AST® Recirculating PolyGeyser (RCPG®)

Model Description & Technical Details

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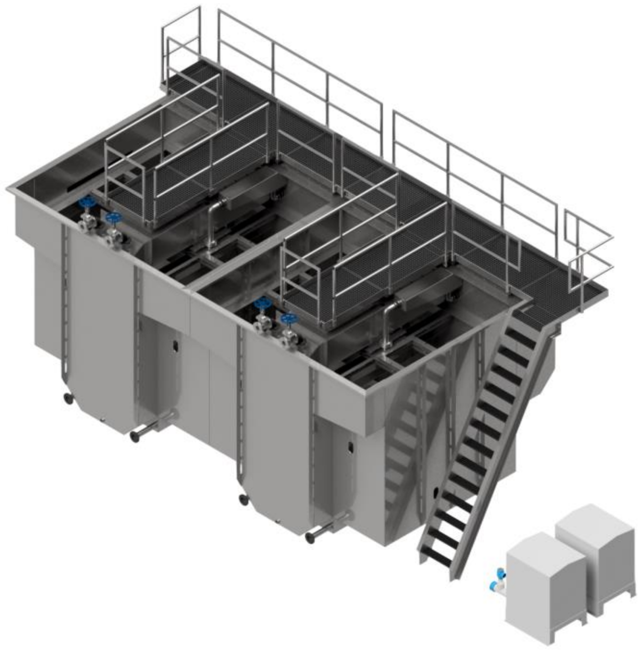

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Model Description & Technical Details

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This is not an operation manual. This document is to be used as a description and technical guide. If you have questions on how to operate an RCPG® Filter, you can call AST at 1.800.939.3659 or find more instructions on our website at ASTFilters.com.

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Recirculating PolyGeyser® (RCPG®) Technical Description

A floating bead filter uses floating media in a submerged, static bed to capture solids by the same mechanism as traditional sand filters. At the same time, the units are designed to operate as a fixed-film bioreactor that oxidizes organics and nitrifiers (Figure 1). These granular beds eventually clog with captured solids and biofilm so they must be periodically backwashed. The newest units, the PolyGeysers®, are designed to wash the bed with air (pneumatically) and then internally clarify the backwash waters so they can be recycled. Sludge is then stored facilitating periodic removal. Breaking the linkage between water loss and backwash frequency allows for better biofilm management enhancing biofiltration. The result is a low water-loss unit that can be used simultaneously to act as a biofilter and solids capture device reducing a traditionally three step process to one (Figure 2).

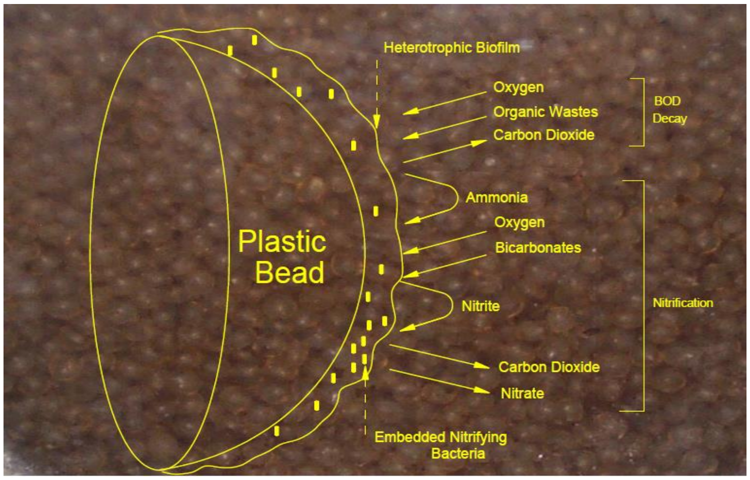


Figure 1. Biofilm develops on the surface of each bead making the RCPG® a very effective fixed film bioreactor capable of removing many dissolved organics while nitrifying.

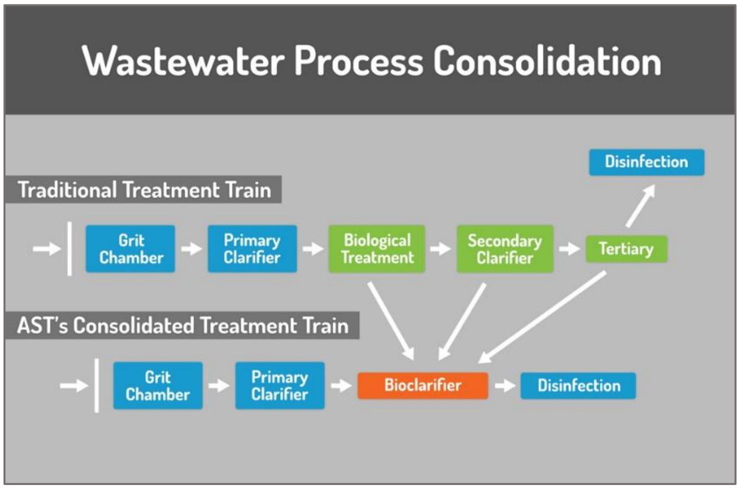


Figure 2. When operated as a bio-clarifier an RCPG® unit can consolidate the secondary treatment with tertiary solids capture and nitrification proving an enhanced secondary treatment in a single step.

The Recirculating PolyGeysers® (RCPG®) line of filters were designed to overcome the oxygen limitations that were encountered when a single pass unit's oxygen delivery capacity was overcome by bacterial consumption when confronted with high Soluble Biochemical Oxygen Demand ($SBOD_5$) and/or Total Ammonia Nitrogen ("Ammonia" or TAN) levels. The original units were composed of a High Profile PolyGeyser (HPPG)

Figure 3. The early recirculating models used a separate tank as a reservoir. Flow was driven by a pump with aeration by spray head, Venturi, or packed column. This unit is attached to a package treatment plant servicing a subdivision and assures new stringent ammonia standards can be met.

recirculating on an aerated tank (Figure 3). These early models used water pumps for circulation and packed beds or spray heads for aeration. The RCPG® 250 (Figure 4) exemplifies the line of filters that were designed for simplified installation and operation using an internal airlift system that saves energy by recirculating and aerating the water in a single step. Oxygen transfer rates in an RCPG® are typically 10-100 times the capacity of a single pass high profile polygeyser eliminating oxygen supply as an issue.

The performance of these RCPG® units is further enhanced by using "Enhanced Nitrification" (EN) beads that protect the slow-growing bacteria during a backwash event (Figure 5). These beads also increase the bed's porosity, lowering head loss so energy saving airlifts can be used to recirculate the water. The result is a compact and energy efficient treatment approach, cleaning the water without contributing unnecessarily to the atmosphere's carbon balance while reducing the cost of treatment.

