GLOBAL WATER PATHOGEN PROJECT

PART FOUR. MANAGEMENT OF RISK FROM EXCRETA AND WASTEWATER

MEDIA FILTERS: TRICKLING FILTERS AND ANAEROBIC FILTERS

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Summary

Media filters are a sanitation technology that use microorganisms that are attached to a high surface area medium to primarily remove soluble organic matter (measured as BOD or COD) as wastewater passes through the medium. Trickling filters use aerobic processes for treatment while anaerobic filters operate under strict anaerobic conditions. Media filters are typically used for the treatment of wastewater in centralized sewerage systems serving urban areas. They can also be used in on-site wastewater treatment systems serving individual dwellings, industries, apartment complexes, and housing clusters. All media filters require primary treatment of suspended solids to avoid clogging of the filter media. Because media filters are designed to remove soluble organic matter, they should not be expected to have high pathogen removal rates. The few available data for properly designed and operated trickling filters integrated with primary and secondary sedimentation suggest removal, at best, of 1.0 log_{10} removal of bacterial pathogens (*Salmonella*), 0.5 log_{10} removal of viruses, 0.8 log_{10} removal of protozoa cysts/oocysts, and 1.4 log_{10} removal of *E. coli* and thermotolerant coliforms. Tricking filters integrated with primary and secondary sedimentation and chlorine disinfection are reported to remove up to 2.8 log_{10} viruses and 1.5 log_{10} protozoan cysts (*Giardia*). Anaerobic filters preceded by primary sedimentation (septic tanks) are reported to remove up to 1.9 log_{10} of fecal coliforms.

Media Filters: Trickling Filters and Anaerobic Filters

1.0 Brief Technology Description

Media filters use microorganisms that are attached to a high surface area medium to primarily remove soluble organic matter (measured as biochemical oxygen demand (BOD) or chemical oxygen demand (COD)) from wastewater as it passes through the medium. Trickling filters use aerobic processes for treatment while anaerobic filters operate under strict anaerobic conditions (Metcalf & Eddy/AECOM, 2014; Chernicharo and Goncalves, 2007; Chernicharo, 2007). Trickling filters and anaerobic filters are also referred to as biofilm reactors and attached-growth processes, which also include rotating biological contactors (biodiscs), submerged aerated biofilters, and various emerging and proprietary technologies (Chernicharo and Goncalves, 2007; Metcalf & Eddy/AECOM, 2014). Constructed wetlands, which are a planted media variant of media filters are covered in detail in Section 60I. Media filters are used for the treatment of domestic and industrial wastewaters in centralized sewerage systems serving urban areas; they can also be used in onsite wastewater treatment systems serving individual dwellings, industries, apartment complexes, and housing clusters. (Figure 1 shows where media filters are used within the sanitation service chain.) Due to a lack of data in the literature on pathogen removal in the various media filters, this chapter will focus on the two most common and studied technologies: trickling filters and anaerobic filters. Historical information on pathogen fate in media filters is available in Feachem et al. (1981, 1983).

