Winning the War in Nutrient Removal: Case Study for SuperBiomedia™ in Trickling Filters

Overview

Biological nutrient removal (BNR) is necessary in the wastewater treatment process to protect local ecosystems after treated water is discharged. As the concentration of nutrients, namely nitrogen and phosphorus, increases in surface water, ecosystems are damaged in return. Algal blooms are a result of the increased nutrient concentration, which deplete dissolved oxygen, kill fish, and suffocate plants in local ecosystems. The facility upgrades needed to reduce nutrient concentrations to safe levels can be costly, requiring significant improvements to the treatment process to create anoxic zones for nitrogen removal. In a case study conducted at a municipal wastewater treatment plant in Ohio, Water Warriors SuperBiomedia™ reduced the overall nitrogen-ammonia (NH_3-N) effluent concentrations on average by 42%, even in colder temperatures. Additionally, SuperBiomedia™ reduced the overall biochemical oxygen demand (BOD_5) and overall chemical oxygen demand (COD) by 67%, and 60% respectively. The total phosphorus (TP) and total suspended solids (TSS) concentrations were not impacted in comparison to rock media. Based on the Velz equation, a depth of only 1.15 ft of SuperBiomedia™ with a recycle ratio of 0.232 was calculated to meet the existing exit BOD_5 and NH_3-N concentrations. A retrofit of existing trickling filters will prevent the need for a major process upgrade, reducing operating costs while also increasing the efficiency of nutrient removal.

Background

At a municipal wastewater treatment plant in Ohio, the effectiveness of SuperBiomedia™ was compared to rock media in a trickling filter. Figure 1 shows the trickling filter used in this case study.

Figure 1: Trickling filter with test bed pictured with four rotating arms and water flowing over rock media.

The city's Division of Water reclamation has been treating wastewater since 1929 and uses a system of 20 trickling filters with all rock media. The trickling filters are each 165 ft in diameter, and 7 ft deep with a calculated volume of 149,697 ft^3 per trickling filter. Each trickling filter is constructed of four arms that rotate over a circular area containing filter media. Influent consistently exits through two arms, whereas the remaining two arms are used when recirculation flow is added. The influent to the plant averages between 48-50 million gallons per day (MGD) and is combined with a recirculated flow after passing through the trickling filters. The recirculated flow combined with new influent into the plant totals to approximately 90 MGD. The recirculation rate is a fixed at an average of 35 MGD but may be changed manually. The recirculation flow is divided over the 20 trickling filters, where half of the flow is sent to the 10 filters on the East Bank, and the other half flows to the 10 filters on the West Bank.

Methods

The test bed was a concrete well inside the bed of rock media. This concrete well allowed for testing of other trickling filter media without disrupting the operations of the plant. The dimensions of the test bed are 49 inches length, 39 inches wide, and 78 inches deep. The total volume of the test bed is 149,058 in^3, making the test bed $^1/_{12}$ the scale of the entire trickling filter. Figure 1 below shows the test bed containing SuperBiomedia™.

Figure 2: Concrete test bed containing SuperBiomedia™ in trickling filter placed inside existing trickling filter.

SuperBiomedia™ pieces were packed into a mesh bag and then placed into the concrete test bed, which remained open to atmosphere. Wastewater flowed through the media before exiting through the bottom. A funnel and open container were positioned below the test bed to collect samples after passing through the SuperBiomedia™. Collected samples were periodically withdrawn over several months from this container and analyzed by an EPA-approved laboratory located in Ohio. Samples were collected from April 3rd, 2019 until February 12th, 2020 to compare performance during varying temperature conditions.

The effectiveness of the trickling filter media was modeled and compared to the existing rock media. The Velz equation was used to model trickling filter media requirements shown in Equation 1 below.

$$\frac{S_E}{S_I} = \frac{1}{([(R+1)*E]-R)} \quad (1)$$

In Equation 1, S_E is the effluent (mg/L), S_I is the influent (mg/L), R is the recycle ratio, and E is the effectiveness of the trickling filter media. The equation for effectiveness, E, is shown below in Equation 2.

$$E = e^{\frac{k20*A_S*H*Temp.Correction}{(q*(R+1)^{n})}} \quad (2)$$

In Equation 2, *k20* is the kinetic rate at 20°C $(gpm/ft^2)^{0.5}$, A_s is the surface area of media per volume of media (ft^2/ft^3), *H* is the depth of media (ft), *Temp. Correction* represents the adjusted temperature in °C from the reference temperature of 20°C, *q* is the total influent over the surface area (gpm/ft^2), and *n* is an empirical constant set to a value of 0.50.