Figure 4. Two RCPG® 250s installed in series to control ammonia discharges on a domestic lagoon system in northern Mississippi.

The RCPG® series provides a format that can process relatively strong wastewaters as roughing filters. Whereas a single pass HPPG is limited by oxygen to an $SBOD_5$ reduction of the order of 5-10 mg/L, the RCPG® can be configured to achieve

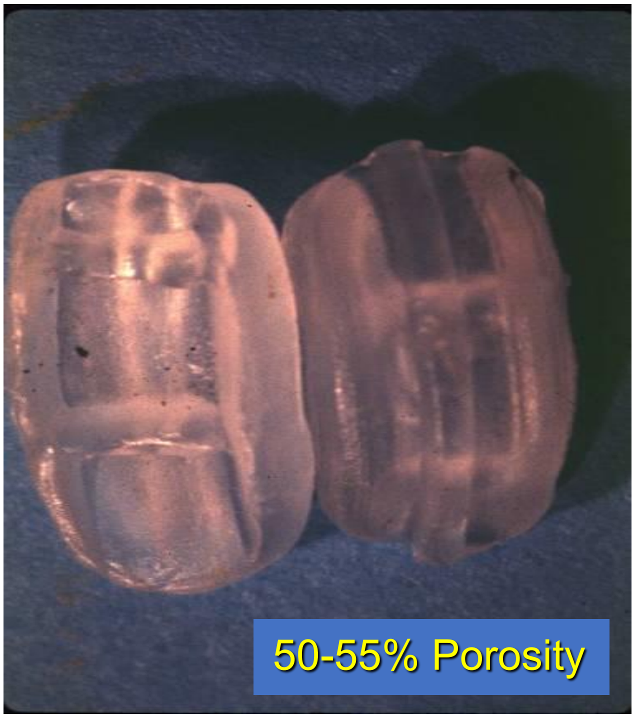
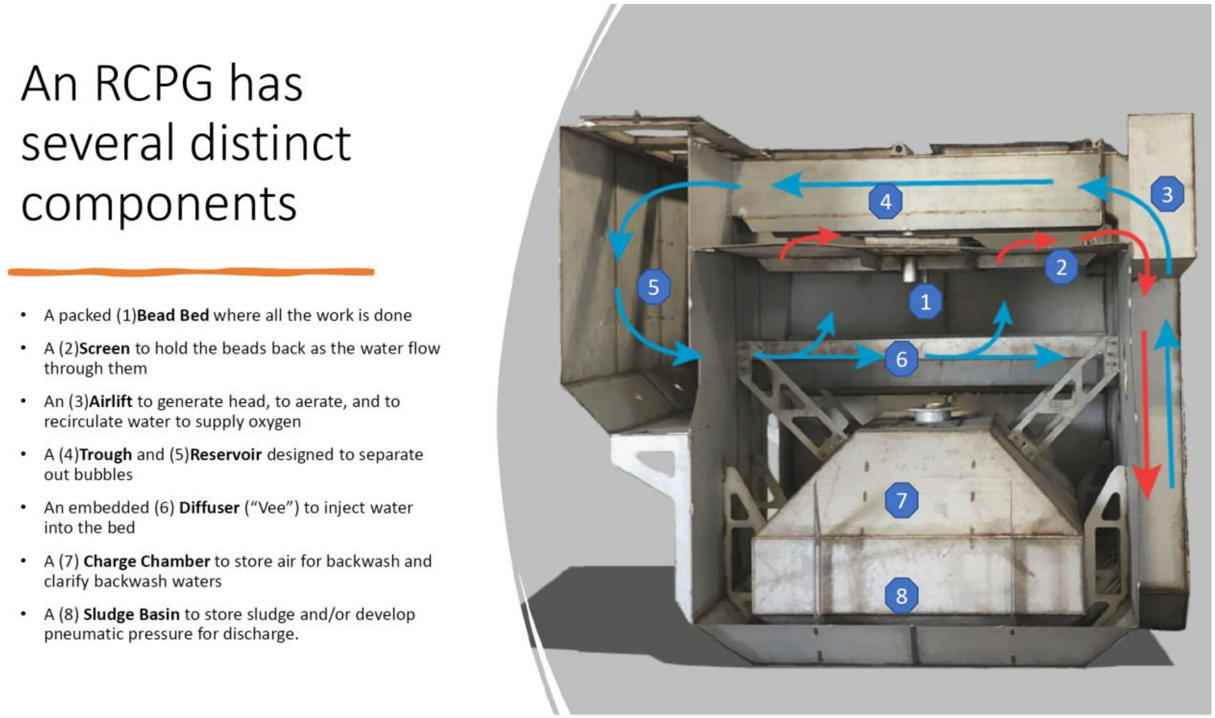


Figure 5. The Enhanced Nitrification bead provides protective pockets encouraging retention of bacteria demanding a longer mean cell residence time during backwash events.

$SBOD_5$ reduction on the order of 500-1000 mg/L. They reduce high concentration levels that are acceptable for discharge to community treatment systems without surcharges. It can also be used to polish the effluent from a lagoon or treatment system to acceptable levels for direct discharge to sensitive receiving systems. They typically do this by simultaneously removing suspended solids, biodegrading dissolved organics (the $SBOD_5$), and with good management, nitrifying in a granular fixed film format. The unit provides relatively precise control on mean cell residence time which becomes critical when wastes targeted include more refractory organic wastes that can be generated from oil and gasoline, hormones, explosives residuals, and a variety of industrial applications.

Background

The heart of the top half of every RCPG® unit is its *Bead Bed*. Located immediately below the *Screen* extending downward nearly three feet to enclose the *Embedded Diffusers* (Figure 6). Water emerging from the *Screen* flows toward the recirculating *Airlift* and cascades down into the gutter that directs the flow to the down chute of the *Airlift.* Air is injected into the water as it enters the draft tube. The air/water mixture is less dense than the pure water column in the down chute so the air-water mixture in the draft tube is pushed up into the *Trough.* That transports the water above the screen to the *Reservoir* as the air bubbles escape. The *Airlift's* action raises the water level in the *Reservoir* forcing water back into the *Embedded Diffusers* that distribute the water below the *Bead Bed* completing the cycle. The heart of the bottom half of the RCPG® is the *Charge Chamber (*Figure 6*).* This is an airtight container that receives air bubbles via a small



An RCPG has several distinct components

- A packed (1)**Bead Bed** where all the work is done
- A (2)**Screen** to hold the beads back as the water flow through them
- An (3)**Airlift** to generate head, to aerate, and to recirculate water to supply oxygen
- A (4)**Trough** and (5)**Reservoir** designed to separate out bubbles
- An embedded (6) **Diffuser** (“Vee”) to inject water into the bed
- A (7) **Charge Chamber** to store air for backwash and clarify backwash waters
- A (8) **Sludge Basin** to store sludge and/or develop pneumatic pressure for discharge.