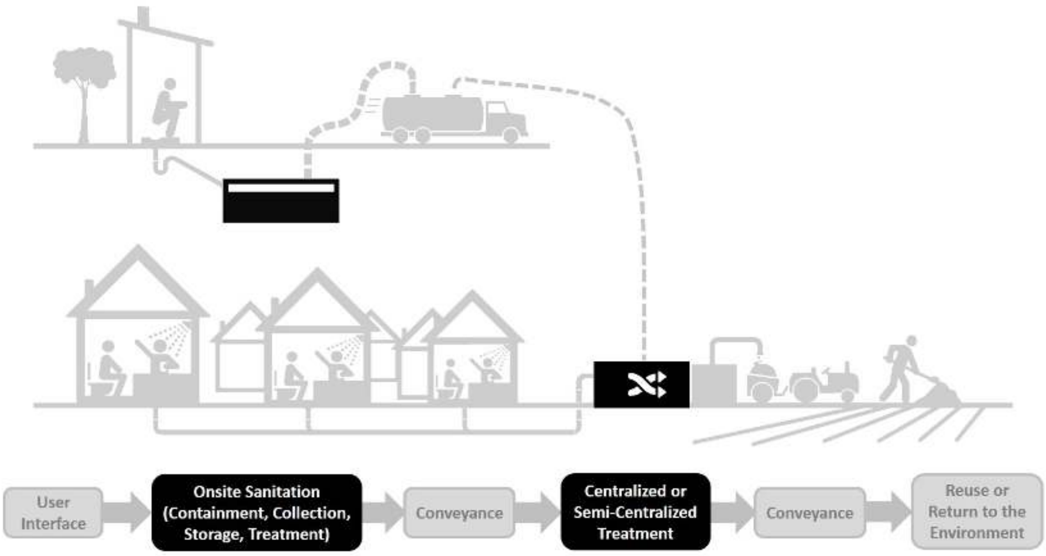

Figure 1. Locations where media filters are used within the sanitation service chain

All media filters require primary sedimentation (suspended solids removal) of the influent to avoid clogging of the filter with solids. In a trickling filter, the influent wastewater is distributed on the top surface and passes vertically downwards (trickles) through a permeable medium (e.g., rocks or plastic). Figure 2 shows a schematic of a trickling filter and Figure 3 shows the components. As the water flows downwards, soluble organic matter is removed by aerobic heterotrophic microorganisms that are contained in a biofilm attached to the medium. The biofilm gradually grows as it comes into contact with the passing wastewater. Aeration occurs through natural convection of air through ventilation ports connected to the underdrain system at the filter base. The filter medium is unsaturated, that is, after the liquid has trickled down, the porous spaces are occupied by air, thus guaranteeing aerobic conditions. As the biofilm grows parts of the biofilm periodically fall off and leave the filter with the effluent through the underdrain system, a process called sloughing. As a result, trickling filters require secondary sedimentation to remove the sloughed biofilm which are measured as suspended solids. Figures 4 and 5 provide examples of trickling filters in operation.

