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UNIFIED FACILITIES CRITERIA (UFC)

ARMY FILTRATION OF LIQUIDS

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UNIFIED FACILITIES CRITERIA (UFC)

ARMY FILTRATION OF LIQUIDS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes Technical Letter No. 1110-1-159, dated 30 September 1994.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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CHAPTER 1

INTRODUCTION

1-1 **PURPOSE**. This document provides practical guidance for the design of filtration systems to remove suspended solids from liquids. Liquid in this document means water.

1-2 **APPLICABILITY**. This UFC applies to all Service elements and all Contractors having responsibility for designs that include liquid filtration processes.

1-3 **REFERENCES**. Required and related publications are listed in Appendix A.

1-4 **SCOPE**. This UFC addresses various solid–liquid filtration systems, their associated filtration media, the use of various filtration process technologies, equipment and component specifications and design, available manufacturers and equipment sources, advantages and disadvantages of different filtration systems, solids disposal, costs, operational requirements (O&M), and safety considerations. The described equipment can be installed alone or at various stages in an overall treatment process, depending on application-specific needs.

Applications will generally be at a flow rate of less than 15 L/s (240 gpm) with suspended solids concentrations of less than 1000 ppm. Filtration technologies include granular media (sand) filtration systems, ranging from pressure filtration vessels to gravity filtration systems to continuous backwash systems, as well as systems using filter fabrics such as bag and cartridge filters. The use of precoats and filter aids are included as applicable.

DG 1110-1-2 covers adsorption systems, which are not included herein and which may be called filters.

1-5 **BACKGROUND**. The separation of solids as part of a waste treatment process is often necessary either to provide effective treatment, to meet end use criteria, or to comply with regulatory mandated disposal requirements. As treatment technologies become more sophisticated and as waste disposal requirements become more stringent, the need to remove solids from the waste stream has become more critical. Liquid waste streams with biological and chemical contamination can often be more effectively treated when the suspended solids are removed.

CHAPTER 2

DOCUMENT USE

2-1 **GENERAL.** This UFC document will provide designers of HTRW treatment systems a methodology for determining what filtration systems may be appropriate for a specific application and for specifying a system that will meet the project needs. The UFC is intended to address applications of less than 15 L/s (240 gpm) and is limited to pre-packaged filtration systems available from various manufacturers.

2-2 CHAPTER DESCRIPTIONS

2-2.1 Chapter 1 describes the purpose, applicability, allowable distribution, location of reference sources, scope and background of the UFC.

2-2.2 This Chapter 2 describes how the document is to be used.

2-2.3 Chapter 3 describes the principles of filtration and filtration theory. This chapter describes the purpose and mechanics of filtration so that the designer will have a clear understanding of what functions are served. The chapter also discusses filtration applications and where filtration fits within the overall treatment process. The chapter describes various waste stream parameters that may influence the type and level of filtration required. Finally, the chapter describes how pilot tests are used when specifying filtration systems.

2-2.4 Chapter 4 describes, in tabular form, how to screen and select processes. Using this table, the design professional will be able to narrow the range of potential filtration options to the one or two processes that are most likely to meet the needs of the proposed application.

2-2.5 Chapter 5 describes in detail the various filtration processes. This chapter is intended to allow the design professional to focus his or her attention on those processes that have been identified from Chapter 4.

2-2.6 Chapter 6 describes non-filtration components that should be taken into account as part of any filtration system design. These include disposal of residuals, pretreatment requirements, process control options, and operation and maintenance considerations.

2-2.7 Chapter 7 describes cost considerations that the engineer or design professional should take into account to ensure that all applicable costs associated with a particular filtration system are accounted for.

2-2.8 Chapter 8 describes items that should be included in any design package developed for USACE HTRW applications.

2-2.9 The Appendices include a list of technical references, design examples, a list of vendors for filtration systems, a glossary of terms used in this UFC, and a list of abbreviations and acronyms.

CHAPTER 3

PRINCIPLES OF OPERATION AND THEORY

3-1 DESCRIPTION OF THE FILTRATION PROCESS

3-1.1 **Purpose of Filtration**. This filtration document describes technologies for the separation of solids from a liquid through a permeable medium, generally a porous, fibrous, or granular substance, which retains the particles. This chapter will discuss the theory of solids removal, the application of filtration within the liquid treatment process, important wastewater parameters, and the application of pilot studies.

3-1.2 **Mechanics of Filtration**. Solids removal within the filter is affected by five major factors: the size of the filter medium, the rate of filtration or surface loading [(L/s)/m^2 or gpm/ft^2], the influent particle size and size distribution, the flow rate, and the amount of solids that has already been removed within the filter. The size of the filter medium determines the total available surface area for removal and the flow channels. The rate of filtration determines the contact time. Influent particle size and size distribution affect the mechanism of removal, available surface area, and porosity, which will change with run time. The flow rate determines shear forces. As solids are removed, available removal sites are decreased and flow channels are altered.

3-1.2.1 The efficiency of particulate collection in a filter is defined as the number of successful collisions for all particulates in the cross-sectional area of the collector divided by the total possible number of collisions between the particulates and the collector. The overall efficiency can be described by the summation of the different mechanisms by which particulates are removed from the aqueous stream. This relationship, as developed by Yao (1971), includes the following three mechanisms.

3-1.2.1.1 **Removal by Interception**. Particles moving along the streamline are removed as they come in contact with the surface of the filtering media.

3-1.2.1.2 **Removal by Impaction, or Settling**. When particles are heavier than water, they do not follow the flow streamlines and, instead, settle out.

3-1.2.1.3 **Removal by Diffusion**. Small particles can diffuse to the collector through Brownian motion.

3-1.2.2 The overall removal can be closely estimated as the sum of these three removal mechanisms. Diffusion will predominate at smaller particle diameters, whereas settling will predominate at larger particle diameters.

3-1.2.3 In addition to these removal mechanisms, straining and adsorption play a part in particulate removal. Straining occurs when the particle is larger than the pore size, resulting in the particle being strained out mechanically. In the case of granular media filtration, excessive straining is undesirable because head loss will increase rapidly because a surface mat forms. Chemical or physical adsorption will occur where bonding, chemical interaction, electrostatic forces, electro-kinetic forces, or van der Waals forces are strong enough to cause particles to deviate from streamlines. Adsorption is not believed to be a significant removal mechanism under normal filtration conditions.

3-1.2.4 The effect of filter rates on the quality of filtrate can vary widely, depending on application. Both the waste stream and any upstream pretreatment (e.g., polymer addition) can result in changes in the acceptable range of feed rates. Generally, large solids are removed initially at the surface by straining. As the hydraulic gradient increases, these flocs may break up and penetrate further into the filter media. As the solids become lodged between the media grains, the void space decreases, and resistance to flow increases. The rate of flow increases through the larger openings and lessens though the clogged openings. There is little or no deposition in the channels where velocities are high. Backwash is initiated when the resistance increases to a limiting level or breakthrough occurs.

3-1.3 **Filtration Applications**. When specifying a filtration system, it should be noted that numerous solids separation techniques other than filtration may be applicable to a given situation. More importantly, from a design standpoint, filtration may not be the most efficient means of removing solids and the design professional should be aware of its limitations.

Ideally, the design professional should have a detailed knowledge of all available options to make proper design decisions. However, Table 3-1 provides a comparative summary of solids separation techniques that can be used as a starting place for assessing options. Similarly, Figure 3-1 provides a visual representation of available treatment options based on particle size.

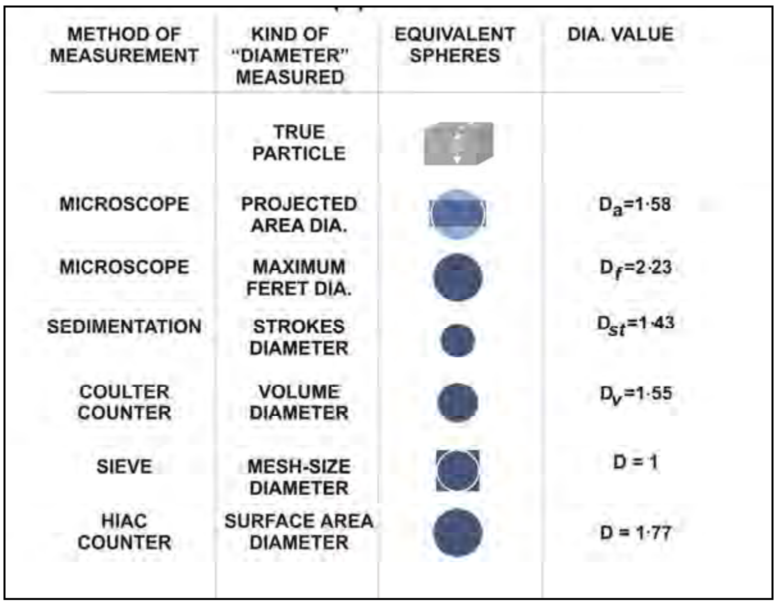
Table 3-1. Comparative Summary of Solids Separation Techniques

Unit Operation	Product parameters			Favorable field conditions	
	Solid in Liquid Stream	Liquid in Solid Stream	Suitability of Filtrate for use as Backwash Water	Solids Concentration	Solids Characteristics
Filtration	Fair to Good	Good	Good	High to medium	Light, coarse to med. floc. fine
Sedimentation	Fair to excellent	Poor	CCD*, low efficiency	Medium to low	Dense, medium or flocculated fine
Centrifugation	Fair	Poor	Fair to excellent	Medium to low	Dense fine
Cycloning	Poor	Poor	Poor	Low to medium	Dense, coarse to medium
Screening (DSM)†	Poor	Poor to fair	Poor	High to medium	Coarse to medium
Ultrafiltration	Excellent	Poor to Fair	Poor	Low	Very Fine

* Counter current decantation
† Dutch State Mines
Source: Swilzbin (1996)

When filtration is required, it may be at various places within the overall treatment process. Typical applications are shown in Table 3-1.

Figure 3-1. Sphere Diameter Equivalents Demonstrating How Different Methods of Measurement Can Result in Widely Varying Equivalent Diameters (D) for the Same True Particle



3-1.4 **Filtration as Stand-alone Treatment.** There are applications where filtration is indicated as the sole treatment process, owing to manageable flows, relatively low solids loadings, and stringent discharge requirements. Generally speaking, however, there are few applications where the solids content of a waste stream is the sole objectionable constituent of concern. When this occurs it is often because of higher solids loadings than can be efficiently managed by filtration alone. In this case, it is often necessary to use other processes, such as settling, prior to filtration.

3-1.5 **Filtration as Pretreatment or as an Intermediate Step**. The most common uses for filtration processes in HTRW treatment are either as pretreatment or as an intermediary step. This may be because the high solids content in the unfiltered waste stream will interfere with subsequent treatment processes, or it may be to meet mandated discharge limits. The design professional must determine the level of filtration required so that the most efficient filtration process can be specified.

3-1.5.1 As an example, groundwater contaminated with jet fuel or cleaning solvents may be treated through a variety of means, including air stripping and carbon adsorption. Where either of these methods is used to treat the extracted groundwater, the solids content of the waste stream can be critical to the efficient operation of the treatment system.

3-1.5.2 Adsorption can be particularly sensitive to solids in the waste stream. Adsorption works by allowing the waste stream to come in contact with an adsorption medium, such as activated carbon, which adsorbs dissolved contaminants onto its surface. In this case, some manner of filter before the adsorption unit is generally recommended whenever suspended solids exceed 50 mg/L (Process Design Manual for Suspended Solids, Removal, U.S. EPA, 1975. See also EPA 832-F-00-017, http://www.epa.gov/owm/mtb/carbon_adsorption.pdf)

3-1.5.3 In other applications, a waste stream may require oxidation prior to ultimate discharge. Because the oxidant works by reacting with organic matter, its ability to react with harmful bacteria can be hampered by the presence of biological solids in the waste stream. Filtration to remove larger solids prior to oxidation may improve the effectiveness of the oxidation process, conserve the oxidant, and prevent excessive amounts of byproducts from forming. Advanced oxidation requirements may also require solids removal from the waste stream as an intermediate step.

3-1.5.4 In another scenario, solids in the waste stream may affect disposal options, possibly causing the waste stream to be considered a hazardous waste or to contain metals at levels higher than can be discharged to the sanitary sewer system. In this case, filtration may be included as an intermediate step in the treatment process.

3-1.6 **Post-Treatment Filtration**. Some applications require filtration as a last step prior to discharge. In this case filtration may be a polishing step needed to meet National Pollutant Discharge Elimination System (NPDES) permit limits or permit equivalence for discharge to a surface water or underground injection control (UIC) requirements.

3-2 **WASTE STREAM PARAMETERS.** When designing a filtration system, the design professional should first understand the nature of the waste stream being treated and the treatment needs. Specific factors that should be considered are:

- Particle size.
- Solids concentration.
- Relative costs.
- Treatment flow rate.
- Metals removal.
- Environmental hazards.
- Oily slurries.
- Objective of solids separation.
- Space limitations.
- Chemical addition.
- Settling velocity.
- Expendable media.
- Solids output.
- Continuous or batch operation.
- Precoat filtration.
- Recovery or disposal of captured solids.

3-2.1 **Particle Size**. Particle size can be very difficult to accurately measure and describe. Generally, particles are irregular in shape and often angular. In practice, however, they are often described as spheres or sphere equivalents. Because it is impossible to accurately measure and describe each particle in a waste stream, numerous methodologies have been developed to estimate the size of typical particles. As shown in Figure 3-1, the methodology used can result in sphere diameter equivalents that can vary by more than a factor of two for the same size particle. When comparing particle removal estimates from different manufacturers, the design professional should make sure that the particle sizes used are determined using comparable methodologies.

3-2.1.1 Liquid particle counters use photozone light blockage, where a pulse is generated proportioned to projected area.

3-2.1.2 Feret diameter is the perpendicular projection onto a fixed direction of the distance between two parallel lines.

3-2.1.3 Stokes diameter is determined through settling and projecting particle diameter through use of stokes law (ASTM D 422-63).

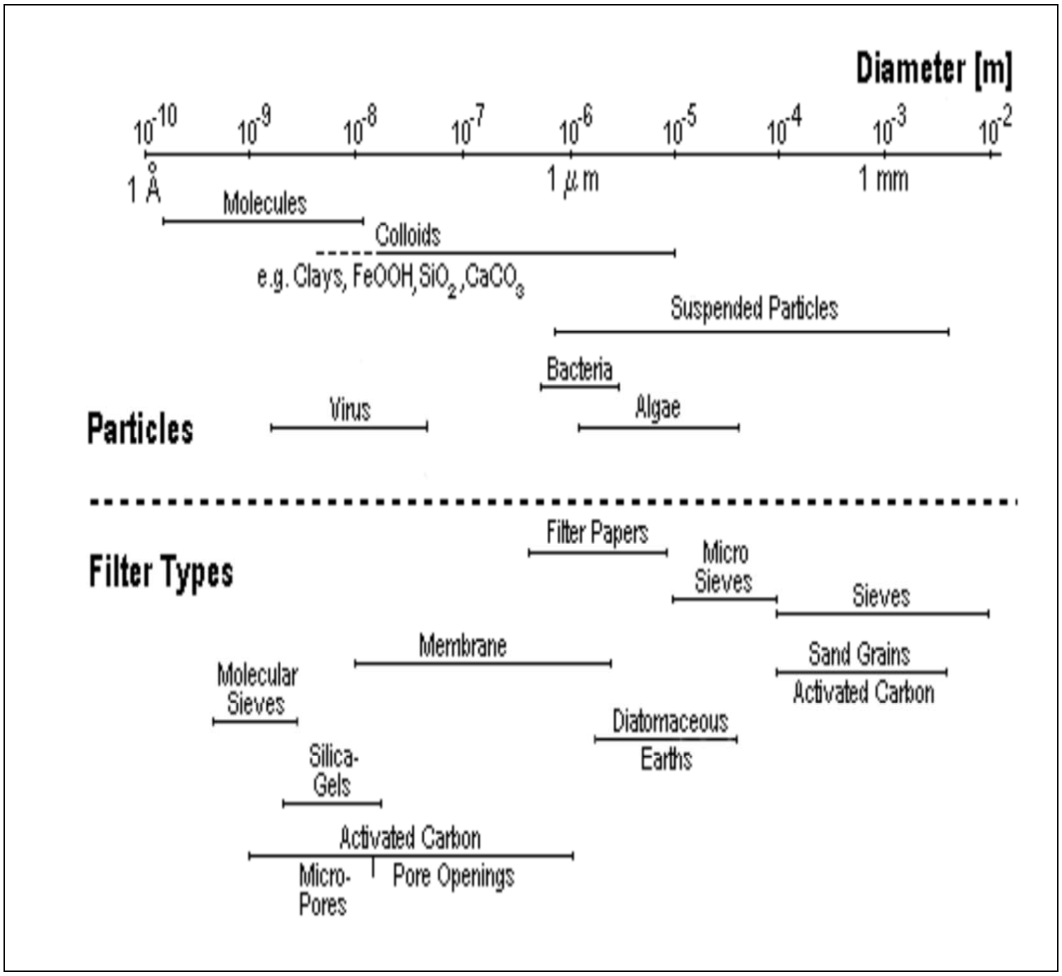
3-2.1.4 Colture contours measure particle diameter through changes in conductivity of particles in a week electrolyte solution.

3-2.1.5 In general, granular media filters can remove particles in the 4 to 6 micron range and pressure filters can remove particles as small as 10 microns. However, the efficiency of particle removal in these micron ranges is very low compared to cartridge and bag filters and the efficiency likely will diminish over the length of the filter run. Therefore, if it is necessary to efficiently remove particles in the range of 4 to 6 microns from a waste stream, bag or cartridge filtration will be needed. The designer should also recognize that, for a bag or cartridge filter to operate efficiently, they may require pretreatment by a media filter. This is particularly true where significant amounts of solids, considerably larger than the desired particle size in the effluent, are present. However, where a significant concentration of large particles is present, smaller micron-size particles may be trapped in the schmutzdeck, which forms at the top of the filter. Hence, granular filtration may still warrant consideration. Figure 3-2 shows typical particle size ranges within the filtration separation spectrum.

3-2.2 **Relative Costs**. Typically, the capital cost for media filtration is higher than the cost of cartridge or bag filtration. Operation and maintenance (O&M) costs increase as the volume of waste to be treated increases. The long-term cost for granular media filters may be less than the cost needed for membrane replacement in bag or cartridge filters or precoat filter media because of the costs of expendable media and potentially hazardous waste disposal.

3-2.3 **Metals Removal**. In many systems, metals are removed by precipitation, sedimentation, and filtration. For waste streams low in solids and metals to be removed, continuous backwash filters can enhance the metals removal by providing a constant stream of return solids to the sedimentation system and increasing solids contact, thereby improving sedimentation and reducing downstream filter loadings. One draw-back with continuous backwash filters is that they typically remove only 95% of the in-fluent solids, suggesting that a downstream bag or cartridge filter may be necessary, depending on effluent requirements. Where there are effluent/discharge requirements with low total metals concentration, multiple filtration process may be required to filter out fine floc often associated with metals precipitation (see EM 1110-1-4012 for addi-tional information).

Figure 3-2. Typical Size Range Within the Filtration Separation Spectrum



3-2.4 **Oily Slurries**. Waste streams, which contain oil should typically have some pretreatment prior to filtration, particularly if the oily material is in a separate phase (i.e., visible, separated oil). One exception to this rule may be the use of bag filters, as bag filters are typically designed to remove solids from viscous oily or organic materials. In this case, the oily material will pass through the filter. Bench or field-testing should be considered. In most cases, when a waste stream contains high levels of oil and grease, some manner of pretreatment, such as oil adsorbent resins and clays or oil–water separator, should be considered, based on the filtration system manufacturer's requirements and recommendations (see DG 1110-1-2, PWTB 200-01-05, or API Publication 421 for additional information).

3-2.5 **Space Limitations**. Where space is limited, bag and cartridge filters are good selections, depending on waste stream characteristics. In some instances, the designer may not be able to consider space saving filter options because of high solids loadings, the high cost of disposal of expendable cartridge and bag filter elements, or high operating costs if frequent filter changes are required. Again, the designer needs to consider whether these filters will provide the ease of operation and effluent quality for a particular application.

3-2.6 **Settling Velocity**. Sedimentation velocity can help the designer determine if settling or filtration may be required for a given waste stream. Waste streams with high settling velocities (more than 0.5 cm/s) typically depend on gravimetric or centrifugal type treatment processes prior to filtration to reduce the quantity of solids. Filtration in this case would be used to remove the solids remaining in suspension. Settling velocities can be determined in the laboratory. Test method "2701 E. Zone Settling Rate" of the 20th Edition of *Standard Methods for the Examination of Water and Wastewater* (APHA 1999) should be considered for determining settling velocities.

3-2.7 **Solids Concentration**. The feed solids concentration is the weight percent of dry solids in the waste stream to be treated. This can be obtained by filtering a known quantity of waste through a tarred and previously weighed dry filter paper (see *Standard Methods*, 20th Edition, Method 2540 D, “Total Suspended Solids” [APHA 1999]). Where solids concentration is high, the designer must consider using gravimetric or centrifugal solids separation processes prior to filtration.

3-2.8 **Treatment Flow Rate**. Treatment flow rate is important in determining the degree of automation that can be economically allowed. In general, low flow rates require less operator attention, thereby reducing O&M costs, versus higher flow rates that may require frequent operator input. The tradeoff is that the lower flows typically have higher capital investments, where the economy of scale decreases as the volume of waste treated increases. For HTRW sites, the treatment flow rate is often determined during the feasibility study (FS) phase of work.

3-2.9 **Environmental Hazards**. If the waste stream to be treated is toxic, flammable, or explosive, it is best treated in an isolated environment. For this parameter, filtration devices that are closed vessels (i.e., pressure filters) are more suitable than open, gravity-type systems. In the case of cartridge filters, operator contact during filter changes may affect selection of this type of filtration device.

3-2.10 **Objective of Solids Separation**. As the concentration of the solids increases (e.g., greater than 100 mg/L) two treatment processes are typically required. The first should remove the bulk of the solids, usually via some sedimentation type device (see EM1110-1-4012), followed by filtration to clarify or remove those solids not removed earlier. At lower solids concentrations, only filtration may be required. Solids separation may also be used to capture and concentrate the solids. In this case media filtration in combination with dewatering devices for the backwash stream or cartridge or bag filtration are possible treatment alternatives.

3-2.11 **Chemical Addition**. Chemical addition means the use of flocculants, coagulants, or other chemicals that will enhance separation. For some processes, adding chemicals may not be desirable from an operational point of view. This is a concern when polymers and sub-micron cartridge filters are used together. The organic polymers may coat or blind the filter media, causing premature failure. Electrolytes are often used to precipitate colloids or enhance filtration of particulates and colloids. To improve particulate removal, electrolytes that have a charge opposite in sign to the particles are used (see EM 1110-1-4012).

3-2.12 **Expendable Media**. Expendable media are mostly filter cartridges, filter bags, or precoat filter aids. For low solids loadings (less than 15 mg/L total suspended solids [TSS]), expendable media may be economical. As the volume of filtered solids increases, so do disposal costs for expendable media. Expendable media and either dry cake or hazardous slurries are frequently incompatible. Filter cartridges or precoat filter aids usually retain significant amount of filtrate and solids. For hazardous wastes, this can substantially increase disposal costs. Expendable media may also be an adsorbent, such as an oil adsorbent clay (see DG 1110-1-2).

3-2.13 **Solids Output**. Solids are removed from the separation or filtration device as either a slurry from backwash of media type filters or as a relatively dry cake, as with cartridge filters. If the solids are to be incinerated, then the driest possible cake is desired. Where slurries may be land farmed or land applied, mechanisms such as dewatering should be considered to reduce overall disposal volume and costs. Other specific elevating requirements apply before solids can be landfilled. (See also UFGS 11360A, 11350, 11393, 11365A, and other USACE Guidance on dewatering processes).

3-2.14 **Continuous or Batch Operation**. Continuous or batch operations usually depend on upstream or downstream processes. When using batch filtration with continuous upstream or downstream processes, the designer must consider the size of intermediate holding tanks to be used as feed or effluent control of the waste stream flow. When using continuous filtration with upstream or downstream treatment processes, the same is true. Typically, continuous backwash filtration processes use much more backwash water (as much as 10%) than batch processes (typically from 1 to 3%). This flow needs to be returned to the head of the treatment system, which must be sized to handle both the design flow and the return flow.

3-2.15 **Precoat Filtration**. Unlike the other filtration systems discussed in this document, precoat filtration relates to a process technique, not a specific filter type. Many commercially available filtration and solids separation processes can be used as precoat filters. Some of these include rotary drum vacuum filters, vertical tube filters, and recessed plate and frame filters. The designer must contact filter representatives regarding available data on the use of their filters for precoat applications. Generally, precoat filters are used when there are high inert solids loadings at levels typically greater than 1000 mg/L TSS. Precoat filters are not within the scope of this document, but are discussed in TM 5-662.

3-3 **PILOT STUDIES.** No completely adequate theoretical approach is available for the design of full-scale filters. Past experience with similar applications usually provide adequate basis for design. However, where the waste stream is unusual or experience is inadequate, pilot studies may be done to ensure that the selected design performs satisfactorily. Generally, pilot studies are not done, but, when essential, they are done by the filter manufacturer and are required as part of the specification submittal approval process. The principal goals of the testing should be selecting filter media and depths, determining appropriate filtration rate and terminal head loss, and establishing the expected duration of the filter runs. Pretreatment needs may be tested via bench-top treatability tests.

Pilot studies are often conducted on a column. Experience indicates that a column with a diameter of at least 15 cm (6 in.) satisfactorily simulates a full-scale filter. Columns of smaller diameter may result in wall effects and can produce data that may not be representative of full-scale operation. A column with a diameter of at least 30 cm (1 ft) can be used to determine backwashing characteristics. Most pilot studies have been conducted on columns constructed of transparent rigid plastic tubes, fitted with plastic flanges at top and bottom and a perforated-plate underdrain to support the filter media. Column height will depend on the design depth of media. The vertical dimensions should fully simulate the conditions to be expected during full-scale operation. The testing shall be of sufficient duration to cover the range of conditions to expect (e.g., temperature, water quality variations). Detailed information regarding pilot testing is presented in Hudson (1997), *Water Clarification Processes: Practical Design and Evaluation.*

Alternatively, studies may be run either on pilot filters or on the unit itself to help optimize performance. This is the preferred method for cartridge or bag filters. In the case of low flows (less than 15 L/s), pilot testing may not be cost effective. In such a case, the filter design should be conservatively sized, based on previous similar experience elsewhere. Information regarding prior testing and operation may be available from equipment vendors.

CHAPTER 4

PROCESS SCREENING AND SELECTION

4-1 **QUICK GUIDE.** Table 4-1 provides a quick guide for selecting filtration systems based on the waste stream parameters described in Chapter 3. The design professional can use this table to identify one or two filtration system options upon which to base his or her design. Using Chapter 5, the design professional can then become familiar with the specific filtration system and complete the design process. Where two filtration systems appear to be applicable, system-specific costs can be examined to determine which is more cost effective.

4-2 **GENERAL.** It should be noted that all filters are susceptible to upsets or fouling that will manifest themselves as either blinding or poor effluent quality. For some systems, recovery, after the problem causing the upset has been corrected, can be as simple as replacing the filter elements (in the case of cartridge and bag filters) or backwashing the filters for the prescribed backwash cycle (in the case of pressure and gravity deep bed filters). In other cases, the fouling may have permeated the entire filter. This is particularly the case with traveling bridge filters, which have relatively shallow filter beds, and continuous backwash filters, which use the entire bed. Recovering from an upset with these filters generally involves more extensive backwashing and cleansing and can often require that supplemental backwash water or clean process water be provided to effectively clean the filter medium.

All systems require some manner of process control. Controls may be relatively simple, such as a head loss shutoff for cartridge and bag filter systems to the complex flow equalization and backwash controls required for traveling bridge and pressure filter systems. Controls required for continuous backwash and gravity filters are generally of moderate complexity, lying somewhere between these extremes.

As with all process equipment, manufacturers generally offer add-on controls and system monitoring options to suit individual application needs.

Table 4-1. Filtration System Selection Guide

Filtration Process	Influent	Effluent*	Backwash	Advantages and Disadvantages
Granular media Pressure filter	>2 L/s (30 gpm) 3.5 (L/s)/m^2 (5 gpm) (7 (L/s)/m^2 (10 gpm peak) < 50 mg/L TSS	4–6 microns	1% of design flow. 10.5 to 14 (L/s)/m^2 (15 to 20 gpm/ft^2). Minimum once/day.	High removal. Does not require flow equalization. Backwash disposal required. High capital cost. Medium operating and labor cost. Not as susceptible to upsets. Moderate complexity of control and operation.

Filtration Process	Influent	Effluent*	Backwash	Advantages and Disadvantages
Granular media Gravity filter	>2 L/s (30 gpm) 1.4 (L/s)/m^2 (2 gpm) < 50 mg/L TSS	4–6 microns	2–3% of design flow. 10.5 to 14 (L/s)/m^2 (15 to 20 gpm/ft^2). Minimum once/day.	Low head. High removal. Larger footprint than pressure filter. Needs pump for backwash. Backwash disposal required. High capital cost. Medium operating and labor cost. Not as susceptible to upsets. Moderate complexity of control and operation.
Granular media Traveling bridge filter	>2 L/s (30 gpm) 1.4 (L/s)/m^2 (2 gpm) dosing. 3.5 (L/s)/m^2 (5 gpm) peak flow 30 mg/L TSS avg. (50 mg/L TSS peak)	5–10 microns	3 to 5% of design flow. Controlled by timer, max level. Minimum once/day. 17.5 (L/s)/m^2 (25 gpm/ft^2) for 90 s/cell.	Low head. No clear well and no mud well. Small Footprint. Air scour available (requiring auxiliary air supply). Cannot have high level of solids or oil and grease. Not as high removal efficiency as gravity up pressure filters. Backwash disposal required. High capital and operating cost. Medium labor cost. Susceptible to upset. Complex control and maintenance.
Granular media Continuous backwash filter	>2.5 L/s (40 gpm) design (can operate at lower flow) 30 mg/L TSS	10–30 microns	10 to 25% of design flow. Continuous.	Continuous; no shutdown. Not as high removal. Backwash disposal required. Auxiliary air required. High capital cost. More susceptible to upset than pressure filters. Moderate controls and maintenance.
Cartridge filter	1 to 2 mg/L TSS at <3 L/s (48 gpm). 5 to 10 mg/L TSS at 0.3 to 0.6 L/s (5 to 10 gpm). 10 to 15 mg/L TSS at < 0.3 L/s (5 gpm).	< 1 micron Flow and removal rating varies per filter element. Common filter elements: Woven wire 5 µm. Woven fabric 10 um. Cartridge 1 um.	None with disposable filter elements.	High removal. Not economical for high solids. Certain solids can qualify used elements as a hazardous waste. Low capital, operating and labor cost for correct application. Not susceptible to upsets but may be easily blinded by high solids loading system. Is not complex and requires little maintenance other than element change out. Few controls and little auxiliary equipment.