Figure 6. This interior view of an RCPG® 250 illustrates the major components and flow path for the filter’s upper and lower halves.

delivery tube that penetrates the RCPG® sidewall. A small Rotameter typically controls the rate of air input. The *Charge Chamber* is equipped with a *Trigger* that retains the air until the *Charge Chamber* is filled. Just before air bubbles escape under the lower *Charge Chamber* lip the trigger discharges almost all the air. A stream of large bubbles penetrates the *Bead Bed* thoroughly dislodging biofilm and solids, which are swept toward the charge chamber as the backwash waters displace the *Charge Chamber* air. The bead bed drops below the *Embedded Diffusers* as the water flows into the *Charge Chamber*. Water from the *Reservoir* now flows into the *Embedded Diffusers* filling the filtration chamber. As the beads float upwards with the incoming water, the water flows down to fill the space they have just evacuated. In this manner, the entire bed is counter-flowed trapping all the dislodged solids below the inflowing waters. Over the next few hours, the backwashed waters are settled clear before the air pressure forces them back into the recirculation loop. The top half of an RCPG® flows continuously in a loop supplying oxygen to the biofilms which are grown and then harvested with a backwash event. Under the action of the *Charge Chamber*, the bottom half of the RCPG® operates more like a tidal pool, rising and falling cyclically. The timing of the tides is controlled by the rate of air input. This simple input controls the time between backwashes. Extending the backwash interval (lowering the rate of air input) gives the bacteria more time to grow increasing the mean cell residence time. This allows the length of the biofilm growth period to be adjusted and specific objectives like mean cell residence time are optimized. Conversely, accelerating air input shortens the backwash interval resulting in a lower mean cell residence time while removing excess bacteria.

Within the *Charge Chamber* is the *Sludge Basin*, an open top basin where the settling solids are captured. Two vertical sludge removal lines extend upward from the *Sludge Basin*. The air pressure generated as the air displaces the water from the *Charge Chamber* also exerts pressure upon the sludge trapped in the *Sludge Basin*. This pressure forces the sludge up the discharge pipes to a level a couple of feet above the reservoir water level, approximately 13 feet off the ground in the RCPG® 250, where gravity can move it to disposal locations without pumps. The *Sludge Basin* can be sized to minimize sludge water loss or in the case of lagoon polishing to optimize sludge return pipe flushing across long distances. This process of pneumatic discharge is implemented without any internal valves or electronics.

Backwash intervals range from a few hours to several times a day depending on the wastewater flow or more specifically, organic loading rate. A unit subject to heavy loading will be backflushed every 2-3 hours, whereas those used for polishing will be set to backflush every day or so. The units should be backwashed often enough to prevent internal bypass of water through the bypass slot in the wall separating the *Reservoir* and the *Screen* area. Bypassed waters fall back into the *Airlift* intake trough.

Some RCPG® models are equipped with a float switch in the reservoir. The switches trigger air input into the charge chamber whenever the head loss across the bead bed reaches a preset level (typically 6-8 inches) avoiding *Reservoir* bypassing. This strategy allows the backwash interval to be optimized in the face of variable loading. These units will automatically adjust backwash frequency in response to hourly load changes. For example, the unit will automatically increase backflush frequency in response to a flow peaking event. Float switches are recommended for units that may be subject to variable or unexpected loading.

RCPG® as a Clarifier

The RCPG® captures suspended solids by the same mechanisms as a granular sand filter (Table 1). In most applications, settling at the microscopic scale is the principal mechanism for the removal of particles above about 30 µm. The use of a 3-4 mm bead encourages removal by settling throughout the bead bed depth. Interception is a major removal mechanism for midrange particles in the 15-50 µm range. Adsorption onto beads or absorption onto biofilm is the principal mechanism for particles in the 1-5 µm range.

Table 1. A PolyGeyser® Captures Solids by Four Mechanisms

Mechanism	Size range (microns)	Comments
Straining	>100 µm	Large particles are captured as they try to pass through small interstitial gaps between beads
Settling	>30 µm	Particles settle out on the topside eddies behind beads
Interception	>15 µm	Gravity or momentum cause particles to deviate from flow lines striking bead surface
Adsorption/Absorption	1-5 µm	Molecules diffusion brings particles in contact with the bead surface or biofilm

Physical straining can be an important process for larger particles (>100 µm) and can trigger short filtration cycles if the bead size is poorly matched to the type of suspended solids, causing surface straining rather than removal throughout the depth. Surface straining issues are rare and can be rectified by layering beads or using a sequence of filters with decreasing bead diameters.

The actual removal realized with a floating bead filter is a function of the flow rate (flux), the bead diameter, the bed depth, the density of the particles, as well as the particle size distribution of the particles suspended in the waste stream. This has been well studied by Aquaculture Systems Technologies (AST®) and other researchers. Yao (1971) reduced these complex interactions into a predictive equation for sand filters, which Louque (2019) calibrated to bead filter data. Thus, that plus extensive empirical measurements makes the solid(s) removal behavior of a floating bead filter predictable.

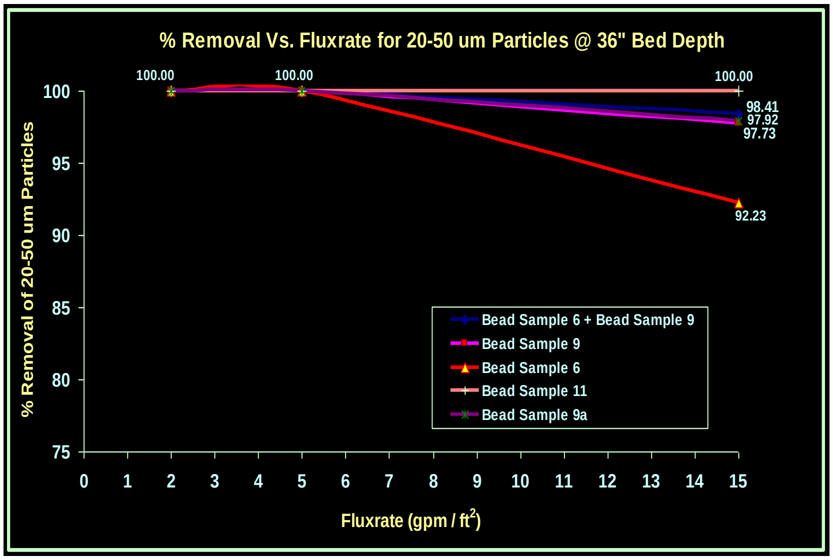


Figure 7. Both standard (9) and Enhanced (6) media are highly effective at removal of particles in the 20–50 µm range with a single pass-through clean bead. With biofilm development removal approaches 100 percent across a wide flux rate range.