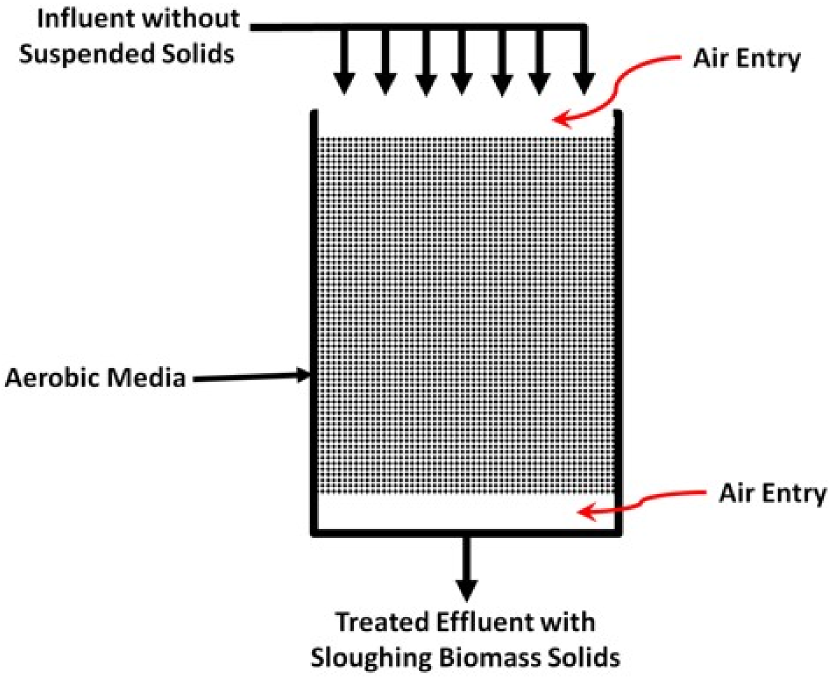

Figure 2. A schematic diagram of a trickling filter

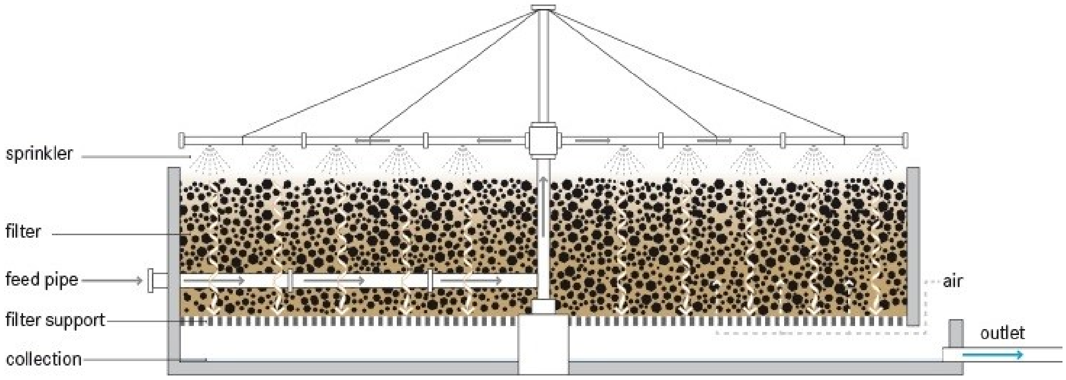

Figure 3. Drawing of a trickling filter that shows a rotating distribution system, filter packing medium, and underdrain collection for effluent (Reprinted with permission of Eawag: Swiss Federal Institute of Aquatic Science and Technology Department Water and Sanitation in Developing Countries (Sandec); from Tilley et al. (2014).

Figure 4. a) A plastic media trickling filter with a rotary hydraulic distribution arm designed for a flowrate of 40,000 m3/day (Cuzco, Peru). Note the ventilation ports around the base in the top photo. (b) close up of distribution system (photos by Stewart Oakley)

Figure 5. A volcanic rock trickling filter with a fixed hydraulic distribution system. This system has been in operation for 35 years with an average daily flow rate of 500 m^3/day. Filter located at the University of San Carlos, Guatemala City, Guatemala (photo by Stewart Oakley)

In an anaerobic filter the influent wastewater passes vertically through a submerged medium that maintains anaerobic conditions (Figure 6). The anaerobic filter can be run in a downward (Figure 6) or upward hydraulic flow pattern (Figure 7). Soluble organic matter is removed as it comes in contact with the anaerobic biofilm; low concentrations of suspended solids can also be removed by being retained within the interstices of the medium and subsequently biodegraded (Chernicharo, 2007). For the treatment of domestic wastewater anaerobic filters have been most commonly used in Brazil as a secondary treatment process for septic tank effluents and UASB reactor effluents (Chernicharo, 2007).

Biofilm sloughing occurs in anaerobic filters butto a lesser extent than in trickling filters; as a result, anaerobic filters do not require secondary sedimentation but do require periodic removal of solids within the filter (Chernicharo, 2007). In anaerobic filters the influent is usually distributed in the bottom part, follows an upward flow and leaves from the top, with the medium remaining saturated (void spaces occupied by liquid). There are also down flow versions of anaerobic filters. In both designs, since there is no entrance of oxygen, anaerobic conditions prevail in the liquid and biofilm.

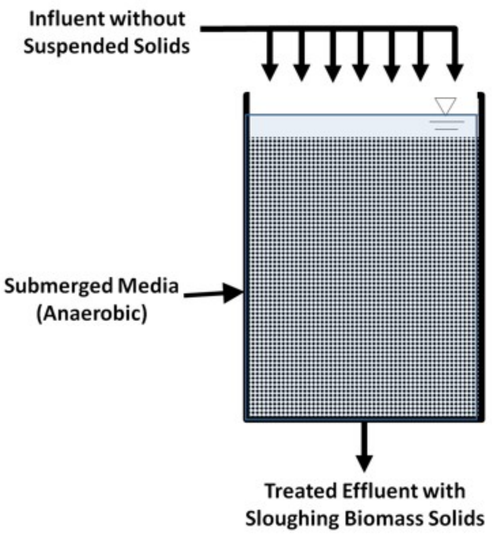

Figure 6. A schematic of a downflow anaerobic filter with submerged media. Anaerobic filters can be designed in downflow or upflow configurations

