Performance of Textile-Based Packed Bed Filters

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Abstract

Small and decentralized wastewater systems may range from individual onsite systems to complete cluster systems. Among the many benefits of onsite and cluster systems is their ability to treat *septic tank* effluent to ***advanced wastewater treatment*** standards (AWT) or better. Many onsite technologies do it more reliably, more affordably, and with considerably less environmental impact than centralized sewers.

For the past couple of decades, packed bed filters (PBFs) — such as single-pass sand filters and recirculating sand and gravel filters — have successfully provided consistent and reliable treatment for small to medium wastewater flows. Textile-based packed bed filters, incorporating an engineered treatment medium, have greatly expanded packed bed technology options by incorporating a manufactured media that is easily serviced and capable of producing high quality effluent. The effluent quality produced by these units is consistently superior to that discharged by the majority of our nation's municipal treatment facilities and is ideal for many water-reuse applications.

Keywords: textile, packed bed filter, decentralized, primary treatment, secondary treatment, advanced wastewater treatment, dispersal, water reuse

Introduction – Packed Bed Filter Technology

Packed bed filters (PBFs) incorporating naturally occurring treatment media such as sand and gravel have been used successfully for treating small to medium volume wastewater flows for decades. These filters produce high quality effluent that is superior to that discharged by the majority of our nation's municipal treatment facilities. Over the past three decades, two types of packed bed sand filters have been most commonly used—the single-pass filter and the recirculating filter. Single-pass sand filters, as illustrated in Figure 1, are capable of treating septic tank effluent to advanced wastewater treatment (AWT) levels or better.

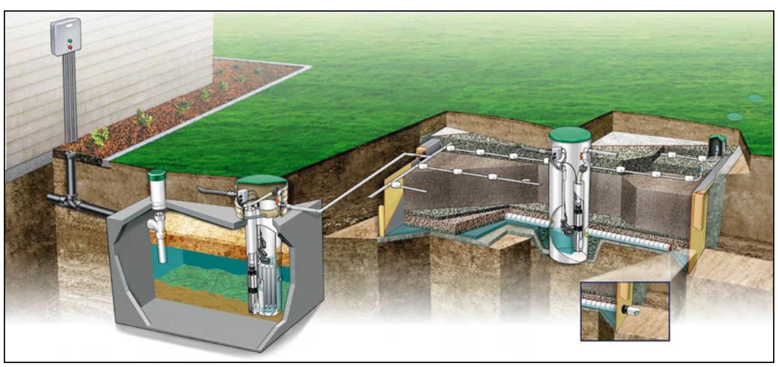

Figure 1: Single-pass sand filter (ISF)

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The following effluent characteristics are typical averages achieved by single-pass residential sand filters using "washed" ASTM C-33 concrete aggregate with less than 2 percent fines passing the 100 sieve:

$cBOD_5$: 5 mg/L
TSS: 5 mg/L
NO_3-n: 30 mg/L

Single-pass sand filters have typically been used in onsite applications for single-family homes or small commercial/office facilities.

Single-pass filters have been most successful when the influent has received primary septic tank treatment and screening with effluent filters to sufficiently ensure that the effluent characteristics applied to the sand filter do not exceed the typical criteria shown in Table 1:

Table 1: Typical Primary Treated and Screened Residential Wastewater Strengths

	Average *mg/L*	**Weekly Peak** *mg/L*	**Rarely Exceed** *mg/L*
BOD_5	130	200	300
TSS	40	60	150
TKN–n	65	75	150
G&O	20	25	25

With higher influent strengths, maintenance may increase, although with a diligent service and monitoring program, performance is not expected to suffer. Typical single-pass sand filter design criteria are:

Type of Operation	**Design Loading Rate** *gpd/ft^2*	**Filter Depth** *inches*	**Effective Size** *D_{10}, mm*	**Uniformity Coefficient** *C_u*	**Dose Limit** *gal/orifice/dose*
Single pass	1.25	24 ±	0.30 ±	3 to 4	0.25

Recirculating (multiple-pass) filters also treat septic tank effluent to advanced wastewater treatment levels or better. Below, in Figure 2, a typical recirculating filter is shown.