Filtration Process	Influent	Effluent*	Backwash	Advantages and Disadvantages
Bag Filter	>10 mg/L TSS	10 microns and greater. Flow and removal rating varies per filter element.	None with disposable filter elements.	Handles viscous waste streams. Lower disposal costs than cartridge filters. Not economical for high solids loadings. Low capital, operating and labor cost for the proper application may be impacted by high pressure associated within pulse flow. Not susceptible to upsets but may be easily blinded by high solids loading system. Is not complex and requires little maintenance other than element change out. Few controls and little auxiliary equipment.
*Optimal effective removal filtration systems of this type indicated can be expected to remove particle of the indicated size or larger.				

CHAPTER 5

FILTRATION PROCESSES

5-1 GRANULAR MEDIA FILTRATION

5-1.1 **Elements of Design and Operating Conditions**. Once a granular filter system has been selected using the guidance provided in Chapter 4, the following design features must be established for a given application:

- Filtration rate.
- Filter media type, size, and depth.
- Filter configuration.
- Terminal head loss.
- Method of flow control.
- Backwashing requirements.

5-1.1.1 For package filtration systems, the manufacturer will have already established these parameters. The designer should check the design of any proposed system to ensure that the given parameters fall within expected design ranges.

5-1.1.2 After the waste stream has been characterized, the first step is to establish the filtration rate and media type, size, and depth. This is normally done based on regulatory requirements of the governing body having jurisdiction, experience with similar treatment applications, or pilot testing for a specific application, if necessary and cost-effective.

5-1.1.3 Once the filtration rate for the facility is established, the facility can be sized on the basis of the required maximum treatment rate. The total filtering area is established, and then the number and dimensions for the individual filters are determined. In determining the numbers of filters required, the designer must evaluate the rate to be handled by each filter and the corresponding backwash rate that would be necessary for a certain size of filter. The decision concerning the number and size of the filters affects the individual filter piping and sizing, flow control requirements, and operational flexibility of the facility. In addition, the designer must consider the requirement for continuous flow and redundancy in determining an acceptable number of filters.

5-1.1.4 When not already dictated by the manufacturer, the configuration of the individual granular media filter may need to be decided. Choices must be made concerning the use of single or dual cell filters and the length and width dimensions of the filter cell. The length and width of the filter cell is normally established on the basis of the filter underdrain system and the auxiliary scour system to be used. Manufacturers of the filter equipment components provide guidelines covering the use of their equipment and filter bed layout information in their product literature.

5-1.1.5 The depth of the filter is established based on the underdrain selection, support gravel requirements, depth of the filter media, and the operating water depth above the filter media.

5-1.1.6 There are many different styles of filter underdrains available. The designer must evaluate them on the basis of their hydraulic distribution capabilities, head loss characteristics, materials of construction, and the associated support gravel requirements. In selecting the underdrain system, the designer would normally contact various filter equipment and underdrain suppliers to discuss the process application with them. The available products, options suitable for the application, and the relative costs can be established. Once this information is obtained, the designer would use his judgment in selecting what type of underdrain is best suited for the project and is to be used as the basis of design. Support gravel requirements are dictated by the underdrain selection. Gravel gradations for the various support gravel layers are provided by the underdrain manufacturer. The gravel is used to prevent plugging of the underdrain with the media and loss of media. The filter media depth is established based on the process requirements and is set on the basis of experience with similar types of applications or pilot testing for a particular application. The last item to establish is the operating water depth over the filter. The depth over the media should be selected to provide an adequate operating range for the filter. The operating range depends on the method of flow control selected and the terminal head loss desired. In the case of constant rate filtration, the method of control most commonly employed, the depth should be set to provide adequate submergence to protect against air binding problems. The range of operating depth above the filter can vary greatly. Normal ranges are from 30 to 45 cm (12 to 18 in.). Additional depth should be provided above the high water level, based on plant hydraulics and overflow considerations and to maintain adequate freeboard from the operating level of the filter.

5-1.1.7 The filter backwashing requirements must be considered in the sizing of the filter, as the filter size influences the sizing of facilities and equipment required for backwash. The size of the filter will dictate the required flow rate and, if applicable, the storage volume required for a filter backwash. The rate of backwash affects the sizing of the wastewater troughs, wash water gullets, backwash supply piping, and waste backwash drain piping from the filter.

5-1.1.8 In the design of filtration facilities, the designer must consider each of the features discussed above to develop the facility layout and must have an understanding of the impacts of the various features on one another. In selecting the number and sizing of the filters, the designer must evaluate and consider the operational flexibility of the facility with regard to the plant flow anticipated and the impacts on the auxiliary systems, such as holding tanks, air compressors, and backwash pumps, required for the filter backwashing process.

5-1.2 **Media**. Most package systems are pre-engineered by the manufacturer with optimum media sizes, loadings, and backwash flow rates already determined. There may be options available to the filtration system designer but these are often limited. If the designer does specify system parameters outside the manufacturer's available options, then care should be taken to ensure that the manufacturer's warranty is not voided. For package systems, it is preferable for the designer to review the manufacturer's available system parameters and options and to write the specifications so that they fall within the ranges described in this design guide.

5-1.2.1 **Types of Media**. The designer will typically provide a filter equipment or media supplier with information about the filter media size, layer depth or performance, or all three. The supplier will calculate the clean bed head loss for the designer. The equations discussed can be used to determine whether the information supplied by the manufacturer is accurate.

The filter media provide the surface upon which particles are separated from the waste stream. The media are specified on the basis of material, size, shape, and specific gravity and will be selected on the basis of the waste stream and required effluent quality. The most commonly used granular media materials available for filtration are silica sand, crushed anthracite coal, and garnet or limonite (high density sands). Manganese greensand is used when soluble iron or manganese must be removed. Activated carbon and ion exchange resins may be used to filter out solids in conjunction with their primary role of removing dissolved compounds. It is important to note that some resin beads are subject to particulate attack, which fractures the resin bead.

Reliable filter performance depends on the proper selection and maintenance of filter media and the effective operation of the process. The different types of media can be used alone or in combination with one another. The following media properties are important in establishing the filter performance characteristics:

- Media size and size distribution.
- Media density.
- Media shape.

The hydraulics of filtration, as well as filter backwashing, are influenced by these properties.

5-1.2.2 **Media Size and Size Distribution**. Filter media size affects filter performance in two conflicting ways. Smaller grain size improves particulate removal, but accelerates head loss development and may shorten run time if the filtration cycle is determined by reaching terminal head loss. Conversely, larger grain size causes somewhat poorer particulate removal, but lowers the rate of head loss development.

5-1.2.2.1 Filter media size can be defined in several ways. In the United States, filter media are characterized by the effective size and the uniformity coefficient. A sieve analysis of a sample of the media determines these values. The sieve analysis should be done in accordance with the American Society for Testing and Materials (ASTM) Standard C136-96.

5-1.2.2.2 The effective size (ES) of the sieve is defined as the opening size for which 10% by weight of the grains are smaller in diameter. The effective size is determined by reading the particle size from the sieve analysis curve corresponding to the 10% passing value and is typically noted as the d_{10} size. In general, with relatively uniformly sized particles, the larger media size is, the greater the porosity or larger the flow passages through the media will be.

5-1.2.2.3 The uniformity coefficient (*U.C.*) is a measure of the size range of the media and is defined as the ratio of the opening size for which 60% of the grains by weight are smaller compared to the opening size for which 10% of the grains by weight are smaller. The uniformity coefficient can be denoted as follows:

$$U.C. = d_{60}/d_{10}$$

The lower the uniformity coefficient value is, the closer the size range of the particles. The uniformity coefficient is particularly important in the design and operation of dual media filters as it influences the backwash rate required.

Typical ranges of values for the effective size and uniformity coefficient of different types of media are presented in Table 5-1.

Table 5-1. Filtration Media Effective Sizes and Uniformity Coefficient

	Uniformity Coefficient	Effective Size (mm)
Silica sand	1.2–1.8	0.4–0.8
Anthracite coal	1.3–1.8	0.8–2.0
Garnet	1.5–1.8	0.2–0.6
Limonite	1.5–1.8	0.2–0.6
Source: Metcalf & Eddy (1991)		

5-1.2.3 **Media Density**. Media density is the mass per unit grain volume. The density of the filter media affects the backwash flow requirements; for materials with the same diameter, those with higher density will require higher backwash rates to achieve fluidization.

The specific gravity of a material is defined as the ratio of the mass of the substance to the mass of an equal volume of water at a specified temperature (g/cm^3). Specific gravity is used to calculate the density of a material. The specific gravity of filter media should be determined in accordance with ASTM C128-01. The test uses a displacement technique at a temperature of 23 degrees C (73 degrees F). (There are three alternative test methods for specific gravity—bulk specific gravity, bulk specific gravity [saturated surface dry] and apparent specific gravity.) The bulk specific gravity (saturated surface dry) would most closely represent conditions that exist with granular media filtration; however, results are difficult to reproduce. Apparent specific gravity is more reproducible than the bulk specific gravity (saturated surface dry) for filter media and its use is generally accepted for the backwash fluidization calculations. Test results for specific gravity should be reported as the apparent specific gravity. Typical values are presented in Table 5-2.

Table 5-2. Typical Properties of Filter Media Material

Material	Density g/cm^3 (lb/ft^3)	Sphericity	Porosity
Silica sand	2.6–2.65 (162–165)	0.7–0.8	0.42–0.47
Anthracite	1.45–1.73 (90–106)	0.46–0.60	0.56–0.60
GAC	1.3–1.5 (81–93)	0.75	0.50
Garnet	3.6–4.2 (224–262)	0.60	0.45–0.55

5-1.2.4 **Media Shape**. Grain shape is important because it affects the backwash flow requirements for the media, the fixed bed porosity, and the head loss during filtration. The measure of grain shape for granular media filtration is sphericity. It is defined as the ratio of the surface area of an equal volume sphere (diameter of d^{eq}) to the surface of the grain. The sphericity of filter media can be determined by measuring the pressure drop through a sample and calculating the sphericity using the Carmen-Kozeny or Egun equations for flow through porous media. This requires determining the equivalent spherical diameter and the porosity of the sample first, so that the only unknown is sphericity. Materials that are more angular, such as anthracite, have lower sphericity. Typical values are presented in Table 5-2.

5-1.2.5 **Fixed Bed Porosity**. The fixed bed porosity of a granular media filter is defined as the ratio of the void volume of the bed to the total bed volume and is expressed as a decimal fraction. Fixed bed porosity is affected by the sphericity of the media; those with lower sphericity will have a higher fixed bed porosity. Porosity is determined by placing a media sample of known mass and density in a fixed diameter, transparent cylinder. The depth of the sample in the cylinder times the cylinder area establishes the total bed volume. The media volume is calculated by dividing the mass of the sample by the density of the media. By subtracting the media volume from the total bed volume, the void volume is determined. The porosity is then calculated as the ratio of the void volume to the total bed volume of the sample.

5-1.2.6 **Typical Media Properties and Design Standards**. Some typically measured values of density, sphericity, and porosity of different types of filter media are shown in Table 5-2. Differences in the densities of the various materials are what permit their use in dual media applications. Larger sizes of the lower density media—anthracite and granular activated carbon—are used as a cap material. These lower density media also have higher values of porosity, which will allow floc penetration. The larger media size and greater porosity will typically result in better deep bed filtration.

5-1.2.6.1 Silica sand is the most common filtration media. Sand filters have historically been used alone or in combination with other media. Silica sand is both economical and fine-grained, which results in a satisfactory quality of effluent. But, single media sand filters generally have short filter runs because the particles become trapped in the fine grains at the top of the medium, quickly increasing head loss to an unacceptable level. To overcome this, sands of varying sizes may be used in an unstratified bed. Alternatively, coarser materials have been used in combination with fine-grained sand, where the lighter, coarser materials will be found at the influent side of the bed. The most common coarse material used is anthracite coal. Garnet and ilmenite are generally used in multi-media filters as the third, or possibly fourth, polishing layer. Most wastewater applications, other than continuous backwash and traveling bridge filters, use dual media.

5-1.2.6.2 Although granular activated carbon may be used as filter media, usually its principal purpose is to remove dissolved organics. As a result, when granular activated carbon is used as filter media, the carbon acts to filter particulate from the water and adsorb organic impurities in the water. The greatest disadvantage of granular activated carbon, especially with regard to hazardous and toxic applications, is that the media's adsorption capacity may be exhausted before its filtration capacity is exceeded. For hazardous and toxic waste sites, activated carbon treatment should occur downstream of the filtration unit. The activated carbon unit's principal function should be to remove organic contaminants, not to filter particulate matter (see generally DG 1110-1-2).

5-1.2.6.3 Manganese greensand is a natural zeolite (glauconite) treated with manganous sulphate and potassium permanganate, giving the media the characteristics of a catalyst. Manganese greensand removal is ion-specific, removing soluble iron and manganese by ion exchange, in addition to filtering out particulate material. Usually, a 1 to 4% solution of potassium permanganate ($KMnO_4$) is fed upstream of the filters to oxidize the soluble iron and manganese to insoluble ferric and manganic precipitates. The majority of the oxides can be removed in the upper layers of the filter bed, which is composed of conventional media (e.g., anthracite coal). Iron and manganese not removed in the upper layers will be filtered out by the bed of manganese greensand. The greensand can remove iron, manganese, and potassium permanganate in insoluble and soluble forms. In this system, the manganese greensand acts not only as a physical filtration media, but also as a catalyst in removing ions by chemical means. Solids can be removed by periodic backwashing. The oxidative capacity of the bed is restored by continuous regeneration with potassium permanganate. It is important to note that chemical feed rates should be proportional to influent rates. Excessive feed of potassium permanganate will result in a fully regenerated bed, leading to leakage of the potassium permanganate causing a pink tinge in the filter effluent. Generally, iron and manganese removal systems employ pressure filters. For more information on manganese greensand filters see EPA 570/9-91-004.

5-1.2.7 **Filter Hydraulics**. The flow of water through a granular medium filter with a clean bed has similar hydraulic characteristics as flow through underground stratum. Various empirical equations have been developed to compute the head loss attributable to the flow of water through clean filter media of uniform size. See Metcalf & Eddy (1991) for additional information on these and other equations. Several of these equations are presented below.

5-1.2.7.1 **Fair-Hatch**

$$h = \frac{kL}{g} vu \frac{(1-\alpha)^2}{\alpha^3} (\frac{6}{Yd})^2$$

5-1.2.7.2 **Carmen-Kozeny**

$$h = \frac{f}{\phi} \frac{1-\alpha}{\alpha^3} \frac{L}{d} \frac{v^2}{g}$$

$$f = 150 \frac{1-\alpha}{N_r} + 1.75$$

$$N_r = \phi \frac{pvd}{\mu}$$

5-1.2.7.3 **Rose**

$$h = \frac{1.067}{\phi} C_d \frac{1}{\alpha^4} \frac{L}{d} \frac{v^2}{g}$$

For N_r less than 1:

$$C_d = \frac{24}{N_r}$$

For $N_r = 1 – 10^4$ C_d can be approximated by:

$$C_d = \frac{24}{N_r} + \frac{3}{\sqrt{N_r}} + 0.34$$

where:

- p = density (kg/m^3)
- h = head loss (m)
- f = friction factor
- α = porosity
- ϕ = shape factor
- L = depth (m)
- d = grain diameter (m)
- $\mathfrak{u}$ = face or approach velocity (m/s)
- g = gravity constant (9.8 m/s^2)
- C_d = coefficient of drag

k = coefficient of permeability (assumed 5 under most conditions of water filtration)
Y = sphericity
μ = dynamic viscosity (N•s/m^2)
v = kinematic viscosity (m^2/s)
N_r = Reynolds number

In a clean filter stratified by backwashing, the equations presented calculate the head loss as the sum of the losses in successive layers of the media. The head loss calculations are performed on the basis of a sieve analysis of the material and consider that the particles between adjacent sieve sizes are uniform. The modified equations for stratified media are as follows.

5-1.2.7.4 **Modified Fair-Hatch**

$$h = \frac{kL}{g} vu \frac{(1-\alpha)^2}{\alpha^3} (\frac{6}{Yd}) \sum \frac{p_i}{d_i^2}$$

where p_i = percentage of weight retained by sieve and d_i = geometric mean size between adjacent sieves.

5-1.2.7.5 **Modified Carmen-Kozeny**

$$h = LK \sum \frac{fp_i}{d_i}$$

where *f* = friction factor for each layer, and

$$K = \frac{1}{\phi} \frac{1-\alpha}{\alpha} \frac{u^2}{g}$$

5-1.2.7.6 **Modified Rose**

$$h = \frac{1.067}{\phi} L \frac{1}{\alpha^4} \frac{u^2}{g} \sum \frac{C_d P_i}{d_i}$$

where C_d = drag coefficient for each layer.

5-1.2.8 **Configuration**. Single media, dual media, and multi-media filters have been used in water filtration. A bed should be configured on the basis of water stream, effluent quality, availability of materials, and backwash design. If necessary and practicable, pilot testing may be used for selecting the media type and configuration. Pilot testing will provide information on head loss and resultant effluent quality for each medium considered. Pilot testing is addressed in Paragraph 3-4. If pilot testing is not done, experience with similar water streams provides guidance in selecting media type and configuration. Backwash requirements should also be considered in making the final media selection.

5-1.2.8.1 Dual media filters employ two layers of media of different size and specific gravity. The flow will contact the lighter, coarser layer first (top size generally greater than 1 mm), with the finer layer used as a polishing step (reverse gradation). Dual media filters produce both good effluent quality and deep bed penetration. Grading the media from coarse to fine allows greater penetration of solids within the bed and greater removal of solids by the coarse media owing to the consequent increased available removal sites (increased "storage" capacity). Removal in the coarser media results in less head loss buildup. Dual media filters are the most common arrangement used in practice. Unless extensive pilot testing is conducted, use of dual media is recommended for gravity and pressure granular media filters. Because of they way they operate, continuous backwash systems are always designed using a single granular medium. Traveling bridge filters may use single or dual media, depending on the manufacturer and the application, although they usually use single media. These filters are described in Paragraphs 5-1.3 and 5-1.4.

5-1.2.8.2 The most common dual media filter configuration is crushed anthracite coal over silica sand. The larger anthracite removes bulk suspended solids; the sand removes finer particles that were carried through the anthracite bed. Other types of dual media filters have been composed of activated carbon and sand, ion exchange resin beads and sand, and resin beads and anthracite.

5-1.2.8.3 Multi-media filters operate in the same way as do dual media filters, but have an additional layer of filtration media, offering a greater potential for tailoring the filter design to the specific waste stream. A multi-media filter will be the most expensive to produce and install. Common multi-media beds are composed of anthracite, sand, and garnet or ilmenite; activated carbon, anthracite, and sand; weighted spherical resin beads, anthracite, and sand; and activated carbon, sand, and garnet or ilmenite.

5-1.2.8.4 One issue with dual media or multi-media configurations is the effect of intermixing of the media at the interface. The degree of intermixing will depend on the density, shape, and size differences between the media at the interface. The media may be graded to maintain a sharp interface (coal size to sand size ratios at the interface of about 2:1) or substantial intermixing may be allowed (coal size to sand size of about 4:1). Better effluent quality generally results with at least a modest amount of intermixing, which is desirable in dual and multi-media filters. An intermixed bed more closely approximates the ideal coarse to fine filter bed, eliminating the impervious layer that may build up at a sharp interface. In practice, some intermixing is unavoidable. No conclusive evidence is available to dictate or suggest the ideal or optimum degree of intermixing. One rule-of-thumb is that at least several inches of pure sand should be available past the zone of intermixing. Intermixing will result in faster head loss buildup owing to increased suspended solids removal. Typical media design parameters are contained in Tables 5-3 and 5-4.

Table 5-3. Typical Media Designs

Characteristics	Values	
	Range	Typical
Dual Media		
Anthracite		
Depth, mm	300–600	450
Effective size, mm	0.8–2.0	1.2
Uniformity coefficient	1.3–1.8	1.6
Sand		
Depth, mm	150–300	300
Effective size, mm	0.4–0.8	0.55
Uniformity coefficient	1.2–1.6	1.5
Tri–Media		
Anthracite		
Depth, mm	200–500	400
Effective size, mm	1.0–2.0	1.4
Uniformity coefficient	1.4–1.8	1.6
Sand		
Depth, mm	200–400	250
Effective size, mm	0.4–0.8	0.5
Uniformity coefficient	1.3–1.8	1.6
Garnet or ilmenite		
Depth, mm	50–150	100
Effective size, mm	0.2–0.6	0.3
Uniformity coefficient	1.5–1.8	1.6

Source: WEF (1992)

Table 5-4. Typical Media Designs

Media Design	Anthracite Coal			Silica Sand			Garnet			Typical Application Conditions
	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	Effective Size (mm)	Depth (mm)	Uniformity Coefficient	
Single	—	—	—	1–2	1525	1.2	—	—	—	A
Single	—	—	—	2–3	1830	1.11	—	—	—	A
Dual	0.9	915	<1.6	0.35	305	<1.85	—	—	—	B
Dual	1.84	380	<1.1	0.55	380	<1.1	—	—	—	A
Tri	1.0–1.1	430	1.6–1.8	0.42–0.48	230	1.3–1.5	0.21–0.23	100	1.5–1.8	B
Tri	1.2–1.3	760	—	0.8–0.9	305	—	0.4–0.8	150	—	C

Note: A = heavy loading, strong floc.
B = moderate loading, weaker floc.
C = moderate loading, strong floc.
Source: EPA 570/9-91-004

5-1.2.9 **Media Support and Underdrain Systems**. With the exception of upflow and downflow continuous backwash systems, granular filtration media are supported by an underdrain system. In addition to providing this support, the underdrain system acts to distribute the backwash water evenly, collect the filtered water, and prevent loss of the filter media with the filtered water. For conventional systems, a layer of gravel is often placed between the media and the underdrain to aid in preventing media loss. The principal consideration in underdrain design is the uniform distribution of backwash water. Some common underdrain systems include pipe laterals with orifices or nozzles; ceramic or plastic block laterals with holes, nozzles, or porous plates; lateral T-Pees; plenum, precast, or monolithic concrete, with holes, nozzles or porcelain spheres (Wheeler-type); plenum with porous plates; and porous plates in ceramic block laterals. Table 5-5, taken from Monk and Willis (1987), compares some conventional underdrain systems.

Table 5-5. Comparison of Underdrain Systems

TYPE	ADVANTAGES	DISADVANTAGES
Pipe laterals with nozzles	Air-scour can be used Less gravel layers needed Shallower filter box required	Nozzles result in greater head loss Cannot use concurrent air and water
Pipe lateral with orifices	Relatively inexpensive material costs Simple to construct and install	Multiple gravel layers needed Integral air-scour cannot be used Gravel layers increase depth of filter box
Precast concrete T-Pees	Very little head loss Can be used to form plenum	Multiple gravel layers needed Integral air-scour cannot be used Casting and laying is labor intensive Gravel layers increase depth of filter box
Ceramic tile block	Good backwash distribution Small head loss Relatively easy to install	Integral air-scour cannot be used Requires up to seven layers of gravel Blocks difficult to handle Deeper filter box because of gravel and depth of block
Plastic dual lateral block	Light to handle Small head loss Water and air can be used concurrently Good water-to-air distribution	Requires up to seven layers of gravel Deeper filter box because of gravel and depth of block Limited flexibility in range of air-scour rates Blocks require care in laying correctly
Plenum with precast concrete block and nozzles	With appropriate nozzles air-scour can be used Good water-to-air distribution Gravel layer not needed	Difficult to construct Deeper box because of plenum Extra care is needed to avoid nozzle clogging
Wheeler-type System	Low head loss Good water distribution	Multiple gravel layers required Integral air-scour cannot be used Costly construction requirement Deeper filter box because of plenum and gravel layers
Plenum with monolithic floor and nozzles	Water and air can be used concurrently Little or no gravel required Nozzles available that can be adjusted to ensure uniform air distribution Air-scour rates can be varied	Deeper box because of plenum Extra care is needed to avoid nozzle clogging Nozzle type must be carefully specified
Plenum with precast concrete blocks and nozzles	Water and air can be used concurrently Little or no gravel required	Deeper filter box because of plenum Less reliable than a monolithic floor Extra care is needed to avoid nozzle clogging

TYPE	ADVANTAGES	DISADVANTAGES
Plenum with porous plates	Excellent water distribution No gravel layers needed	Integral air-scour cannot be used Filter box is deeper because of plenum History of damaged plates Little, if any, competitive market Usually not recommended for wastewater filtration

Source: Monk and Willis (1987)

Considerations in selecting an underdrain system include the size of the underdrain, depth of the gravel layer, head loss during backwash, and material of construction. The size of the underdrain will affect the depth of the filter box. The gravel layer depth depends on the orifice size and spacing. Orifice size will greatly affect head loss during backwash. The underdrain should be constructed of a material that will be resistant to any contaminants in the water to be filtered.

Concrete filters are not generally used for flows less than 12 L/s (200 gpm). Package systems used for low-flow applications will generally have standard underdrains designed for the system. The manufacturers will provide guidance on whether the particular application requires a different underdrain system.

5-1.2.10 **Number of Cells**. The number of filtration cells must be sufficient to assure that the backwash flow rates do not become excessively large and that when one filter cell is taken out of service for backwashing, routine maintenance, or repairs, the loading on the remaining cells is within acceptable design criteria. The number of cells should be kept at a minimum to reduce the cost of piping and construction. After peak filtration and plant flow rates are established, the number of cells should be determined based on total required surface area and space, and cost. Where multiple cells are specified, the number of cells should be based on one cell being out of service at all times. Usually, the minimum number of cells is two, with four often recommended. For package pressure filter systems, it is common to size the system with three cells, anticipating that the design load through two cells will be exceeded for short periods of time while the filtrate from those two cells is used to backwash the cell requiring cleaning. For some low-flow HTRW applications and continuous backwash systems, one cell may be sufficient if it is acceptable to interrupt filtration (e.g., shut off recovery wells or increase equalization storage) for backwash or maintenance.

5-1.2.11 **Filter Size**. Generally, the surface area required is based on the peak filtration and peak flow rate. Bed depth, filtration rate, head loss, and filter run length also help determine the required filter size. Capital and operating costs must also be considered in designing the filter. The filter box must be large enough to house the media, underdrain, any control mechanism, and troughs. Additionally, the filter box size will be, in part, determined by the backwash requirements (the bed expands during backwash) and control system.

5-1.2.12 **Valves and Piping**. The necessary valves and piping are for influent flow control, effluent flow control, and the backwash cycle. Additionally, washwater troughs must be designed.

5-1.2.12.1 Valves are used to control flow. Valves are selected based on desired service. Some function only when fully closed or fully open; by throttling, to reduce the pressure and flow rate of the water; or to permit flow only in one direction or under certain conditions of temperature and pressure. Valves basically function by placing an obstruction in the path of the water, providing resistance to flow. Some basic valves are briefly described below.

- **Gate Valves**. Gate valves are used to minimize pressure drop in the open position and to stop the flow of fluid rather than to regulate it.
- **Globe Valves**. Globe valves are used for controlling flow. The flow passes through a restricted opening. Associated pressure drop is large.
- **Butterfly Valves**. Butterfly valves operate by rotating a disk from a parallel position to one perpendicular to the fluid flow.
- **Ball Valves**. Ball valves use a spherical sealing element. The valves may be used for throttling. Pressure drop is low.
- **Check Valves**. Check valves permit flow in one direction only. When the flow stops or tends to reverse, the valve automatically closes by gravity or by a spring pressing against a disk.

More information on these and additional valves is available in *Perry's Chemical Engineers' Handbook* (McGraw-Hill 1997), EM 1110-1-4008, and vendor literature.

5-1.2.12.2 Piping is specified in terms of its diameter and wall thickness. The optimum size of pipe for a specific situation depends upon the relative cost of investment, power, maintenance, and stocking pipe and fittings. Velocities between 0.5 and 2.5 m/s should ordinarily be favored, especially in gravity flow from overhead tanks. The facilities layout should minimize pumping and piping requirements.

5-1.2.12.2 Backwash troughs collect the backwash water and transport it to the disposal facilities. The troughs must be correctly located relative to each other and to the media. Backwash gutters should be as close to the media as possible to minimize the amount of dirty water left after backwashing and to minimize the height of the filter box, but should be high enough to prevent loss of media. The gutter must be large enough to carry all the water delivered to it. A dimensionless relationship to help determine correct trough spacing is:

$$H = 0.34S$$

where H = height of the top edge of the trough above the fluidized bed, and S = center-to-center spacing of the troughs.

5-1.2.12.3 Two or more troughs are usually provided. The clear horizontal distance between troughs should not exceed 1.5 to 2 m (5 to 6 ft), and the top of the troughs should not be more than 750 mm (30 in.) above the top of the bed (TM 5-813-3).

5-1.2.12.4 Common materials used for backwash gutters are concrete, steel, aluminum, and fiberglass. Materials of construction should be chosen based upon compatibility with the water to be filtered (TM 5-814-3).