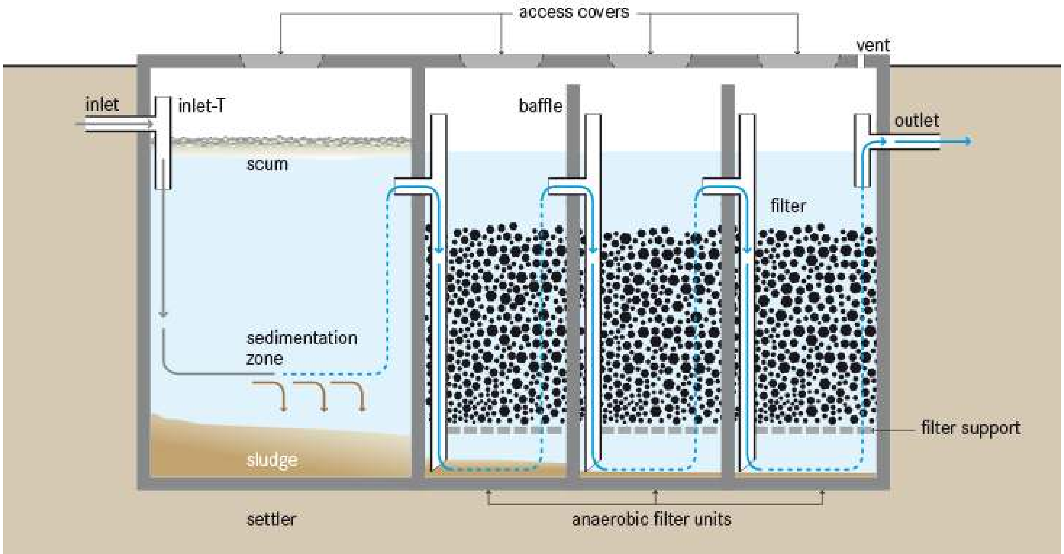

Figure 7. Schematic of an upflow anaerobic filter (Reprinted with permission of Eawag: Swiss Federal Institute of Aquatic Science and Technology Department Water and Sanitation in Developing Countries (Sandec); from Tilley et al. (2014).

Detailed information on the design and operation of trickling filter processes can be found in Metcalf & Eddy/AECOM (2014) and von Sperling (2007). Chernicharo (2007) presents detailed information on the design and operation of anaerobic filters.

2.0 Inputs and Outputs for Media Filters

Trickling filters and anaerobic filters are used to treat the following liquid waste streams: domestic wastewaters, a large variety of high strength industrial wastewaters (e.g., pulp and paper wastes, brewery wastes, textile wastewaters),and combined domestic/industrial wastewaters. Figure 8 shows the principal inputs and outputs for media filters. Trickling filters receive primary-treated wastewater effluent or upflow anaerobic sludge blanket (UASB) reactor effluent, while anaerobic filters commonly receive septic tank effluent or UASB effluent. The outputs from media filter processes include secondary effluent and secondary sludge, both of which require further treatment for stabilization and pathogen removal. Secondary effluent can be disinfected before discharge or reuse. Secondary sludge from trickling filters is most commonly stabilized by anaerobic digestion with primary sludge and then dewatered. Secondary sludge from anaerobic filters is directly dewatered when removed. Sludges will likely contain high concentrations of pathogens and must be treated if they are to be used in agriculture.