Samples from both medias are modeled using the Velz equation to compare performance for both BOD_5 (mg/L) and NH_3-N (mg/L) treatment. Using the equation for effectiveness in combination with the Velz equation, the appropriate media depth and volume is calculated.

Discussion

Several different parameters were evaluated to compare rock media versus the SuperBiomedia™. Biological oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (NH_3-N), total phosphorous (TP), and total suspended solids (TSS) were analyzed and compared to evaluate the effectiveness of each media type. The average ambient air temperatures from April to May ranged from 49°F to 79°F, with temperatures reaching as high as 83°F during the June and July collections. Recorded temperatures in the winter were as low as 35.4°F, 32.8°F, and 33.0°F for December, January, and February respectively [1].

Figure 1 below compares the effluent over influent ratios of BOD_5 in wastewater after flowing through both the media types ranging from April to February.

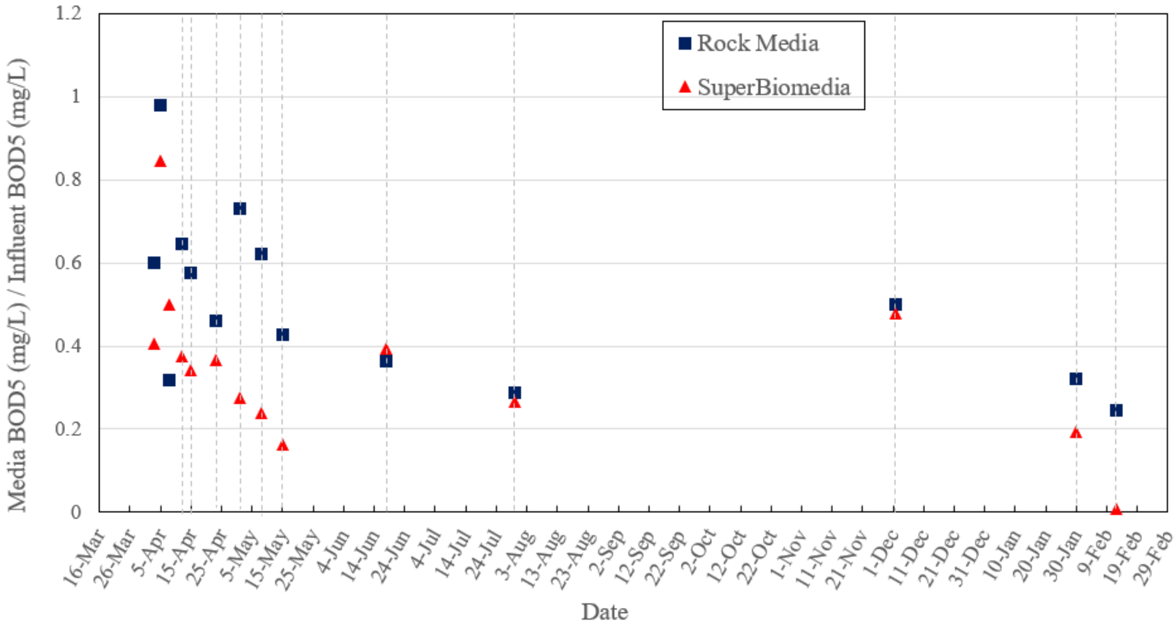

Figure 3: Ratio of BOD_5 (mg/L) effluent over influent BOD_5 (mg/L) compared for rock media and SuperBiomedia™.

The SuperBiomedia ™ was installed in the trickling filter test bed on March 15th, 2019 until February 12th, 2020. The first sample was collected on April 3rd, 2019. Over the collection period, the average influent BOD_5 entering both trickling filter medias was 193 mg/L ± 98 mg/L. The ratios of media effluent over trickling filter influent represent the comparison between media types in BOD_5 reduction after passing through the trickling filter. The average rock media ratio is 0.51 mg/L ± 0.20 mg/L, while the SuperBiomedia ™ was 0.35 mg/L ± 0.19 mg/L. The results showed SuperBiomedia ™ reduced the overall influent BOD_5 on average by 67%, from 193 mg/L to 63 mg/L. In comparison, rock media reduced the influent BOD_5 on average by 54%, from 193 mg/L to 89 mg/L.