5-1.2.13 **Backwash**

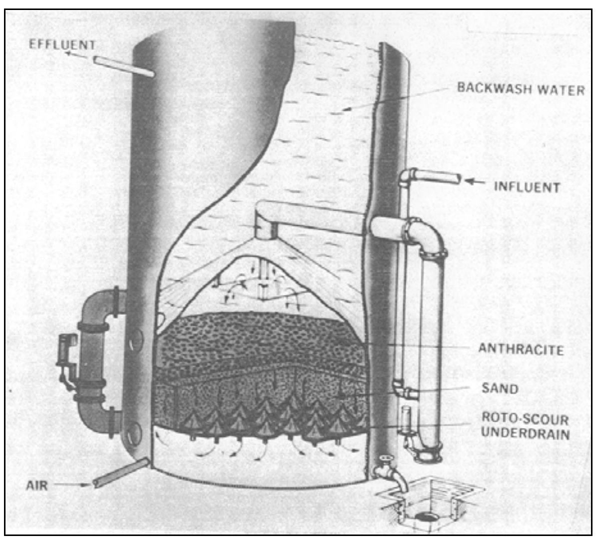
5-1.2.13.1 **Process Description**. A necessary component for long-term operating success of granular media filters is adequate bed cleaning. Traditionally, this has been accomplished using an upflow water wash with full-bed fluidization. Backwash water is introduced into the bottom of the filter bed through the underdrain system. The filter media gradually assumes a fluidized state as backwash flow is increased. Recently, surface washing or air scour have been used to supplement water backwash. Surface wash systems consist of orifices located 50 to 80 mm above the fixed-bed surface that inject water over the bed prior to and during water backwash. Air scour supplies air to the full filter area from orifices located under the filter medium. Air scour may be used either prior to the water backwash or simultaneously with the water backwash. Proprietary systems have been developed in which the media are cleaned continuously. This is accomplished in the deep bed continuous backwash filter by removing media from the filtration zone for cleaning and returning the media once cleaned.

5-1.2.13.2 **Disposal Options**. Backwash water is usually disposed of by re-filtering, settling in an upstream clarification unit, or dewatering to concentrate the solids. Generally, it is advisable to provide either treatment (e.g., clarification or dewatering, or both) or storage prior to re-filtering the backwash stream. Storage is more typically used, except for continuous backwash systems. The water can be stored and delivered at a uniform rate to the influent flow. A storage tank is usually necessary to avoid sending a high solids or high volume "slug" through the filter at once. To dewater, the waste stream is typically collected, conditioned, and settled. If dewatering is used, the wet stream from the dewatering unit is often returned to the process stream ahead of the filtration unit. If a separate treatment train is not desirable, or the process train configuration lends itself to simple re-treatment, the waste stream may be returned to upstream settling and clarification units for solids separation. The designer should always consider the hydraulic effects on upstream unit processes when the backwash waste is returned directly to the treatment train. Alternatively, the backwash water may be disposed of off-site. The disposal of both the backwash water, and eventually the media, is a significant design consideration for hazardous and toxic waste applications. The designer is referred to the *Resource Conservation and Recovery Act* (RCRA) and the *Clean Water Act* regulations and other applicable Federal, state and local regulations to determine the required treatment or permitting prior to release. The designer should try to minimize all waste streams that are subject to regulation and treatment as a hazardous waste.

5-1.3 **Gravity and Pressure Filtration**. The following is a brief description of how gravity and pressure filtration systems work and general design parameters. Package systems have been designed by their respective manufacturers and generally come as a unit that is inserted into the treatment process. The range of options available to a system designer specifying package systems is limited, although each manufacturer may configure its system in a slightly different fashion. It is the designer’s responsibility to ensure that the design proposed by the chosen manufacturer is adequate for the intended application.

5-1.3.1 **Description of Gravity Filter**. Gravity filters are granular filters that are open to the atmosphere. Suspended solids are removed as the influent passes through the porous, granular media. The removal occurs within the interstices of the filter medium by interception, impaction, and straining. The hydrostatic pressure over the bed provides the driving force to overcome head loss through the unit. Maximum head loss typically is less than 2.5 to 3 m (8 to 10 ft), and depends on the hydraulic profile of the treatment system. Backwash is initiated at this limiting head loss. The direction of water flow may be downflow, upflow, or biflow. The downflow designs are most common. If an upflow configuration is used, a retaining grid must be placed above the media bed to minimize loss of media in the effluent. This limits filtration rates in upflow filters. Biflow configurations, where influent is introduced to the bottom and top of the bed with the effluent withdrawn from a strainer placed within the bed, have been used principally in Europe. Backwash is always upflow, regardless of the operating flow direction. Backwash may consist of water wash in conjunction with surface wash or air scour. Flow rate may be controlled using either constant-rate filtration or declining-rate filtration. These controls will be discussed in Paragraph 6-3. A typical gravity filter is shown in Figure 5-1.

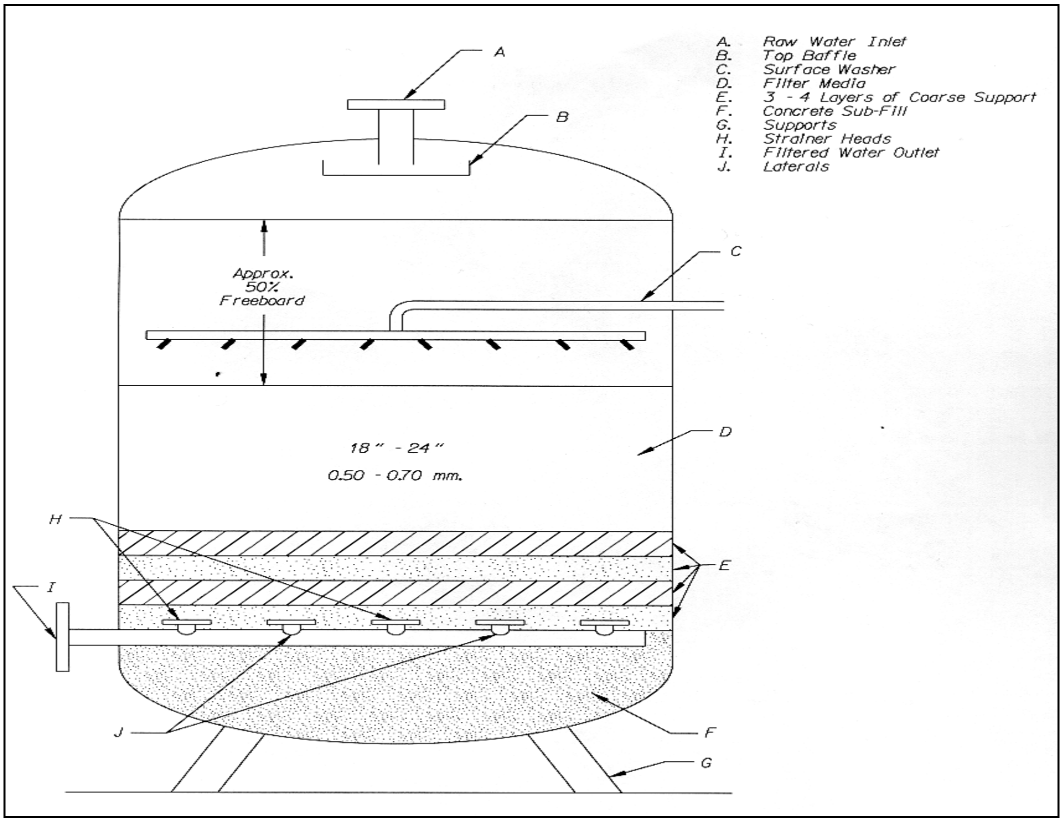
Figure 5-1. Gravity Filter



5-1.3.2 **Description of Pressure Filtration System**

5-1.3.2.1 Pressure filtration systems operate in essentially the same manner as gravity filtration systems, except that pressurized conditions, achieved by pumping, supply the required driving force. Pressure filters may be operated with terminal head losses up to 10 m (30 ft). A typical pressure filter is shown in Figure 5-2. Again, downflow, upflow, and biflow configurations are available. In addition to control by constant-rate filtration and variable-declining-rate filtration, pressure filtration can also be operated at constant-pressure. Pressure filtration units are usually constructed of cylindrical steel shells with either horizontal or vertical axes. Backwash is executed in substantially the same manner as for gravity filters.

Figure 5-2. Pressure Filter



5-1.3.2.2 Single medium stratified filter beds are not typically used for wastewater treatment, except in continuous backwash filters. However, for HTRW and industrial applications, single media stratified beds may be considered. For typical gravity and pressure filtration systems, single medium filter beds will become stratified with finer grains on top after backwash. This results in unfavorable head loss buildup resulting from surface straining of the solids within the finest medium layer. Instead, if a single medium is to be used, the bed should be unstratified. Two types of unstratified single medium beds have been used. One type uses a single, uniform, coarse medium (approximately 1–3 mm in diameter) in a deep filter (approximately 2 m or 6.5 ft). Effluent quality may suffer somewhat with use of this type of bed, as the coarse media may not entrap fine particles. Additionally, prohibitively high backwash rates may be required to fully fluidize the bed. For example, the minimum backwash velocity needed to fluidize 2-mm-diameter sand grains is approximately 1800 (L/min.)/m^2 (45 gpm/ft^2) as opposed to a more typical required backwash velocity of 600 (L/min.)/m^2 (15 gpm/ft^2). The second type of unstratified single media bed uses a single medium of varying sizes to a depth of approximately 1 m (3 ft) with a combined air–water backwash. Use of this type of unstratified bed results in uniform average pore size throughout the filter bed. Therefore, in-depth filtration is more likely, which results in longer filter runs. Use of air–water backwash eliminates the need for fluidization and consequent stratification of the media. This type of filter has been most commonly used in potable water treatment. Generally, it is advisable to use dual media filters.

5-1.3.2.3 Tables 5-3 and 5-4 present typical media designs for filters. Additional information is presented in TM 5-814-3 and TM 5-813-3.

5-1.3.3 **Design Considerations**. Typical filtration rates for granular filters are 40 to 100 (L/min.)/m^2) (1 to 2.5 gpm/ft^2) for rapid filters and 100 to 600 (L/min.)/·m^2 (3 to 15 gpm/ft^2) for high rate filters. Higher filtration rates are generally preferred to decrease the capital cost of the filter (less filter area required) and the higher filtration rates result in greater penetration of solids into the bed. The trade-off is potentially poorer effluent quality. When designing a filter for a specific net production (m^3/hr or gpm), downtime for backwash and time associated with treatment of the backwash water, if applicable, must be considered. Head losses of approximately 3 m (10 ft) permit a reasonably long run in gravity filters. Lower head losses (2 m [6.5 ft]) may be acceptable for dual media configurations. The loss of head through the filter is determined by summing the incremental losses through the underdrain (and supporting gravel, if applicable), media, static height, and valves and piping.

Gravity filters may be of concrete or steel shell construction. Concrete gravity filter boxes are usually arranged in rows along one or two sides of a common pipe gallery, minimizing piping required for influent, effluent, wash water supply, and wash water drainage. Concrete units are usually rectangular and steel units are round. Generally, the steel units are made for smaller influent flows than the concrete units and may be more practical for HTRW applications.

Pressure filters shells can be either steel or fiberglass and must withstand high operating pressures. They must be manufactured in strict accordance with the American Society of Mechanical Engineers (ASME) standards for pressure vessels (ASME Boiler and Pressure Vessel Codes, Section VIII, Divisions 1,2 and 3). Pressure filter units are sized to use commercially available shells. The shells can be mounted either vertically or horizontally. The vessel will house the media; media support structures; distribution and collection devices for influent, effluent, backwash water and waste; supplemental cleaning devices; and necessary controls. Media support structures are typically pipe laterals with nozzles or orifices or a plenum with porous plate-type structure using a framework similar to a well screen. Allowable head losses approach 10 me (30 ft) (WEF, 1992). With pressure filtration, only single pumping typically is required. If pretreatment is not needed, water may be pumped from wells, for example, through the filters and to further waste treatment or storage facilities.

5-1.3.4 **Backwash Alternatives**

5-1.3.4.1 **Process Description**. Granular media filters are cleaned by reversal of the flow through the bed based on a triggering measurement, such as effluent quality or head loss or after a predetermined time. During backwashing, the media are usually fluidized to allow the captured particulate to be released into the water and collected in wash water troughs. Air injection, surface wash, or jets of water may supplement the washing process. Auxiliary cleaning is recommended, particularly when filtering wastewaters. Surface wash and surface air scour are used to loosen and remove deposits from upper levels of the medium. Air scour may also be used to reduce wash water requirements and clean the deeper portion of the filter bed.

The USEPA has promulgated rules under the *Safe Drinking Water Act* Amendments of 1996 regarding the disposal of backwash water. Most HTRW applications are not regulated by the *Safe Drinking Water Act* but, if the Act does apply to a particular application, then the designer should be familiar with the *Filter Backwash Recycling Rule* (40 CFR Parts 9, 141 and 142). Summarily, the *Ten State Standards* (critical reference) may include backwash criteria applicable to potable water.

Factors governing backwash system design include size distribution, depth, shape, and specific gravity of media, density of bed, influent solids characteristics, pretreatment, any supplemental cleaning by surface wash or air scour, and disposal of backwash waste.

5-1.3.4.2 **Process Alternatives.** Water backwash uses the shearing action of the water to dislodge the accumulated material on the media. The dislodged material is flushed through the bed and wasted through the wash water gutters. Traditionally, the media have been fluidized or expanded to assist in the shearing and removal of solids. Some manufacturers have found that water wash alone is insufficient to adequately clean the filter bed, especially when filtering wastewater, and provide for supplemental surface wash.

Surface wash can be used to provide additional shearing force. The surface wash system produces high velocity water jets 50 to 80 mm (2 to 3 in.) above the unexpanded media. The jets are introduced by orifices located on a fixed piping grid or on a rotating arm. Surface wash water rates are generally from 40 to 120 (L/min.)/m^2 (1 to 3 gpm/ft^2) at 3.5×10^5 to 7×10^5 Pa (50 to 100 psi). The cycle is started 1 to 3 minutes before water backwash, is operated for a period (5 to 10 minutes) simultaneous with water backwash, and is then shut off. The orifices will become submerged during the water backwash. The surface wash should be shut off at least 1 minute before the end of the backwash cycle. This is particularly important with dual media and multi-media beds, where the horizontal currents must be dissipated before the media settles and restratifies.

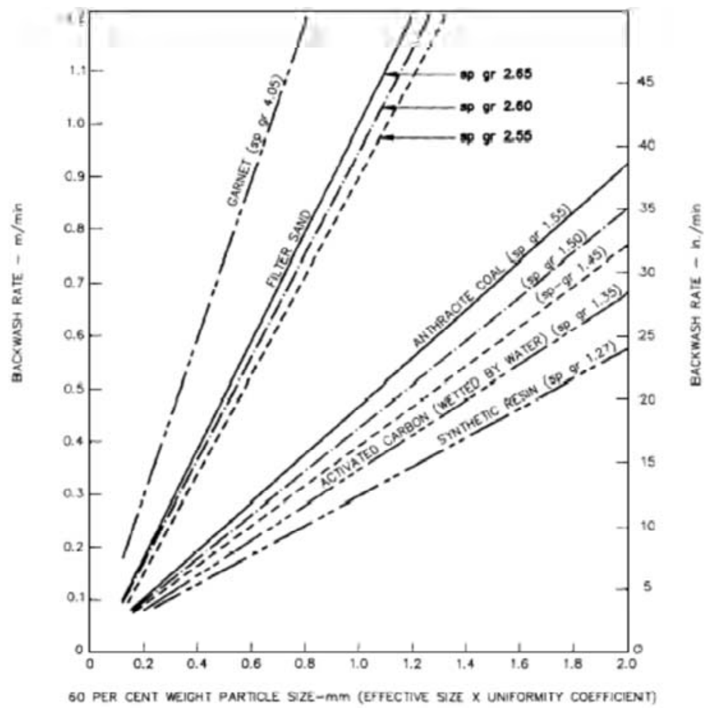
The diameter of a sweep washer should be selected so that approximately 80 mm (3 in.) of clearance is available at the nearest wall. If the filter is constructed in a rectangular shape, it may be advisable to use multiple surface washers to cover the area adequately. The washers should be located such that they remain parallel to the media surface. Sufficient clearance must exist beneath the wash troughs to allow for rotation as well as 50–80 mm (2–3 in.) between the washer arm centerline and the media surface. Auxiliary agitation may also be achieved by air scour. Air is introduced at the bottom of the filter medium prior to water backwash at approximately 1 to 1.5 (m^3/min.)/m^2 (3 to 5 cfm/ft^2) for 3 to 10 minutes. Water backwash is then initiated, and air scour may continue until the water is about 250 mm (10 in.) from the wash water trough. Air may be introduced either above the gravel layer or through the orifices of the underdrain. For design, it should be assumed that there is no reduction in a backwash rate when air scour is used.

5-1.3.5 **Backwash Control**

5-1.3.5.1 **Rates/Times**. Backwash must be carried out at a rate sufficient to fluidize the entire bed and for a time sufficient to wash the dislodged particles out of the bed and into the wash water gutter. For combined water–air backwash, fluidization is not necessary (although the bed will expand a bit). The backwash rate should be adjusted at the end of the cleaning cycle to ensure reclassification of the filter media. Quick shutdown may result in increased packing and consequent smaller porosity and less pore space for filtration. For operation on hazardous and toxic waste sites, the designer must keep in mind that the turbulence during backwash may release volatile emissions. Potential design solutions for this problem may include enclosing the vessel and scrubbing off-gases or using an upstream unit operation to remove volatile constituents prior to the filtration process. Maximum backwash rates are typically between 600 and 1000 (L/min.)/m^2 (15 and 25 gpm/ft^2) and the filter is backwashed for a period of at least 90 seconds or possibly for as long as 8 to 10 minutes, depending on the manufacturer's requirements. The required backwash rate for a given filter depends on the filter media particle size and density, and the backwash water temperature. More detailed information regarding the calculation of the required backwash rate is presented below. Appropriate filter backwash rates at a water temperature of 20 degrees C are shown in Figure 5-3.

5-1.3.5.2 **Source/Storage**. The source of the backwash water can either be filtered water (effluent stream) or water from an off-site source (i.e., potable water supply). The backwash water generally should be stored in a wash water tank to provide adequate capacity for backwashing. The volume of the tank will be determined by filter size, rate and time of backwash, and frequency of backwash. The water may be supplied for backwashing by using an elevated tank or a wash water pump. Typical required storage capacity is 6 m^3/m^2 of filter area (150 gal/ft^2). The daily backwash volume is normally in the range of 1 to 4% of the daily treatment rate, but during peak conditions, 10% or more may be necessary. On multiple unit pressure filter systems, backwash may also come from other filter units operating in parallel, thus obviating the need for a backwash reservoir.

Figure 5-3. Appropriate Filter Backwash Rates at a Water Temperature of 20 Degrees Celsius



5-1.3.5.3 **Pressure Loss and Fluidizing Velocity**. Pressure loss during backwash includes loss through the underdrain orifices or plates, loss through the expanded filter bed, loss through the gravel layer, friction and minor losses in underdrain channels and piping from the source of backwash supply, and elevation differences to the top edge of the wash water trough. The most significant pressure loss is usually that through the underdrain. Head losses through the underdrain system are obtained from the manufacturer. Loss through the gravel layer may be estimated by treating the gravel layer as porous media. Loss through valves and piping may be calculated using standard fluid flow equations.

Backwash fluidization in a granular media filter bed can be described as the upward flow of water through the media with sufficient velocity to suspend the grains in the water. As the rate of backwashing is increased the head loss through the media is linear until the rate is reached where the head loss is equal to the weight of the media grains in water. At this point, no further increase in head loss will occur. Figure 5-4 shows head loss vs. surficial velocity. As the flow rate is increased further, the media expand and provide a larger flow area that can accommodate the higher flow without additional head loss. A typical curve for fluidization of granular media is shown in Figure 5-5.

Figure 5-4. Head Loss vs. Surficial Velocity

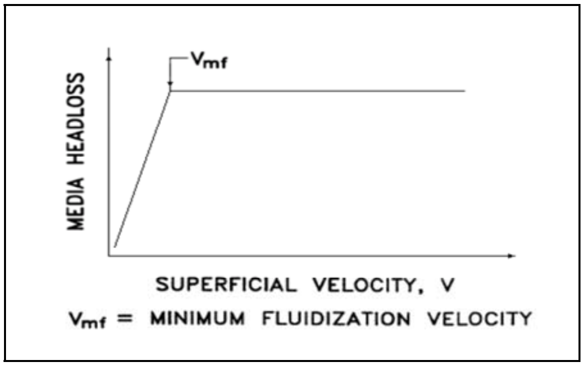
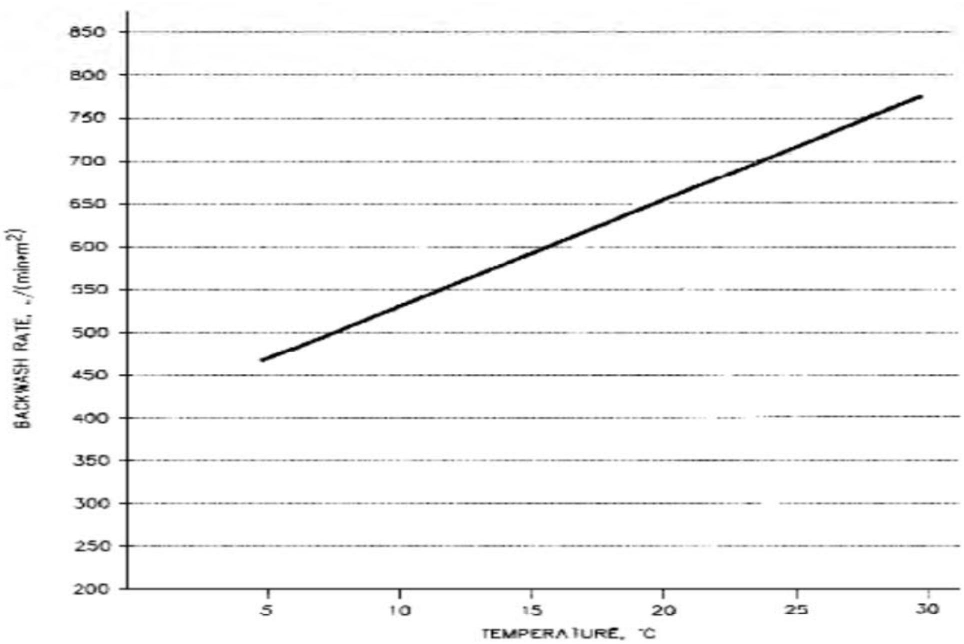


Figure 5-5. Typical Curve for Fluidization of Granular Media



The point of the curve labeled V_{mf} is called the point of incipient fluidization, or more simply, the minimum fluidization velocity. It is the superficial velocity required for the onset of fluidization and can be determined by the intersection of the fixed bed and fluidized bed head loss curves. The pressure drop at the point of fluidization can be calculated from the following equation:

$$h = L(SG_m - 1)(1 - \alpha)$$

where

- h = head loss in meters (feet) of water pressure
- L = bed depth in meters (feet)
- α = porosity of expanded bed

SG_m = specific gravity of the media.

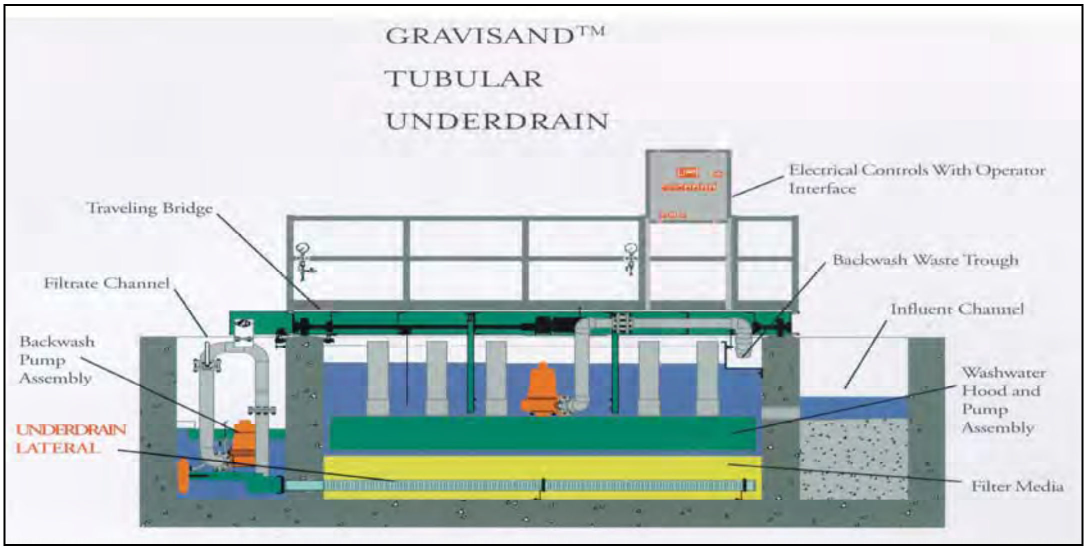
In the filter bed, there is a range of grain sizes as determined from the sieve analysis of the media. The particles do not all fluidize at the same superficial velocity; smaller particles fluidize at a lower velocity than the larger particles. Therefore, to assure complete bed fluidization, it is necessary to check fluidizing velocity of the coarser grains. The d_{90} size, that is, the particle size corresponding to the sieve opening size for which 90% of the grains are smaller, is typically used for this. The d_{90} size can be used as an acceptable approximation for the d_{eq} size of the largest particle in the bed. It is necessary to know the density of the media particles, and this can be found by running a specific gravity test on the media. This is especially important in multi-media applications where a lighter medium is used as a cap. The fluidizing velocity depends on the temperature of the water as well, as the density and viscosity of the water are factors of the equations. Higher water temperatures require higher fluidizing velocities. Once the required fluidizing velocity is calculated, a safety factor of 1.3 is normally used to assure that an adequate wash rate is provided.

5-1.4 **Continuous Backwash Filtration**. Two types of continuous backwash systems are commercially available: the traveling bridge filter and the upflow or downflow deep bed granular media filter.

5-1.4.1 **Traveling Bridge Filter**. The traveling bridge filter is a gravity filter divided up into several individual filter cells. A hood travels horizontally along the cells, backwashing individual cells while the other cells continue to filter water. The influent floods the bed to a depth of 600 mm (2 ft), flows via gravity through the media and exits through effluent ports. Typically, the media bed ranges from approximately 300 to 600 mm (12 to 24 in.) deep and may consist of single or dual media. Typically, wastewater applications use dual media with silica sand, 0.55 to 0.65 mm, and a uniformity coefficient of 1.5 under an anthracite layer sized at 1.1 mm with a 1.5 uniformity coefficient. The filter functions at the surface rather than at depth.

5-1.4.1.1 The low terminal head loss (usually less than 610 mm [2 ft]) creates the surface filtration. Concurrent with the filtering, a hood travels along a track system. The hood isolates an individual cell for backwashing. A backwash pump draws filtered water from the effluent chamber, pumping the water back through the effluent port to fluidize and backwash the bed. Another pump picks up wash water collected in the hood and discharges it to the wash water trough. Bed cleaning enhancements may include air scour or hydraulic spray jets to supplement backwash, or a scarifier blade to plow the media and loosen the solids mat as the hood moves into position to backwash. Backwash may be triggered by a certain head loss measured by water level probes, started automatically by a timer, or started manually. Figure 5-6 shows a traveling bridge filter system in cross section.

Figure 5-6. Traveling Bridge Filter (Section View)



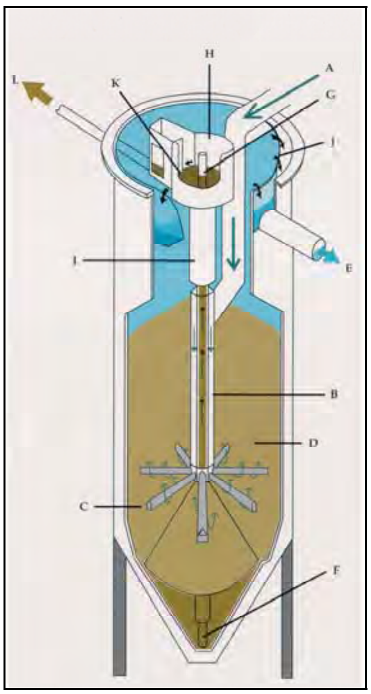
5-1.4.1.2 Typically, traveling bridge filters operate at a normal dosing rate of 80 (L/min.)/m^2 (2 gpm/ft^2) or a peak loading of 200 (L/min.)/m^2 (5 gpm/ft^2). Their design solids loading is typically on the order of 30 mg/L with a peak loading of 50 mg/L. Backwash rates are typically 800 to 1000 (L/min.)/m^2 (20 to 25 gpm/ft^2) of cell area for a period of 1 to 2 minutes. Backwash usage will typically be 3% of design flow. Since filter flow is by gravity, backwash water must be pumped to achieve sufficient head for bed fluidization.

5-1.4.1.3 Traveling bridge filters offer the advantage of gravity filtration, plus the additional advantage of not periodically shutting down the system for backwash. In addition, no backwash holding tanks are required, as backwash water is obtained from the effluent chamber and the filter can use a single medium. However, traveling bridge filters may require excessive maintenance (electric gear motors, drive shafts, bearings to lube and maintain), and they have also suffered alignment problems.

5-1.4.1.4 For more information, see *Evolution of the Traveling Bridge Filter* (Williams, 1995).