Laboratory results (Figure 7) typically show nearly complete removal of suspended particles above 30 µm in the first pass. With 20-40% removal below 10 µm (Figure 8). Single pass units filled with standard media (No. 9) or Enhanced Nitrification (EN) media (No. 6) are highly effective at removal of suspended particles above 30 µm. AST® has tested floating plastic media in a wide variety of shapes and sizes. The finest beads can achieve nearly complete removal down below 5 µm, but these beads are difficult to retain and are subject to biofouling issues in a variety of applications.

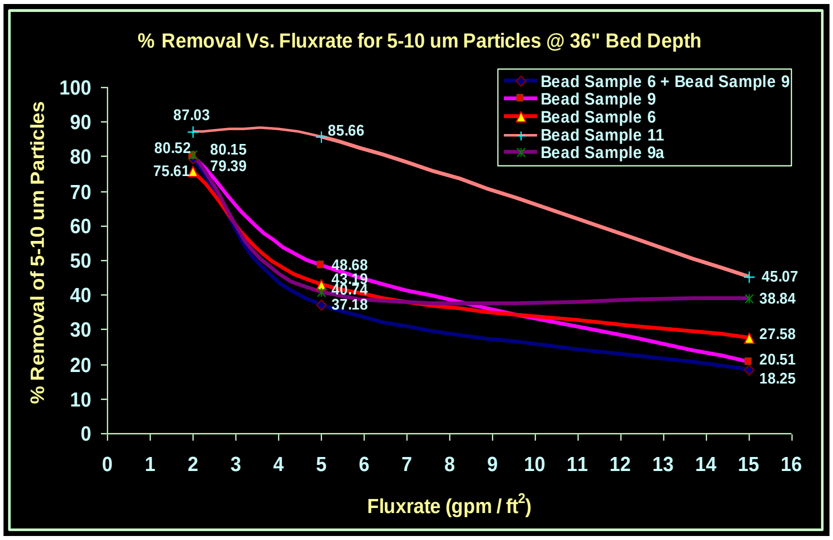


Figure 8. Both Standard media (9) and Enhanced Nitrification media (6) provide partial removal down in the 5-10 µm size in a single pass-through clean bead. Biofilm development improves fine solids capture as does passing the water through the bead several times.

The RCPG® models are designed to support the treatment of wastes with high organic or nitrogenous loading. These are multi-pass units that are excellent at the removal of inert suspended particles and can generally be sized to produce total suspended solids concentrations well below 10 mg/L. However, they are generally packed with larger, 3-5 mm beads that are highly resistant to biofouling problems and thus are inherently limited in their ability to capture particles (<5 μm) that contribute heavily to water clarity (turbidity) issues. If turbidity is an issue, then the use of a coagulant and/or a fine media, using an HPPG polishing unit after RCPG® treatment, or serial RCPG® treatment should be considered to separate fine solids removal from heavy organic loading.

RCPG® as a Biofilter

RCPG® units represent a robust and very manageable fixed film biofiltration unit for the control of readily biodegradable organics and ammonia. The unit can be used with complementary treatment processes to target refractory organics, such as hormones, pesticides, petrochemicals, and other industrial wastes. The RCPG® represents a robust treatment format that can also be used as a roughing filter to treat BOD_5 concentrations measured in the hundreds, or as polisher to achieve the most stringent standards. The EN media used in the RCPG® is designed to support a diverse bacterial population. The EN bead is externally shaped to provide protection to the biofilm during backwash events. With a porosity of about 50%, the bed facilitates the rapid transport of water and oxygen throughout the bead bed. Fast-growing heterotrophic bacteria rapidly fill the pore spaces and are sheared off during a backwash event. Deep pockets provide a habitat for slow-growing, long-lived bacteria. The gently washed (Golz et al., 1999) pneumatic backwashing is tuned to disrupt but not destroy the biofilm. The specific surface area of the bead bed is approximately 1150 m^2/m^3 and consumes virtually all the available oxygen as the water passes though it only to be replaced with fresh oxygen rich waters from the recirculating airlifts.

RCPG® as a Bioclarifier

The typical treatment process calls for the removal of organically rich suspended solids prior to biological treatment which targets dissolved organics, and this BOD_5 must be removed prior to nitrification. This is typically a four-step process: 1) primary clarification, 2) biological treatment, 3) secondary clarification removing biosolids, and, finally, 4) nitrification. This approach is the cornerstone for wastewater treatment trains that optimize each objective before proceeding to the next. This approach has been highly successful for most treatment obstacles but does not necessarily produce the most cost-effective approach.

Using an RCPG® as a bioclarifier provides a cost-effective alternative process this sequential treatment presumption. Giving our technical training, combining solids capture simultaneously with removal of dissolved organics with nitrification is oxymoronic. There is truth in the observation that the dissolution of solids confounds the removal of dissolved organics. And there is truth in the observation that high C/N (organic/ammonia) ratios can inhibit nitrification. But these rules were developed before the linkage between backwashing and water loss was broken, before the benefits of high frequency backwashing could be fully realized.

Gently washed floating bead filters can mitigate the adverse impacts of solid accumulations and organic loading on nitrifying biofilms by adjustments in backflush frequency. Filters managed with high frequency "gentle" washing typically display their highest nitrification capacities at the highest solids and organic loadings. Rapid gentle washing (8-24 times daily) removes solids and shears heterotrophic biofilms without substantially damaging nitrifying films. Conducting four treatment steps in one, results in a substantial economic advantage.

A floating bead bed must be managed to mitigate high loadings, i.e., loading must be matched with the correct backwash frequency. If the backwash frequency is optimized, and the organic loading is then increased. The filter performance will decline until the backwash frequency is proportionally increased. RCPG® units are equipped with bead bed view ports. Look at the beads. If you see bare plastic, then increase the time between backwashes. If the bead looks more like a football than a rowboat, then decrease the time between backwashes. The optimum bead coating looks very similar across a wide band of loading regimes. Manual adjustments in backflush frequency are normally made seasonally. A filter can be made responsive on an hourly basis by adding a float switch to the reservoir. Under constant recirculation conditions, the head loss across a RCPG® bead bed is directly related to the accumulation of solids and biosolids in the bead bed. An increase in biosolids is reflected in an increase in reservoir water surface level.