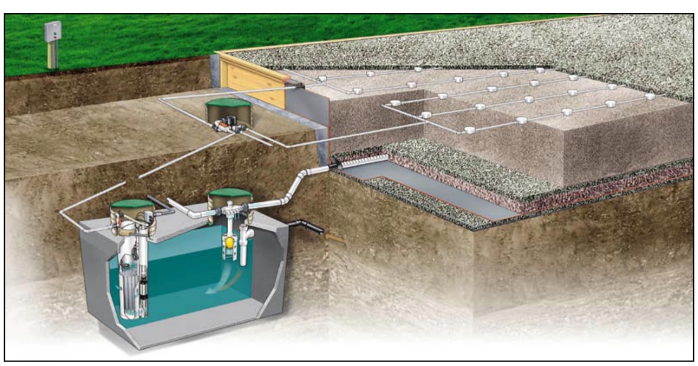


Figure 2: Recirculating sand filter (RSF)

Multiple-pass recirculating sand/gravel filters typically achieve the following average effluent levels:

$cBOD_5$: 10 mg/L
TSS: 10 mg/L
NO_3-n: 30 mg/L

Multiple-pass recirculating sand/gravel filters (RSFs or RGFs) have been most popular in applications with medium to large wastewater flows. They are ideal wastewater treatment systems for parks, restaurants, schools, office complexes, and large developments, and they are especially suited for communities with STEP and/or STEG effluent sewer collection systems. Typical multiple-pass recirculating sand/gravel filter design criteria are:

Type of Operation	**Design Loading Rate** *gpd/ft²*	**Recirc Ratio** R:R	**Filter Depth** *inches*	**Effective Size** *D_{10}, mm*	**Uniformity Coefficient** *C_u*	**Dose Limit** *gal/orifice/dose*
Recirculating	5	5:1	24	1.5 to 2.5	2	0.5 to 1.5

While sand/gravel media PBFs are, and will continue to be, an excellent choice for wastewater pretreatment, certain limitations have prevented them from being considered at all sites:

- **Land area** — Some sites lack the land area required for a sand filter. Single-pass sand filters for single-family homes typically require between 300 and 400 square feet, depending on jurisdictional design or flow criteria.

- **Media quality and accessibility** — Good quality sand media is occasionally not locally available, resulting in either high transportation costs or the use of inferior local media. In addition, getting sand to some sites—such as islands, mountainous regions, or other isolated areas—can be difficult.

- **Installation quality** — Sand filters are typically built onsite with locally available materials, and the quality of installation is partially contingent on the consistency of these materials, and the knowledge and ability of the installing contractor.

- **Serviceability** — The ease of maintaining a buried onsite single-pass sand filter has been a long-term design concern that resulted in robust designs with low loading rates. The low loading rates are intended to ensure 10 to 20 years of continuous usage with little to no intrusive filter maintenance because replacing the sand media can be difficult and costly.

Textile-Based Packed Bed Filters

The efforts to improve loading capacities and serviceability have led to extensive research into a wide variety of media (e.g., foam, glass, styrene, plastic products, expanded clays, zeolite, limestone, furnace slag, peat, etc.). Over the past decade, this research has led to the development of an advanced technology for packed bed filters that uses an engineered textile medium assembled in a variety of configurations. Textile provides all the benefits inherent in the packed bed filter design but overcomes the limitations listed above.

- **Land area** — The land area needed is significantly smaller than that for sand filters because loading rates are 5 to 30 times higher (typically, 15-30 gpd/ft^2 with peak flow capacity/factor (PF) of 2.0 or greater, based on residential effluent quality as described in Tables 1 and 2). Thus, the footprint area for a textile filter serving a typical four-bedroom single-family home is now only about 20 square feet. If the textile filter is positioned over the processing tank, virtually no additional area is required.

- **Media quality and availability** — The manufactured textile medium ensures consistent quality and availability.

- **Installation quality** — Lightweight textile medium (4.0 lb/ft^3) and small filter size make pre-manufactured treatment units practical, eliminating onsite construction and reducing installation time, labor, and construction errors. These characteristics make textile systems ideal for cost-saving self-help programs and particularly suited for difficult-to-access and remotely located sites.