5-1.4.2 **Upflow Continuous Backwash Filter**. Granular media filters with upflow continuous backwash are proprietary systems. The media are housed in a cylindrical tank. Water enters the lower part of the filter tank and moves upward, contacting the granular filtration media. Each manufacturer has its own influent dosing mechanism, by which the influent stream is introduced to the filter bed. Generally, effluent is discharged over an effluent weir. Concurrent to filtration, the media are constantly moving downward, through the dirty sand hopper, to be removed from the filtration zone for washing, and returned to the top of the filtration zone when clean. The media are removed from the filter bed through an eductor pipe. The eductor pipe provides sufficient suction to the media bed to draw the filter sand from the system. Compressed air is generally introduced at the bottom of the pipe, causing the media to be drawn from the bed upward to the washer unit. In addition to providing transport, the eductor tube, or airlift system, scours the media with air. The media undergo an additional cleaning step, usually in a washbox located within the filter tank. A percentage of filtrate is allowed to flow upward into the washbox, which is baffled, allowing for counter-current washing and gravity separation of the cleaned sand and the concentrated waste solids. Solids generally are discharged through a reject pipe for disposal. Alternatively, the media may be cleaned in a separate washer unit. This type of system may not require compressed air. Instead, water is used in the eductor pipe to transport sand to the media wash unit. The wash process consists of a number of co-current media washes by filtered water within the baffled media washer. Figure 5-7 shows a typical upflow continuous backwash system configuration. (Andritz Sprout-Bauer, Inc., Eimco, Parkson Corporation.)

Figure 5-7. Typical Upflow Continuous Backwash System

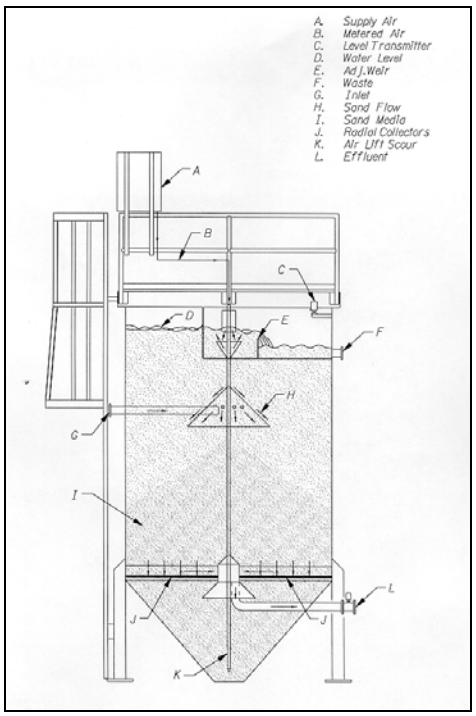


A. Inlet
B. Feed Pipe
C. Feed Radials
D. Sand Bed
E. Filtrate Effluent
F. Airlift Pipe
G. Airlift Sand Effluent
H. Reject Compartment
I. Sand Washer/Separator
J. Filtrate Weir
K. Reject Weir

Generally, the sand used in the upflow continuous backwash filter is coarser than the sand layer in granular media filters used in batch processes (1–2 mm as opposed to 0.4–1 mm for the sand layer in dual media filters). The media depth will be on the order of 1.2 m (4 ft) with a surface loading of 8–14 (m^3/m^2)/hr (3.3–5.7 gpm/ft^2). The backwash rate is typically about 10% of the surface loading. Because of the coarser media grain size and the continuous agitation of the medium and removed solids, the removal efficiency of the upflow continuous backwash filter is not as high as is available through gravity and pressure granular media filters. Generally, effluent on the order of 10 mg/L TSS can be expected.

5-1.4.3 **Downflow Continuous Backwash Filters.** The downflow continuous backwash filter using granular media is also a proprietary system. Influent enters at the top of the filter module (several modules are grouped together to create the filter cell, whose size and shape will be determined by flow rate). The influent passes through layers of increasingly finer sand, enters a filtrate chamber, and is discharged. The coarse-to-fine gradation occurs as clean sand falls from the washbox to the top, and center, of the filter bed. The coarsest sand "rolls" to the periphery of the filter cell while the finest particles remain at, or near, the peak of the filter bed. This grading process is the result of gravity's effect on the varying sizes of sand as it seeks its natural angle of repose. The coarse-to-fine gradation is maintained throughout the depth of the filter as the airlift pump continually removes the lowest layer of sand for cleaning. The airlift tube assembly transports the sand media and captured solids to the top of the filter. The turbulence within the assembly separates the sand from the solids. Both sand and solids are placed into a sand washer chamber, which operates in essentially the same manner as that employed by the upflow system. The heavier sand falls back into the sand bed and the solids are discharged through the reject pipe. Figure 5-8 shows a typical downflow continuous backwash system configuration.

Figure 5-8. Typical Downflow Continuous Backwash System



Generally, the sand used in the downflow continuous backwash filter is coarser than the sand layer in granular media filters used in batch processes (1–2 mm as opposed to 0.4–1 mm for the sand layer in dual media filters). The media depth will be on the order of 1.2 m (4 ft) with a surface loading of 8–14 (m^3/m^2)/hr (3.3–5.7 gpm/ft^2). The backwash rate is typically on the order of 10% of the surface loading. Because of the coarser media grain size and the continuous agitation of the medium and removed solids, the removal efficiency of the downflow continuous backwash filter is not as high as is available through gravity and pressure granular media filters. Generally effluent on the order of 10 mg/L TSS can be expected.

5-1.4.4 **Media Configuration**. The frequency of backwash and filter configuration for both the traveling bridge and deep bed filters allow for silica sand to be used effectively as a single medium. Silica sand can be used as a single medium in traveling bridge filters because surface filtration is the primary method of solids removal within the filter. The frequency of backwash makes this practicable. Surface filtration allows the traveling bridge filter media bed to be relatively shallow. Typical bed depths are approximately 300 mm (12–18 in.).

Continuous backwash filtration systems successfully use silica sand as a single medium. Traditional common problems associated with use of a single medium are avoided because the bed is continuously moving. The absence of a backwash cycle results in no stratification of the bed. Also, surface straining and resultant solids matting and head loss buildup are avoided. However, one drawback of the continuous backwash system is generally higher suspended solids in the effluent as compared to gravity or pressurized granular media filters (typically 10 mg/L TSS for continuous backwash filters vs. 5 mg/L for traveling bridge filters and removal in the 4–6 micron range for deep bed granular filters). Typically, continuous backwash filters maintain a bed of approximately 1 m (40 in.), with sand approximately 1.2 mm in diameter. Deeper and shallower beds are available from certain manufacturers for appropriate applications.

5-1.4.5 **Underdrain**. Traveling bridge filters generally use porous plate underdrains with no gravel layer. The porous plate is advantageous for this application because no air scour is needed to supplement water backwash owing to backwash frequency and no gravel is required, helping to minimize total bed depth. (Aqua-Aerobic Systems, Inc.; Infilco Degremont, Inc.)

No support system is required for downflow and upflow continuous backwash systems because the media moves through the filter shell. This eliminates the need for both media support and backwash distribution, the purposes of the underdrain.

5-1.4.6 **Design Considerations**. In addition to the filter tank, media, media support, distribution and collection devices, and the necessary controls, the traveling bridge filter also has the traveling backwash hood and rail upon which it moves. Traveling bridge filters are proprietary systems. They are constructed of concrete or steel. The bridge design and construction can vary substantially based on the hood itself and the transport system. The filter bed is divided horizontally into several cells. Each cell operates as a gravity filter. Backwashing occurs under the hood. Backwash can be automatic or based on a triggering mechanism. Package filtration systems are commercially available.

All continuous backwash filters are proprietary. The manufacturers offer systems that operate at a range of capacities. Generally, the filters use a single medium (sand), which is housed in a cylindrical shell. These shells may be stand-alone units or multiple units may be housed in a concrete tanks if the influent flow warrants. The systems can be manufactured from a variety of materials, ranging from mild-steel with various coatings to fiberglass-reinforced plastics to stainless steel. Several different sizes of upflow and downflow continuous backwash systems are commercially available. The systems treat throughput ranging from approximately 1–60 L/s (15–950 gpm). Traveling bridge systems are similarly sized. Because backwash is continuous there is no limiting head loss or breakthrough condition that must be determined.

The shell of upflow and downflow continuous backwash systems generally houses the media, media distribution system to re-inject the media into the bed after washing, the media removal system to remove the media requiring cleaning from the bed, and influent, effluent and reject wash water distribution systems, weirs, and lines. Additionally, they will have a media cleaning system located either external to or within the filter shell.

5-1.4.7 **Backwash**. Traveling bridge systems are designed such that individual gravity filter cells may be backwashed while the remaining cells continue to filter influent water. Backwashing occurs underneath a hood that is suspended below the bridge or carriage. The hood moves slowly along the filter system. The backwash shoe frame slowly blocks off filtering flow out of each cell through the effluent port. Concurrently, backwash flow into the cell is slowly increased as the shoe moves over the cell. When the shoe completely isolates the cell, full backwash flow occurs. Then, backwash flow is slowly reduced as the shoe moves off the cell, and filtering resumes. The backwash pump draws filtered water back through the effluent port to backwash the cell. Another pump picks up wash water collected in the hood, and discharges it to a wash water trough. These pumps are sized for the manufacturer's designed backflow rate, typically 1000 (L/min.)/m^2 (25 gpm/ft^2). Backwash may be triggered by head loss (water level probes), automatically (timer), or manually. Typical reject rates range from 3 and 5% of influent flow.

Continuous backwash systems allow the system to function continuously by cleaning the used media in a washer unit located separate from the media. In downflow and upflow continuous backwash systems, the media moves within the bed to a removal port and are then washed via air scour or water, or both, before reinjection into the bed. The media are re-injected using an eductor pipe, compressed air system, sand washer chamber, and reject line. The turbulence within the tube scours the solids from the media. The solids are then separated from the media grains in a separation or washer chamber. Alternatively, the media may be washed in an external device to separate out the solids. The media washer is basically a baffled chamber that uses gravity to separate the solids from the media. The baffles allow for countercurrent washes. Upward flowing water results in sluicing away low-density solids, and settling of the media. After being washed, the media are returned to the filter shell. Reject rates for continuous backwash systems typically range between 10 and 15% of the feed stream flow rate, but may be up to 25%. Although reserve filtrate is generally used for backwash, in some cases a potable water supply may be required.

Because continuous backwash systems have a continuous waste stream they are not used as a primary or the only treatment process at HTRW sites. They are almost exclusively used in conjunction with an upstream clarification unit to handle solids returned from the reject stream.

5-1.5 **Advantages and Disadvantages in Granular Media Filtration Systems**. Gravity filtration systems are the simplest granular media filtration systems. Reasonably long filter runs can be achieved, but there is the possibility of negative gauge developing within the filter bed, resulting in "air binding." Air binding problems typically result where particle removal is occurring in only the top few inches of the filter bed and the entire depth of the bed is not being used for removal. When the head loss at any level in the filter exceeds the static head to that point, a head condition below the atmospheric level (vacuum or negative gauge) occurs. This is commonly called a negative head condition and can cause air binding of the filter. When a negative head condition exists, dissolved gases in the water are released and gas bubbles are formed within the filter bed. These trapped gas bubbles cause additional head losses, aggravating the problems even further.

5-1.5.1 Negative gauge pressure is generally absent in pressure filtration systems. Pressure filtration systems can be operated at higher terminal head losses, which generally result in longer filter runs and reduced backwash requirements. High power costs are associated with pressure filtration systems, limiting their practicality by cost considerations. Additionally, because the elements are enclosed in a steel shell, access for normal maintenance and observation is limited.

5-1.5.2 The continuous filters have deep beds, allowing for maximum solids capture. Continuous backwash systems also offer the advantage of avoiding periodic backwash cycles. This results in continuous, steady state operation with constant pressure drop, and also eliminates the auxiliary equipment associated with the backwash process. But, alternative equipment and systems must be installed and operated to clean the media. For example, special influent dosing mechanisms, the washer chamber, the compressed air system, and the sand lift mechanism must be provided. In addition problems have been reported with upflow systems' ability to handle high influent solids loading.

5-1.5.3 Where filtrate is being returned for domestic or industrial reuse, special considerations may apply. Certain states are no longer giving approval for operation of continuous backwash systems for potable water applications. With the traveling bridge system especially, but also to a degree with the upflow system, the potential for contact between influent and effluent water creates a disinfection issue. Similar considerations may be an issue with HTRW applications. Potential cross-contamination is an issue whether the designer is dealing with hazardous waste water or with potable water. Specifically, the most common complaints are the single wall between filtrate and unfiltered water, no air scour or water wash, no water to waste after backwash, insufficient media depth, and open filtrate channel. When a unit process designed for removal of a category of HTRW contaminants (e.g., air strippers for removal of VOCs) is present upstream from the filtration system, cross-contamination concerns would usually not be relevant. Cross connections are often not of concern between units at HTRW facilities.

5-2 **PRECOAT FILTRATION.** Precoat filtration systems employ septa that support the filter medium or filter aid and conduct the filtrate to a collection manifold. Filter media can vary according to the filtration needs and the feed stream chemistry. Diatomaceous earth or perlite are generally used as the filter aid. The cycle consists of three steps: precoat application, filtration of water, and removal of the spent filter cake. For precoating a thin layer, approximately 1.5 to 3 mm (0.06 to 0.12 in.) of the filter media is applied to the septum before the feed is introduced to the system. This thickness can be achieved by applying approximately 0.5 to 1 kg/m^2 of diatomite or perlite to the septum (0.10 to 0.20 lb/ft^2). This precoat serves to protect the filter septa from blinding caused by the filtrate and also serves to bridge the larger septa pores. This bridging reduces the size of filtrate particles removable from the feed stream. For additional information, refer to TM 5-662.

5-3 CARTRIDGE FILTRATION

5-3.1 **Description of Unit**. Disposable cartridge filtration uses pleated or non-pleated disposable filter media. As a rule of thumb, a cartridge filter system should be expected to handle a solids loading of 1 to 2 mg/L TSS at the cartridge system's design flow. For example, a 10-in. long 4-in. pleated filter, sized with an absolute rating of 10 microns, is rated for a flow of up to 1 L/s (15 gpm). At 2 ppm, such a filter would retain approximately a third of a pound of solids per day. This will mean that the filter element may have to be changed every day. A cartridge system can handle greater solids loadings, such as10 or 20 mg/L suspended solids, but the number of filters cannot be sized based on the listed flow capacity. The best performance will be obtained when the filter capacity is sized by dividing the rated flow capacity per filter by the TSS concentration in mg/L and using that number to determine the number of filters required for a given flow.

5-3.1.1 Each filter medium is usually associated with a particular removal rating, ranging from sub-micron up to 150-micron particles. The cartridges are often cylindrical, with the media configured as pleated woven fabric or as a non-woven depth medium. The medium is bonded to plastic or metal hardware. Housings are available in plastic, lined metal, or metal construction to meet various operating conditions of pressure, temperature, and waste stream compatibility.

5-3.1.2 Cartridge filters are usually composed of a porous medium or fabric that is either pleated or configured for depth filtration. Depth-style cartridges may be either:

- String wound, which does not have a fixed or uniform pore structure.
- Molded fiber, which does have a uniform pore structure.
- High efficiency, with continuously graded pre-filter layers in decreasingly smaller pore sizes.

5-3.1.3 Pleated filters generally feature a fabric medium that is folded in either triangular or crescent shaped pleats. There are also laterally pleated media with folds perpendicular to the axis of the filter. Figure 5-9 shows a typical pleated cartridge media cross section. An example of a multi-unit cartridge filter media housing is shown in Figure 5-10.

5-3.1.4 Typically, pleated elements are rated for a higher flow rate than depth filters of the same size configuration because pleated filters offer a greater surface area to the incoming waste stream flow. Of the pleated filters, the crescent pleat offers greater surface area, and, thus, a longer filter life, than the triangular pleated filters occupying the same size housing.

Figure 5-9. Pleated Cartridge Filter Media Cross Section

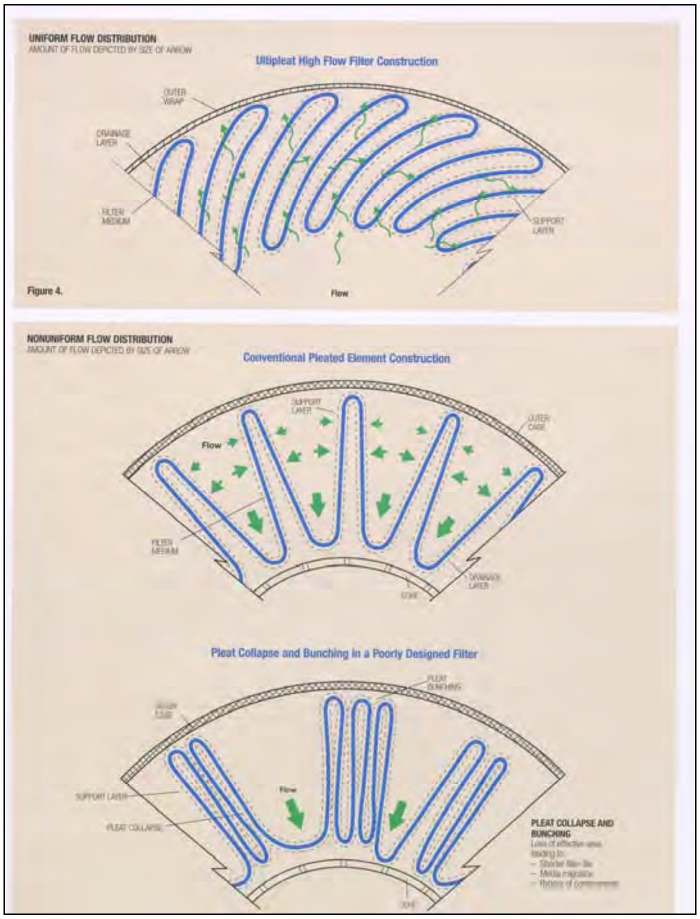
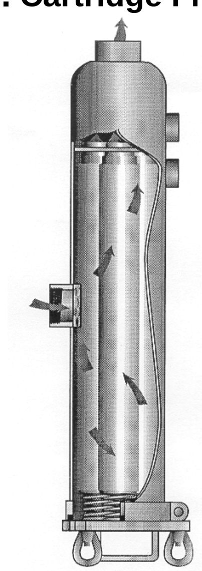


Figure 5-10. Cartridge Filter Housing



5-3.2 **Media**

5-3.2.1 **Type of Media**. The types of media used to manufacture cartridge filters include cotton, nylon, polypropylene, polyester, acetate, acrylic, glass, polyethylene, modacrylic, rayon, saran, and fluorocarbons. Ceramics and metals may also be used in non-disposable filters. In addition to the various types of filter media, filters are constructed of woven fabrics, felts, and non-woven fibers, porous solids, and polymeric membranes. The media and media construction are selected according to waste stream characteristics, filter operating conditions, and desired effluent quality. Summarized below are some general information and uses for media material and construction type.

5-3.2.1.1 **Fabrics of Woven Fibers**. There are four basic types of weave used as the base material for filters: plain or square weave, twill, chain weave, and satin. All the weaves can be made from textile fiber of natural or synthetic origin. Generally, the smoother the filter fabric is, the tighter the weave and the smaller the pore openings. Filter fabric made from larger diameter fibers will offer greater strength than fiber made from finer fibers of the same material. However, the greater the fiber diameter, the looser the weave, and the larger the spore spacing.

5-3.2.1.2 **Metal Fabrics or Screens**. Filters made of metals are available in a variety of weaves and types of metal, including nickel, copper, brass, bronze, aluminum, steel, stainless steel, and other alloys. Good corrosion and high temperature resistance of properly selected metals make metal media desirable for long-life uses, particularly since they can be cleaned. Metals are also suitable for applications involving high differential pressures and vibration or shock conditions.

5-3.2.1.3 **Pressed Felts and Cotton Battings**. Felts and cotton battings are non-woven fabrics made from natural fibers. These materials usually operate as filters by deposition of the particles on and throughout the weave. They are often used to filter deformable materials such as gelatinous particles from paint.

5-3.2.1.4 **Non-woven Fabrics**. These filters are made of synthetic fibers such as polyester and nylon and are lighter than felts. They are used to filter highly viscous fluids to remove particles as small as 5 microns. They are often configured as string wound or other depth filtration type cartridges.

5-3.2.1.5 **Filter Papers**. Filter papers are available in a wide range of permeability, thickness, and strength. They generally require a perforated back-up plate for support.

5-3.2.1.6 **Rigid Porous Media**. These media are available in a wide range of materials, including stainless steel, ceramics, and some plastics. They are ideally suited for waste streams that require a wide range of chemical and temperature resistance.

5-3.2.1.7 **Combinations of Media**. Because some filters are composed of several media types, it is important to make sure that each filter medium is compatible with the particular waste stream. Tables 5-6 and 5-7 summarize the types of filter media and compatibility with generic waste streams. Table 5-7 gives a broader discussion on materials compatibility. While these tables are a generic guide to compatibility, corrosion handbooks, field experience, and vendor literature should be reviewed to determine compatibility with specific known compounds and characteristics of the waste stream. Additional material compatibility information is contained in EM 1110-1-4008.

5-3.2.2 **Configuration**. Cartridge assemblies are units that contain one or more replaceable filter elements. The housings are constructed of material that is compatible with the system operating pressure. Typical materials of construction include PVC and stainless steel.

5-3.2.2.1 Filters are selected based on the desired particulate effluent quality and compatibility with the waste stream to be treated. Where high effluent quality, low particle counts (i.e., number of particles remaining after filtration with a specified micron rating), or removal of sub-micron particles is required, the filter pore size can be staged in series with progressively finer removal ratings to minimize the cost of the more expensive sub-micron particulate filters. Most often, the method for selecting filter sizes for staging is determined in the field. Alternatively, filtration rates using multiple pore size membranes can be tested in the laboratory prior to field-testing.

Table 5-6. Characteristics of Filter Materials

Generic Name	Abrasion Resistance	Resistance to Acids	Resistance to Alkalis	Resistance to Oxidizing Agents	Resistance to Solvents	Maximum Operating Temperature, Degrees C (Degrees F)
Acetate	G	F	P	G	G	99 (210)
Acrylic	G	G	F	G	E	150 (300)
Glass	P	E	P	E	E	316 (600)
Metallic	G	varies	varies	varies	varies	varies
Modacrylic	G	G	G	G	G	82 (180)
Nylons	E	F-P	G	F-P	G	107 (225)
Polyester	E-G	G	G-F	G	G	150 (300[2])
Polyethylene	G	G	G	F	G	74 (165[3])
Polypropylene	G	E	E	G	G	121 (250)
Rayon	G	P	F-P	F	G	99 (210)
Saran	G	G	G	F	G	72 (160)
Cotton	G	P	F	G	E-G	99 (210)
Fluorocarbons	F	E	E	E	G	288 (550[4])

Symbols have the following meaning: E = excellent; G = good F = fair; P = poor.
1. degree C = (degree F –32)/1.8; K = (degree F + 459.7)/1.8
2. Low-density polymer. Up to 230 degrees F, for high-density.
3. Heat-set fabric; otherwise lower.
4. Requires ventilation because of release of toxic gases above 400 degrees F.

5-3.2.2.2 Cartridge filters generally come as disposable pleated filters, where filter elements fit into a cylindrical container or housing. These filters come in 500 mm (20 in.) to 1500 mm (60 in.) lengths, with diameters on the order of 150 mm (6 in.), depending on the style and manufacturer. They are typically installed in parallel to provide more surface area. To determine how much filter area may be required for a particular operation, the designer must first know the system flow rate. Most filter elements have throughputs of 0.1 (L/min.)/m^2 to 1 (L/min.)/m^2 (0.25–4.0 gpm/ft^2). Therefore, the number of filters required can be calculated using the following equation:

$$N = \frac{Q}{J(A)}$$

where:

N = number of filter units required
Q = system flow rate (gpm)
J = flow density (surface loading) through the filter medium (gpm/ft^2)
A = surface area available in each unit (ft^2).

Table 5-7. Chemical Resistance Chart

Material	Resistance	Max Permissible Temp. (Water) Constant	Max Permissible Temp. (Water) Short-Term
Polyvinyl Chloride (PVC, UPVC)	Resistance to most solutions of acids, alkalis, and salts and organic compounds miscible with water. Not resistant to aromatic and chlorinated hydrocarbons.	60 degrees C 140 degrees F	60 degrees C 140 degrees F
Chlorinated Polyvinyl Chloride (CPVC)	Can be used similarly to PVC but at increased temperatures	90 degrees C 195 degrees F	110 degrees C 230 degrees F
Polypropylene (PP)	Resistant to water solutions of acids, alkalis, and salts, as well as to a large number of organic solvents. Unsuitable for concentrated oxidizing acids.	60 degrees C 140 degrees F	80 degrees C 175 degrees F
Polyvinylidene (PVDF)	Resistant to acids, solutions of salts, aliphatic, aromatic, and chlorinated hydrocarbons, alcohols, and halogens. Conditionally suitable for ketones, esters, ethers, organic bases, and alkaline solutions.	90 degrees C 195 degrees F	110 degrees C 130 degrees F

Material	Resistance	Max Permissible Temp. (Water) Constant	Max Permissible Temp. (Water) Short-Term
Polytetrafluro-ethylene (PTFE)	Resistant to all chemicals listed in vendor literature.	140 degrees C 285 degrees F	150 degrees C 300 degrees F
Nitrile Rubber (Buna-N)	Good resistance to oil and gasoline. Unsuitable for oxidizing agents.	90 degrees C 195 degrees F	120 degrees C 250 degrees F
Butyl Rubber Ethylene Propylene Rubber (EPDM, EPR)	Good resistance to ozone and weather. Especially suitable for aggressive chemicals. Unsuitable for oils and fats.	90 degrees C 195 degrees F	120 degrees C 250 degrees F
Chloroprene Rubber (Neoprene)	Chemical resistance very similar to that of PVC and between that of Nitrile and Butyl rubber.	80 degrees C 175 degrees F	110 degrees C 230 degrees F
Fluorine Rubber (Viton)	The best chemical resistance to solvents of all elastomers.	150 degrees C 300 degrees F	200 degrees C 390 degrees F

5-3.2.2.3 The designer should always check vendor literature for the rated flow density and total available surface area for the selected cartridge filter and the pressure drop through the housing.

5-3.2.2.4 While the equation above will give the minimum number of filter units required for a given application, the life of a filter (the time over which it can be used before blinding) is significantly increased as flow density (surface loading) is decreased. The relationship is described by the following equation (Swiezbin 1996):

$$\frac{T_2}{T_1} = \left(\frac{J_1}{J_2}\right)^n$$

where:

T = total throughput for a filter run prior to terminal head loss (gal.)
J = flow density through the filter medium (flow per unit area) (gpm/ft^2) or[(L/s)/m^2]
n = extension factor (dimensionless).

5-3.2.2.5 The life extension factor is experimentally determined but is generally on the order of $1 \leq n \leq 2$. For filtered solids that are uniform, non-compressible, and do not cake to filter that is finer than the medium, *n* will approach 2. This means that in situations where the particles being separated are dirt and sediments from groundwater extraction wells, doubling the filter surface area (i.e., doubling the number of units installed) can quadruple the filter life for the same system flow rate. Filters elements will load equally and will be changed out all at the same time.

5-3.2.3 **Media Housing System**. Filter housings are an integral part of cartridge filtration in that they need to be compatible with the system pressure and operating temperature, handle corrosive fluids, economically house the number of cartridges required, provide reliable seals to prevent fluid bypassing, and allow for easy replacement of filter elements.

5-3.2.3.1 To handle corrosive waste streams, housings can be constructed of a variety of steel and nickel alloys with multiple type liners available. Housings must meet pressure vessel codes, and if temperature needs to be maintained to prevent solidification of some fluids, a heated jacket for some filter housings is available.

5-3.2.3.2 Filter housings can accommodate numerous filter elements that operate in parallel. As demonstrated above, systems that use multiple filter elements tend to have greater solids holding capacity per unit length of filter.

5-3.2.3.3 One of the most important features of filter housings is the sealing system that prevents bypassing of the filter. A common seal uses double open-ended cartridges and a squeezing mechanism on the housing. Piston type O-ring seals are most often used in single cartridge housings.

5-3.2.3.4 Cartridge elements have the designation DOE for double open ended seals and SOE for single open-end designs. The most common sealing system in multi-cartridge units is the DOE design. The DOE design provides a knife-edge or flat gasket seal on the seat at the top of the filter cartridge.

5-3.3 **Operating Conditions**. Filters are changed either at predetermined time intervals, based on projected flow rates and contaminant levels, or when the pressure differential across the system restricts the flow through the unit, or when effluent quality degrades because the cartridge filter deforms. Depending on effluent quality needs, filters may be staged through a pre-filtration arrangement, according to removal rating, thereby minimizing cost for small pore size filters. System parameters that affect filter selection include temperature, pressure, fluid compatibility, removal efficiency, fluid viscosity, type and quantity of contaminant, maximum allowable pressure drop across the filter assembly, required throughput, and flow rate.

5-3.3.1 **Temperature**. Glass, ceramic, and metal filters are the most commonly used filters where continuous operating temperatures exceed 260 degrees C (500 degrees F). In the temperature range of 150–260 degrees C (302–500 degrees F) fluorocarbon filters as well as glass, ceramic, and metal filters are often used. From 80–260 degrees C (176-500 degrees F), almost all other media types can be used provided metal hardware is used. Below 80 degrees C (180 degrees F), all filter media can be used with either plastic or metal hardware. Refer to Table 5-7 for maximum operating temperature for each filter material.

5-3.3.2 **Pressure**. System pressure is needed to maintain flow as the cartridge accumulates particles. In determining operating pressures, the designer must also consider the pressure necessary for other resistances, such as pipe elbows and valves. Excessively high pressure can cause structural damage to the filter. It is, therefore, important to know the minimum pressure to maintain flow through the filter and evenly distribute solids across it, as well as the maximum operating pressure that can damage the filter. As the filter plugs, high differential pressures across it are realized, causing particle or pore deformation. Some vendors can provide systems with differential pressure alarms to warn of impending filter failure.

5-3.3.3 **Fluid Compatibility**. As previously discussed, filter compatibility with the waste stream must be determined from available literature and from experience. In addition to the literature review, a chemical compatibility test can be done by immersing the cartridge filter in the fluid for at least 48 hours, or according to the manufacturer's recommendation. At the end of the selected soak period, observe the filter for changes in color, structural integrity, swelling, softening, deformation, and any other changes in it and its hardware's physical appearance. Also observe changes in the fluid, including changes in color, clarity, and viscosity.