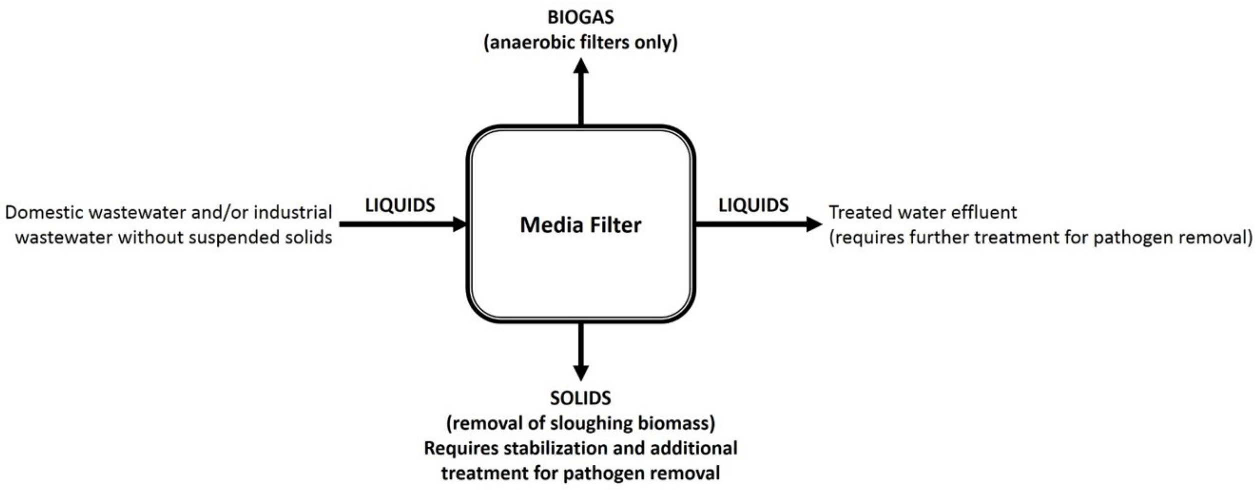

Figure 8. Typical inputs and outputs for media filter processes

3.0 Factors Affecting Pathogens in Media Filters

Trickling filters and anaerobic filters are designed specifically for organic matter removal; therefore, any removal of viral, bacterial, protozoan or helminth pathogens in treated effluents is coincidental to the design objectives. For trickling filters that are combined with secondary sedimentation, the reduction of pathogens has been reported to range from 0 to 2 log10 units for viruses, 1 to 2 for bacteria, 0 to 1 for protozoa, and 1 to 2 for helminths (WHO, 2006). There are few data on pathogen removal in anaerobic filters. However, Oliveira and von Sperling (2008) reported a geometric mean of 0.9 log_{10} removal of thermotolerant coliforms (25 percentile = 0.55; 75 percentile: 1.02) for fourteen systems in Brazil that consisted of a septic tank followed by an anaerobic filter.

The principal removal mechanisms for pathogens in trickling and anaerobic filters are: 1) retention in the biofilm by adsorption and 2) sedimentation in the sloughing biofilm (Figure 9).