Setting the float switch to trigger whenever the water level reaches that water level associated with optimum biofilm development will allow the unit to adjust automatically to hourly changes in loading. Of course, it pays to occasionally look at the biofilm through the viewport even when a float switch has been used.

Figure 9. RCPG® 10 was designed for on-site sizing evaluations. This unit is positioned next to a lagoon, linear air pump powers the backwash, unseen rotary vane air blower drives the airlift. Splitter box and PSE sludge discharge lines visible on top and pitot tubes on side for head loss evaluation on recirculation loops.

"Proof is in the Pudding"

The RCPG® 10 is the smallest of the recirculating bead filters. It is designed to be placed on site and operated as a pilot study and provide sizing guidance on new waste streams (Figure 9). Some of these test sites are remote and an RCPG® 10 unit can be (is designed to be) left alone. In some situations, an RCPG® 10 won't even be visited for a week at a time. All RCPG® 10 units deployed to the field are now deployed with float switches since you never know when a bulldozer is going to come in and dig a lagoon up, or a pump is going to lose power for several days, or it rains and the flow to the unit is doubled. Having a float switch allows the filter to be responsive to unexpected change and keep the biofilm near optimum.

Lagoons are mother nature's treatment system. A lagoon, or more commonly a series of lagoons, can be used to reduce a wastewater stream down to the typical 30/30 standard for BOD_5 and TSS respectively. However, as a lagoon ages, the population contributing tends to go up and the lagoon typically starts to fill up and eventually they may fail to meet modern standards; discharge violations typically for BOD_5 or ammonia begin.

An RCPG® can be placed on the bank of a lagoon to treat discharges for suspended solids (usually algae), BOD_5, and/or ammonia simultaneously to eliminate receiving stream impacts. Once, an RCPG® is delivered to a site, instructions are provided, then the AST® staff provides support as the local staff operates the unit and has a third party conduct a sampling and analysis program.

Case study #1: A rural southern lagoon is required to meet new emerging carbonaceous BOD_5 standards (<3 ppm) and ammonia (<1 ppm-N). This is clearly a polishing application. The city has a population of 1300 and a well-trained wastewater treatment staff.

Table 2. Domestic lagoon study with BOD5 and ammonia issues, facing stringent effluent standards in Georgia, Spring 2021 (Case Study #1)

Constituent	**Influent (mg/L)**	**Effluent (mg/L)**	**Conversion (kg/m^3-day)**
Ammonia (n=45)	11.5±3.5	0.71±0.74	1.1±0.34
BOD_5 (n=33)	37.2±11.9	9.9±3.9	1.8±0.78
$CBOD_5$ (n=10)	19.9±5.7	5.6±24	1.4±0.71
TSS (n=40)	20.9±8.6	8.4±4.6	N/A

Here backwashing is manually set, seasonally. The AST® engineers estimate the flow capacity of the RCPG® 10. An eight-month study is conducted through the winter and spring to verify "cold" weather treatment capabilities. Table 2 summarizes the results. As we can see the lagoon is operating reasonably producing a mean lagoon $CBOD_5$ quality of 19.9 mg/L and ammonia at 11.5 mg-N/L. The RCPG® 10 successfully meets the rigorous discharge standards with $CBOD_5$ averaging 5.6 gm/L and ammonia at 0.71 mg-N/L. This is a moderate organic load for this unit and an extended backwash interval proves successful. No statistically significant impact of winter weather is observed. No suspended solids limits were constraining this application but performance in this category was below AST® expectations so our engineers redesigned bubble separation capabilities in later units.

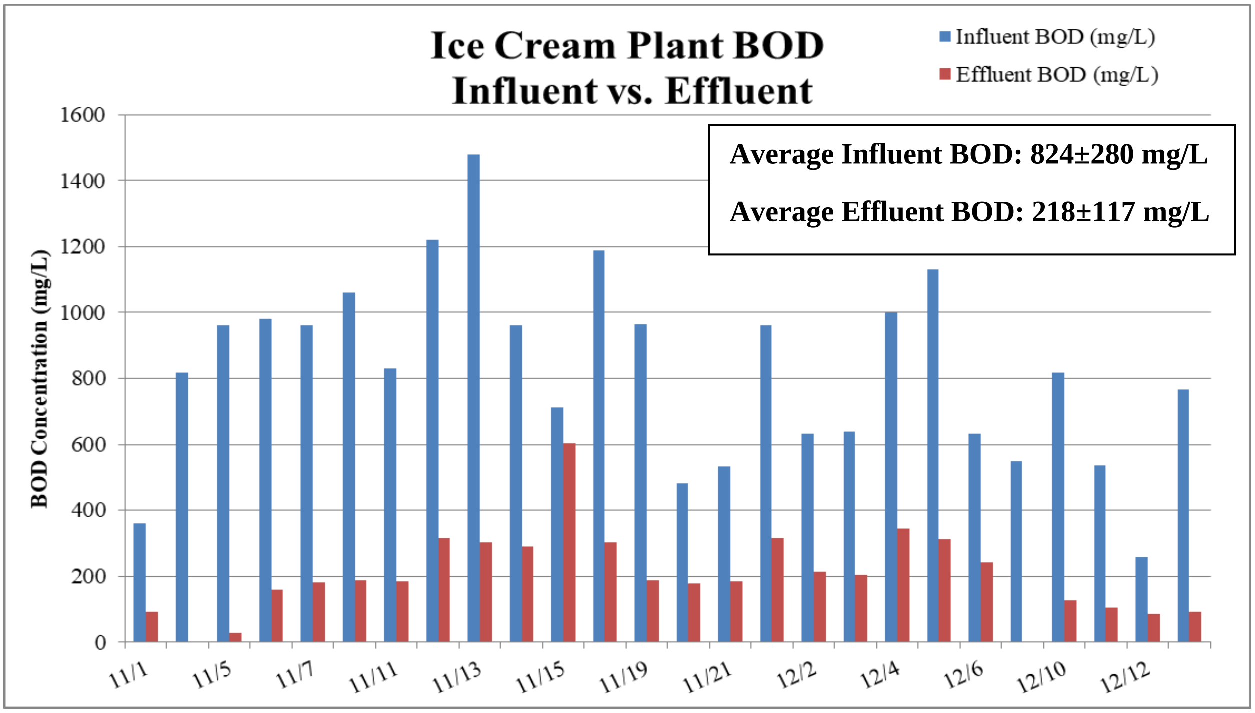


Figure 10. This is a test of the RCPG® 10's ability to handle a high organic load without biofouling. AST® engineers install two RCPG® 10s in sequence to reduce filter sizing. The unit successfully reduces the BOD_5 from a mean of 824 mg/L to 218 mg/L allowing the company to avoid the surcharge structure. (Case Study #2)