5-3.3.4 **Filter Efficiency**. Filter efficiency means the percentage of particles of a specific size that will be removed from the waste stream. Suppliers of cartridge filters use different test methods for rating a filter's performance. In many cases these test methods cannot be correlated. Filter ratings include nominal filtration rating, absolute filtration rating, beta ratio, and filtration ratio.

5-3.3.4.1 Nominal filtration rating represents some percentage of removal of particles of a given size or larger. The percentage test method, and thus the rating, varies from manufacturer to manufacturer. It is not typically reproducible from cartridge to cartridge and should not be relied on.

5-3.3.4.2 Absolute filtration rating is the diameter of the largest spherical particle that will pass through the filter under test conditions specified by the vendor that are sometimes performed in air environments. While an absolute filter rating will, for all practical purposes, tell what particles will definitely be removed, there will also be many much small particles that will be removed as well. As a result, relying on the absolute filter rating can lead to over-designing a filter system and removing particles that do not affect the ultimate downstream processes of effluent requirements.

5-3.3.4.3 Different filter elements can be best compared not on an absolute rating or some nominal rating devised by each manufacturer, but instead by the Beta ratio derived from empirical testing. A filter's Beta ratio is the most useful means of expressing filter efficiency over its service life. The Beta ratio ($ß_x$) is the total number of particles in an influent waste stream greater than a specified size (*x*) divided by the number of particles in the treated effluent waste stream of the same size or larger. Thus, the removal efficiency for a certain particle size (*x*) can be described as:

$$\frac{(\beta_x - 1)100}{\beta_x}$$

5-3.3.4.4 In this way, a $ß_x$ of 1 represents 0% efficiency at size *x* and a $ß_x$ of 2 represents 50% efficiency at size *x*. Therefore, a beta ratio of $ß_{10}$ = 10 means that 90% of particles 10 microns and larger will be removed by the filter, whereas, a Beta ratio of $ß_{10}$ = 5000 means that 99.98% of particles 10 microns and larger will be removed (Swiezbin, 1996).

5-3.3.5 **Fluid Viscosity**. Filter type, area, and pretreatment needs are all influenced by pressure drops associated with fluid viscosity. Doubling the viscosity will double the pressure drop. For coarse filtration and high viscosities above 3000 centipoises (cP) (7230 lb/hr ft), metal mesh cartridges be used because of their high permeability and strength. Non-pleated cartridges have been used at viscosities of 20,000 cP (48,400 lb/hr ft) but at low flux rates of <0.2 L/s per cartridge (0.3 gpm). To reduce pressure drops caused by fluid viscosity, filter area can be increased.

5-3.3.6 **Type and Quantity of Contaminant**. The type and physical characteristic of the contaminant influences filter type and area. Hard, irregular, inert type particles are more easily filtered with cartridge filters than are gelatinous materials. Contaminants of an organic nature influence cartridge selection, depending on relative concentrations. At low levels the cartridges may fail on differential pressure before the solvent breaks down the structural integrity of the filter. At higher organic loadings, the structural integrity may be impaired prior to failure because of solids loading and pressure drop. Excessive pressure and flow rate may cause the pores of the filter to become misshapen and widen, possibly resulting in poor filter performance and effluent quality.

5-3.3.7 **Maximum Allowable Cartridge Pressure Drop**. This is a parameter often specified by the manufacturer and represents the maximum operating pressure at which the filter will fail structurally. Often overlooked, pressure drops are those associated with housing and system hardware that should be considered when selecting a filter for available pressure drop. Filter selection should minimize the ratio of hardware losses to total available pressure drop. Typically, the initial clean differential pressure will be <5 psid. Once the filter begins to blind. the differential pressure will begin to increase. Disposable cartridge filters can generally withstand 60 to 80 psid in the forward direction before structural failure. If higher pressures are present, then metal filters or metal filter cores should be considered (Swiezbin, 1996).

5-3.3.8 **Required Throughput and Flow Rate**. Throughput per cartridge is best determined by laboratory tests, which are relatively easy to do and are specified by the manufacturer. It is important that the test fluid is representative of the waste stream to be treated. From pilot or bench scale tests, throughput per cartridge can be determined and the surface area needed for filtration to maintain pressure drop across the cartridges can be optimized without affecting the structural integrity of the filters. Depending on the waste stream to be treated, throughput per cartridge can range from 0.1 to 1.0 (L/min.)/m^2 (0.25 to 4.0 gpm/ft^2). The actual throughput is affected by fluid viscosity and filter media pore size. Generally, all of the factors above influence filter throughput and they must all be considered when sizing the system. For new facilities, waste stream parameters need to be estimated and pilot testing is generally not practical.

5-3.4 **Advantages/Disadvantages**. Cartridge filters are flexible in that different ratings and materials of construction can be interchanged to accommodate changing conditions in waste streams. Multiple cartridges housings are available to supply the surface area needed to meet desired throughput and flow rate while minimizing pressure drop. Multi-cartridge housings also have the advantage of requiring little space. Multi-cartridge housings can be anywhere from 216 mm (8.5 in.) to 914 mm (36 in.) in diameter and 2261 mm (89 in.) to 3277 mm (129 in.) in length, depending on the manufacturer and the number of cartridges installed within a single unit.

5-3.4.1 Cartridge filtration can be used for any flow rate simply by adding more filter area. Some applications have flow rates of 4 to 8 million L/day (1 to 2 mgd), such as in the semiconductor industry. In this application the wet stream undergoes rigorous pretreatment to minimize changing of filter elements. For HTRW applications, cartridge filters can be used to remove pinpoint flocs not readily removable by granular media filters. In addition, there is no need for backwash tanks, or pumps, and there is no need for upstream treatment. As discharge limitations become more stringent, cartridge filtration will have a larger role at HTRW sites.

5-3.4.2 The biggest limitation for cartridge filters is their inability to treat waste streams with solids loadings greater than 1 or 2 mg/L. Higher solids can be handled but only through the addition of more filter elements. For this reason cartridge filters are often used as a polishing step or to protect a downstream treatment unit subject to biological or particulate attack. On an equivalent-flow basis, for a waste stream with a moderate level of suspended solids, filter cartridges would often be more expensive than granular media owing to the greater required frequency of cartridge change out (i.e., higher O&M costs for cartridge relative to granular media in this situation).

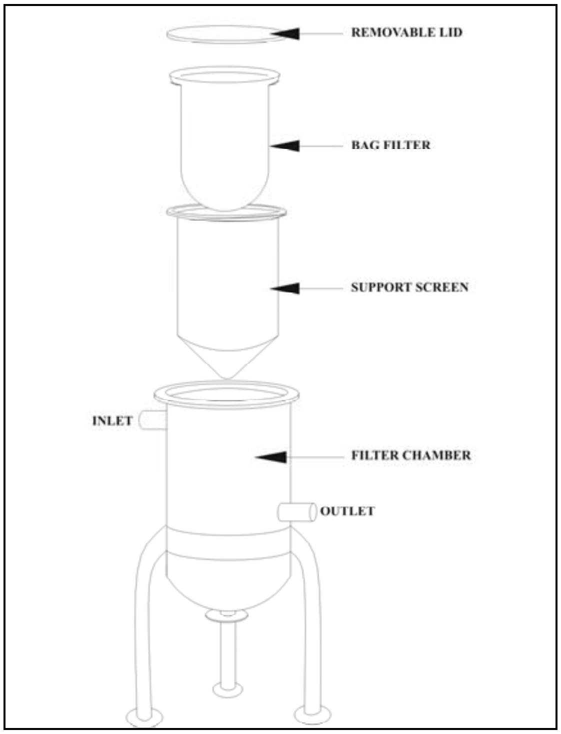
5-3.4.3 Disposable cartridge filters are limited in use on hazardous waste sites because the cartridge housing needs to be opened to replace filter elements. This creates health and safety concerns. Such concerns include possible exposure to vapors and dermal contact during cartridge removal, thus necessitating increased levels of personal protective equipment. When used in treating hazardous waste, the costs for disposal of a single cartridge is significant when compared to the total quantity of contaminant removed. Other systems that can be backwashed have the advantage of being able to remove the solids from the filter bed without disposing of the media. Because there is no need to change the media, as with cartridge filtration, there can be significant cost savings. However, it should be noted that capital costs for cartridge filter systems are typically less than for other types of filtration systems (e.g., pressure or gravity granular media systems).

5-4 BAG FILTRATION

5-4.1 **Description of Unit**. Bag filtration is similar to cartridge filtration in that it uses numerous types of fabricated media enclosed in housings, and that the filter media and housings are constructed of materials compatible with the waste stream being treated. Some bag filters may be backwashed to extend media life and operation. Bag filters are effective at straining slurries and dispersions and removing particle sizes in the range of

10–200 microns. Bag filters can remove particles down to 5 microns and, on occasion and depending on waste stream characteristics, they have been used to filter particles in the 1–3 micron range. They have less filter media surface area than cartridge filters of similar dimensions but are often better at handling gelatinous materials that may clog granular media or bridge across pleated cartridge media. A typical bag filter housing is shown in Figure 5-11.

Figure 5-11. Typical Bag Filter Housing



5-4.2 **Media**

5-4.2.1 **Type of Media**. The types of media used to manufacture bag filters are similar to those used to manufacture cartridge filters and include cotton, nylon, polypropylene, polyester, Teflon, glass, and saran. Material such as ceramic and metals are not used for manufacturing of bag filters, but these materials may be used in bag filter restrainers, fittings, and housings. Selection of the media, as with cartridge filters, depends on waste stream characteristics, filter operating conditions, and desired effluent quality. Similar to cartridge filters, bag filters can also be composed of several medium types. It is important to ascertain the compatibility of each filter medium with the particular waste stream. Refer to Tables 5-6 and 5-7 for filter media compatibility with various waste streams.

5-4.2.2 **Configuration**. There are two basic bag filtration system designs—open and closed. Open systems are most often used in straining liquid slurries or dispersions where particles are screened by the filter fabric while the slurry or dispersion passes through the filter media. The closed design has advantages in that operations staff are not exposed to the material being filtered and, on backwashing systems, filter cake can be removed from the filter and housing without staff having to open the filter. During filtration, cake builds up on the filter media. On backwashing systems, the solids collect on the outside of the bag, often in an upflow configuration. As pressure drop across the system increases, the system can be back-pulsed with either air or water to remove the cake from the filter. Filter cake is then removed from the bottom of the housing. For some systems the back pulsing takes only 1 to 3 seconds and filtration begins again, providing almost continuous operation.

5-4.2.3 **Media Support System**. As with cartridge filters, bag filter housings need to be compatible with the system pressure and operating temperature, handle corrosive fluids, economically house the number of elements required, provide reliable seals to prevent fluid bypassing, and account for easy replacement of filter elements.

To handle corrosive waste streams, housings can be constructed of a variety of steel and nickel alloys with multiple type liners available. Housings must meet pressure vessel codes. (See ASME Boiler and Pressure Vessel Codes, Section VIII, Divisions 1, 2 and 3,)

In addition to providing a tight seal to minimize waste stream by-pass, bag filters may require metal, ceramic, or plastic restrainers inserted inside the bag to maintain bag shape under pressure.

5-4.3 **Operating/Design Considerations**. Bag filters are sealed in their housing to assure that waste stream particulate contaminants do not bypass the filter medium and enter the effluent stream.

Depending on the system selected, the bags should be easily accessible and removable. For open systems, all the contaminants should be contained in the bag. For closed systems, the particulate cake builds up on the outside of the filters and, in continuous operating systems, the cake should be easily removed from the housing without the need to open the system. Also, in closed systems, the restrainers should not impair flow or affect the life of the filter element.

Most manufacturers offer a range of filter ratings within a certain bag size. When solids loadings exceed 2 mg/L within the range being filtered, then the bag's design capacity should be adjusted so that more bags are provided in parallel. As described in Paragraph 5-3.1, above, higher solids loadings can be accommodated, but the design flow rate for the particular bag should be adjusted in proportion to the increase in solids.

5-4.4 **Advantages/Disadvantages**. Bag filters come in a variety of sizes ranging from 0.05 to 0.40 m^2 per bag (0.5 to 4 ft^2) with respective flow rates of 1.5 to 12.5 L/s (25 to 200 gpm). Bag filter housings can hold from 1 to 24 bags. The designer should consult vendor literature for specific details on bags and housings.

Economically, one bag filter has the equivalent capacity of several cartridges and can operate at higher flow rates than cartridge filters with lower pressure drops. The filtrate can be removed from the bag for disposal, unlike cartridge filtration where the entire filter element must be disposed of. For closed systems there is little need for the operators to handle contaminated material except during removal of filters for cleaning or replacement. Bag filters can also treat highly viscous fluids up to 200,000 cP (484,000 lb/hr ft). Because of their high volume throughput they can provide space saving, polishing filtrate from clarifier/thickener overflows, and from sand and vacuum filters.

One drawback of filter bags is that sharp objects present in the waste stream, such as metal fillings, can cut into the bags during operation, affecting effluent quality and decreasing filter life. In addition, bag filters do not come in as low a removal rating as cartridge filters. Also, owing to the lesser surface area, bag filters will not retain the same amount of non-deformable solids before being blinded and needing cleaning or replacing.

CHAPTER 6

AUXILIARY EQUIPMENT PROCESSES

6-1 **DISPOSAL OF RESIDUALS.** Filters are designed either to remove filtered solids by backwashing or to dispose of them when the filter medium with the solids incorporated (disposable media) is discarded. Whether to use a backwashing filtration system or disposable media is generally a question of economy, based on the concentration of solids in the waste stream and the ability to treat the backwash water.

Backwash water is generally returned to the head end of the plant or backwash water recovery facilities. Because backwashing occurs at very high flows for short durations, the design of treatment facilities where the backwash water is returned to the process stream or backwash water recovery facilities must take into account high intermittent flows that could produce hydraulic upsets. Some manner of holding tank or flow equalization is often necessary and these flows and loadings should be considered in any pre-filtration settling system design.

For the particulate residuals, the quantities of sludge produced can be estimated based on the suspended solids in the raw water and the anticipated treated effluent water quality. Calculations used to estimate sludge generation must also include any coagulant used as a filtration aid. Particulate residuals generated during filtration of hazardous or industrial wastes must also be characterized to determine if the sludges are hazardous and require secure, off-site disposal. In some cases sludges from HTRW treatment may continue to be regulated as hazardous if the waste stream was associated with a listed hazardous waste. The designer should always check the source of contamination when identifying treatment and disposal options. RCRA must be considered when identifying sludge treatment and disposal options.

6-2 **PRETREATMENT REQUIREMENTS.** Pretreatment of the influent wastewater can significantly enhance the treatability and improve effluent quality. Pretreatment can be particularly important for hazardous and toxic wastewater streams. For example, gravity separation or dissolved air flotation, or both, may need to be used when two-phase liquid wastes (e.g., petroleum hydrocarbons and water) are present; chemical pretreatment may be required where emulsions are present; or sedimentation may be necessary where total suspended solids concentrations are prohibitively high. Pretreatment may include oxidation of soluble forms of reduced metals, reduction of suspended solids by chemical flocculation and sedimentation, chemical precipitation of dissolved metals or other dissolved ions such as phosphorous, or coagulation by addition of chemical filtration aids, such as poly-electrolytes. Where pretreatment is used to enhance filtration, the designer should keep in mind that the pretreatment must not be designed independently from the filtration system, as the pretreatment facilities will depend on the type of filtration system selected. Also, where direct discharge to surface water is anticipated, water quality standards must be considered (e.g., for aluminum or iron).

6-2.1 Laboratory studies are generally required to determine type and degree of pretreatment. These studies may range from simple jar-tests to column studies to plant studies on the actual filters (ASTM D2035-80 [1999]). It is necessary to determine the most effective pretreatment method and dosage to maximize the filtration. Pre-treating the influent too extensively may result in increased filter clogging and shorter filter runs. This is particularly the case when polyelectrolytes are overdosed, blinding the media because the amount of filter aid far exceeds the solids loading that would otherwise be in the waste stream.

6-2.2 Alum has traditionally been used in filtration as a coagulant to produce a heavier floc with greater settling velocities. More recently, cationic polymers have been used alone or in combination with alum or clay. Studies have shown polymer coagulation is more effective and problem-free than alum coagulation. When using alum (versus polymers), the operator generally must add lime for pH adjustment. Also, alum is more difficult to use than polymers because various polymer combinations can be tolerated without significant effect on effluent turbidity. Additionally, the polymer floc is significantly more resistant to shear than the more fragile alum floc. The alum floc tends to trap water, which may result in dewatering problems. When using polymers, though, surface wash is strongly recommended. Excessive polymer feed to upstream units can result in carry over to the filtration system, which causes the media to stick together, excessively high head losses, short filter runs, and eventually blinding. This requires the media be changed out.

6-2.3 Ferric chloride is also commonly used as a coagulant. Such metal salts can be used to precipitate phosphorous from waste streams. These fine floc particles do not necessarily settle well and filtration may be the only way to meet stringent phosphorous limitations. It is dangerous to use ferric chloride if groundwater is to be re-injected, as iron tends to precipitate at the well screen, thereby affecting the capacity to re-inject water.

6-2.4 Polymers or alum may be rapidly mixed with the water directly before the filtration process, eliminating the need for prolonged sedimentation. Flocculation periods may be short with high intensity flocculation, or somewhat longer with less intense mixing. This process is called direct filtration. Usually, direct filtration is used with dual media and multi-media filters. Single medium filters cannot handle the high solid loading that direct filtration creates. A waste stream needs to be purified to a greater degree, e.g., sedimentation, before it is introduced to the single media filter. However, too high a solids loading will clog any filter. Overdosing of polymer can blind the bed. Charge destabilization (i.e., destabilizing the charge of the particle so that the particles will coagulate) is the mechanism by which a polymer coagulates. Once charges are destabilized, excess polymer will unnecessarily add to solids loading. This will result in significant head loss because greater quantities of solids need to be removed from the influent stream. Alum, on the other hand, is more forgiving for variable source particle loadings. Additional information is available in EM 1110-1-4012.

6-2.5 Direct filtration is generally used with dual media filters. When contaminants are soluble and can be precipitated to form floc particles, direct filtration may be applicable. In direct filtration, the water is rapidly mixed and flocculated, followed directly by filtration. Direct filtration can be used only when floc can form quickly. In some instances, flocculating periods as short as 3 minutes are used. Flocculation is conducted in a static in-line mixer, eliminating the need for rapid mix tanks. The designer must consider adequate flocculation times. (See EPA 815-R-99-010.)

6-2.6 Systems filtering physical–chemical flocs tend to use lower filter rates and finer media than those filtering biological floc. This may be because biological flocs tend to be stronger and more resistant to shear than chemical flocs. But, because of the strength and character of the biological floc, greater surface filtration occurs, resulting in excessive head loss because the floc does not penetrate the bed. Polymer filter aids may be added to the filter influent to strengthen weak chemical flocs, to permit higher flow rates, but backwash rates, surface wash, or air scour, or all three, may be needed owing to higher attachment forces to the media.

6-3 **PROCESS CONTROL OPTIONS.** The major filter functions that require monitoring and control are head loss, influent and effluent quality (turbidity), flow rate through the filters, and backwash sequence, rate, and duration. Generally, filtration systems should be equipped with an influent and effluent turbidimeter, head loss and flow indicators, and backwash timers. These parameters may be controlled through constant pressure filtration, constant-rate filtration (effluent rate control), and declining-rate filtration. Declining-rate filtration is often the preferred method for control of granular media filters for potable water, but constant rate filtration may also be preferred in HTRW applications as there are not large flow variations. Generally, package filtration systems will already have control systems. The designer will only need specify special needs that are different from the standard control system. Process controls can be specified based on capital cost considerations, as well as on the availability of operations and maintenance personnel to manage less automated systems.

6-3.1 In constant-pressure filtration, the total available pressure drop is applied across the filter throughout the filter run. The control mechanism is compressed gas maintained at a constant pressure. This maintenance of the total available pressure drop results in this constant pressure providing the driving force. Because the driving force stays constant, the flow will decrease as the filter bed becomes clogged with solids. Constant-pressure filtration is not often used.

6-3.2 Traditional constant-rate filtration is achieved by adjusting the effluent flow rate through the filter so that it is kept constant by means of the effluent flow rate valve. Control may be achieved directly or indirectly. Direct control is difficult because varying influent will greatly affect control needs. Indirect control is usually achieved by a set point controller linked to a pneumatic or hydraulic valve operator. Significant head may be lost in the controller. The plant flow is equally divided among the plant filters by means of a venturi and modulating butterfly valve. The venturi element communicates with the controller, which adjusts the butterfly valve to ensure that each filter is filtering an equal volume of the influent water. A level element is installed to signal when excessive head has built up and backwash must begin.

6-3.3 Influent flow splitting on gravity filters can achieve constant rate filtration by dividing the flow among filters via a flow splitting tank or channel. The water level over the filter is maintained at a constant level or is varied during the filter run. Influent flow splitting with constant level incorporates individual weirs in the header channel entrance to each filter. An element in each filter communicates with a controller to keep the level of water over the media constant. This is done with a modulating valve. No level elements, controllers, or modulating valves are necessary for influent flow splitting with varying water levels. After splitting, the water level is based upon the head loss through the filter. As the head loss increases, the water level increases to achieve a constant rate established by an orifice plate in the effluent piping. The splitting allows flow variations to be equally distributed among the filters. Often influent flow splitting may not be needed for low flow systems where the flow may be interrupted.

6-3.4 Variable-declining rate filtration controls the flow to the multiple filters by varying the upstream or downstream water level with centrifugal pumps. Each filter operates under the same head, but at different flow rates, depending on degree of filter clogging. The influent enters below the low water level of the filters, resulting in less head loss. As one filter becomes clogged, the head loss builds, slowing the rate of filtration. The other filters then pick up the capacity lost by the dirty filters. Variable-declining rate filtration generally provides better effluent quality and higher unit filter run volumes.

6-4 **OPERATIONS AND MAINTENANCE CONSIDERATIONS.** Depending on the variability of the wastewater characteristics, an equalization basin may be provided ahead of the filters. The equalization basin results in less variation in influent characteristics. A steadier stream can result in higher consistency in filtration and reduced operational problems.

6-4.1 Commonly encountered problems in the filtration of wastewater are described in Table 6-1. These include turbidity breakthrough, mudball formation, buildup of grease, oil and carbonates, development of cracks and contraction of filter bed, loss of filtering media, air binding, and gravel mounding. Every attempt should be made to design the filter to avoid these problems. Suggestions are incorporated in the *control measures* column. Additionally, upstream processes, such as an oil/water separator, should be considered to control potential waste constituents that may cause operation problems.

6-4.2 All prepackaged equipment should come with a list of O&M issues and recommended spare parts. Patented equipment, especially traveling bridge filters and continuous backwash filters, will have specific manufacturer's recommended troubleshooting guides. Similarly, control equipment will need to be maintained according to the manufacturer's recommendations.

Table 6-1. Commonly Encountered O&M Problems

	Description	Control Measures
Turbidity breakthrough	Unacceptable levels of turbidity in effluent before terminal head loss is reached.	Pre-treat with chemicals or polymers, or both, upstream of the filter bed. More frequent backwashing. Reduce solids loading through pre-filtration solids removal, such as sedimentation.
Mudball formation	Masses of solids, dirt, and media, the mudballs sink into the filter bed, reducing the effectiveness of filtering and backwash.	Auxiliary washing processes (e.g., air scour, surface wash) with, or followed by, water wash
Buildup of grease and oil	Oil or grease emulsifying within the bed.	Air and surface wash usually help. May be necessary to install washing system using special solutions. Pre-treat for oil and grease.
Carbonate buildup	Carbonate buildup on media after lime neutralization.	Acid rinse or, for small systems, replace media. Influent pH adjustment.
Cracks / contraction	Develop when filter bed is not cleaned properly.	Adequate backwash and scour.
Loss of media	Loss during backwashing or through underdrain system.	Correct placement, sizing of wash water troughs, and underdrain system. Correct backwash flow or pressure.
Air binding	Gases coming out of solution in the water because of negative heads.	Backwash at terminal head loss no greater than the depth of submergence of the top of the filter media or increase submergence.
Gravel mounding	Support gravel disruption during backwash.	Overlay gravel support layer with layer of high density material, such as ilmenite or garnet. Correct backwash flow rate or pressure.
Excessive head loss	Filter element clogged without alarm sounding.	Change elements and check alarm for malfunction.
Excessive turbidity without head loss	Filter element damaged.	Change element more frequently and look for waste stream components that could damage filter fabric.
Excessive filter element changeout	Filtration system improperly sized for waste stream.	Increase the number of filter elements operating in parallel. If allowed by the application, increase the cartridge removal rating so that fewer solids are retained. Influent pretreatment to reduce solids loading.
Biofouling	The growth of a biologic mass, such as algae, either within the waste stream or the treatment process, that creates a solids loading of a concentration and character that cannot be effectively filtered.	Chemical pretreatment at the source or within the treatment process using hydrogen peroxide or chlorination. Identify the factors contributing to biomass growth (e.g., heat, excessive holding time, high organics in the waste stream) and eliminate them.

6-4.3 In dual and multi-media beds, mudballs formed in the filter remain above the coal–sand interface where they are subject to auxiliary scouring, an advantage over single media beds where mudballs tend to sink to the bottom of the bed.

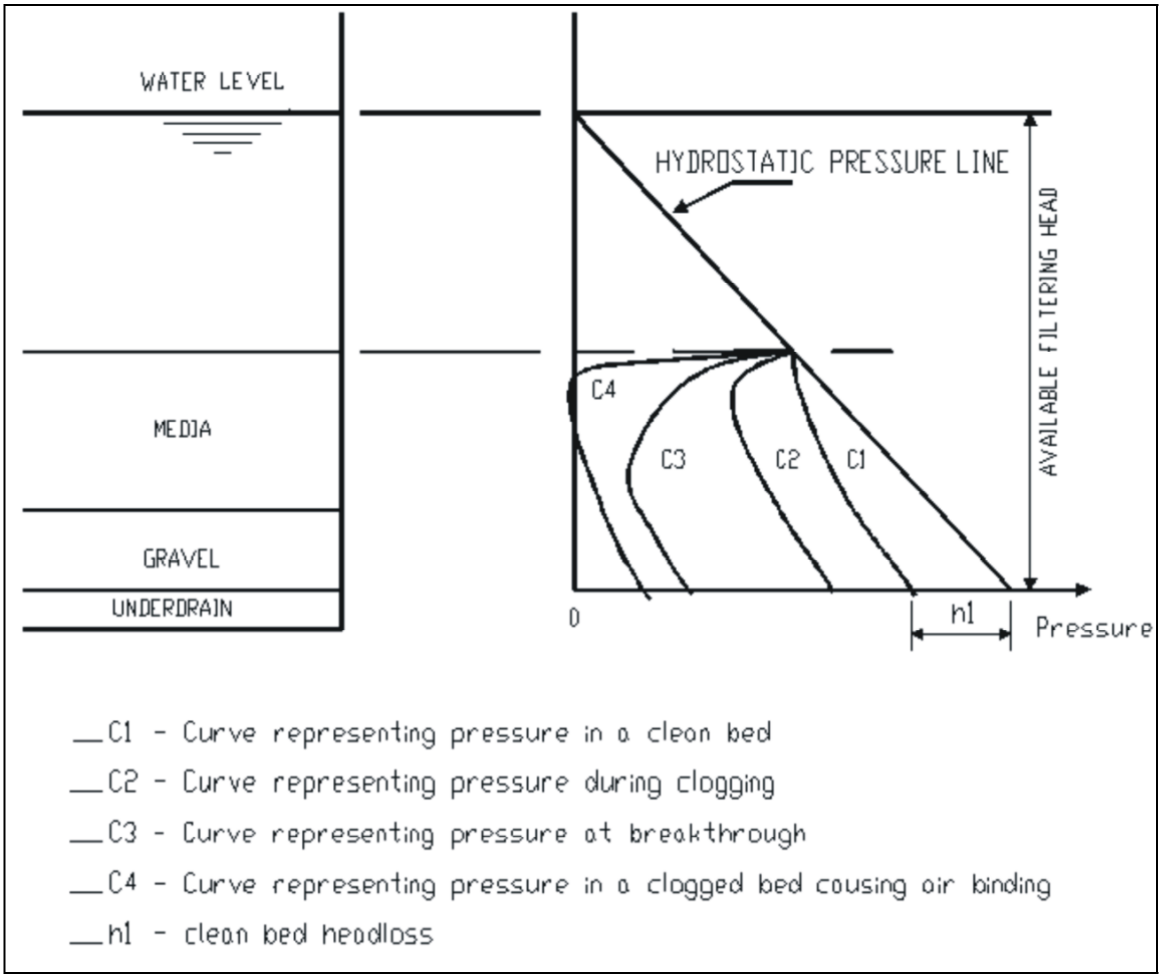
6-4.4 When the head loss at any level in the filter bed exceeds the static head to that point, a head condition below the atmospheric level (vacuum) occurs. This is commonly called a negative head condition and can cause air binding of the filter. When negative head conditions occur, dissolved gases in the water are released and gas bubbles are formed within the filter bed. These trapped gas bubbles cause additional head losses and aggravate the problem even further. Air binding problems are most prevalent when there is insufficient water depth over the media and at times when the surface water is saturated with atmospheric gases because of the rising water temperatures in the spring.

6-4.5 If pressure taps were provided at various depths in the filter, it would be possible to establish the relative head loss at different points in the bed. Figure 6-1 is a diagram of representative pressure curves through the filter bed during filtration. The hydrostatic pressure line shown in the diagram indicates the static pressure at each depth in the filter based on the water level in the filter and the available filtering head. Head loss through the filter bed can be considered as the difference between the hydrostatic pressure line and the representative pressure curves at the respective points along the pressure axis. Curve C1 represents the pressure in a clean bed at a specific filtering rate and h^1 is the clean bed head loss. The shape of the curve shows that the clean bed head loss is proportional to the depth of the media. Curve C2 represents the pressure during clogging of the media. The upper portion of the curve shows a decrease in pressure owing to the removal and storage of particles in the upper portion of the media, and correspondingly, an increase in filter bed head loss. The point where the C2 curve turns and is parallel to the C1 curve represents the depth of particle penetration into the bed; this is applicable to the other curves as well. Curve C3 shows the pressure conditions at turbidity breakthrough. At no point does the curve parallel the clean bed curve, thus indicating that the particles have penetrated through the full depth of the bed. Curve C4 represents the pressure with a clogged bed condition causing air binding. There is a large pressure drop in the upper portion of the bed, which is less than the static pressure to that point. This pressure is less than the atmospheric pressure and will result in dissolved gases from the water being released and forming air bubbles in the bed, even though filtering head is still available. Air binding is of particular concern at an HTRW site because hazardous volatile emissions may result from the air binding.