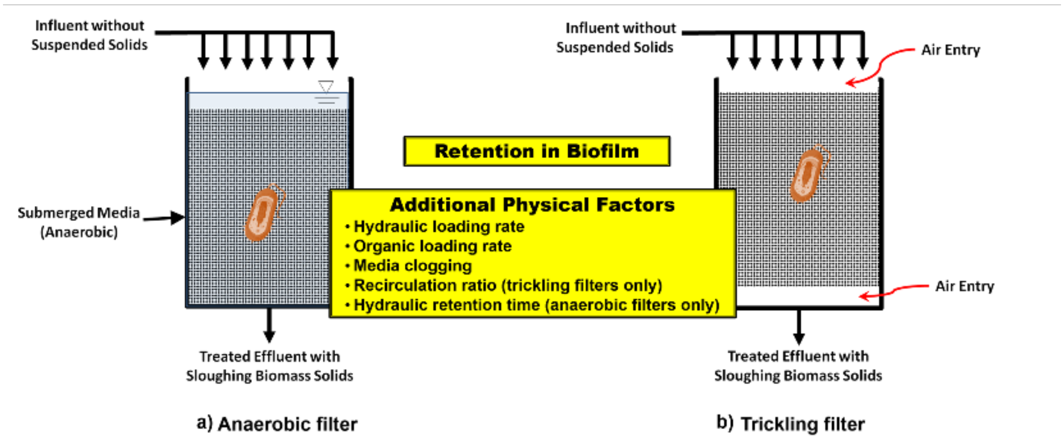

Figure 9. Major factors affecting pathogens in (a) trickling filters and (b) anaerobic filters. Note that the media in the anaerobic filter are submerged to maintain anaerobic conditions

3.1 Retention in the Biofilm

Media filters remove soluble organic matter as the wastewater passes through the medium and comes in contact with the attached biofilm. Pathogenic microorganisms in the wastewater can also be adsorbed to the biofilm during this process. When the biofilm sloughs (discussed previously), the adsorbed pathogens will either leave with the suspended solids, where they may be removed by sedimentation or be released to the water that makes up the effluent. Also, in trickling filters some pathogens may be removed on the biofilm by predation by other organisms.

3.2 Additional Physical Factors

The physical factors that reduce the performance of media filters in treating organic matter removal can also be expected to influence pathogen removal by adsorption to the biofilm. These include (USEPA, 2000; Chernicharo, 2007):

- Hydraulic and organic loading rate
- Distribution system efficiency
- Media clogging
- Recirculation ratio (trickling filters)
- Hydraulic retention time (anaerobic filters)
- Suspended solids removal in final effluent
- Peak wastewater flows

Table 1 presents a summary of the main factors and mechanisms associated with pathogen removal in media filters.

Table 1. Summary of factors and mechanisms for the removal of pathogens from wastewater in media filters: Retention in the biofilm

Summary of removal mechanism

One of the mechanisms for the removal of pathogens from wastewater treated in media filters is the retention of pathogens in the biofilm due to adsorption.

Factors contributing to removal	**Evidence of Pathogen Vulnerability**			
	Viruses	**Bacteria**	**Protozoa**	**Helminths**
Important factors affecting removal efficiency are assumed to be the same as the factors that affect performance for organic matter removal and include: • Hydraulic and organic loading rate • Distribution system efficiency • Media clogging • Recirculation ratio (trickling filters) • Hydraulic retention time (anaerobic filters) • Suspended solids removal in final effluent • Peak wastewater flows • Predation could play a role in trickling filters • Sludge age could influence pathogen removal in anaerobic filters	Enterovirus was removed by 0.04 and 0.54 log10 units, respectively, at two trickling filter WWTPs in New Zealand (Lewis et al., 1986). Kitajima et al. (2014b) found the following log_{10} removal values for the final effluent of a trickling filter WWTP in Arizona (94,600 m3/d capacity) that included primary and seconday sedimentation, and chlorine disinfection: Norovirus GI: 2.57 Norovirus GII: 2.85 Norovirus GIV: 1.10 Sapovirus: 1.65 Enteroviruses: 2.25 Rotavirus: 1.15 Aichi virus: 0.99 Pepper mild mottle virus: 0.99 Adenovirus: 1.35 JC polyomavirus: 2.56 BK polyomavirus: 1.60	Yaziz and Lloyd (1979) reported an average 1.16 log_{10} removal of *Salmonella* sp. for a trickling filter with secondary sedimentation and recirculation after 7 months of sampling at a WWTP in UK. Fecal coliforms were removed by 0 and 1.2 log_{10} units, respectively, at two trickling filter WWTPs in New Zealand (Lewis et al., 1986). Marin et al. (2015) reported 1.41 log_{10} and 0.35 log_{10} removal of *E. coli*, respectively, for the first and second of two trickling filters in series, each followed by sedimentation tanks, at a WWTP in Spain. Oliveira (2006) and Oliveria and von Sperling (2008) reported up to a 1.9 log_{10} removal of fecal coliforms in 14 septic tank/anaerobic filter systems in Brazil.	Robertson et al. (2000) reported the following log_{10} removal values for trickling filters including primary sedimentation at two WWTPs in Scotland: *Giardia* cysts: 0.59 to 0.82 *Cryptosporidium* oocysts: 0.02 to 0.21 Kitajima et al. (2014a) found the following removal rates for the final effluent of a trickling filter WWTP in Arizona (94,600 m3/d capacity) that included primary and seconday sedimentation, and chlorine disinfection: *Giardia* cysts: 1.52 *Cryptosporidium* oocysts: 0.81	No data were found for the removal of helminth eggs in media filters. A theoretical removal efficiency of 1.0 to 2.0 log_{10} based on adsorption mechanisms has been suggested by WHO (2006).

