductions
- Effects of chemical conditioning on TP speciation (if required)
- Differences in maintenance requirements for the UF-CMF medium

Influent TP speciation was performed prior to the test in order to confirm that soluble non-reactive phosphorus (sNRP) was sufficiently low to allow the 0.1 mg/L effluent TP concentration to be met with conventional tertiary filtration. Analysis revealed a 0.03 mg/L sNRP that suggested achieving the target was viable, as illustrated in Figure 7.
Figure 7. Influent Phosphorus Speciation

New media installation was performed by Hart Engineering (Cumberland, RI) under the City of Brockton’s supervision. Final installation inspection and certification was performed by an AASI service technician.

Three Glacier Transportable automatic samplers (Teledyne-ISO, Lincoln, NE) were installed by city personnel to monitor individual filter performance. One unit sampled the common inlet to both filters and the remaining units sampled each filter’s effluent chamber. Flow to each filter unit was monitored and controlled, and operating parameters were recorded on the plant’s SCADA system.

Daily influent and filtrate composite samples were collected by plant staff and delivered with chain of custody forms to Phoenix Environmental Laboratories, Inc. (Manchester, CT) for analysis. Phosphorus analyses determined total, reactive and non-reactive forms of both dissolved and total analytes in accordance with SM4500P (Standard Methods). TSS and turbidity values were determined in accordance with SM2450B and SM2130B, respectively.

Influent and filtrate composite sample particle population analyses were performed by AASI’s laboratory using a Hach portable MetOne WGS27 particle analyzer that is factory programmed to monitor populations in six (6) size channels: 2-6, 6-10, 10-15, 15-20, 20-30, and >30 µm. Each reported particle value represents the average of three consecutive 30-second instrument readings generated at a 100 mLs/minute flowrate.

Chemical addition was performed prior to the secondary clarifiers using a 33.5% ferric chloride solution (as FeCl₃) with typical dosing between 2 and 6 g FeCl₃ per g of TP removed. Adjustment of chemical dosing was performed in response to TP levels measured prior to, and
after filtration. Polymer addition was not deemed necessary to meet the objectives, nor was intermediate chemical addition after the secondary clarifiers (and prior to the UF-CMF filters).

**Test Period**
The validation testing was conducted from December of 2012 to April of 2013. Throughout the four-month period, the two filters received common influent from the plant’s secondary clarification system. The full-scale study was configured to quantify the incremental performance attributes of the newly designed UF-CMF by operating the two filtration systems under identical flow and loading conditions.

Testing was conducted in three phases in order to explore filter performance during (i) normal operating conditions of approximately 6 m$^3$/m$^2$/hour (2.4 gpm/ft$^2$), (ii) at the average design hydraulic loading rate (HLR) of 8 m$^3$/m$^2$/hour (3.25 gpm/ft$^2$) and (iii) at the peak HLR conditions approaching 16 m$^3$/m$^2$/hour (6.5 gpm/ft$^2$).

**RESULTS**
The UF-CMF demonstrated consistently lower effluent TP concentrations in comparison to the existing CMF material. While both the ultra-fine microfiber and existing standard-fine fiber media types were able to achieve Brockton WWTF’s current 0.2 mg/L TP effluent permit, the new polyester microfiber material was able to remove the additional particulate phosphorus necessary to achieve the 0.1 mg/L target. The UF-CMF system produced an average effluent TP concentration of 0.08 mg/L (n=22, ±0.02), representing a 27% reduction compared to the existing CMF’s performance of 0.11 mg/L (n=22, ±0.02), with relative TP performance shown in Figure 8.

![Figure 8. Relative TP Removal Performance](image-url)
In addition, the UF-CMF outperformed the existing cloth medium with respect to final TSS, NTU, PSD and Fe concentrations at prevailing conditions and maintained a high level of performance at the design average and peak HLR testing, as shown in Table 1 and Figure 9.

Table 1. Overall Summary of Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>CMF Effluent</th>
<th>UF-CMF Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (mg/L)</td>
<td>3.89</td>
<td>1.04</td>
<td>0.66</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>0.77</td>
<td>0.32</td>
<td>0.23</td>
</tr>
<tr>
<td>pH (s.u.)</td>
<td>6.85</td>
<td>6.96</td>
<td>6.84</td>
</tr>
<tr>
<td>Iron (dissolved, mg/L)</td>
<td>0.08</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>Iron (total, mg/L)</td>
<td>0.44</td>
<td>0.26</td>
<td>0.12</td>
</tr>
<tr>
<td>Iron (particulate)</td>
<td>0.36</td>
<td>0.18</td>
<td>0.07</td>
</tr>
<tr>
<td>Total Alkalinity (mg/l as CaCO₃)</td>
<td>95.6</td>
<td>123.0</td>
<td>111.0</td>
</tr>
<tr>
<td>Total Phosphorus (mg/L P)</td>
<td>0.19</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>Dissolved Phosphorus (mg/L P)</td>
<td>0.07</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Particulate Phosphorus (mg/L P)</td>
<td>0.12</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Figure 9. Relative Particle Size Removals
The additional solids capture by the UF-CMF was further corroborated by a commensurate increase in backwash volume (Figure 10). Backwash volumes were just under 1.0% of the applied flow for the CMF medium compared to about 1.3% for the UF-CMF.

![Figure 10. Comparative Backwash and Solids Waste Volumes](image)

**DISCUSSION**

The human impact on existing water resources will continue to challenge the need to preserve native aquatic ecosystems as the global population rises. Nearly 7,000 water bodies have been identified as impaired in the US to date, specifically attributed to excessive nutrients (U.S. EPA, 2013). Many of our water bodies are inescapably dependent upon the input of human-based activities in urban environments. In turn, this dichotomy will force waste water reclamation facilities to seek innovative approaches to adapt to unprecedented nutrient limitations in a cost effective and socially-responsible manner. Rather than adopting a wait and see stance, the Brockton Advanced Water Reclamation Facility has taken the initiative to find a practical solution to achieve ultra-low TP levels in their discharge to the Salisbury Plain River.

At this time, the City of Brockton is anticipating a TP discharge limit of 0.1 mg/L in the upcoming draft permit, but this numeric criterion has not been promulgated. Brockton has completed the installation of four ADIFC 1680 AquaDiamond filters, each utilizing the ultra-fine, microfiber cloth media in preparation for the potentially lower effluent TP requirement.
CONCLUSIONS

- Excessive nutrients, including phosphorus, are a leading cause failing to meet water quality standards in a large portion of our nation’s surface waters.
- Many urbanized areas have grown up around our lakes, rivers and streams which have become dependent upon the water introduced by human activity.
- Wastewater reclamation facilities will face increasing pressure to treat to lower and potentially unprecedented TP levels.
- Cloth media filtration is an adaptive technology that can be readily retrofitted into existing sand filter structures to increase capacity and elevate removal efficiencies.
- Ultra-fine microfiber cloth media is engineered to maximize depth filtration necessary to consistently attain TP levels below 0.1 mg/L at hydraulic loading rates of 16 m$^3$/m$^2$/hour (6.5 gpm/ft$^2$).

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Brockton Advanced Wastewater Reclamation Facility for their initiative, participation, cooperation and access to the plant site which permitted validation of this innovative technology.

REFERENCES

Water Environment Research Foundation (November 2010). Striking the Balance Between Wastewater Treatment Nutrient Removal and Sustainability.