6-4.6 An additional operation issue is the time required for a filter to operate effectively immediately following backwash. Filter operation varies from manufacturer to manufacturer, but on some systems, after backwash, some time is needed for the filtrate turbidity to drop to an acceptable level (filter ripening). Three methods have been used to deal with this initial quality problem: filter to waste, slow initial filtration, or polymer conditioning. Filter to waste (returning the initial filter run to the head of the treatment system) requires additional treatment capacity and may present a disposal issue on HTRW sites. Although unusual, it can be good practice where biological growth is a problem. The slow start alternative involves slowly opening of the filter outlet valve over a period determined by the particular filter. Polymer conditioning uses a small amount of polymer in the backwash water in the last few seconds of the backwash cycle. A conditioning system requires polymer batching plant, pumps, and an automatic control system. It may be advantageous to use slow-start in conjunction with polymer conditioning.

6-4.7 Hazardous waste disposal is a significant operations issue when handling streams from HTRW sites. The attendant concerns include cost and time and care required for proper handling.

Figure 6-1. Relative Head Loss Within Granular Media Bed



6-5 **SUPPORT FACILITY REQUIREMENTS.** Based on the initial selection of equipment, utility requirements for ventilation, power, water, air, telephone, and other utilities can be determined. Although some of these calculations may be requirements for the entire treatment facility, incremental calculations may be needed that apply specifically to equipment or facilities required for the filter operation. Generally, for the package systems addressed, the manufacturer will supply required information.

6-5.1 Additional calculations and design data will need to be assembled for a variety of equipment to support the filtration system. These items include but are not limited to the following.

6-5.1.1 **Pumps**. Head loss calculations and power requirements are needed for backwash water supply pumps, spent backwash water pumps to transfer filtrate back to the head of the plant, settled sludge removal pumps from the spent backwash holding basin, and filter feed pumps.

6-5.1.2 **Air supply**. This is necessary for valve operations and air scour if provided.

6-5.1.3 **Tankage**. Filter feed pump tank, filtered water storage, clean backwash water storage, and spent backwash water storage all may be required.

6-5.1.4 **Controls**. Filter head loss rate, backwash sequence, flow rate, interlocks, and alarms all may be required.

6-5.1.5 **Chemical Feed**. Chemical storage, mixing, day tank, and chemical feed pump sizing, chemical selection, feed concentration, and physical storage are all concerns.

6-5.1.6 **Access**. Sample collection, monitoring, and maintenance of equipment all require some kind of access.

6-5.3 In addition to utility requirements, additional design and calculations related to architectural and structural components will be required. These types of calculations are application specific, and, therefore, no specific calculations are provided.

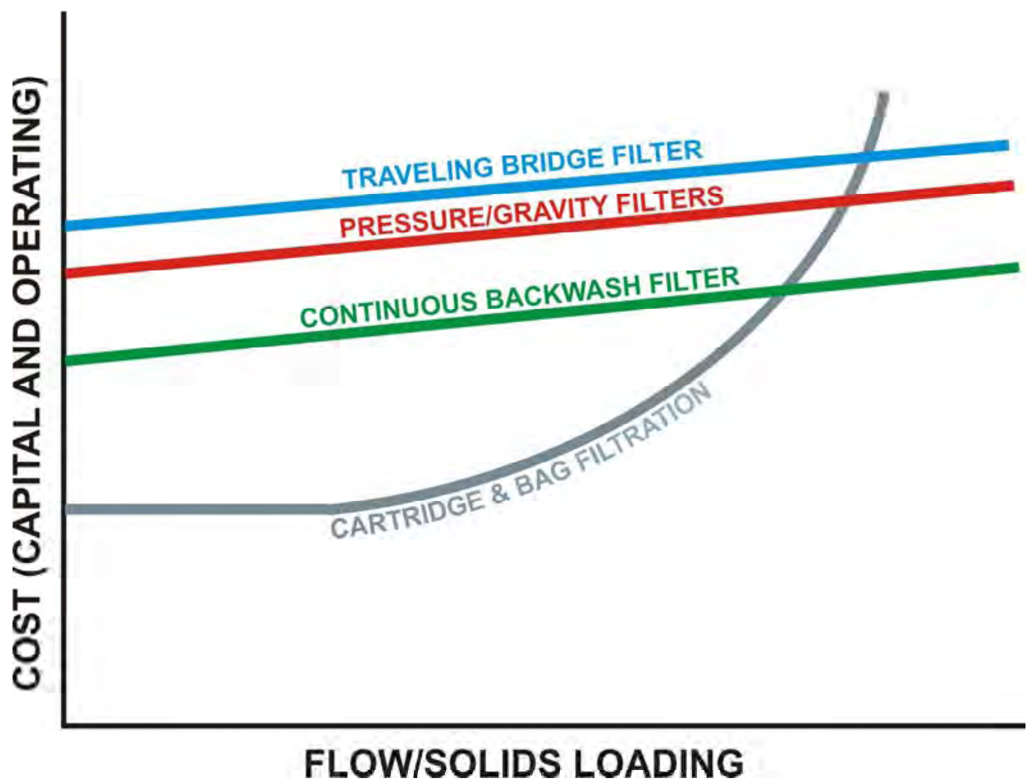
CHAPTER 7

COST CONSIDERATIONS

7-1 **INTRODUCTION.** There are numerous manufacturers providing a wide range of filtration products. As a result, equipment and component pricing and quality can vary considerably. Figure 7-1 qualitatively compares costs for various filtration systems.

The total cost of a filtration system, however, is more than just the component and maintenance cost. It depends on numerous other factors that may be related to the filtration system itself, or may be controlled by the overall waste stream treatment system. These cost considerations include the following.

Figure 7-1. Relative Cost Comparisons



7-2 **FLOW CONSISTENCY.** Some filtration systems can work well with varying flows while others, such as continuous backwash filters, need a constant flow. If the waste stream is characterized by peak and low flows then certain systems may require flow equalization to function properly. Flow equalization, depending on the treatment setup, can require holding tanks and even additional pumping, all of which add to the capital as well as operating costs.

On the other hand, if the waste stream is being pumped from groundwater extraction wells at a constant rate 24 hours per day, then flow equalization is not a problem but flow interruption for backwashing or filter media replacement may need to be considered. If the system cannot be periodically shut down, then redundancy or other provisions for continuous operation need to be considered.

7-3 **LEVEL OF FILTRATION.** The higher the level of filtration, the finer the particle that is removed, and the greater the cost. Pressure filters and gravity filters provide a higher level of treatment than traveling bridge and continuous backwash systems but they cost more. If the waste stream does not need to be clarified to the extent provided by a more expensive filter system, then it might not be necessary to incur that expense.

Similarly, cartridge filters come in a wide range of removal ratings. However, the higher the removal rating, the greater is the cost and, often, the media need more frequent replacement. If permit conditions or downstream treatment system requirements only call for particles larger than 5 microns to be removed, then there is no need to install a 0.5-micron rated filter element.

Finally, the design professional needs to consider the downstream treatment cost. Greater levels of filtration may provide cost savings in subsequent treatment systems. For example, carbon adsorption can be used on a waste stream with a suspended solids content of up to 50 mg/L. However, this does not mean that such a high level of solids will be good for an adsorption unit. Even though the carbon adsorption will work at that level, additional filtration will remove particles that may clog the carbon pores and lead to more frequent media replacement and additional cost. Whenever filtration is being provided to benefit a downstream treatment component, the manufacturer of that component should be consulted to determine the optimum level of filtration for the waste stream going to that equipment.

7-4 ALLOWABLE HEAD LOSS THROUGH A SYSTEM. Different filtration systems require different levels of pressure to function properly. Similarly, different waste stream treatment systems may be designed for different hydraulic gradients.

Groundwater being extracted from a well may already be under pressure, and that pressure can be used to process wastewater through the entire treatment system without additional pumping.

Each component of the treatment process, including the filtration system, will have certain inlet requirements as well as head loss through the system. Auxiliary pumping may be required to maintain these design levels. On the other hand, it may be better for a waste stream to flow by gravity through the entire treatment process. In this case a low head gravity filtration system may be required.

7-5 **PROCESS CONTROLS.** As with any equipment, the greater the number of automated features there are, the higher the cost. Conversely, automated controls are not luxuries but are designed to save manpower and the cost of constant supervision. The cost of one must be weighed against the other.

7-5.1 Most backwashing filters are intended to backwash on the basis of a certain head loss through the filter that indicates that the collected solids have exceeded the filter's optimum capacity. However, in practice, most manufacturers will activate the backwash procedures based on a timer (e.g., once per day) regardless of head loss. This more frequent washing prevents clogging and cuts down on maintenance cost.

7-5.2 Similarly, cartridge filters may need to be replaced on the basis of head loss through the filter. However, such maintenance can be sporadic and lead to system upset and even breakthrough, if the need does not coincide with available personnel. It is often preferable to have a head loss alarm activated through a transducer but to have regularly scheduled filter replacement based on time (e.g., monthly or annually) or on treatment volume (e.g., every million gallons).

7-5.3 Most manufacturers will have minimum required controls on their systems with additional controls available as options. The cost effectiveness of manual vs. automated vs. telemetric controls will depend on the availability of operations and maintenance personnel and the relative isolation of the treatment system site. Generally, automated and remote sensing controls are preferred over manual operation.

7-6 MAINTENANCE. Capital costs are just one component of installing and operating a filtration system. Cartridge and bag filtration systems have the lowest capital costs, but when there are high solids loadings and frequent media element replacements, the operating costs can become quite significant.

Similarly, systems that require a lot of pumps and air compressors can use a great deal of energy and require additional maintenance.

The design professional should look at each of the energy components and the recommended maintenance schedule for any filtration system being considered to determine whether one alternative will entail greater operating costs than another.

CHAPTER 8

DESIGN REQUIREMENTS

8-1 **DESIGN DRAWINGS.** Drawings should conform to Appendix C of ER 1110-345-700. Suggested design and detail drawings are listed below. All the listed drawings may not be required, especially for low flow, package filtration units. Additionally, the list may not be exhaustive. Project-specific needs will dictate the required drawings.

- System general arrangement plan.
- Hydraulic profile.
- System sectional elevation.
- Pumps for backwash and recirculation.
- Basin and filter shell detail (section and plan).
- Underdrain installation detail.
- Media installation detail.
- Weir detail.
- Backwash supply and holding facilities.
- Washwater trough detail (mounting, weir, discharge).
- Piping, valves, and pump detail.
- Instrument panel layout.
- Electrical schematic.
- PFD and PID detail.
- Blower and compressor detail.
- Anchoring detail.
- Chemical feed equipment.
- Flocculator tank.
- Carriage and rail detail (for traveling bridge system).

8-2 **DESIGN ANALYSIS REQUIREMENTS.** A design analysis report must accompany all new construction projects and old projects involving major alteration or expansion of existing facilities, unless specifically exempted. The requirements and procedures for the preparation of the design analysis must be in accordance with Appendix B of ER 1110-345-700.

8-2.1 The design analysis is an assembly of all functional and technical requirements, and all design provisions and calculations applicable to project design summarized in a format appropriate for:

- Review, approval and record.
- Revision of designs during construction as required.
- Use in adapting designs to other sites.
- O&M enhancement and cost reduction.
- Post-occupancy evaluation.

8-2.2 The design analysis consists of three basic sections: general description, design requirements and provisions, and O&M provisions. The general description will discuss issues such as purpose of the project, authorization, project description, and the economic factors influencing the design choices. The design requirements and provisions will discuss general parameters, which may affect the project design, functional and technical requirements, design objectives, design calculations, and coordination with the installation or outside agencies for civil, architectural, structural, mechanical, electrical, and fire safety design components. The O&M section will address user O&M responsibilities and O&M enhancement and cost reduction.

8-2.2 Related construction documents (see http://www.wbdg.org/ccb/)

- ER 1110-2-8155
- UFGS 01240
- UFGS 01351
- UFGS 01450
- UFGS 11211
- UFGS 11212
- UFGS 11220
- UFGS 11225
- UFGS 11242
- UFGS 11393
- UFGS 13405
- UFGS 15200

8-3 DESIGN CALCULATIONS

8-3.1 **Introduction**. Filter design calculations apply design criteria to size equipment, to edit guide specifications, and to develop construction drawings. Based on the preliminary selection of equipment, additional calculations can also be done to determine parameters such as utility requirements, and supporting mechanical and electrical requirements. Design examples illustrating the use of several of these calculations are presented as appendices to this document.

8-3.1.1 An assortment of data sources is available to use as the basis of the design calculations. Typical data sources include pre-engineering reports and treatability studies, standard reference materials, and other sources, such as telephone conversations with manufacturers. Any source of data or basis used for the design calculations should be identified and referenced appropriately in the design analysis.

8-3.1.2 Pre-engineered designs are typically used as the basis of the design calculations. For applications where package filters will be used, treatability studies may not be practicable or necessary. Each data source used should be clearly identified within the design calculation and properly referenced with the date, title, or other pertinent information that will identify the data source and its validity.

8-3.1.3 Data and information from reference materials, other than data from pre-engineering reports and treatability studies, can also be used for filter design calculations. Reference materials consist of applicable codes, standards, textbooks, standard tables, and manufacturer's catalogs and examples of manufacturer's literature. Because this UFC focuses on package unit applications, manufacturer's catalogs and literature will provide invaluable assistance. Each reference source used should be properly referenced with the date, title, issue, or other pertinent information to completely identify it.

8-3.1.4 In addition to reference and design data from the design analysis report, telephone conversations to equipment suppliers and manufacturers and regulatory agencies may also be used for the design calculations.

8-3.2 **Granular Media Filters**. Multiple filter units are used to permit continuous operation during backwashing or maintenance of another unit. The number of units must be sufficient to avoid excessive backwash flow and to properly accommodate flow, unless flow can be interrupted during backwashing. The total filter surface area is defined as:

Filter area [m^2 (ft^2)] = plant flow [L/s (gpm)] / filter rate [L/ m^2 s (gpm/ft^2)].

8-3.2.1 The total filter area required may then be used to determine the filter bed size. Using rectangular units, referring to standard manufacturer filter bed widths, the designer may determine the filter length by:

Filter length [ft (m)] = required area [m^2 (ft^2)] / standard width [m (ft)]

This total length should be divided where multiple units are desired. Similarly, for circular filters, the minimum diameter can be solved and the nearest standard manufacturer filter bed diameter used.

8-3.2.2 Filtered effluent is generally used for backwashing filters. As such, the absolute minimum influent is limited to the backwash flow rates required during the cleaning cycle. The minimum influent flow must exceed the backwash flow rate so that sufficient effluent will be available for backwashing. Refer to vendor data to determine the backwash flow rates.

8-3.2.3 Solids loading is determined by the equation:

Solids loading [kg/m^2d] = suspended solids [mg/L] / 1,000,000 mg/kg × flow rate [L/m^2s] × 86,400 s/d

Solids loading [(lb/ft^2)/day] = flow rate [gpm/ft^2] 0.01199 lb/gal. ppm × suspended solids [ppm]

8-3.2.4 Backwash frequency will depend on the types of solids, the solids loading rate, the filter length, and the acceptable head loss. Each filter within a system should have the capability of operating separately from other filter units.

8-3.3 **Gravity Granular Media Filters**. Typical operation of a filter includes piping and valves for influent, effluent, washwater supply, washwater drain, surface wash and filter-to-waste lines. The influent to the filter bed should not agitate the surface of the medium in any way. This may include any or all of the following, depending on the type of filter used:

- An initial gullet that disperses the velocity head.
- A throttling control on the influent valve.
- A distribution header, series of distribution troughs, and splash plates.

The effluent washwater supply and filter-to-waste piping is usually manifolded for a common connection with the filter underdrain system. Piping, conduits, gates, and valves are usually designed for the velocities and flows shown in Table 8-1. Using a given hydraulic design flow of the system, the designer can determine the maximum flow of the system as:

Maximum flow [L/s (gpm)] = hydraulic design flow [$L/m^2s(gpm/ft^2)$] × filter area [m^2 (ft^2)].

Table 8-1. Design Velocities and Flow Volumes

Flow Description	Velocity, mps (fps)	Maximum Flow per Unit of Filter Area, m/hr* (gpm/ft^2)
Influent	0.3–1.2 (1–4)	7.4–19.6 (3–8)
Effluent	0.9–1.8 (3–6)	7.4–19.6 (3–8)
Washwater supply	1.5–3.0 (5–10)	36.8–61.3 (15–25)
Washwater drain	0.9–2.4 (3–8)	36.8–61.3 (15–25)
Filter-to-waste	1.8–3.6 (6–12)	2.5–14.7 (1–6)
Ref: WEF Manual of Practice No. 8, ASCE Manual and Report on Engineering Practice No. 76, Water Environment Federation and American Society of Civil Engineers, 1992. * m/hr x 16.65 = L/(min. m^2)		

8-3.3.1 **Influent Piping and Valve**. The area of the influent pipe should be determined using the above maximum flow and a given design velocity i.e., 0.5 m/s (2 fps):

$$\text{Required influent pipe area } [m^2\ (ft^2)] = \frac{\text{maxium flow [gpm (L/min)]}}{\text{design influent velocity [fps (m/s)]}} \times \text{conversion factor}$$

$$[2.28 \times 10\ 10^{-3}\ \frac{cfs}{gpm},\ 1.67 \times 10^{-5}\ \frac{m^3/s}{L/min}]$$

A required pipe diameter is chosen such that the diameter provides for a velocity within the optimum influent design velocity of 0.3–1.2 m/s (1–4 fps) (see Table 8-1) at the above maximum flow.

8-3.3.2 **Backwash Supply Piping and Valves**. Using the given design maximum hydraulic washwater rate for the system and the given filter area, the designer can determine the maximum backwash flow as:

Backwash velocity = design maximum washwater rate × filter area × conversion factor [1000 L/m^3 (449 gpm/cfs)]

The required backwash pipe area is determined by the maximum backwash flow and a given design velocity, i.e., 1.2 m/s (4 fps):

Required backwash pipe area = {max. washwater flow [L/s (gpm)] / design velocity [m/s (fps)]} × conversion factor [10^{-3} m^3/L (228 × 10^{-3} cfs/gpm)]

Similar to the influent line, the required backwash pipe diameter is chosen by using a pipe diameter that provides a backwash velocity less than the given design velocity at the above maximum backwash flow, while still being within the optimal washwater supply range of 1.5–3.0 m/s (5–10 fps) (Table 8-1).

8-3.3.3 **Effluent Piping and Valve**. The effluent pipe required area can be determined using a similar methodology as the influent and backwash piping—the maximum flow divided by a given design effluent velocity, i.e., 1.8 m/s (6 fps), and the appropriate conversion factor. It is important to note that while the effluent maximum flow is the same as the influent maximum flow, the effluent velocity may be different. The effluent velocity usually exceeds the influent velocity.

8-3.3.4 **Filter-to-waste (FTW) Piping and Valve**. The filter-to-waste (FTW) piping should be determined using the maximum system flow and dividing by a given design FTW velocity, i.e., 3.6 m/s (12 fps) multiplied by the appropriate conversion factor.

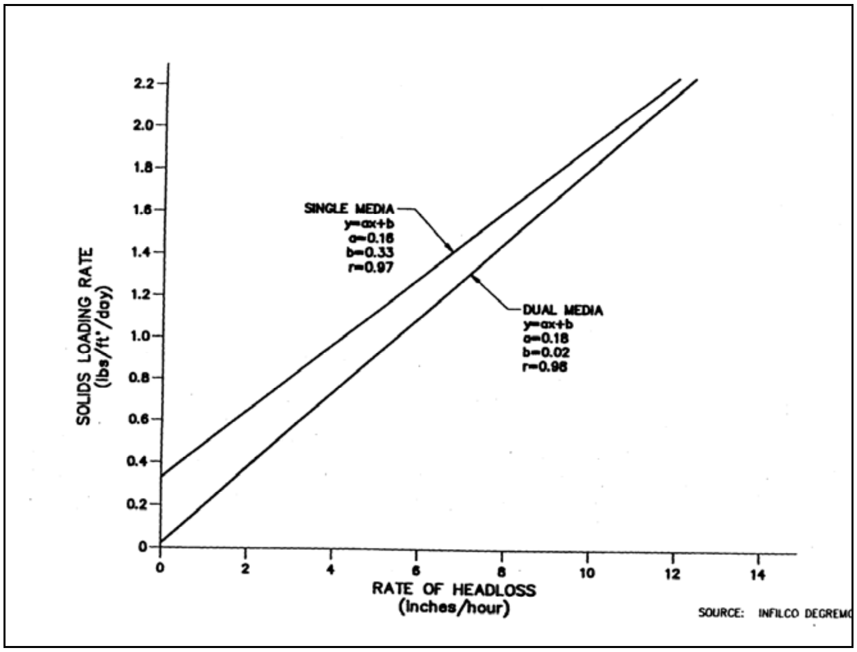
8-3.4 **Other Granular Media Filters**

8-3.4.1 **Pressure Filters**. Pressure filters operate with higher filtration rates than gravity filters. Pressure filters can operate on filtration loading rates as high as 7 L/s m^2 (10 gpm/ft^2), and terminal head losses of up to 10 m (30 ft) without solids breakthrough. Pressure filters are especially preferred over gravity filters when limited capital resources and space constraints exist for a facility. There is also the advantage of longer filter runs and lessened backwash requirements. Pressure filters, however, require more energy to be run and more elaborate controls than gravity filters.

8-3.4.2 **Traveling Bridge Gravity Filters**. Generally, the filter is sized based on a suggested average and peak hydraulic loading. Typically, manufacturers have suggested hydraulic loading rates of between 1.4 L/s m^2 (2 gpm/ft^2) and 3.4 L/s m^2 (5 gpm/ft^2). Increased hydraulic loading will result in increased head loss and rate of head loss, possibility of solids penetration and breakthrough, and possibility of surface blinding. If high peak flows in relation to average flow are expected or if peak flows are frequent, peak flow size should govern. Where multiple units are desired, the total length should be divided between the desired number of filter units.

8-3.4.2.1 Figure 8-1 is a sample curve of head loss increase versus influent solids loading rate for both dual and single media filters. Designs with loading rates greater than 5 kg/ d m^2 (1 lb/d ft^2) should be approached with caution.

Figure 8-1. Solids Loading Rate Versus Rate of Head Loss



8-3.4.2.2 Frequency of backwash will depend on the type of solids, solids loading rate, filter length, and acceptable head loss. Frequency of backwash is calculated using Figure 8-1. The increased head loss may be determined from the solids loading rate. The time required to reach terminal head may be determined by dividing the operating head by the rate of increased head loss. The time required for the carriage to transverse the filter during the backwash cycle is available from the manufacturer. The total time required from completion of one backwash cycle to the completion of the next backwash cycle is the sum of the traversing time and the time required to reach terminal head. Dividing 24 hours by the total time will provide the number of backwash cycles per day.

8-3.4.2.3 The percentage of backwash water required per day is determined by:

> Backwash water required [gal. (L)] = backwash flow rate [gpm (L/min.)] × traversing time [min.] × [backwashes/day]

Percent backwash is the backwash water required divided by the total throughput. Backwash water requirements below 2–4% are common. The requirements are incorporated into design as hydraulic loading.

8-3.4.3 **Continuous Backwash Filters**. Because all continuous backwash filters are proprietary, relatively little flexibility is available in selecting the unit once a single manufacturer has been chosen. Similar to the approach for sizing a traveling bridge filter, the manufacturer will determine filter size based on flow rate and hydraulic loading. Hydraulic loading rates may vary between 1.4–8.15 L/s m^2 (2–12 gpm/ft^2), with a typical rate of 3.4 L/s m^2 (5 gpm/ft^2). Table 8-2 gives acceptable continuous backwash filter loading rates for particular water treatment applications. The manufacturer can provide further guidance on acceptable hydraulic loading rates for an influent stream with a given total suspended solids concentration and solids size and density. Using the plant flow and the hydraulic loading, the designer can determine the filter area as:

Filter area [ft^2 (m^2)] = plant flow [L/s (gpm)] / hydraulic loading [L/s m^2 (gpm/ft^2)]

Once the required filter area is determined, the filter may be selected. Table 8-2 shows typical sizes available and the requirements for tank size, reject percentage, air flow and media for the appropriate filter.

Table 8-2. Continuous Backwash Filter Application Guideline

Water Treatment Application	Loading Rate (gpm/ ft^2)	Maximum Inlet Solids (mg/L)	Expected Effluent Solids (mg/L)	Applica-ble Particle Size (microns)
Surface water	2–6	10–100 NTU	0.1–0.5 NTU	9–12
Tertiary filtration	3–5	150	< 5–10	9–12
Phosphorous removal	3–5	10 (as P)`	< 0.3	9–12
Pulp and paper effluent	3–5	100	5 10	9–12
Metal finishing	3–6	200	2–5	9–12
Mill scale	8–12	500	5–10	9–12
Oily wastewater	2–6	200 (free oil)	5–10 (free oil)	9–12
Algae removal	2–4	100	10–20	9–12

8-3.5 **Cartridge and Bag Filters**. Summarized below is a general approach to designing cartridge and bag filters. The design approach assumes that cartridge or bag filtration has already been selected. Many of the steps necessary in selecting cartridge or bag filters and the hardware for housing them are the same. Where there are differences, it will be noted in the text.

8-3.5.1 The first step in selecting a cartridge or bag filter is to identify the contaminants present in the waste stream and identify filter materials of construction that are compatible. This is done by comparing the waste stream components to vendor supplied compatibility charts. The filter components that need to be checked for compatibility are the filter media, support core or outer cage and o-rings, or all three. Several materials of construction may be suitable. Alternatively, some vendors suggest conducting your own chemical resistance test. One procedure is outlined below.

8-3.5.1.1 Immerse a cartridge or bag filter of the desired micron rating in the fluid to be treated and at the desired operating temperature for at least 48 hours.

8-3.5.1.2 Examine the cartridge for any change in color, structural integrity, swelling, softening, deformation, or any other physical changes.

8-3.5.1.3 Observe the solution to see if any chemical reaction has taken place. Check for changes in color, clarity, viscosity, etc.

8-3.5.1.4 If there has been no perceptible change in the cartridge or solution, then the filter may be considered for use.

8-3.5.2 Having selected the material of construction, check which materials can operate in the temperature range of the waste stream to be treated. Some materials can only operate at temperatures up to 70 degrees C (160 degrees F) while other materials can operated at temperatures up to 300 degrees C (600 degrees F).

8-3.5.3 Based on influent suspended solids and particle size data, select the micron rating for the filter to meet desired effluent suspended solids and particle size criteria. Note that the smaller the micron rating is the lower the solids holding capacity of the filter. For example, a wound cotton cartridge filtering a liquid with 1 mg/L (1 ppm) solids feed rate would have the following holding capacities at various micron ratings shown in Table 8-3. Refer to Paragraph 5-3 for further information.

Table 8-3. Holding capacities of a wound cotton cartridge.

Micron rating (micrometers)	Solid holding capacity (grams per unit filter)
1	15
5	35
10	60
20	100

8-3.5.4 The above data were generated at a 0.0631 L/s (2.5 gpm) flow rate on a 250-mm (10-in.) filter and failed at a maximum pressure differential of 207 kPa (35 psi). See *Chemical Engineering*(1988) for additional information on selecting cartridge filters. Actual solids holding capacity should be checked under process conditions, as many filter manufacturers rate the solids holding capacity under controlled laboratory conditions and actual solids holding capacity can vary significantly.

8-3.5.5 The fluid viscosity at the operating temperature should be determined. If the system will be operating under varying conditions, then the temperature that gives the highest viscosity in centipoise must be known.

8-3.5.6 At this stage of design the following filter selection criteria have been identified:

- Materials of construction for the filter, based on waste stream compatibility and maximum operating temperature.
- Micrometer rating of the filter, based on influent conditions and desired effluent quality. Typically this information is provided in vendor literature.
- Solids holding capacity of the filter from vendor literature or bench or pilot testing of the process stream.

- Maximum viscosity of the fluid to be treated.

8-3.5.7 The designer can now use vendor literature to determine the number of filters required for design flow rate. Based on the system flow, the designer must next select a flow rate per unit filter. The designer needs to confirm from the filter supplier or their specification bulletin what the maximum flow rate per unit filter or flow rate per unit area of filter is. In the case of this example, the supplier would need to be contacted. To determine the number of filters required the following equation can be used:

System flow rate / flow rate per unit filter

The number of filters used can be altered by using filters with lengths greater than 250 mm (10 in.). There are standard cartridge filter lengths up to 1 m (40 in.).

8-3.5.8 To determine the pressure drop per filter use the water flow rate/differential pressure curves as shown in the design example appendices. Each supplier must be consulted to determine how they account for fluid viscosities greater than 1 centipoise (one centipoise being clean water at standard temperature and pressure).

8-3.5.9 Having identified the number of cartridges, the system housing needs to be selected. As with the filter, the materials of construction should be chosen based on compatibility with the waste stream being treated, including chemical compatibility, temperature, and operating pressure. The internal components of the housing need to be selected so that they are compatible cartridge ring configurations. The following housing components need to be specified by the designer.

- Ring cartridge configuration.
- Materials of construction.
- Number of and length of filter elements per housing.
- Inlet and outlet styles, side in–side out, side in–bottom out

8-3.5.10 The number and length of filter elements per housing is not only determined by the number and length of filters needed by the design but it is also based on standard housing configurations from the supplier. For example, the system may require the use of 500- by 500-mm (20- by 20-in.) filters but the supplier’s standard housing may be designed for 600- by 500-mm (24- by 20-in.) filters. In this case the four extra filters will improve performance. If the supplier’s standard housings accommodate some number of filters less than the design quantity, then the designer should consider the effect on performance from the increased hydraulic and solids loadings, or consider parallel operation of smaller housings.