The reduction in BOD_5 in the SuperBiomedia ™ effluent is largely due to the open-cell foam design, creating a significant increase in surface area. Figure 3 displays a closer view of the SuperBiomedia ™.

Figure 4: SuperBiomedia ™ features an open-cell foam design with a surface area to volume ratio (ft^2/ft^3) of 0.96 and dimensions of 6 in x 9 in.

Wastewater can flow through the open structure of the cell which increases the contact with the biofilm layer growing on the media. Rock or slag media is porous, but only on the surface which limits the effectiveness of the trickling filter. SuperBiomedia ™ features a surface area to volume (ft^2/ft^3) ratio of 0.96, where rock media is only 0.40. Additionally, the open cell foam design enables a higher rate of oxygen transfer into the biofilms. The open design allows more air to flow through the open cells by natural convection, thereby establishing a higher dissolved oxygen rate on the surface.

The COD (mg/L) showed similar results in comparison to the rock media. Figure 4 below shows the ratio of media COD effluent over COD influent for both media types.

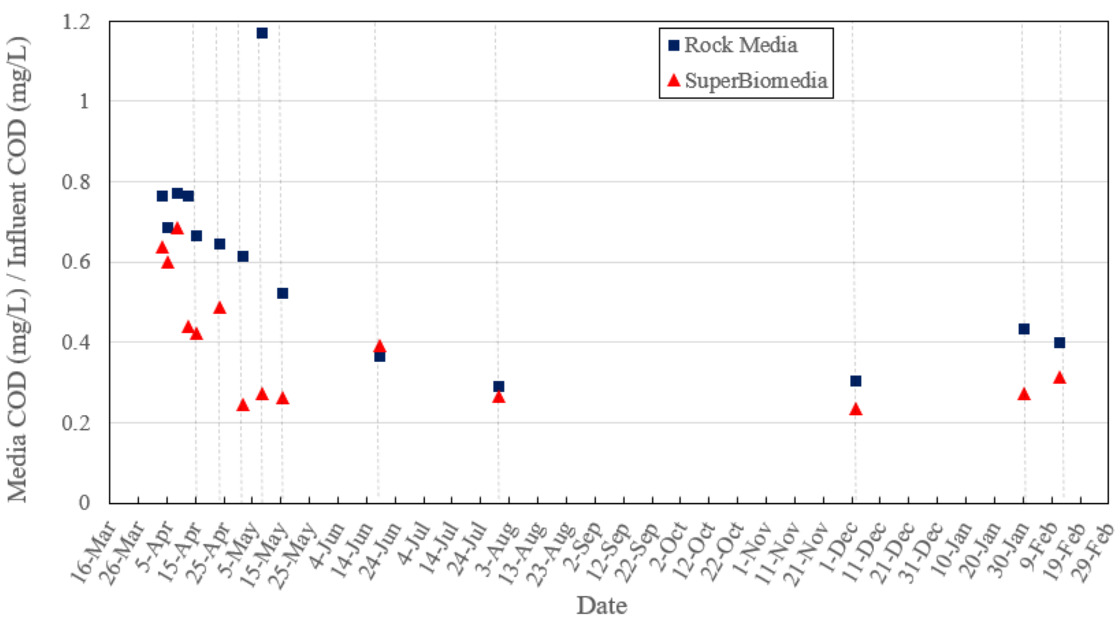

Figure 5: Comparison between rock media and SuperBiomedia ™ based on ratio of media COD effluent (mg/L) over trickling filter influent (mg/L).

The average influent COD into the trickling filter was 383 mg/L ± 58 mg/L. The ratios of media effluent over trickling filter influent represent the comparison between media types in reducing COD after passing through the media. The ratio for rock media is 0.60 mg/L ± 0.24 mg/L and the ratio for SuperBiomedia ™ 0.40 mg/L ± 0.16 mg/L. The results show SuperBiomedia ™ reduced the COD influent on average by 60%, from 383 mg/L to 154 mg/L. In comparison, rock media reduced the COD influent on average by 40%, from 383 mg/L to 229 mg/L.