- **Serviceability** — Special configurations allow for ease of maintenance and cleaning without expensive or large excavation equipment, or the need for replacing the medium. A single-family residential filter can now be cleaned and serviced in as little as an hour.

The initial research on the textile medium began with small chips or "coupons" with a complex fiber structure, which offered an extremely large surface area for biomass attachment. Later research has been focused on developing textile filter blends and configurations that address early packed bed filter issues regarding ease of serviceability without sacrificing equivalent performance.

Porosity, attached growth surface area, and water-holding capacity contribute to the textile media's treatment performance.

- **Porosity** — The porosity of the textile media is several times greater than that of sand, gravel, and other particle-type mediums. The more porous the medium, the greater its hydraulic conductivity, the greater its air space (which enhances the capacity of passively ventilated systems and free air movement), and the greater its capacity for the accumulation of solids and biomass development.

- **Surface area** — Textile media can be blended with a variety of fibers to achieve relatively large total surface area per unit volume (ft^2/ft^3). In current media blends, the typical attached-growth surface area is 4-8 times greater than recirculating filter media. Expanding the biomass growth area provides a greater surface potential for air and effluent to interface and come in contact with the biomass.

- **Water-holding capacity** — The water-holding capacity of textile media also varies considerably depending on the media density, type of material, and blend of fibers. The water-holding capacity in textile media is also several times greater than expected in the sands and gravels used in filters. Water-holding capacity performs a key function in the treatment process. Together with the programmed dosing time and frequency, it governs the effluent retention time within the filter and ultimate effluent quality. In Figure 3, complex fiber structure and void space of textile fibers is compared to that of typical 0.30-mm and 1.5-mm sand particles.

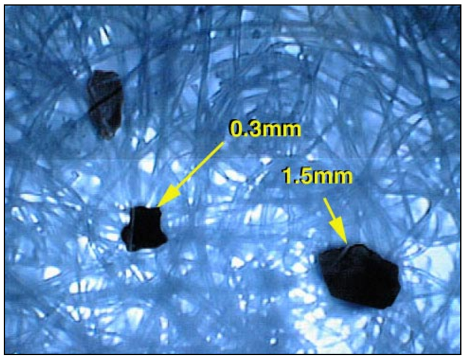


Figure 3: Textile fiber porous structure, relative to sand and gravel particles

Performance of Textile-Based Packed Bed Filters

In the past three years, performance evaluations have been conducted and reported on by facilities such as the University of California, Davis Campus; NSF International; and NovaTec Consultants, Inc. of Vancouver, British Columbia. The University of California Davis study (Leverenz, et al., 2000) was conducted following standard method composite sampling and testing procedures. The evaluations performed by NSF International and NovaTec Consultants (Vassos and Turk, 2002) were conducted per ANSI/NSF Standard 40 protocol. The ANSI/NSF Standard 40 evaluation resulted in the first ever certification of a packed-bed textile filter under ANSI/NSF Standard 40 for Residential Wastewater Treatment Systems. Over the course of the NSF40 evaluation, the average effluent $cBOD_5$ was 5 mg/L and the average effluent TSS was 4 mg/L at a hydraulic loading rate of 29.1 gpd/ft^2. The units evaluated contained vertically aligned textile sheets (AX) as shown in Figure 4. The evaluations successfully established the ability of this configuration to meet advanced wastewater treatment levels and surpassed, by a considerable margin, the effluent quality performance requirements established by ANSI/NSF Standard 40 for Class I effluent.

Figure 4: AX20 AdvanTex® filter with aligned textile sheets

Additional performance evaluation demonstrated the ability of the unit to function under peak design hydraulic and solids-loading conditions for extended periods of time, without service. Over a span of nearly 14 months, NovaTec Consultants (Vassos and Turk, 2002) continuously evaluated performance under peak hydraulic loading conditions (HLR). For 10 of those months, the HLR exceeded 60 gpd/ft^2, and for a period of about 3.5 months the loading rate was 48.3 gpd/ft^2.

During these evaluations, influent organic levels and solids loading levels reached or exceeded peak monthly limits, with daily influent levels reaching highs of 525 mg/L $cBOD_5$ and 1600 mg/L TSS. This demonstrated the resiliency of this unit, under adverse conditions, to consistently produce secondary and advanced treatment quality effluent.