8-3.5.11 Inlet and outlet style selection is based on how the filter housing is to be piped into the rest of the system and not necessarily on system hydraulics. Items such as inlet and outlet connections are often selected by the supplier based on the maximum flow ratings per filter system.

8-3.5.12 To determine approximate run time between filter changes, use the following equation:

> Run time [days] = solids loading, 250 mm filter × number of 250-mm filters / feed suspended solids concentration × 1440 min./day

8-3.6 **Support Facility Requirements**. Based on the initial selection of equipment, utility requirements for ventilation, power, water, air, telephone, and other utilities can be determined. Although some of these calculations may be needed for the entire treatment facility, incremental calculations that apply specifically to equipment or facilities required for the filter operation may be necessary. Generally, for the package systems addressed, the manufacturer will supply required information. Additional calculations and design data will need to be assembled for a variety of equipment to support the filtration system. These items include but are not limited to:

- **Pumps**. Head loss calculations and power requirements for backwash water supply pumps, spent backwash water pumps to transfer filtrate back to the head of the plant, settled sludge removal pumps from the spent backwash holding basin, filter feed pumps.
- **Air Supply**. For valve operations and air scour if provided.
- **Tankage**. Filter feed pump tank, filtered water storage, clean backwash water storage, spent backwash water storage.
- **Controls**. Filter head loss rate, backwash sequence, flow rate, interlocks, alarms.
- **Chemical Feed**. Chemical storage, mixing, day tank, and chemical feed pump sizing, chemical selection, feed concentration, and physical storage concerns.
- **Access**. Issues related to sample collection, monitoring, and maintenance of equipment.
- **Calculations**. In addition to utility requirements, additional design and calculations related to architectural and structural components will be required. These types of calculations are application specific, and therefore no specific calculations are provided.

APPENDIX A

REFERENCES

GOVERNMENT PUBLICATIONS:

1. U.S. National Archives And Records Administration (NARA)

Code of Federal Regulations, Title 40 (Protection of Environment):

Clean Water Act (CWA) 1977.

PL95-17, Amendments to the Federal Water Pollution Control Act of 1977: Clean Water Act

Part 261.3 (Identification and Listing of Hazardous Waste, Definition of Hazardous Waste)

Safe Drinking Water Act, Amended 1996

Resource Conservation and Recovery Act (RCRA), 1976 and Amended 1984.

2. Departments of the Army, Navy and Air Force

U.S. Army Corps of Engineers (USACE) and the Naval Facilities Engineering Command (NAVFAC) and the Air Force Civil Engineering Support Agency (AFCESA. United Facilities Guide Specifications (UFGS)

01240 Cost and Performance Report
01351Safety, Health and Emergency Response (HTRW/UST)
01450 Chemical Data Quality Control
02521A Water Wells.

11211A Pumps Water Horizontal Centrifugal.

11212A Pumps Water Vertical Turbine.

11220A Precipitation/Coagulation/ Flocculation Water Treatment.

11225 Downflow Liquid Activated Carbon Adsorption Units
11242A Chemical Feed Systems.

11350A Sludge-Collecting Equipment

11360A Recessed Chamber Filter Press system

11356A Trickling Filter

11393A Filtration System.

13405A Process Control.

15200A Pipelines, Liquid Process Piping.

3. Departments of the Army, and Air Force

Technical Manual TM 5-813-3/AFM 88-10, Volume 3, Water Supply, Water Treatment, September 1985.

Technical Manual TM 5-814-3/AFM 88-11, Volume 3, Domestic Wastewwater Treatment, 31 August 1988.

4. Department of the Army, U.S. Army Corps of Engineers

Engineer Regulation ER 1110-1-8155, Hydrometeorological Data Management and Archiving. July 1996.

Engineer Regulation ER 1110-345-700. Design Analysis. Drawings and Specifications. May 97.

Engineer Regulation ER 1110-3-1301, Cost Engineering Policy Requirements for Hazardous, Toxic Radioactive Waste (HTRW) Remedial Action Cost Estimate

Technical Manual TM 5-662. Swimming Pool Operation and Maintenance. February 1986.

Engineer Manual EM 1110-1-4008. Liquid Process Piping. September 2002.

Engineer Manual EM 1110-1-4012, Precipitation/Coagulation/Flocculation. November 2001.

Design Guide DG 1110-1-2, Adsorption Design Guide 1 March 2001.

Engineer Technical Letter No. ETL 1110-3-457. Engineering and Design Plate and Frame Filter Press 30 September 1994.

Public Works Technical Bulletin PWTB 200-01-05, Oil Water Separator Selection, Installation & Maintenance: Lessons Learned 12 May 1997.

5. U.S. Environmental Protection Agency

Manual No. EPA 570/9-91-004. Individual and Non-Public Water Supply Systems

Process Design Manual for Suspended Solids Removal. January, 1975

EPA 832-F-00-017. Granular Activated Carbon Absorption and Regeneration

EPA 815-R-99-010. Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions

NON-GOVERNMENT PUBLICATIONS:

1. American Public Health Association (APHA)

Standard Methods for the Examination of Water and Wastewater, 20th Edition (1999)

2. American Petroleum Institute (API)

Publication 421, Design and Operation of Oil-Water Separators (1990)

3. American Society of Mechanical Engineers (ASME)

Boiler and Pressure Vessel Codes, Section VIII, Divisions 1, 2 and 3.

4. American Society for Testing and Materials International (ASTM)

D2035-80 (1999) Standard Practice for Coagulation – Flocculation Jar Test of Water.

D422-63 (2002) Standard Test Method for Particle-Size Analysis of Soils.

C136-96 (1996) Standard Specification for Sieve Analysis of Fine and Coarse Aggregates.

C128-01 (2001) Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.

5. Great Lakes – Upper Mississippi River Board of State Sanitary Engineers
Recommended Standard, for Water Works (1997 ed.)

6. Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers.
Recommended Standards for Wastewater Facilities (1997 ed).

7. Hudson, Herbert E., Jr.
Water Clarification Process; Practical Design and Evaluation. Van Nostrand Reinhold Environmental Engineering Series (1997).

8. Metcalf & Eddy.
Wastewater Engineering: Treatment Disposal Reuse. McGraw-Hill, Inc. (1991).

9. Monk, Robert D.G., and Willis, John F
Designing Water Treatment Facilities. AWWA Journal, February 1987.

10. McGraw-Hill Professional
Perry's Chemical Engineering Handbook, 7th Edition, June 1997.

11. American Institute of Chemical Engineers, New York, N.Y.
Shoemaker, Wells, ed. "What the Filter Man Needs to Know About Filtration" 1977 AIChE Symposium Series No. 171, Vol. 73.

12. Swiezbin, J.R.
Chemical Engineering, January 1996.

13. Yao, K.-M., Habibian, M. T., and O'Melia, C. R
Water and Waste Water Filtration; Concepts and Applications. Environmental Science and Technology 5, 1105-1112. 1971.

14. Water Environmental Federation (WEF).
Manual of Practice No. 8 1992.
ASCE Manual and Report on Engineering Practice No. 76

15. Williams, R. T. — “Evolution of the Traveling Bridge Filter,” *Public Works,* April 1995.

16. *Chemical Engineering* — 18 January 1988

APPENDIX B

DESIGN EXAMPLE: PRESSURE FILTER

B-1 **INTRODUCTION.** This example is a groundwater remediation system consisting of five recovery wells, each well yielding up to 0.378 L/s (6 gpm). The groundwater is contaminated with volatile organic compounds such as 1,1,1-trichloroethane, 1,1-dichloroethane, trichloroethylene, 1,2-dichloroethene, and low concentrations of aldrin. The groundwater also contains iron at 1.10 mg/L (1.10 ppm) and manganese at 0.12 mg/L (0.12 ppm). The chlorinated organic compounds will be removed by air stripping followed by activated carbon adsorption, which will also remove the aldrin. The presence of iron and manganese in the groundwater can cause iron and manganese oxide scale to form in the air stripping unit. In this design example, it is also assumed that the groundwater contains 50 mg/L (50 ppm) of suspended solids. To prevent scale formation in the air stripping system and potential plugging of the carbon adsorption system with iron and manganese oxides and suspended solids, a pressure filter with permanganate oxidation was selected to remove the iron and manganese and suspended solids prior to air stripping and carbon adsorption. Before the design process is begun, it is assumed that the designer would discuss the application with several pressure filter manufacturers to obtain filter efficiency, loading rates, filter size, filter media, and other design and operational parameters. The design example is based on information supplied by a particular pressure filter manufacturer.

B-2 PRESSURE FILTER DESIGN PARAMETERS

- Flow: 1.9 L/s (30 gpm) total average flow from five wells.
- TSS: 50 mg/L (50 ppm).
- Manganese: 0.12 mg/L (0.12 ppm) influent (no effluent limit).
- Iron: 1.10 mg/L (1.10 ppm) influent (no effluent limit).

B-3 TREATMENT SYSTEM

- Flow equalization.
- Pressure filter, dual media anthracite and silica sand with potassium permanganate addition for iron and manganese removal and polymer for stabilization of chemical floc.
- Air stripping for VOC removal.
- Activated carbon for additional VOC and aldrin removal.

B-4 **PRESSURE FILTER DESIGN BASIS.** Design the system using a single pressure filter. It is assumed that the groundwater extraction pumps can be taken off-line so that maintenance can be done on the pressure filter (estimated 2 to 4 hours per month).

After consultation with several manufacturers, this design example will use a loading rate for anthracite and sand media of 1.4 to 2.0 L/m^2s (2.0 to 3.0 gpm/ft^2) with a maximum rate of 3.40 L/m^2s (5 gpm/ft^2).

The recommendation for backwash time from several manufacturers is 10 minutes at a range of 5.1 to 10.2 L/m^2s (7.5 to 15 gpm/ft^2).

B-5 **PRESSURE FILTER.** The manufacturer recommends 1.4 to 2.0 L/m^2s (2 to 3 gpm/ft^2), use 1.7 L/m^2s (2.5 gpm/ft^2) for preliminary design. Calculate the filter surface area:

A = total flow / flow per unit area, 1.9 L/s / 1.7 L/m^2s = 1.12 m^2

(30 gpm / 2.5 gpm/ft^2 = 12 ft^2)

Calculate the filter diameter:

d = 2 x square root (A / π)

$2 \times (1.12\ m^2 / \pi)^{1/2} = 1.19$ m

($2 \times [12\ ft^2 / \pi]^{1/2} = 3.9$ ft)

Use a 122-cm (48-in.) diameter filter with the corresponding 1.17-m^2 (12.57-ft^2) surface area.

From the manufacturer's published literature, filter bed depth is 0.76 m (30 in.), and the clean media pressure drop is 3.43 kPa (0.5 psig) at an application rate of 1.7 L/m^2s (2.5 gpm/ft^2). The estimated total pressure drop, including valves and flow distributors, is 68.9 kPa (10 psig) for clean media. The manufacturer's literature recommends that the pressure drop across the bed not exceed 82.8 kPa (12 psig) Therefore, design the filter to initiate backwash when the pressure drop is 68.9 kPa (10 psig) across the bed or 134.4 kPa (19.5 psig) across the filter.

B-6 **SOLIDS LOADING.** In this design example, the solids loading to the pressure filter is 50 mg/L (0.031 lb/ft^3). Calculate the solids loading on the pressure filter:

Solids loading [kg/day] = mg/L x MLD
= 50 mg/L x kg / 10^6 mg x 1.893 L/s x 3600 s/hr x 24 hr/day
= 8.2 kg/day

(solids loading [lb/day] = ppm x 8.34 lb/gal. x MGD)
(= 50 ppm x 8.34 lb/gal. x 30 gpm x 60 min./hr x 24 hr/day x MG/10^6 gal.)
(= 18.0 lb/day)

Calculate the surface solids loading using the surface area of a 122-cm (48-in.) diameter filter:

(8.2 kg/day)/1.17 m^2 = 7.00 kg/m^2 day

([18.0 lb/day]/12.57 ft^2 = 1.43 lb/ ft^2 day)

For this loading rate the filter manufacturer recommends up to two backwash cycles per day based upon the above loading rates.

B-7 **BACKWASH FLOW.** For design, assume 10.17 L/m^2s (15 gpm/ft^2) backwash flow rate for 10 min. for the 1.17 m^2 (12.56 ft^2) surface area.

10.17 L/m^2s x 1.17 m^2 x 10 min. x 60 s = 7140 L

(15 gpm/ft^2 x 12.57 ft^2 x 10 min. = 1885 gal.)

2 x 7140 L = 14,280 L (3772 gal.)

Use a 7250-L (2000-gal.) backwash supply holding tank, and pipe backwash waste to the system equalization tank. Assume that fine particles will build up in the system if backwash flow goes to the equalization tank, and that the equalization tank will have to be periodically emptied to remove the accumulated fines. Space should be provided in the design to accommodate the future addition of a backwash thickening tank if fine particle buildup causes frequent shutdowns.

B-8 **FLOW EQUALIZATION.** Flow from five wells into the equalization tank is 1.893 L/s (30 gpm) total. Assume two backwash cycles per day of 10 minutes each, and, to allow time for backwash operation, size the equalization tank to hold flow from the wells for 30 minutes.

B-9 **TANK SIZE.** From wells:

1.893 L/s × 30 min. × 60 s/min. = 3407 L
+ 14,280 L backwash volume = 17,687 L

(30 gpm × 30 min. = 900 gal.
+ 3770 gal. backwash volume = 4670 gal.)

Use an 18,000-L (5000-gal.) equalization tank. Determine the size of the transfer pump from the clarification process to the pressure filter:

Minimum daily flow:

1.893 L/s × 3600 s/hr × 24 hr/day
+ 14,280 L = 177,835 L/day

(30 gpm x 60 min. hr × 24 hr/day
+3770 gal. = 46,970 gal./day)

Minimum flow rate:

(177,835 L/day)/(24 hr/day)/(3600 s /hr) = 2.06 L/s

([46,970 gal./day]/[24 hr/day]/[60 min./hr] = 33.0 gpm)

Pressure drop across the filter bed at the start of backwash is 138.3 kPa (20 psi). Assume 68.9 kPa (5 psi) additional losses in the system from friction and elevation change; the transfer pump should be sized to deliver a minimum flow of 2.15 L/s (33 gpm) at 172.6 kPa (25 psi) maximum head loss. Based on manufacturer's literature and texts, the flow across the filter bed should not exceed 3.4 L/m^2 s (5 gpm/ft^2) x 1.17 m^2 (12.56 ft^2) for the 122-cm (48-in.) diameter filter or 4.0 L/s (63 gpm) when the bed is clean. We will use 2.70 L/m^2 s (4 gpm/ft^2) or 3.16 L/s (50 gpm) to provide a small factor of safety and ensure that the backwash frequency is not excessive. The maximum flow rate for the transfer pump should not exceed 3.2 L/s (50 gpm) at 104.0 kPa (15 psi) for clean media. The specification for the transfer pump should indicate both operating conditions, 2.15 L/s (33 gpm) at 172.6 kPa (25 psi) and not greater than 3.16 L/s (50 gpm) at 104.0 kPa (15 psi). Limiting the range of flow over the entire filter cycle is preferable to avoid the need for pacing the flow of chemical addition, if possible.

B-10 **BACKWASH PUMP.** Discussions with the filter manufacturer about this design example yield the recommendation that the backwash pump be specified to develop a pressure of 4.22 kg/cm^2 (60 psi). Backwash flow rate:

$$10.17 \text{ L/m}^2\text{ s} \times 1.167 \text{ m}^2 = 11.87 \text{ L/s}$$

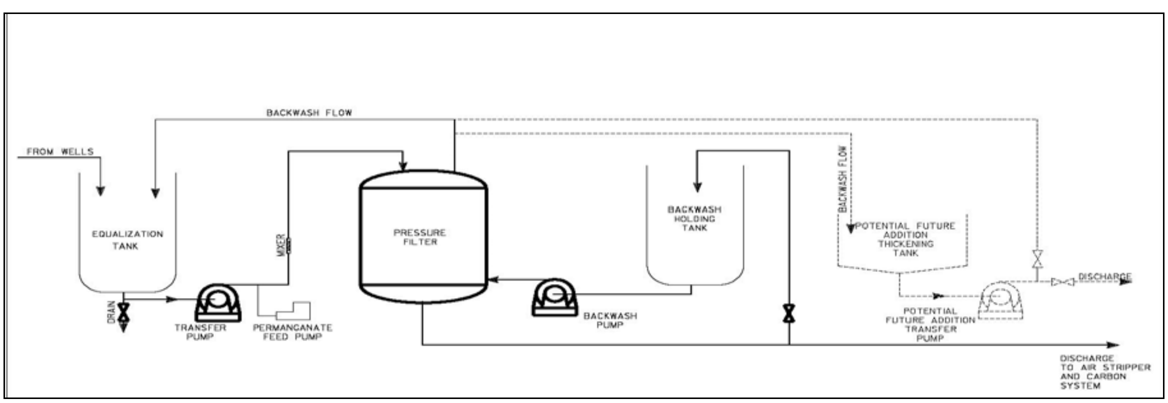
$$(15 \text{ gpm/ft}^2 \times 12.56 \text{ ft}^2 = 188 \text{ gpm}).$$

B-11 SYSTEM SUMMARY

- 1 - 18,000-L (5000-gal.) equalization tank.
- 1 - Transfer pump: 2.2 L/s (33 gpm) at 172.6 kPa (25 psi) and < 3.16 L/s (50 gpm) at 104.0 kPa (15 psi).
- 1 - Chemical feed system: Permanganate addition for manganese oxidation.
- 1 - Pressure filter: 1.22-m (48-in.) diameter with dual media (anthracite and silica sand 0.76 m [30 in.] deep).
- 1 - 7250-L (2000-gal.) backwash holding tank.
- 1 - Backwash pump: 11.87 L/s (188 gpm) at 413.8 kPa (60 psi).
- 1 - Air stripper.
- 1 - Dual carbon adsorption system.

Make provisions for future addition of backwash thickening tank if required.

Figure B-1. Example Pressure Filter



APPENDIX C

DESIGN EXAMPLE: CONTINUOUS BACKWASH FILTER

C-1 **UPFLOW CONTINUOUS BACKWASH FILTER.** The water to be filtered is pumped from a groundwater remediation system. Five recovery wells each yield up to 0.378 L/s (6 gpm) of groundwater contaminated with diphenyl and diphenyl ether with suspended solids concentration up to 50 mg/L. The groundwater will be treated using a continuous backwash filter to remove the suspended solids, followed by activated carbon adsorption for removal of the diphenyl and diphenyl ether before discharge to surface waters under the provisions of a NPDES permit**.** A system that could operate in a facility with intermittent staffing, being unattended for days at a time, was desired. Continuous backwash filters were selected owing to their relatively high solids loading rate and low maintenance. Redundant units were not deemed necessary, given the reliability of the process. A pilot test was conducted to determine filter efficiency versus loading rate with and without polymer addition, filter size, filter media, and other design and operational parameters. This example design was based on pilot test results.

C-1.1 **Design Parameters**

- Flow: 1.893 L/s (30 gpm) total average flow from 5 wells.
- TSS: 50 mg/L (50 ppm).
- Manganese: 0.12 mg/L (0.12 ppm) influent (no effluent limit).
- Iron: 1.10 mg/L (1.10 ppm) influent (no effluent limit).

C-1.2 **Treatment System**

- Flow equalization.
- Upflow continuous backwash filter with silica sand and polymer addition.
- Sludge thickening tank.
- Carbon adsorption.
- Sludge drying bed.

C-1.3 **Continuous Backwash Filter Design Basis**. Design the system using a single upflow continuous backwash filter.

From the pilot test, the manufacturer's recommended loading rate was 1.70 $L/m^2 s$ (2.5 gpm/ ft^2) for 1.4-mm (0.06-in.) sand media.

The manufacturer recommended a design having a filter reject rate of 0.19 L/s (3 gpm) to 0.32 L/s (5 gpm).

C-1.4 **Upflow Continuous Backwash Filter.** The manufacturer recommended a 1.70-$L/m^2 s$ (2.5-gpm/ ft^2) hydraulic loading rate. The total influent flow rate to the filter is 1.90 L/s (30 gpm) from the wells, plus up to 0.32 L/s (5 gpm) reject flow rate.

1.90 L/s + 0.32 L/s = 2.22 L/s

(30 gpm + 5 gpm = 35 gpm)

C-1.5 **Filter Diameter**. Calculate the filter surface area:

A = total flow / flow per unit area

(2.22 L/s) / ([1.70 L/s]/ m^2) = 1.30 m^2

([35 gpm] / [2.5 gpm/ ft^2] = 14 ft^2)

1.90 m^2 x 10,000 cm^2 / m^2 = 13,100 cm^2

(14 ft^2 x 144 $in.^2$/ ft^2 = 2016 $in.^2$)

Calculate the filter diameter:

$d = 2 \times (A/\pi)^{1/2}$

$(13{,}100\ cm^2 / \pi)^{1/2} \times 2 = 129$ cm

$([2016\ in.^2] / \pi)^{1/2} \times 2 = 50.6$ in.)

Use 1.4-m (54-in.) diameter filter with the corresponding 1.5-m^2 (15.9 ft^2) surface area.

C-1.6 **Solids Loading to Upflow Continuous Backwash Filter.** Calculate the solids loading to the continuous backwash filter: 50 mg/L (50 ppm).

solids loading = concentration x flow

50 mg/L x 10^{-6} kg/mg x 1.90 L/s x 86,400 s/day = 8.21 kg/day

(50 ppm x 8.34 x 10^{-6} [lb/gal.]/ppm x 30 gpm x 1440 min./ day = 18.06 lb/day)

C-1.7 **Reject Flow and Sizing of Thickening Tank.** Assume up to 0.32 L/s (5 gpm) of reject flow rate. Reject flow can be split, with a portion returned to the equalization tank and a portion flowing to the sludge thickening tank. To be conservative, size the sludge thickening tank to accept the reject flow, 0.32 L/s (5 gpm). Assume that the operator would split the flow to achieve optimal results. Pilot test data indicated up to 95% filter removal efficiency (with polymer addition). From above, solids loading to the filter will be.

8.21 kg/day x 95% efficiency = 7.80 kg/day

(18 lb/day x 95% efficiency = 17.1 lb/day)

Removal in the reject flow.

Polymer will be added to enhance floc formation in the to reject water to aid settling in the thickening tank. Jar settling tests conducted during the pilot test determined the settling rate of the solids in the reject flow, and that a settling time of 12 hours provided good results. Size the thickening tank to provide 1 day of storage to allow solids settling and sufficient detention time so that the thickener tank requires decanting once each day. Thickened solids will be pumped to a drying bed as required.

C-1.8 **Size Thickening Tank for One-Day Storage**

0.32 L/s x 3600 s/hr x 24 hr/day = 27,648 L

(5 gpm x 60 min./hr x 24 hr/day = 7200 gal.)

Assume that it takes 2 hours to empty the tank of sludge and water. Additional volume required for 2 hours is

0.32 L/s x 3600 s/hr x 2 hr = 2304 L

(5 gpm x 60 min./hr x 2 hr = 601 gal.)

For freeboard and additional capacity, use a 37,850-L (10,000-gal.) thickening tank.

C-1.9 **Flow Equalization Tank.** Flow from five wells into the equalization tank is 1.90 L/s (30 gpm) total. Assume that all the reject flow from the upflow filter is returned to the equalization tank—0.32 L/s (5 gpm). The flow from the equalization tank is equal to the flow rate from the well field plus the reject rate, which is recycled to the head of the plant.

1.90 L/s + 0.32 L/s = 2.2 L/s

(30 gpm + 5 gpm = 35 gpm)

C-1.9.1 Allow 2 hours to empty the sludge thickening tank to the equalization tank. Flow from the sludge thickening tank to the equalization tank is:

(27,648 L / 2 hr) / 3600 s/hr = 3.84 L/s

([7,200 gal. / 2 hr] / 60 min./hr = 60 gpm).

C-1.9.2 Total flow into the equalization tank in 2 hours is:

(1.90 L/s + 3.84 L/s) x 3600 s/hr x 2 hr = 41,328 L

([30 gpm + 60 gpm] x 60 min./hr x 2 hr = 10,900 gal.)

C-1.9.3 Flow out of the equalization tank in 2 hours:

(1.90 L/s + 0.32 L/s) x 3600 s/hr x 2 hr = 15,984 L

([30 gpm + 5 gpm] x 60 min./hr x 2 hr = 4200 gal.)

C-1.9.4 Minimum tank volume required:

41,328 L – 15,984 L = 25,334 L

(10,900 gal. – 4200 gal. = 6700 gal.)

C-1.9.5 A 25,400-L (7000-gal.) equalization tank is minimum; use 30,000-L (8000-gal.) tank for a safety margin.

C-1.10 **Transfer Pump from Equalization Tank to Upflow Continuous Backwash Filter.** Design system piping to keep flow velocity under 1.5 m/s (5 fps) to minimize potential for water hammer. From piping tables, at a flow of 2.2 L/s (35 gpm), use 5.0 cm (2-in.) diameter piping. Flow velocity is 1.1 m/s (3.6 fps) at 2.2 L/s (35 gpm) for 5.0 cm (2-in.) schedule 40 pipe. At that flow velocity, assume a pressure drop for valves and fitting of 10.34 kPa (1.5 psi). The total from that transfer pump across the continuous backwash filter is equal to the sum of the piping loses and the loss across the filter, based on information contained in vendor literature or

44.5 kPa + 10.3 kPa = 54.8 kPa ~ 55 kPa.

(6.45 psi + 1.5 psi = 7.95 psi ~ 8 psi).

Size the transfer pump to deliver 2.2 L/s at 0.56 kPa (35 gpm at 8 psi). The designer should note that the head loss across the filter would vary with the manufacturer.

C-1.11 **Return Flow Pump from Thickening Tank to Equalization Tank.** Return flow rate: 3.8 L/s (60 gpm), assume 6.1 m (20 ft) elevation head or

6.1 m x (0.099 kg/cm^2)/m = 0.604 kg/cm^2 = 59.23 kPa.

(20 ft x 0.43 psi/ft = 8.6 psi)

Using 5.0 cm (2-in.) pipe, we assume a pressure drop through valves and fitting of 31.4 kPa (4.5 psi) for a total pressure drop of

60.8 kPa + 31.4 kPa = 92.2 kPa.

(8.6 psi + 4.5 psi = 13.1 psi)

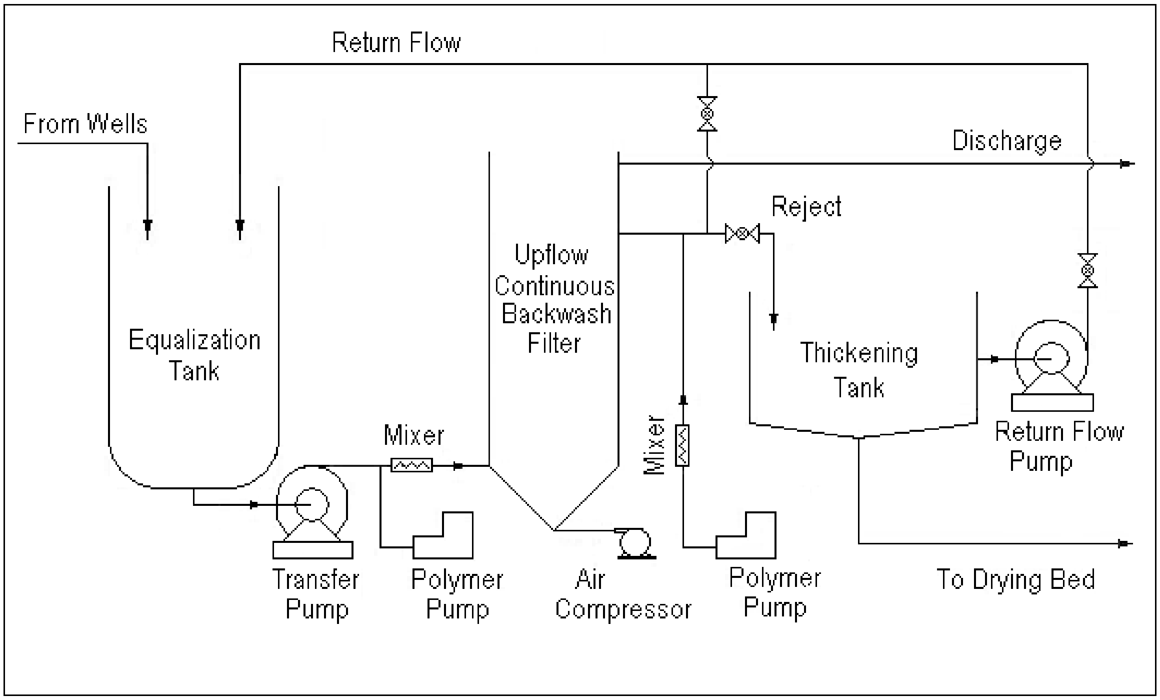
Size the pump for 3.78 L/s at 92.2 kPa (60 gpm at13.1 psi).

C-1.12 **System Summary.** The groundwater treatment system is composed of the following equipment. Figure C-1 is a flow diagram for the system.

- 1 - Equalization tank: 30,000 L (10,000-gal.).
- 1 - Transfer pump: 2.2 L/s at 55 kPa (35 gpm at 8 psi).
- 2 - Chemical feed systems for polymer (1 optional).

- 1 - Upflow continuous backwash filter: 1.4-m (54-in.) diameter with 1.4-mm (0.055-in.) sand media with compressor.
- 1 - Thickening tank: 37,850 L (10,000-gal.).
- 1 - Return flow pump: 3.8 L/s at 92.2 kPa (60 gpm at 13.1 psi).
- 1 - Sludge drying bed.