Nitrogen-ammonia (NH_3-N) effluent over trickling filter influent ratios were also compared for both media types in Figure 5.

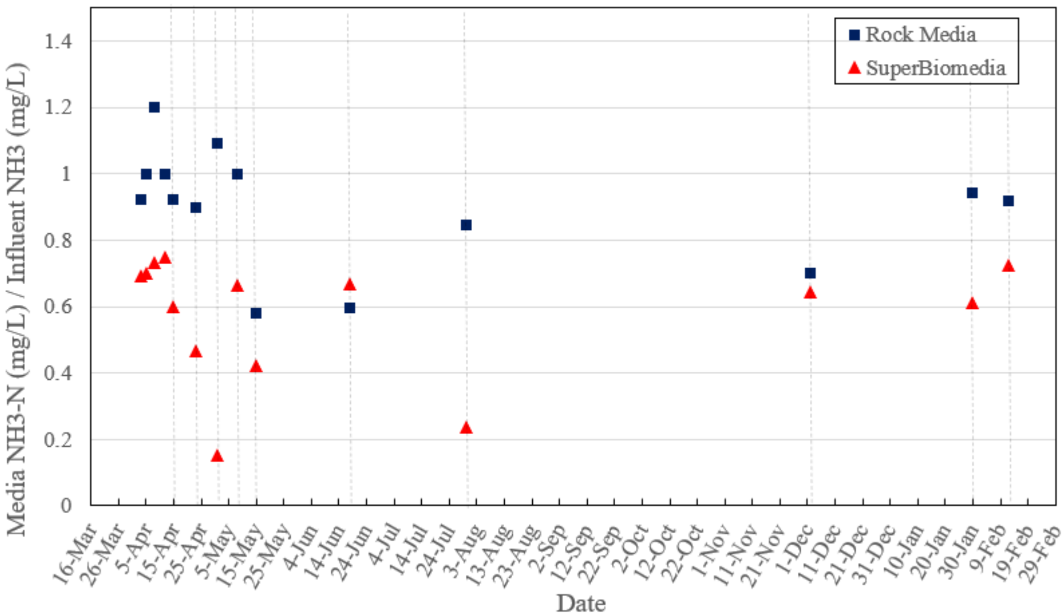

Figure 6: Nitrogen-ammonia (NH_3-N) for both media types compared based on media effluent over trickling filter influent.

The average influent NH_3-N was 12.8 mg/L ± 2.6 mg/L over the collection period. The media effluent over trickling filter influent for rock media was 0.90 mg/L ± 0.18 mg/L compared to 0.58 mg/L ± 0.19 mg/L for SuperBiomedia ™. Additionally, SuperBiomedia ™ reduced the inlet NH_3-N concentration on average by 42%, from 12.8 mg/L to 7.5 mg/L. Rock media reduced the inlet NH3-N concentration on average by 9%, from 12.8 mg/L to 11.6 mg/L. The NH_3-N concentration was reduced using SuperBiomedia™, even when ambient air temperatures were as low as 33°F [1]. The ratio of rock media effluent over influent is nearly equal to 1.0, meaning the rock media does not treat NH_3-N. This observation may be the result of a few reasons. First, a low dissolved oxygen concentration in the wastewater. This is due to clogged spacings between rocks with sloughed-off biomass. Clogged spacings would reduce the flow of air through the wastewater, causing a lower dissolved oxygen concentration. Second, a low temperature difference between the water and ambient air, such as the summertime, would reduce the natural convection rate of air through the media. Third, the BOD_5 of the influent flow must be low in proportion to NH_3-N for nitrifiers to oxidize the NH_3-N to nitrate and nitrite, which then converts to nitrogen gas. This is possible due to the aerobic and anoxic conditions created by the

SuperBiomedia™. The aerobic conditions are present on the exterior of the open cell foam, which allow for the first step of nitrogen processing. The anoxic conditions on the interior of the foam give anerobic bacteria the necessary conditions to then convert nitrite into N_2 gas, which escapes into the atmosphere.