4.0 Design, Operation, and Maintenance Guidelines for Pathogen Removal

Media filters are designed specifically to remove soluble organic matter and there are no design guidelines for pathogen removal. The design engineer should therefore ensure that wastewater treatment systems using media filters also have downstream treatment processes to remove pathogens from the final effluent to the extent necessary for its safe reuse or discharge; these downstream processes include secondary sedimentation of sloughing sludge and disinfection of the final effluent. Media filter sludge will likely contain elevated concentrations of pathogens and must also be treated appropriately before reuse or final disposal.

Table 2 presents a summary of key factors that potentially could influence the partial removal of the four major groups of pathogenic organisms in a trickling filter and anaerobic filter.

Table 2. Key factors potentially affecting pathogen removal in trickling filter and anaerobic filter processes

Factor	Pathogen Removal is Potentially ↑ Enhanced or ↓ Reduced Under the Following Conditions:
Hydraulic Loading Rate	Lower Hydraulic Loading Rate = ↑ Pathogen Removal
Organic Loading Rate	Lower Organic Loading Rate = ↑ Pathogen Removal
Hydraulic Distribution to Filter	Well Designed & Operated Distribution = ↑ Pathogen Removal
Recirculation of Filter Effluent	Recirculation = ↑ Pathogen Removal
Sedimentation of Sloughed Biofilm	Well Designed & Operated Sedimentation that follows the Filter= ↑ Pathogen Removal
Hydraulic Overloading	Hydraulic Overloading = ↓ Pathogen Removal
Excessive Biofilm Accumulation	Excessive Biofilm = ↓ Pathogen Removal
Post-Treatment	Media filters require downstream treatment of effluent and sludge for pathogen removal

5.0 Summary of Data on Pathogen Removal in Media Filters

Figure 10 and Table 3 summarize the literature data on pathogen removal in trickling filter and anaerobic filter processes. There are a scarcity of data on pathogen removal from individual media filter unit processes at full-scale wastewater treatment plants; as a result the removal data for bacteria, fecal coliforms, viruses and protozoa include primary and secondary sedimentation for trickling filters and primary sedimentation (septic tanks) for anaerobic filters.