Case Study #2: An Ice Cream Production Facility is paying high surcharges for high BOD_5 discharges to local Municipal Wastewater treatment facility. Objective: Lower $CBOD_5$ below 250 mg/L. This is a test of the RCPG®'s ability to handle a high organic load without biofouling. AST® engineers install two RCPG®s in sequence to reduce filter sizing. Backwashing is automatically set with a float switch. Tests are conducted and on average the two serial units obtain a ninety percent reduction in BOD_5. Figure 10 illustrates the results. After a brief period of adjustment, the unit successfully reduces the BOD_5 from a mean of 824 mg/L to 218 mg/L allowing the company to avoid the surcharge structure. The RCPG® was operated as a bioclarifier so some removal may be attributable to direct removal of organic particulate matter. This was clearly a source of largely "readily digestible" organics.

Case Study #3: A meat processing plant is paying stiff surcharges and violating maximum limits for both BOD_5 and TKN in danger of having to reduce production in the state of Georgia. TKN measures both organic nitrogen (in this case, likely proteins) and ammonia, so, the discharge limits can only be met if the units nitrify in the face of heavy organic loading. This evaluation is being conducted in the middle of summer.

Table 3: Meat processing surcharge avoidance pilot study in Georgia with TKN focus, 2022 (Case Study #3)

Constituents	Influent (mg/L)	Effluent (mg/L)	% Removal	Conversion Rate (kg/m^3-day)
BOD_5 (n=10)	974	97	90%	8.1
TKN (n=10)	150	55	N/A	1.6

This is a large complex facility; qualified wastewater staff is in residence at the meat processing operation. After installation, the unit is allowed to acclimate for couple of weeks and the unit is sampled somewhat prematurely. Focus here is on TKN which is causing the municipality the most problems. BOD_5 treatment with minimal adjustment of flows is fine, but TKN results are initially disappointing. Protein is being broken down, but ammonia is not being converted on to nitrate (thus lowering TKN). After a couple of weeks, nitrifiers acclimate and promising TKN results are achieved. AST® engineers observe that most nitrification was occurring in the second filter. Results (Table 3) demonstrate that significant nitrification occurs with heavy BOD_5 loadings. Both units were operated on float switches without adjustment, but without adjustment in backwash frequency in the first unit, it is observed that high C/N ratio did have an adverse impact on nitrification.

Case Study #4: A well operated municipal treatment facility benefits financially from industrial surcharges on ammonia. They wish to improve their ammonia removal capabilities so they can accept more surcharged ammonia loading. Here we have a sophisticated wastewater treatment team. An RCPG® 10 is dropped off and they first install it as a polishing unit at the end of the plant. Happy with the end-of-plant operation, they move it to the front of the plant, post primary settling.

Table 4. This domestic treatment plant in Georgia first used the demo unit to polish the facility effluent (top row) then moved the unit to the head of the plant behind the primary. The results were excellent at both locations. (Case Study #4)

Treatment Site	**NH_3 Influent (mg/L)**	**NH_3 Effluent (mg/L)**	**BOD_5 Influent (mg/L)**	**BOD_5 Effluent (mg/L)**	**TSS Influent (mg/L)**	**TSS Effluent (mg/L)**
Jekyll Island Polishing	0.86±0.46	0.08±0.04	5.11±2.3	2.26±0.5	2.5±0.9	1.13±0.5
Jekyll Island Full Treatment	22.6±1.1	6.7±0.6	75.6±20.0	6.6±4.0	57.3±9.9	3.2±1.7

The results (Table 4) show that not only did the RCPG® 10 perform well as a polisher for ammonia at the end of the plant, but it also performs with excellence at the front of the plant. Here the C/N ratio had little effect on nitrification with inlet $CBOD_5$ concentrations in the range of 100 mg/L. and the AST® engineers get a clear demonstration of the ability of the RCPG® to replace both secondary treatment steps and act as a tertiary filter.

Sizing Process

It was observed in early studies that the $CBOD_5$ removal performance of a recirculating bead filter is a predictable function of loading not concentration. An RCPG® operates as a completely mixed reactor to the extent that the BOD_5 concentration within the unit is defined by the effluent quality, not the influent quality. And the rate of conversion (Kg/m^3 of beads-day) is defined by the product of the influent concentration and flow (Figure 11). The ability of a filter to remove BOD_5 goes up with loading in a non-linear fashion. The AST design curve for BOD_5 conversion (Figure 11) was developed from early field data (Wagener et al., 2003; Bellelo, 2006) from RCPG® type configurations treating domestic wastewater sources. Comparisons to recent field data have not warranted any change although a maximum conversion estimation has been topped off at 10 kg/m^3-day to avoid hard conflicts with the oxygen transport capacity of the RCPG®.

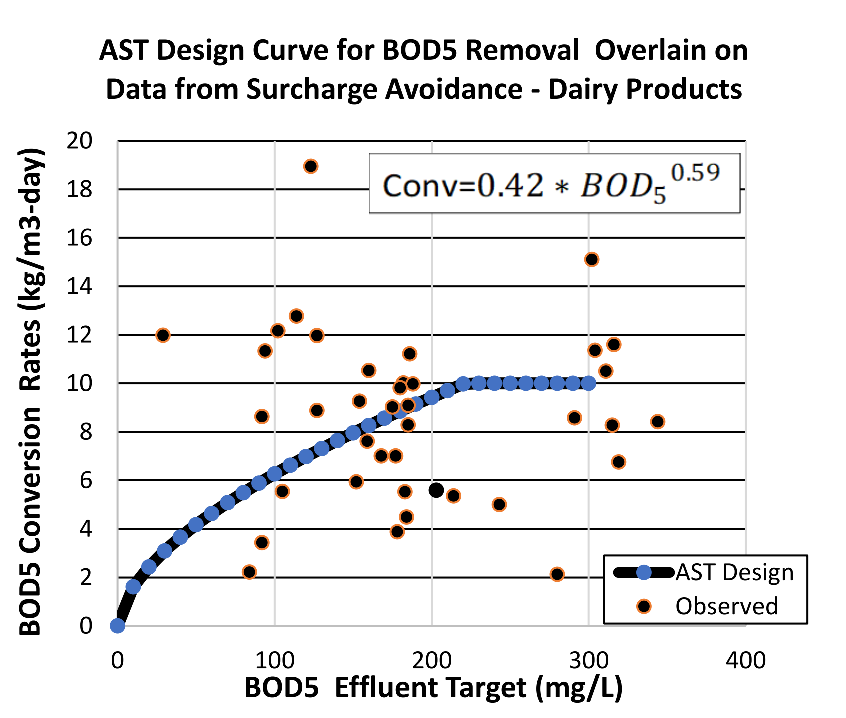


Figure 11. The AST® design curve used engineering overlain on some independently collected BOD5 data shows good agreement sans a safety factor.