Figure 5 illustrates the relative levels of effluent quality achieved by the three AX units throughout these evaluations. The graph represents over 360 data days of composite sampling over a time span of more than two years.

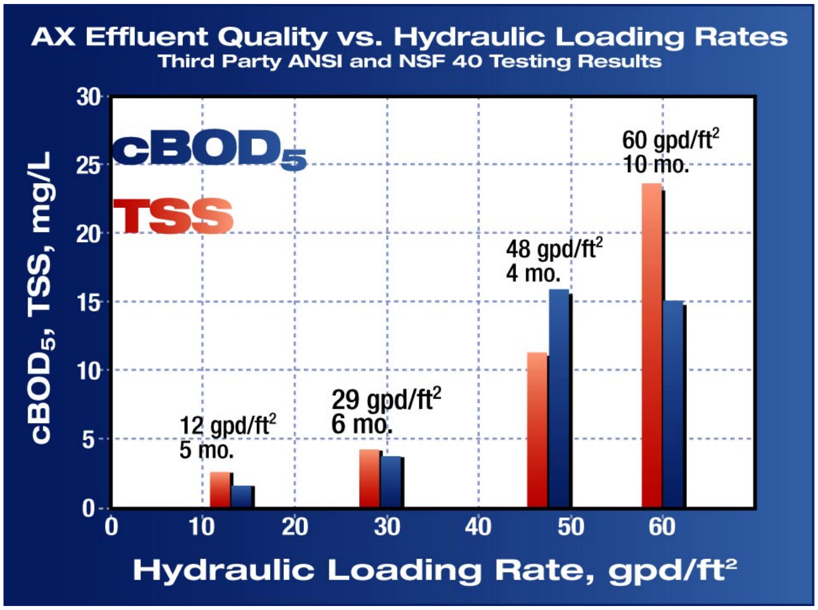


Figure 5: Effluent quality achieved relative to actual hydraulic loading rates

Figures 6a and 6b illustrate the correlation between $cBOD_5$ and TSS removal and direct influent loads, as well as the system's strong removal capacity, overall.