Nitrification would not be possible without the highly porous SuperBiomedia™. The open-cell foam inside the football-shaped structure is significantly greater than the rock media, where 1 ft^3 of SuperBiomedia™ is equal to about 10 ft^3 of rock media. SuperBiomedia™ is more effective in treating NH_3-N in comparison to rock media and will allow for greater treatment capacity of NH_3-N in wastewater.

The total phosphorous (TP) effluent over influent ratios for both rock media and SuperBiomedia™ is compared below in Figure 6.

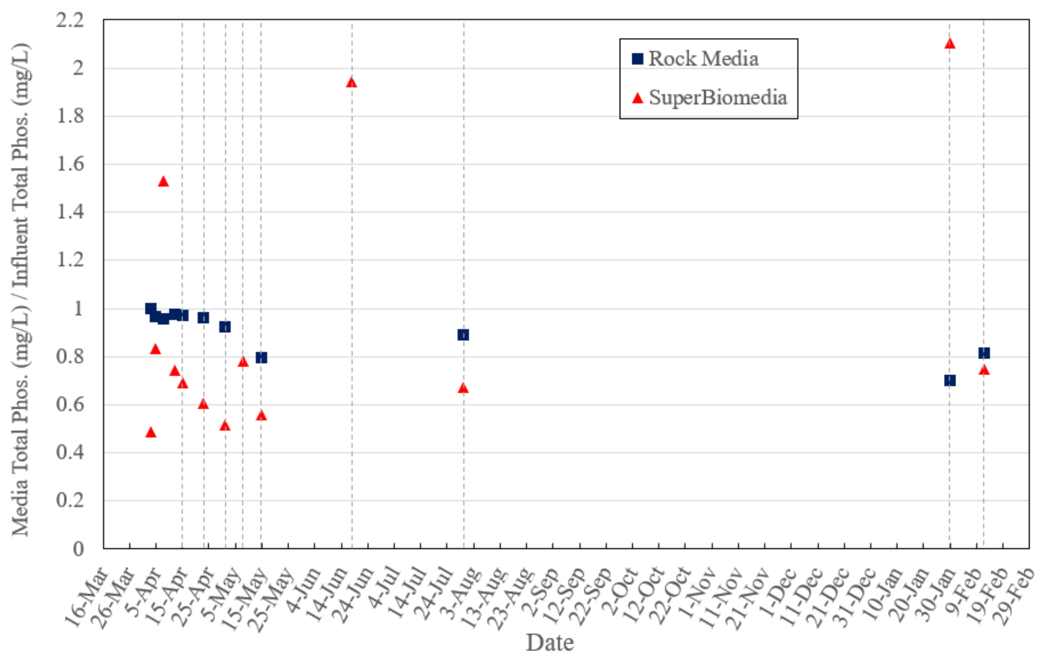

Figure 7: Total phosphorus (mg/L) for both media types compared based on media effluent over trickling filter effluent.

The average ratio of TP effluent over TP influent for rock media is 0.91 mg/L ± 0.1 mg/L, compared to 0.94 mg/L ± 0.55 mg/L. Several outliers were removed from the data before analysis. One of the removed outliers included data collected for both medias on December 2, 2019, where measured effluent to influent ratios for TP were 67.5 and 4.86 for rock media and SuperBiomedia ™ respectively. This was due to a low phosphorus concentration in the wastewater dissolving the biomass already adhered on the media surfaces. Additionally, other data points with high phosphorus concentrations occurred on April 8th, May 8th, June 18th, and January 30th. A high secondary flow on April 8th caused increased values for phosphorus effluent in the SuperBiomedia ™. Several separate influxes of wastewater caused high effluent values for the rock media on May 8th. On June 18th higher effluent values were reported for SuperBiomedia™ due to required cleaning of the trickling filter media. Finally, on January 30th a large TP effluent was also reported for SuperBiomedia™. These outliers are all simply explained because neither trickling filter medias treat dissolved phosphorus but rather accumulate biomass on the media surface, and eventually slough off into the effluent stream. SuperBiomedia™ does not show any advantage in treating dissolved phosphorus over rock media but shows similar overall performance.

The total suspended solids (TSS) removal for both media types is compared in Figure 7.