The AST® design equation here projected mean operational performance, so design performance is presumed:

$$R_b = \frac{0.42*L_e^{0.59}}{SF} * V_b = \frac{0.42*L_e^{0.59}}{1.5} * V_b$$

And the biodegradation rate must equal the projected load at peak flow:

$$R_b = \frac{0.42 * {L_e}^{0.59}}{1.5} * V_b = Q_{max} * (L_i - L_e)$$

Or solving for V_b:

$$V_b = (1.5 * \frac{Q_{max} * (L_i - L_e)}{0.42 * {L_e}^{0.59}})$$

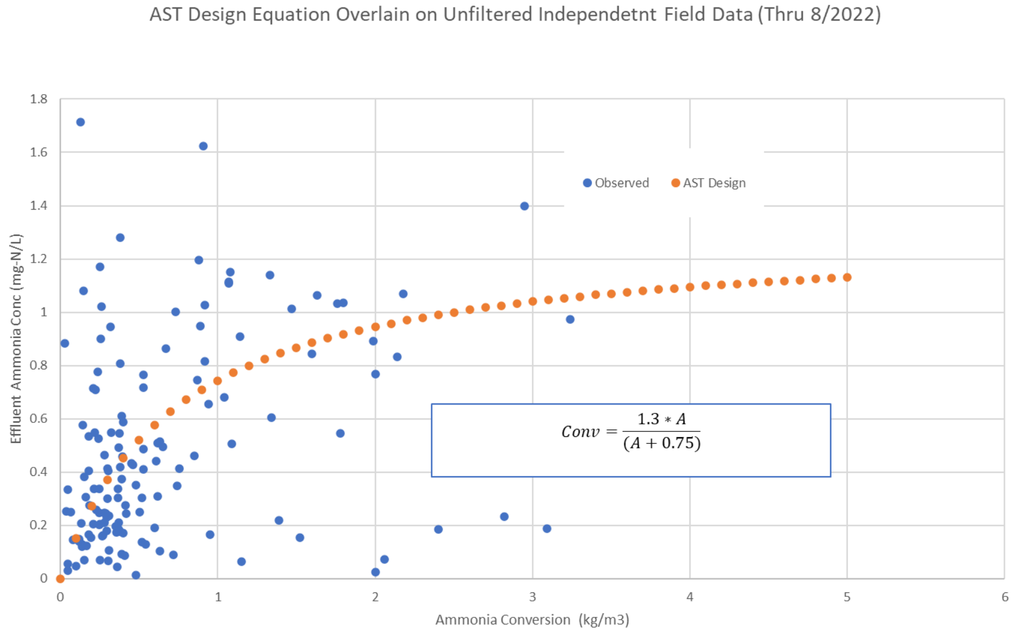


Figure 12. The AST® design curve imposed on independently collected nitrification data shows general agreement sans safety data. Data was not filtered for acclimation and backwashing not optimized so this is not a calibration curve.

Sizing for ammonia removal follows a similar pattern. Figure 12 superimposes the AST® RCPG® Performance Curve on observed data from several RCPG® applications. This figure illustrates how the AST RCPG® Nitrification Performance curve compares to the observed performance observed from several RCPG® applications over the last five years (2017-2022). This data was not filtered for the degree of acclimation, temperature, backflush frequency, carbon loading, or pH. All observations were known to have pH values above 7.0 and sufficient alkalinity (>100 mg-$CaCO_3$/L) for high-rate nitrification. These results are from bioclarifiers that were being used to simultaneously capture solids and reduce organic levels (BOD oxidation). The backwash frequency was not generally optimized for nitrification, as often BOD reduction was the primary objective.

Here the Performance Curve is generated under the common assumption that the process follows a hyperbolic curve that reflects the underlying enzyme kinetics (Michaelis-Menton Kinetics) which in the sanitary field is generally referred to as Monod Kinetics. The mathematics generally, represent a functional relationship between ammonia concentration and the nitrification rate. This rate is linear when the ammonia concentration is low (<1.0) and zero-order when ammonia concentration is high. AST uses a linear relationship (Malone and Pfeiffer, 2006) to describe nitrification in aquaculture applications, but the range of wastewater ammonia standards are so wide that a hyperbolic Monod relationship (Malone et al. 2006) is more appropriate:

$$R_n = \frac{VTR_{max} * A_e}{(A_e + K_a)} * V_b$$

In the United States, the vast majority of ammonia effluent standards are set at values above 2 mg-N/L so it is often assumed that the nitrification performance will be at or near the VTR_{max} value which is currently (2022) believed to be around 1.8 kg-N/m^3-day for units operated for nitrification with reasonably controlled BOD levels ($CBOD_5$<20 mg/l). So, the predominant sizing equation used is:

$$V_b = (1.5 * \frac{Q_{max} * (A_i - A_e)}{1.8})$$

The 1.5 represents a minimal safety factor considering the variability of conditions encountered in practice. Additional safety factor adjustment may be warranted in the definition of the peak loading i.e., the definition of Q_{max} and the associated A_i depending on how the discharge standards are defined.

The oxygen delivery capacity is controlled internally with robust safety factors; thus, catastrophic shortfalls are unlikely. However, it is prudent to sum the oxygen demands for organic oxidation (Assume conservatively, 0.75 mg-O_2 / mg-BOD_5 removed) and nitrification (assume a net of 4.3 mg-O_2/mg-N removed) under the assumption that the recirculation rate is 10 gpm/ft^3 beads (1.33 m^3/m^3-day). A bed effluent concentration of 2 mg-O_2/mg-O_2/L will eliminate concerns about oxygen limitation.