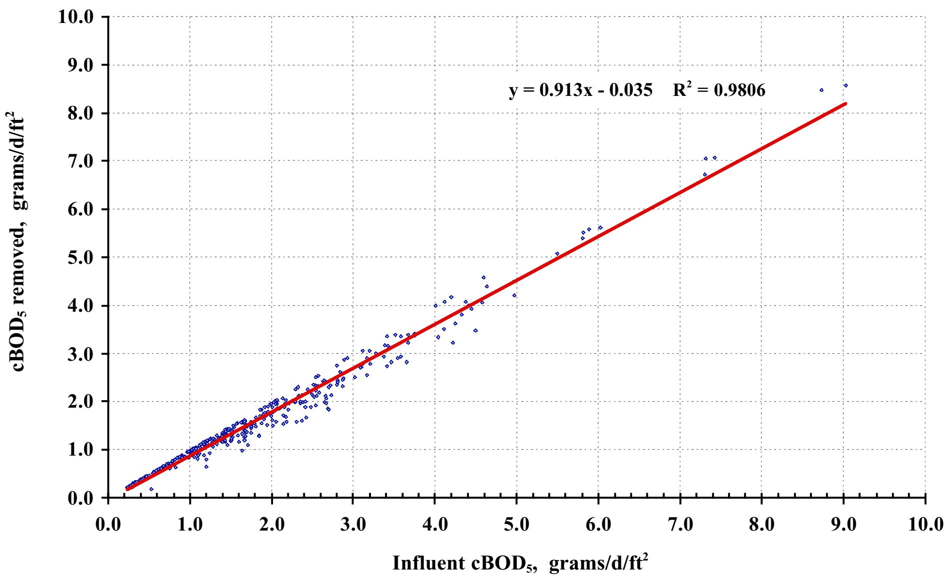


Figure 6a: $cBOD_5$ removal relative to influent loading

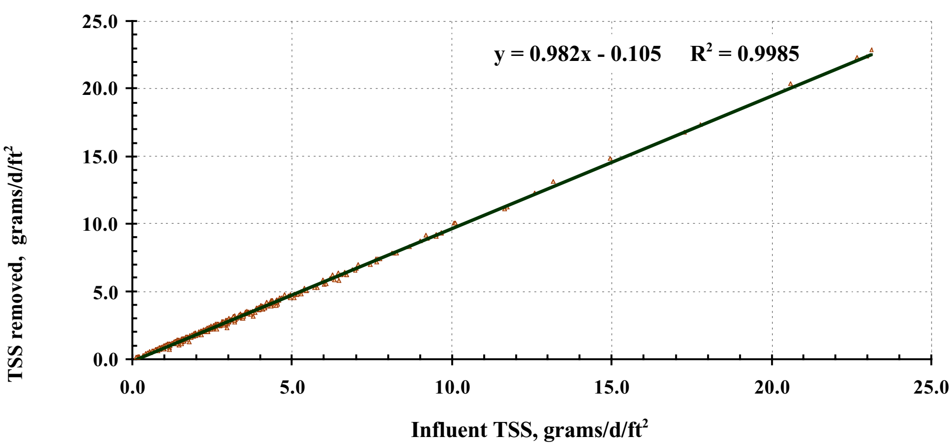


Figure 6b: TSS removal relative to influent loading

Textile filter performance, showing effluent quality consistently better than 10/10 mg/L $cBOD_5$ and TSS has also been documented in several case studies (Bounds/Ball, 2000). Textile filters are currently being used in more than two thousand commercial, cluster, and residential sites across the U.S and Canada.

Additional Attributes of Packed Bed Filters

All small-scale wastewater systems serving individual homes or clusters of homes need to meet the following requirements:

- Quick startup
- Efficient performance with highly variable wastewater strengths and flows, including occasional hydraulic and biologic overloads
- No release of untreated sewage if a malfunction occurs

- Consistent trouble-free operation; low maintenance (e.g. annual service call recommended; on-site routine service time 1 hour ±)
- Ease of maintenance (components should be easily accessible and serviceable)
- Low energy consumption
- Adequate storage during power outages (normally 24 hours or more at typical flows)
- Recoverable and expandable
- Reliability in providing the level of treated water required to final dispersal treatment processes

Packed bed filters are inherently well suited for small-scale wastewater systems. They meet and typically exceed the above-listed requirements, due to the design and operational features described below:

The Role of Watertight Tanks
Watertight septic tanks, which precede PBFs, provide several benefits:

1) Allow primary settling of solids so that the packed bed filter treats largely liquid waste,
2) In conjunction with programmable timer controls, modulate and buffer large and uneven inflow, and
3) Provide emergency storage during power outages or equipment breakdowns. In multiple-pass recirculating PBFs, the recirculation tank provides even more buffering capacity by diluting the incoming septic tank effluent with treated effluent, to mitigate the effects of organic shock loading.

"Fail-safe" design — Most PBF designs do not allow completely untreated sewage to be released since, unlike passive gravity-in/gravity-out systems, wastewater must pass through the treatment media before discharge. This feature also prevents deliberate attempts to disable the treatment system. With passive gravity-in/gravity-out suspended growth aerobic systems, it is not uncommon for users to "unplug" their aeration system to lower their electrical bill. With typical packed bed filters, only the filtrate is discharged, ensuring high effluent quality dispensed for final dispersal.

Flow management — PBF systems with programmable timers in their control panels have the ability to detect excessive inflow caused by infiltration, leaky plumbing fixtures, or higher-than-normal water consumption by the user. This "flow management" provided by the programmable timer is a fundamental tool that allows operators to detect and diagnose problems that would otherwise go undetected until complete system failure. The programmable controllers also provide improved treatment through frequent "micro-dosing" of the PBF.

Speed of startup — The startup capability of PBFs is generally unsurpassable. Since PBFs utilize mechanical filtration as a means of physically removing matter, they are able to achieve high levels of effluent quality within hours of startup. The textile filters evaluated under the testing protocols described earlier demonstrated the ability to remove more than 80% $cBOD_5$ within the first day of operation, and TSS concentrations under 15 mg/L were measured.