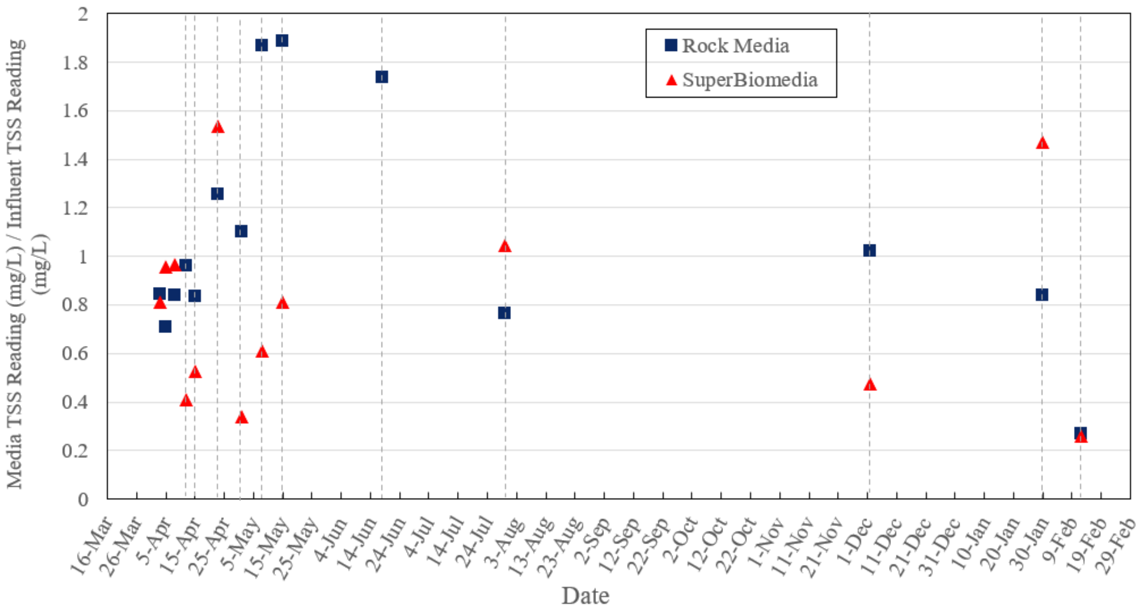

Figure 8: Total suspended solids (TSS) media effluent over TSS influent compared for both rock media and SuperBiomedia™.

Comparing the ratios of TSS effluent through the different media types to TSS influent, the rock media shows an average of 1.1 mg/L ± 0.47 mg/L, compared to an average of 0.79 mg/L ± 0.41 mg/L for the SuperBiomedia™. Both medias exhibit a high standard deviation in the results. One outlier was removed from the SuperBiomedia™ data collected June 18th due to the cleaning procedure causing an increase in TSS effluent. The media in the trickling filter was cleaned causing TSS particles to slough off the surface. While the SuperBiomedia™ does filter TSS, smaller particles will be able to pass through the open-cell foam. Neither medias are used to treat TSS in wastewater but do show similar results. Both medias act as a filter for larger particles which will adhere to the surface, and later detach to be treated downstream.

Design Recommendations

The Velz equation was used to calculate the trickling filter media depth required to meet the BOD_5 (mg/L), and NH_3-N (mg/L) requirements for the same Ohio municipal wastewater treatment plant, and the adjusted recycle ratio. The design recommendations were calculated based on the influent and recycle flows to one trickling filter to meet the existing effluent BOD_5 and NH_3-N using the rock media. A summary of the modeled trickling filter design in comparison to the rock media is detailed in Tables 1 and 2.

Table 1 and 2: Performance comparison in BOD_5 (mg/L) reduction and NH_3-N removal (mg/L) between rock media and SuperBiomedia™.