Figure 13. The RCPG® line is fabricated out of 304 Stainless Steel with internal recirculation rates ranging from 100 to 5,000 gpm. Through put flow range from 1-10% of recirculation depending on effluent targets and incoming water concentrations.

RCPG® Models and Capacities

Table 5 provides some sizing and performance estimates for the basic RCPG® line which range in size from 10 to 250 ft^3. (Figure 13) These basic units can be doubled or tripled up to achieve treatments that require intermediate sizing. For example, summary information is provided for the popular RCPG® 500 which is composed of two 250 cubic feet modules. The internal recirculation rate for this family of filters ranges from 100,000 to several million gpd effectively eliminating oxygen as a concern. Estimated conversion rates are provided for BOD_5 and ammonia removal. Basic dimensions and critical elevations are provided along with weights for units in shipping and operation.

Table 5: Select Characteristics of Selected Characteristics of The Base RCPG® Models1)

Characteristic	RCPG® Model					
	10	**25**	**50**	**100**	**250**	**500**
Bead volume (ft^3)	10	25	50	100	250	250x2
Recirc. Flow (mgd)	0.1	0.36	0.72	1.4	3.6	7.2
Air Flowrate (cfm)	30	70	140	280	700	1400
Air pressure (psi)	2	4	4	4	4	4
Blower (hp)	1	5	7.5	10	20	20x2
Voltage	110/210	230/460	230/460	230/460	230/460	230/460
Blower (phase)	1	3	3	3	3	3
Blower (amps)	10	15/7	22/11	28/14	54/27	54/27
Compressor (hp)	1	2	2	2	4	4x2
PSD Volume (gal/cycle)	40	50	100	250	450	900
Recirc Oxygen (kg/day)	2.7	6.8	14	27	68	137
Bead SA (m^2)	326	815	1,630	3,260	8,150	16,300
BOD5 @10 ppm (kg/day)1)	0.46	1.2	2.3	4.6	11.6	23.2
BOD5@30 ppm1) (kg/day)1)	0.88	2.2	8.8	8.8	22	44
BOD5@250 ppm1),2) (kg/day)1)	1	9.4	18.4	37.7	94.3	188
Ammonia @ 0.5 ppm (kg/day)1)	0.25	0.64	1.27	2.55	6.37	12.7
Ammonia>2 ppm (kg/day)1)	0.5	1.3	2.5	5.1	12.7	25.4
Length (inches)	72	70	128	180	159	302
Height (inches)	63	84	84	97	135	135
Width (inches)	49	78	78	100	165	165
PSD peak pressure (in)3	70	105	105	118	154	154
PSD Elevation (in)3	58	82	82	93	130	130
Reservoir Bypass (in)3)	56	81	81	93	128	128
Outlet Elevation (in)3	35	57	57	63	81	81
Screen Elevation (in)3	43	65	65	76	102	102
Hull Weight (lbs)	1,500	5,000	7,500	11,000	15,500	13,750
Bead Weight (lbs)	275	688	1,375	2,750	6,875	13,750
Operational wt.	8,000	14,500	25,500	48,000	85,500	170,000

1) Base models can be assembled in series of 2-3 to achieve serial treatment to raise capacity.

2) Average projected conversion at 25°C; no safety factor

3) Inches above slab

4) Inches above slab to sludge discharge pipe invert

Glossary & Index of Terms and Definitions

AST®	Aquaculture Systems Technologies, LLC
BOD	Biochemical Oxygen Demand
CBOD$_5$	Carbonaceous Biochemical Oxygen Demand (Day 5)
C/N	Carbon to Nitrogen Ratio
EN	Enhanced Nitrification
HPPG	High Profile PolyGeyser
pH	Potential of Hydrogen or Power of Hydrogen
RCPG®	Recirculating PolyGeyser
RCPG® 10	Recirculating PolyGeyser with a Bead Volume of 10 ft^3
RCPG® 25	Recirculating PolyGeyser with a Bead Volume of 25 ft^3
RCPG® 50	Recirculating PolyGeyser with a Bead Volume of 50 ft^3
RCPG® 100	Recirculating PolyGeyser with a Bead Volume of 100 ft^3
RCPG® 250	Recirculating PolyGeyser with a Bead Volume of 250 ft^3
RCPG® 500	Recirculating PolyGeyser with a Bead Volume of 500 ft^3
RCPG® 750	Recirculating PolyGeyser with a Bead Volume of 750 ft^3
SBOD$_5$	Soluble Biochemical Oxygen Demand (Day 5)
TAN	Total Ammonia Nitrogen
TSS	Total Suspended Solids
TKN	Total Kjeldahl Nitrogen – Sum of Organic Nitrogen, Ammonia, & Ammonium
30/30 Standard	30 mg/L: 30 mg/L

Glossary & Index of Mathematical Terms and Definitions

amps	Ampere – Base unit of electrical current in SI units
A_e	Total ammonia nitrogen concentration in the filter effluent ((g-N)/m^3)
A_i	Ammonia concentration flowing into the filter at peak flow ((g-N)/m^3)
°C	Temperature unit: degrees in Celsius
cfm	Cubic feet per minute
ft	Feet
ft^3	Cubic foot
gpd	Gallons per day
gal/cycle	Gallon per cycle
gpm	Gallons per minute
gpm/ft^3	Gallons per minute per cubic feet
hp	Horsepower
K_a	Ammonia concentration when VTR is at 50% of VTR_{max}
kg/m^3	Kilograms per cubic meter
kg/m^3-day	Kilograms per cubic meter of day
kg-N/day	Kilograms of nitrogen per day
kg/day	Kilograms per day
L_e	Effluent BOD_5 quality targeted (mg/L)
L_i	BOD_5 concentration in the water (mg/L)
lbs.	Pounds (mass)
mg/L	Milligrams per liter
mm	Millimeters
m^2/m^3: m^{-1}	Square Meter per cubic meter
m^3/m^3-day	Cubic meter per cubic meter of day
mg-O_2	Milligrams of oxygen
mg-BOD_5	Milligrams of biochemical oxygen demand (Day 5)
mg-$CaCO_3$/L	Milligrams of calcium carbonate per liter
mgd	Millions of gallons per day
mg-N/L	Milligrams of nitrogen per liter
µm	Microns
ppm	Parts per million
ppm-N	Parts per million of nitrogen
psi	Pounds per square inch
Q_{max}	Maximum design flow
R_b	Rate of BOD_5 Conversion (kg-BOD_5/ day)
R_n	Rate of nitrification (kg-N/day)
SF	Safety factor
V_b	Packed bead bed volume (m^3)
VTR_{max}	Maximum volumetric nitrification rate
wt.	Weight

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