Low power requirements — Power costs are low because of the intermittent operation of small fractional horsepower pumps. A typical single-pass PBF for an average single family home only requires 4-12 kWh/mo. At the national average of 8 cents per kWh, the power cost ranges from 32 to

96 cents per month. Depending on the operating recirc-ratio, multiple-pass recirculating PBFs may cost 3 to 5 times more to operate than single-pass PBFs, depending on the operating recirc-ratio.

Low routine maintenance requirements — Annual routine maintenance for PBFs is recommended and normally includes inspection of effluent for clarity (e.g., turbidity, grease and oily films, foam, color, etc.) and odor, as well as cleaning pump filters and flushing distribution piping if necessary. Because PBFs are designed to limit cell mass growth by controlling the organic loading rate and encouraging endogenous respiration, sludge removal is not required from the PBF itself. Solids do build up in the septic tank and must be removed periodically. The pumping of septic tank solids can be as infrequent as every 12 years or more, if solids accumulations are "monitored" every 2-3 years to determine when the tank actually needs pumping.

Ease of maintenance — Maintenance of pre-manufactured, packaged PBF's is particularly service friendly and especially suited for management programs, due to a) Training and certification of installers and service providers, b) Detailed installation and operation manuals that identify specific sevice, testing and troubleshooting techniques, c) Specially engineered mediums, as shown in Figure 9, that can be cleaned with a small pressure washer in the event of system abuse or overuse and put back into service within a matter of minutes, and d) Controls that monitor and alert service providers directly upon electro-mechanical malfunctions, as well as water usage and system functioning abnormalities.

As a result, the management of onsite systems can be as user-friendly, effective, reliable, and trouble-free as the municipal gravity alternative and, in the event of an individual malfunctions, much more manageable and environmentally friendly.

Figure 9: Typical servicing of AdvanTex textile medium. (An underdrain valve is opened during a filter washdown that allows sloughed solids to flush back into the process tank, so there is no removal or wasting of media.)

General Design Considerations

In more than 12 years of research with textile media, several design variations have been tested in both intermittent and recirculating operations and in several different multi-pass recirculating "modes," which optimize nutrient reduction. Like commercial sand and gravel filter installations, commercial textile filter installations are typically operated in multiple-pass recirculating modes. However, unlike residential sand filter installations, which are normally operated as single-pass systems, residential textile technology filters are also configured as multi-pass, recirculating systems, as shown in Figure 7.