	Rock Media	SuperBiomedia
Diameter of Filter (ft)	165	165
Depth of Media (ft)	7	1.15
Cross-sectional area (ft^2)	21,382	21,382
Volume of Media (ft^3)	149,697	24,589
k20 ((gpm/ft^2)^0.5)	0.00168	0.00168
Inlet Flowrate (MGD)	2.75	4.3
Recycle Flow (MGD)	1.75	0.2
Recycle Ratio	0.636	0.047
Inlet BOD5 (mg/L)	193	193
Exit BOD5 (mg/L)	89	88
Organic Loading (lbs BOD/day/1000 ft^3)	48.4	294

	Rock Media	SuperBiomedia
Diameter of Filter (ft)	165	165
Depth of Media (ft)	7	1
Cross-sectional area (ft^2)	21,385	21,385
Volume of Media (ft^3)	149,697	21,385
k20 ((gpm/ft^2)^0.5)	0.00045	0.00045
Inlet Flowrate (MGD)	2.75	3.65
Recycle Flow (MGD)	1.75	0.85
Recycle Ratio	0.636	0.232
Inlet NH3-N (mg/L)	12.8	12.8
Exit NH3-N (mg/L)	11.64	11.64

The diameter of the filter was held constant at 165 ft, with only the media depth varied between the different media types. The specific surface areas (ft^2/ft^3) also varied due to differences in the media design. The specific surface area for the rock media was selected at 15 ft^2/ft^3, and a conservative value of 60 ft^2/ft^3 was selected for the SuperBiomedia™ [2]. The average influent to the plant combined with the recirculation flow totals to approximately 90 MGD, where the recirculation flow totals 35 MGD. The total flow is divided between 20 filters, making the influent flow equal to 2.75 MGD and the recycle flow 1.75 MGD. These same conditions were kept in modeling both BOD_5 and NH_3-N.

Using the collected BOD_5 measurements from the trickling filter and effluent, the k20 value of 0.00168 $(gpm/ft^2)^{0.5}$ was calculated and applied for the Velz equation model for

SuperBiomedia™. The organic loading rate for the rock media is 48.4 lbs BOD_5/day/1000 ft^3, which is close to the expected value found in literature [2]. After balancing the organic loading rate, inlet and recycle rates, and exit BOD_5 a proper trickling filter design using SuperBiomedia™ was determined. With the same measured inlet and exit BOD_5, only 1.15 ft of SuperBiomedia™ is required to treat the same 4.5 MGD total flow of wastewater. The recycle rate of the wastewater could then be reduced to 0.2 MGD saving operation costs due to pumping. The organic loading using the SuperBiomedia™ meets the loading requirements of 300 lbs BOD_5/day/1000ft^3 for a roughing filter found in literature [2].

When modeling the NH_3-N removal, only 1 ft of SuperBiomedia ™ was required to meet the existing 11.6 mg/L NH_3-N effluent with 12.6 mg/L NH_3-N entering the trickling filter. A *k20* value of 0.00045 $(gpm/ft^2)^{0.5}$ was determined from the rock media NH_3-N data and was applied to the SuperBiomedia ™ model. In addition to a reduced media depth, the influent flow can be increased to 3.65 MGD and recycle flow decreased to 0.85 MGD to meet the same outlet requirements. The reduced volume and weight of the SuperBiomedia™ reduces the maintenance costs associated with the rock media placing heavy stress on the trickling filter walls.

Conclusion

SuperBiomedia™ outperforms rock media in reducing NH_3-N, COD, and BOD_5 in wastewater treatment. SuperBiomedia™ provides an increased surface area for biofilm growth which increases overall treatment capacity for BOD_5 and COD treatment compared to rock media. Additionally, the high porosity increases the air flow rate due to natural convection, therefore increasing the dissolved oxygen in the wastewater. SuperBiomedia ™ enables aerobic and anoxic conditions causing greater NH_3-N treatment through the nitrification process, even in the winter months. Comparing TP and TSS treatment, SuperBiomedia™ showed similar performance to rock media. Moreover, using collected data from the wastewater plant and the Velz model, only 1.15ft depth of SuperBiomedia™ is required to meet the same BOD_5 and NH_3-N specifications as 7ft of existing rock media. A lower recycle rate of 0.85 MGD will satisfy both the BOD_5 and NH_3-N effluent requirements. The associated pumping costs required to treat the same volume of wastewater will then decrease as a result. Using SuperBiomedia™ is effective in nutrient removal, which protects ecosystems as well as reducing operating and facility costs for wastewater treatment plants.

About Us

Water Warriors Inc. is a scientifically driven company on a clean water mission. Its products are designed to address the world’s wastewater crises through innovative, natural approaches to traditional wastewater treatment techniques.

To learn more, visit:
www.waterwarriorsinc.com

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