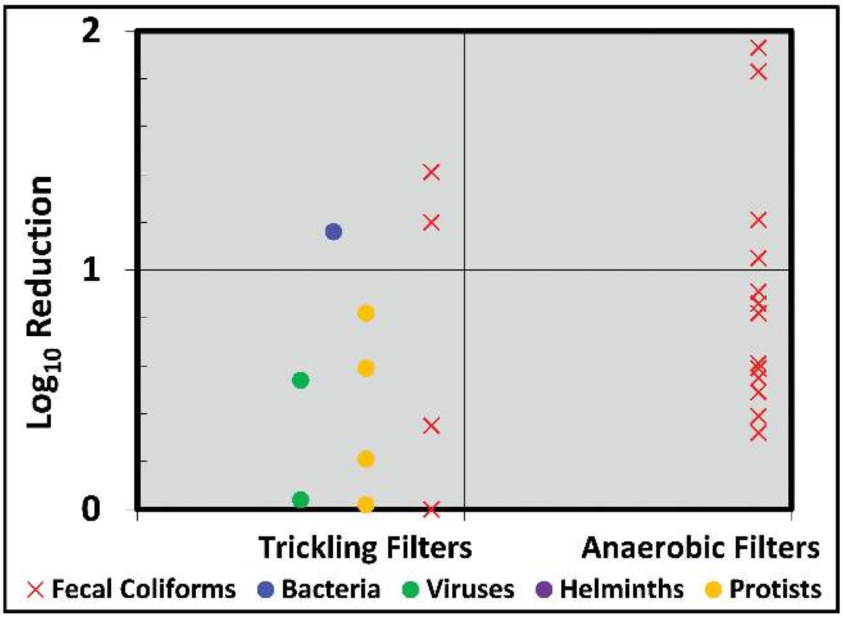

Figure 10. Reported $\log_{10}$ removal of pathogens and fecal coliforms (including *E. coli*) in trickling filter and anaerobic filter systems. Data for trickling filter systems include primary and secondary sedimentation; data for anaerobic filters include a septic tank followed by anaerobic filter. (Sources of data: Kitajima, et al., 2014a; Lewis, et al., 1986; Marin, et al., 2015; Oliveira, 2006; Oliveira and von Sperling, 2008; Robertson, et al., 2000; Yaziz and Lloyd, 1979)

Table 3. Summary of pathogen removal from wastewater in trickling filter and anaerobic filter processes

Process	Typical Pathogen and Fecal Indicator $\log_{10}$ Removal Values				
	Bacterial Pathogens	**Viruses**	**Protists**	**Helminth Eggs**	**Fecal Coliforms (Including *E. coli*)**
Trickling Filters[a]	1.16	0.04 to 0.54	0.02 to 0.82	NR	0 to 1.41
Anaerobic Filters[b]	NR	NR	NR	NR	0.32 to 1.93[c] 0.55 to 1.02[d]

Sources: Kitajima, et al., 2014a; Lewis, et al., 1986; Marin, et al., 2015; Oliveira, 2006; Oliveira and von Sperling, 2008; Robertson, et al., 2000; Yaziz and Lloyd, 1979.

[a]Systems of trickling filters preceded by septic tanks or primary sedimentation basins. Data for protists are for trickling filters with primary and secondary sedimentation with chlorine disinfection; [b] Systems of anaerobic filters preceded by septic tanks; [c]Minimum and maximum from 14 septic tank/anaerobic filter systems; [d] 25th and 75th percentiles from 14 septic tank/anaerobic filter systems.

6.0 Summary of Data on Pathogens in Sludge from Media Filters

There are few published data on pathogen concentrations in trickling filter and anaerobic filter sludges. Media filter sludges could potentially contain elevated concentrations of certain pathogens and, as a result, they should be managed in a sanitary manner to protect public health. Detailed information on pathogen content and removal in sludges is found in Section 60M Sludge Management.

7.0 Conclusions

Media filters are designed for the removal of soluble organic matter and cannot be expected to have high pathogen removal rates. The few available data from the literature for trickling filters with primary and secondary sedimentation suggest that, at best, a 1.0 $\log_{10}$ removal of bacterial pathogens (*Salmonella*), a 0.5 $\log_{10}$ removal of viruses, a 0.8 $\log_{10}$ removal of protozoa cysts/oocysts, and a 1.4 $\log_{10}$ removal of *E. coli* and thermotolerant coliforms can be obtained. Tricking filters with primary and secondary sedimentation and chlorine disinfection have been found to remove up to 2.85 $\log_{10}$ viruses and 1.5 $\log_{10}$ protozoan cysts (*Giardia*). Anaerobic filters preceded by primary sedimentation (septic tanks) have removed up to 1.9 $\log_{10}$ of thermotolerant coliforms. All media filter effluents require further treatment such as disinfection for adequate pathogen removal to meet regulatory or reuse requirements.

Sludges from media filters can be assumed to contain elevated concentrations of pathogens and must be managed accordingly to protect public health before reuse or disposal.

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