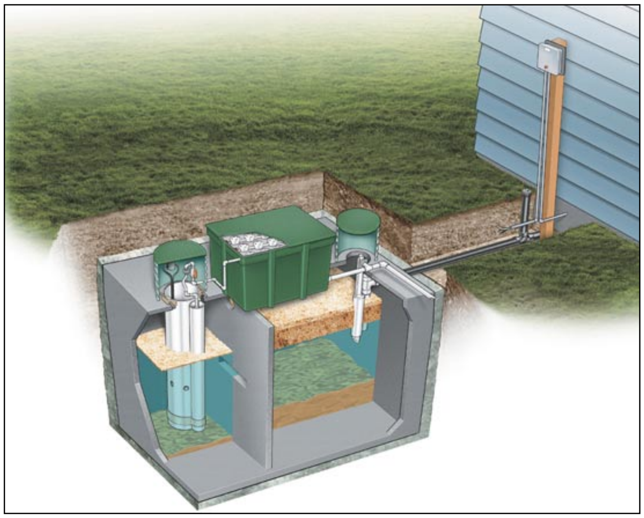


Figure 7: Perspective view of textile filter unit and processing tank system

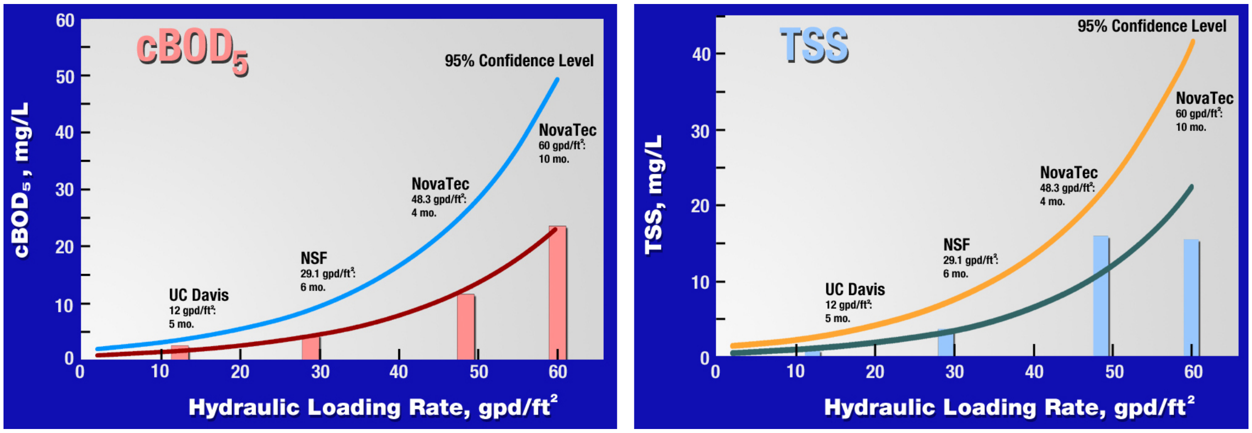
Because the loading rates are dependent on the influent characteristics, a careful and critical evaluation of the contributing source(s) is the first crucial step in adequately accounting for the filter's design size and capacity. Hydraulic, organic, and inorganic inputs (loads) are characteristics that will play critical short and long-term parts in all wastewater treatment designs.

In single-pass applications, it is common to find a screened pump vault located at the outlet of the septic tank, where the septic tank's effluent is drawn from the clear zone of the tank in a decanting manner. The screened effluent is often dosed directly to the single-pass filter. In multiple-pass recirculation processes the clear-zone supernatant discharges into a secondary chamber or tank, which is typically called the recirculation, recirc/blend, or dilution/blend chamber or tank. Typically primary treated effluent from a septic tank *should not average higher than the following parameters, shown in Table 2,* when being further treated by *onsite* filtration and disposal:

Table 2: Typical Residential Wastewater Characteristics

Source	Flow *gpcd*	BOD_5 *mg/L*	TSS *mg/L*	Grease *mg/L*	Reference
Raw Domestic Sewage	*47*	*371*	*338*	*73*	*EPA, M&E Building sewers*
Raw Domestic Sewage	*50*	*450*	*503*	*164*	*Crites-Tchobanoglous, SDWM-1998*
Septic Tank Effluent	*48*	*156*	*84*	*17*	*EPA non-screened ST effluent*
Screened ST Effluent	*60*	*133*	*30*	*n/a*	*Screened ST effluent (12 Communities)*

Designing at 95% confidence levels, as shown in Figure 8a and 8b, tends to ensure reliability in meeting discharge limits consistently within the variability of the occasional excessive loading and operating conditions.



Figures 8a and 8b: AdvanTex® effluent quality relative to hydraulic loading rates, at 95% confidence levels

Conclusion

Test data from residential and commercial packed bed filters incorporating textile media has shown that textile filters provide consistent, high quality wastewater treatment: better than 10/10 $cBOD_5$/TSS. Consequently, they have proven to be an ideal solution in the following, diverse applications:

- New onsite wastewater treatment systems
- Repairs and reclamation projects
- Jurisdictions requiring nutrient reduction
- Seasonal or periodically used facilities
- Facilities with extreme variations in daily flows
- Overloaded single and multiple-pass sand and gravel filters
- Wherever water reuse is essential

Moreover, effluent sewers incorporating textile filter treatment units can be used to replace failing conventional collection and treatment systems.

Because textile is lightweight, it can be incorporated into small, affordable, pre-manufactured treatment units. And because the units are modular, they permit easy system expansion in the event of continued over-use or under-design.

Orenco's AdvanTex® brand textile packed bed filters have made a major impact in addressing user, environmental, and management issues relating to onsite wastewater treatment. Like many onsite technologies, AdvanTex® brand textile packed bed filters treat wastewater more reliably, more affordably, and with considerably less environmental impact than centralized sewers do. With designers, regulators, distributors, installers, maintenance personnel, and users all working together to deliver a high quality, highly serviceable product, textile packed bed filters can help us take a significant step towards demonstrating the viability of decentralized and onsite systems.

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