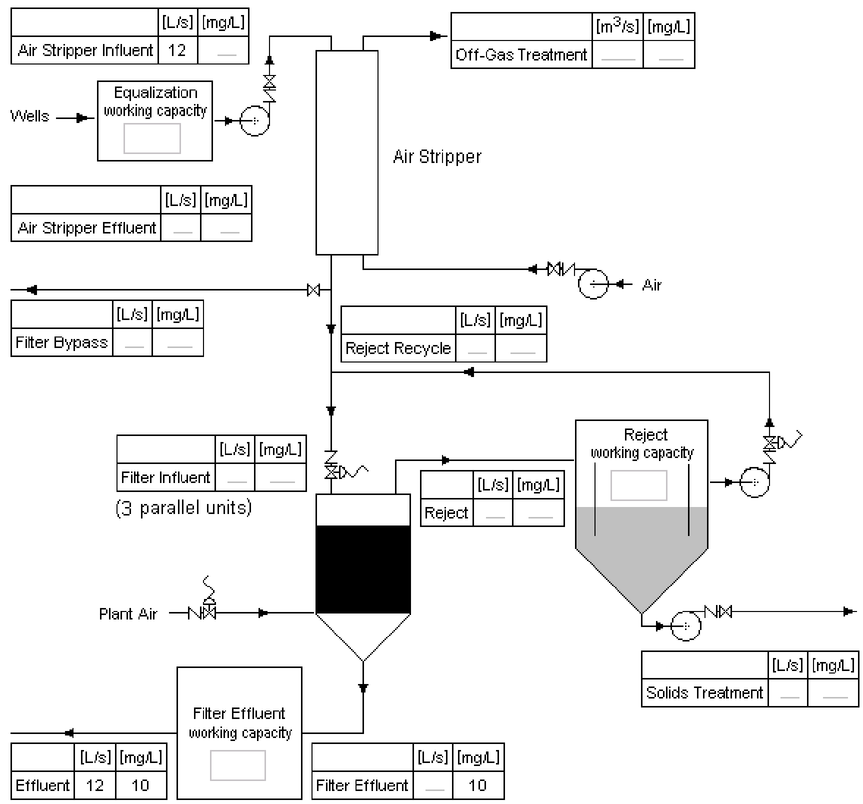
Figure C-1. Upflow Continuous Backwash Filter Schematic



C-2 **DOWNFLOW CONTINUOUS BACKWASH FILTER.** The water to be filtered is pumped from a groundwater remediation system. Recovery wells each yield 12 L/s (190 gpm) of contaminated groundwater. A system was needed that could operate with intermittent staffing. Air stripping for removal of the volatiles will precede the filter or filters**.**

C-2.1 **Treatment System.** The treatments system will be as generally indicated in Figure C-2. Design a unit operation for the continuous effluent from a single air stripper at 12 L/m^{2}s (190 gpm) to be in service 24 hours per day 7days per week.

Figure C-2. Preliminary Flow Diagram for a Downflow Continuous Backwashing Filter



Flow	Rate	Duration	Flow	SS	
	[L/s]	[hr/day]	[L/ day]	[mg/L]	[kg/day]
Influent	12	24	1,036,800		
Effluent	12	24	1,036,800	10	10.37
Filter Bypass					
Filter Influent					
Filter Effluent					
Reject Influent					
Reject Effluent					
Reject Recycle					
Solids Treatment					

C-2.2 **Design Parameters.** Characterize the influent conditions with background inorganics and minimum water temperature. Table C-1 shows the inorganic data summary from the RI/FS.

Table C-1. Background Inorganic Concentrations

Ion	mg/L	GMW*	Valence	GEqW**	meq/L	mg/L as $CaCO_3$
pH 6.8 [pH units]						
CO_2	0.00	44				
H_2S	0.00	34				
O_2	0.00	32				
Anions						
SO_4	60	96	–2	48	1.25	62.50
Cl	54	35.5	–1	35.5	1.52	76.06
HCO_3	30	61	–1	61	0.49	24.59
CO_3	0.00	60	–2	30	0.00	0.00
Alkalinity Subtotal						(100.65)
Total					3.26	163.15
Cations						
Ca	40	40	+2	20	2.00	100.00
Mg	10	24	+2	12	0.83	41.67
Hardness Subtotal						(141.67)
Fe	0.3	56	+2	28	0.01	0.24
Mn	0.05	55	+2	27	0.001	0.19
Na	10	23	+1	23	0.43	21.94
Cu	ND	64	+2	32		ND
Total					3.28	164.04

* The [gram] molecular weight of the species (*GMW)*.
** The [gram] equivalent weight of the species (*GEqW = GMW / Valence).*

Because the sampling method used during the RI/FS is not reliable for suspended solids, those values were not used. The anticipated concentration is 100 mg/L from the combined effects of sediment picked up in pumping and oxidation of inorganics and biological growth in the stripper.

If either oil or grease is anticipated, make provisions to remove it. Design a pre-treatment system to prevent scale or slime from clogging the air stripper and the filter if water is scaling (hardness >> 85, iron above 0.3 mg/L or manganese above 0.2 mg/L) (personal communication with Tony Ramirez, Marlo Incorporated ramirezt@marlo-inc.com). From Table C-1, at a pH of 6.8, treatment for metals is not considered to be cost effective.

C-2.3 **Establish Effluent Requirements and Confirm Need For Filtration.** Whenever the effluent suspended solids requirement is 30 mg/L or above, consider use of sedimentation in lieu of filtration; this gives the same effect with less maintenance. Consider what the effect on the suspended solids may be. From experience at other sites and discussions with filter suppliers, install a downflow continuous backwashing filter to prevent exceeding the suspended solids limit.

Table C-2. Suspended Solids Removal Requirements
at 12 L/s (190 gpm) = 1,036,800 L/day (273,900 gpd)

	Effluent Standard	Influent	Removal Requirement	
mg/L	10	100	90	90%
kg/day	10.368	103.680	93.312	90%
lb/gal.	0.000083	0.000834	0.00075	90%
lb/day	22.86	228.56	205.7	90%

C-2.4 **Develop the Design Basis.** Conversion units for filter loading

1 L/m^{2}s = 1.473 gpm/ft^2

1 gpm/ ft^2= 0.679 L/m^{2}s

Table C-3. Performance Capabilities

Application	Particle Sizes	Loading Rates		TSS [mg/L]	
	[microns]	[L/m^2 s]	[gpm/ft^2]	Influent	Filtrate
Algae removal	9–12	2–2.7	3–4	20–150	1–20
Metal hydroxides	9–12	2–4	3–6	20–100	2–5
Mill scale	9–12	2–7.5	3–11	20–250	5–10
Phosphorus removal	9–12	2–3.4	3–5	20–100	5–10
Surface water direct filtration	9–12	2–4	3–6	10–100 [NTU]	0.1–0.5 [NTU]
Tertiary filtration	9–12	2–3.4	3–5	20–150	1–10
Reference: Vendor B internet catalog					

Determine filter size based on flow rate and hydraulic loading. Select a loading rate for preliminary design. Table C-3 gives generally acceptable loading rates listed by Vendor B for selected water treatment applications. For the applications given, the maximum hydraulic loading varies from 2.7 to 7.5 L/m^{2}s (4 to 11 gpm/ft^2); the minimum hydraulic loading is 2 L/m^2 s (3 gpm/ft^2) for all, with a typical rate of 4.1 L/m^{2}s (6 gpm/ft^2). Relatively little flexibility is available in sizing the unit because continuous backwash filters are proprietary. The size and number of units is to be determined with Vendors A, B and C (data presented in this example) and evaluated against criteria and specifications.

For rough sizing in this example, use 4.0 L/m^2 s (5.9 gpm/ ft^2) and select the next larger stock diameter.

C-2.5 **Filters**. Size and number of units is to be determined. Each manufacturer can provide further guidance on acceptable hydraulic loading rates for an influent stream with a given total suspended solids concentration and solids size and density. Allowable hydraulic loading is inversely related to solids loading. Using the plant flow and the hydraulic loading, the filter area is determined as:

Filter area [m^2 (ft^2)] = plant flow [L/s (gpm)] / hydraulic loading [L/m^{2}s (gpm/ft^2)]

Determine a preliminary filter diameter for the sustained pumping rate, using 4.0 L/m^{2}s (5.88 gpm/ft^2) for the surface loading.

C-2.5.1 Consider a single filter at Q = 12 L/s (190 gpm), determine d_f = filter diameter, A = filter surface area, and Q/A = hydraulic loading rate.

Q/A = Q/A
4.0 L/m^2 s = 12 L/s / A
A = 12 L/s / 4 L/m^{2}s
A = 3.00 m^2
d = 1.954 m (6 ft, 5 in.)

C-2.5.2 Consider two units in parallel at 6 L/s (95.1 gpm) each, with a_f = area of each filter.

a_f = A/number
a_f = 3.00 m^2 / 2
a_f = 1.50 m^2
d_f = 1.38 m (4 ft, 7 in.)

C-2.5.3 Consider three units in parallel at 5 L/s (79.3 gpm) each.

a_f = A/number
a_f = 3.00 m^2 / 2
a_f = 1.50 m^2
d_f = 1.38 m (4 ft, 7 in.)

C-2.5.4 Consider three units in parallel at 5 L/s (79.3 gpm) each.

a_f = A/number
a_f = 3.00 m^2 / 3
a_f = 1.00 m^2
d_f = 1.13 m (3 ft, 8 in.)

C-2.5.5 Adjust the calculated diameter to the nearest larger stock diameter and recalculate the loading, including recycled streams. Verify that stock diameters are for the various manufacturers. Adjust the calculated diameter to the nearest stock diameter and recalculate the loading, including recycled streams. Vendor A, Vendor B, and Vendor C units are to be evaluated against criteria and specifications.

Table C-4. Vendor A [SI]

Model	*Minimum Feed Rate [L/s]	*Maximum Feed Rate [L/s]	Tank Diameter [m]	Tank Height [m]	Filtration Area [m^2]	Sand Bed Depth [m]	*Reject Rate [L/s]	Pressure Drop [Pa]	Air Feed Rate [scm/s @ 210 kPa]
7	0.95	3.8	0.91	3.3	0.65	1	0.2–0.38	25–60	0.0002–0.0005
12	2.2	6.3	1.2	3.7	1.1	1	0.2–0.50	30–75	0.0002–0.0009
19	3.5	10	1.5	4	1.8	1	0.2–0.63	30–75	0.0002–0.0009
28	4.7	13	1.8	3.2	2.6	1	0.2–0.76	30–75	0.0005–0.0014
38	6.3	19	2.1	4.5	3.5	1	0.25–0.95	30–75	0.0005–0.0019
50	9.5	25	2.4	4.7	4.6	1	0.32–1.3	30–75	0.0005–0.0024
64	11	32	2.7	4.9	5.9	1	0.32–1.6	30–75	0.0005–0.0024
78	15	38	3	5.2	7.2	1	0.44–1.9	30–75	0.0005–0.0024

Reference: metric conversion of Vendor A internet catalog data
*Depends on application

Table C-4. Vendor A [English]

Model	*Minimum Feed Rate [gpm]	*Maximum Feed Rate [gpm]	Tank Diameter [ft]	Tank Height [ft-in]	Filtration Area [ft^2]	Sand Bed Depth [in.]	*Reject Rate [gpm]	Pressure Drop [in.]	Air Feed Rate [SCFM @ 30 psig]
7	15	60	3	10-10	7	40	3–6	10–24	0.5–1
12	35	100	4	12-0	12	40	3–8	12–30	0.5–2
19	55	160	5	13-0	19	40	3–10	12–30	0.5–2
28	75	210	6	13-11	28	40	3–12	12–30	1–3
38	100	300	7	14-11	38	40	4–15	12–30	1–4
50	150	400	8	15-6	50	40	5–20	12–30	1–5
64	180	500	9	16-0	64	40	5–25	12–30	1–5
78	230	600	10	17-0	78	40	7–30	12– 30	1–5

Reference: Vendor A internet catalog
*Depends on application

Table C-5. Vendor B [SI]

Minimum Inlet Flow [L/s]	Tank Diameter [m]	Tank Height [m]	Filtration Area [m^2]	Est. Tank Weight [kg]	Est. Operating Weight [kg]	Inlet Diameter [cm]	Outlet Diameter [cm]	Waste Diameter [cm]	Media Volume [m^3]
0.883	0.914	2.51	0.66	1,100	2,500	5.08	7.6	3.2	0.680
1.58	1.22	2.81	1.17	1,500	4,400	6.35	8.9	5.1	1.27
2.46	1.52	3.12	1.82	2,600	7,300	7.62	15.2	6.4	2.18
3.60	1.83	3.35	2.63	3,500	11,020	8.89	15.2	7.6	3.31
4.86	2.13	3.73	3.58	4,500	15,700	10.16	20.3	8.9	4.81
6.37	2.44	3.14	4.67	5,600	21,500	15.24	20.3	8.9	6.65
8.01	2.74	4.34	5.91	6,800	28,300	15.24	20.3	10.2	8.92
9.91	3.05	4.57	7.29	8,000	36,500	15.24	25.4	15	11.6
14.3	3.66	5.182	10.5	11,000	57,000	20.32	30.5	15	18.4

Reference: metric conversion of Vendor B internet catalog
Note that Vendor B does not give a maximum feed rate. For purposed of this example, it was be assumed to be similar to the maximum rate of Vendor C for the same size unit, assuming adequate pretreatment.

Table C-5. Vendor B [English]

Minimum Inlet Flow [gpm]	Tank Diameter [ft]	Tank Height [ft-in]	Filtration Area [ft^2]	Est. Tank Weight [lb]	Est. Operating Weight [lb]	Inlet Diameter [in.]	Outlet Diameter [in.]	Waste Diameter [in.]	Media Volume [ft^3]
14	3	8-3	7.1	1,100	5,500	2	3	1.25	24
25	4	9-3	12.6	1,500	9,600	2.5	3.5	2	45
39	5	10-3	19.6	2,600	16,100	3	6	2.5	77
57	6	11-0	28.3	3,500	24,300	3.5	6	3	117
77	7	12-3	38.5	4,500	34,600	4	8	3.5	170
101	8	13-3	50.3	5,600	47,300	6	8	3.5	235
127	9	14-3	63.6	6,800	62,400	6	8	4	315
157	10	15-0	78.5	8,000	80,400	6	10	6	409
226	12	17-0	113.1	11,000	125,700	8	12	6	651

Reference: Vendor B internet catalog
Note that Vendor B does not give a maximum feed rate. For purposed of this example, it was be assumed to be similar to the maximum rate of Vendor C for the same size unit, assuming adequate pretreatment.

Table C-6. Vendor C [SI]

Effluent Flow rate [L/s]	Reject Flow rate [%]	Inside Diameter [m]	Filtration Area [sq m]	Inlet Height [m]	Outlet Height [m]	Reject Height [m]	Air [m^3/s]	Sand [kg]
0.88–2.65	2–15	0.91	0.65	4.14	3.35	3.28	0.00028–0.00061	1,450
1.58–4.73	2–15	1.22	1.16	4.06	3.76	3.63	0.00028–0.00061	2,994
2.4–7.2	2–15	1.52	1.77	4.29	3.99	3.79	0.00047–0.00094	4,536
4.8–14.4	2–15	2.13	3.53	4.73	4.37	4.24	0.00094–0.00141	8,618
8.1–24	2–15	2.74	5.95	6.16	5.77	5.77	0.00142–0.00189	18,144
Reference: metric conversion of Vendor C internet catalog								

Table C-6. Vendor C [English]

Effluent Flow rate [gpm]	Reject Flow rate [%]	Inside Diameter [ft]	Filtration Area [ft^2]	Inlet Height (ft-in.)	Outlet Height (ft-in.)	Reject Height (ft-in.)	Air [scfm]	Sand [tons]
14–42	2–15	3.0	7.0	13-7	11-0	10-9	0.6–1.3	1.6
25–75	2–15	4.0	12.5	13-4	12-4	11-11	0.6–1.3	3.3
38–114	2–15	5.0	19.0	14-1	13-1	12-8	1.0–2.0	5.0
76–228	2–15	7.0	38.0	15-6	14-4	13-11	2.0–3.0	9.5
128–384	2–15	9.0	64.0	20-6	18-11	18-11	3.0–4.0	20
Reference: Vendor C internet catalog								

C-2.5 **Evaluate the Parameters Using One, Two, or Three Units.** If a single filter is out of service, for repair or maintenance, the filtration system must be bypassed or the flow stored. Consider the next smaller and next larger sizes. The next smaller size is inadequate for the flow. Consider the next larger size if long outages requiring substantial storage and higher pumping rates may be encountered. A 7-ft (2-m) diameter unit is very large and difficult to replace; an 8-ft (2.5-m) unit even more so. Refer to vendor cut sheets. Carefully consider the anticipated solids loading and any previous rounding up before application of safety factors. Reject rate is independent of influent loading and adds back to hydraulic loading.

Table C-7. Loading at 12 L/s (190.2 gpm)

	1 unit 2.134 m (7 ft-0 in.) diameter	2 units 1.524 m (5 ft-0 in.) diameter	3 units1.219 m (4 ft-0 in.) diameter
Flow Each	12 L/s (190.2 gpm)	6 L/s (95.1 gpm)	4 L/s (63.4 gpm)
Area Each	3.53 m^2 (38 ft^2)	1.77 m^2 (19 ft^2)	1.11 m^2 (12 ft^2)
Hydraulic Loading Each	3.40 L/m^2s (5.01 gpm/ft^2)	3.40 L/m^2s (5.01 gpm/ft^2)	3.59 L/m^2s (5.28 gpm/ft^2)
Reject Rate Each	0.25 to 0.95 L/s (4 to 15 gpm)	0.19 to 0.63 L/s (3 to 10 gpm)	0.19 to 0.50 L/s (3 to 8 gpm)
Total Hydraulic Loading Each	3.67 L/m^2s (5.40 gpm/ft^2)	3.76 L/m^2s (5.53 gpm/ft^2)	4.04 L/ m^2s (5.95 gpm/ft^2)
Reject Rate Total	0.95 L/s (15 gpm)	1.26 L/s (20 gpm)	1.51 L/s (24 gpm)
Total Hydraulic Loading	12.95 L/s (205.2 gpm)	13.26 L/s (210.2 gpm)	13.51 L/s (214.2 gpm)
With one filter unit out of operation			
Flow Each	NA	12 L/s (190.2 gpm)	6 L/s (95.1 gpm)
Area Each	3.53 m^2 (38 sq. ft.)	1.77 m^2 (19 sq. ft.)	1.11 m^2 (12 sq. ft.)
Hydraulic Loading Each	NA	6.8 L/m^2s (10.01gpm/sq. ft.)	5.38 L/m^2s (7.93 gpm/sq. ft.)
Reject Rate Each	NA	0.19 to 0.63 L/s (3 to 10 gpm)	0.19 to 0.50 L/s (3 to 8 gpm)
Total Hydraulic Loading Each	NA	7.16 L/m^2s (10.54 gpm/sq. ft.)	5.83 L/m^2s (5.53 gpm/sq. ft.)
Reject Rate Total	NA	0.95 L/s (15 gpm)	1.26 L/s (20 gpm)
Total Hydraulic Loading	NA	12.95 L/s (205.2 gpm)	13.26 L/s (210.2 gpm)

It is recommended that duplex 1.5 m (5'-0") diameter units with a nominal loading of 3.40 L/m^2s (5.01 gpm/ ft^2) and effective loading of 3.76 L/m^2s (5.54 gpm/ ft^2) be specified. During the expected minimum downtime with one of the units is out of service the single unit rated capacity of 10.1 L/s (160 gpm) would be exceeded which would result in excessive head losses. It may be necessary to recirculate flows of 2.85 L/s (45.2 gpm) back to the air stripper or to reduce the influent to the treatment plant by that amount. Reduction of the flow to an air stripper is not usually desirable. A pair of larger filter units would have substantial excess capacity.

Any of these sizes and loadings would require a spare filter, storage or bypassing to maintain the flow through rate while a unit is off-line.

Table C-8. Preliminary Flow Diagram [SI]

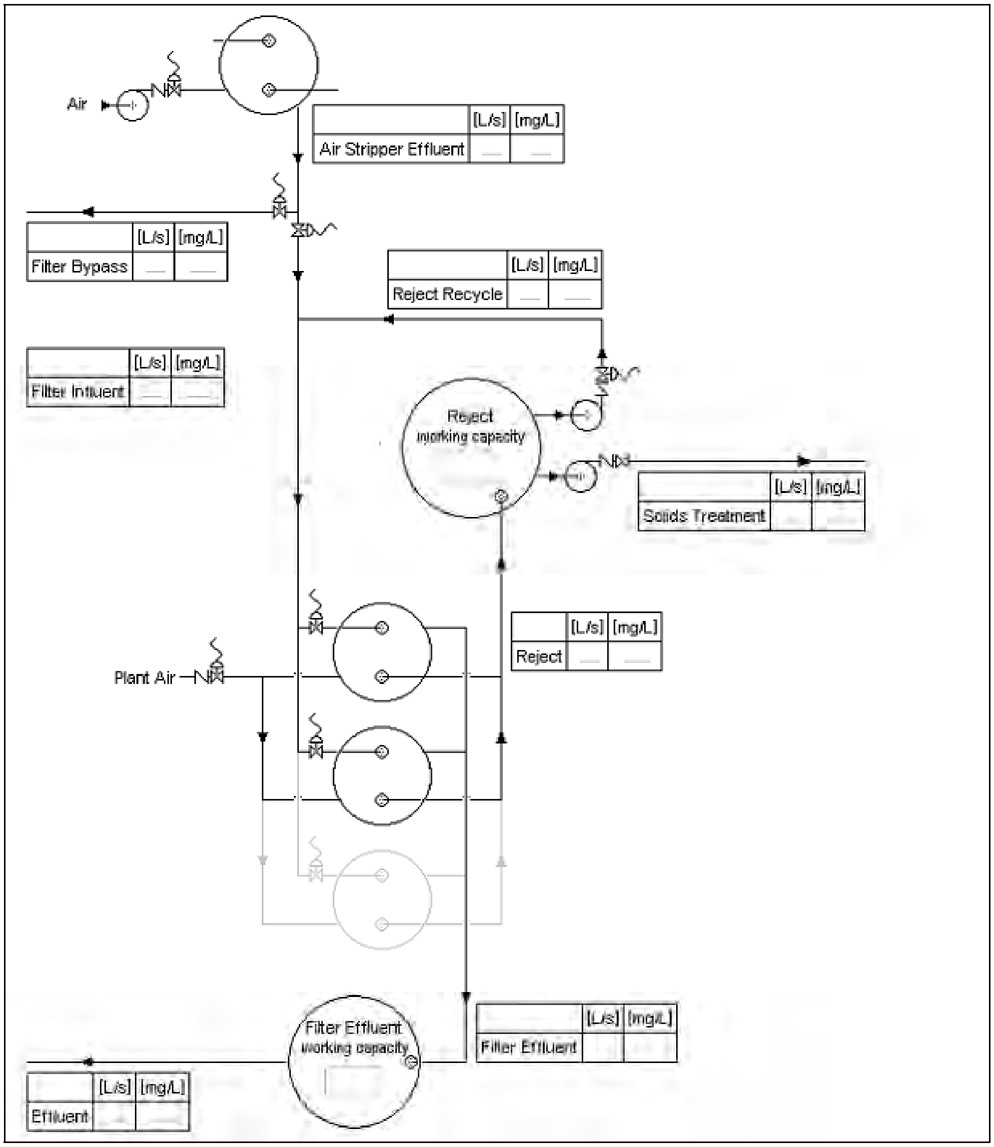
Flow	Rate	Duration	Flow	SS	
	[L/s]	[hr/day]	[L/day]	[mg/L]	[kg/day]
Influent	12.0	24	1,036,800	NA	NA
Effluent	12.0	24	1,036,800	10	10.37
Filter Bypass	0	0			
Filter Influent	6.19–6.63	24		100	
Filter Effluent	6.19–6.63	24		10	
Backwash Influent	0.19–0.63	24			
Backwash Effluent	0.19–0.63	24			
Backwash Recycle	0.19–0.63	24			
Solids Treatment	0.19–0.63	0.5			

Table C-8 Preliminary Flow Diagram [English]

Flow	Rate	Duration	Flow	SS	
	[gpm]	[hr/day]	[gpd]	[ppm]	[lb/day]
Influent	190	24	273,894		
Effluent	190	24	273,894	10	22.8
Filter bypass					
Filter influent				100	228
Filter effluent					
Backwash influent					
Backwash effluent					
Backwash recycle					
Solids treatment					

C-2.6 **Complete the Flow Diagram**.

Figure C-3. Schematic of a Continuous Downflow Backwash Filter



C-2.7 **Criticality of Operation**. Consult with the user and the rest of the design team to determine whether part or all of the unit operation can be shut down for maintenance. If bypassing is not an allowable option, storage and treatment at a higher rate may be essential. A frequently cited advantage of continuous backwashing filters is elimination of backwash storage and repumping. Verify the relative cost effectiveness of providing spare flow through capacity versus storage and pumping. Determine whether a spare filter or storage and repumping is the best solution for filter outages.

C-2.7.1 Allow Vendor A, Vendor B and Vendor C units in the specification by elimination of any non-critical provisions that might make the specification proprietary. Seek information on more vendors of continuous backwash filters that may be suitable.

C-2.7.2 Install two 5-ft (1.5-m) diameter filters with provisions for bypass back to the equalization tank ahead of the air stripper, allowing constant flow to the stripper while filtering at a reduced rate during filter outages. Reminder: Put provisions for scheduling concurrent down time for stripper and filters in the O&M Manual.

C-2.7.3 Provide a settling tank for the reject stream with approximately 4 hours retention and a pumping system to return the decanted liquid.

C-2.7.4 Calculate the system head losses, including the media, the filter system inlet and the exit losses. Size equipment, including blowers and pumps. Design a pump system with controls to be compatible with the filter system, being careful not to specify flow and head conditions in excess of the filter system. See Paragraphs C-1.6 through C-1.11.

C-2.8 **Complete the Design**. The following drawings are required.

- Site plans.
- Profiles.
- Layout drawings.
- Elevations
- Schematics
- P&ID
- Details.

C-2.8.1 Write a Design Analysis in compliance with ER 1110-345-700 containing the following:

- Narrative.
- Documentation.
- Description.
- Calculations as indicated in this appendix and in Chapter 8.
- Computer print out with documentation.
- O&M Provisions.

C-2.8.2 Write Specifications in compliance with ER 1110-1-8155 including the following United Facilities Guide Specifications (UFGS)

- 02521A.
- 11211A.
- 11212A.
- 11220A.
- 11242A.
- 11393A.

- 13405A.
- 15200A.

C-2.8.3 Write a Cost Estimate in compliance with ER 1110-3-1301, Cost Engineering Policy Requirements for Hazardous, Toxic Radioactive Waste (HTRW) Remedial Action Cost Estimate.

C-2.8.4 Write a Draft O&M Manual including bypass and cleaning procedures, as well as the O&M of the mechanical equipment.

APPENDIX D

CARTRIDGE FILTER

D-1 WASTE STREAM CHARACTERISTICS

- Maximum flow: 7 L/s (110 gpm).
- Maximum operating temperature: 60 degrees C (140 degrees F).
- Design influent suspended solids: 1 mg/L (1 ppm).
- Design effluent particle size: 10 microns.
- Filter change out frequency: twice weekly (maximum).
- Influent pH: 8.0.
- The waste stream to be treated also contains residual soluble alum from up-stream treatment process and aluminum nitrate(s) and barium chloride(s), which is to be treated by a downstream membrane process. Trace amounts of amyl alcohol are also present in the waste stream (s = soluble).

D-2 **SELECTION OF FILTER MATERIALS OF CONSTRUCTION**. The chemicals in the waste stream are compared to the general chemical resistance chart, Table D-1. The chemical resistance chart is compared to polypropylene cartridge filter material. Based on the comparison, polypropylene is compatible with the chemicals in the waste stream. A review of Table D-1, the “General Chemical Resistance Chart,” shows that Polypropylene is also compatible with the maximum operating temperature and its resistance to alkalis indicates that the pH of 8 will not impact filter performance. Therefore, the cartridge filter materials of construction can be polypropylene. The Vendor A cartridge filter bulletin (not attached) shows the filter, filter core and outer filter cage are available in polypropylene, and has a polypropylene filter cartridge with a 10 micron rating.

Table D-1. General Chemical Resistance Chart (Vendor A)

Material	Resistance	Max Permissible Temperature (Water) degrees C (degrees F)	
		Constant	Short Term
Polyvinyl Chloride (PVC, UPVC)	Resistance to most solutions of acids, alkalis, and salts and organic compounds miscible with water. Not resistant to aromatic and chlorinated hydrocarbons.	60 (140)	60 (140)
Chlorinated Polyvinyl Chloride (CPVC)	Can be used similarly to PVC but at increased temperatures.	90 (195)	110C (230F)

Material	Resistance	Max Permissible Temperature (Water) degrees C (degrees F)	
		Constant	Short Term
Polypropylene (PP)	Resistant to water solutions of acids, alkalis, and salts, as well as to large number of organic solvents. Unsuitable for concentrated oxidizing acids.	60 (140)	80 (175)
Polyvinylidene (PVDF)	Resistant to acids, solutions of salts, aliphatic, aromatic and chlorinated hydrocarbons, alcohols, and halogens. Conditionally suitable for ketones, esters, ethers, organic bases, and alkaline solutions.	90 (195)	110 (130)
Polytetrafluroethylene (PTFE)	Resistant to all chemicals listed in the chart.	140 (285)	150 (300)
Nitrite Rubber (Buna-N)	Good resistance to oil and gasoline. Unsuitable for oxidizing agents.	90 (195)	120 (250)
Butyl Rubber Ethylene Propylene Rubber (EPDM, EPR)	Good resistance to ozone and weather. Especially suitable for aggressive chemicals. Unsuitable for oils and fats.	90 (195)	120 (250)
Chloroprene Rubber (Neoprene)	Chemical resistance very similar to that of PVC and between that of Nitrite and Butyl rubber.	80 (175)	110 (230)
Fluorine Rubber (Viton)	The best chemical resistance to solvents of all elastomers.	150 (300)	200 (390)

D-3 **NUMBER OF FILTERS REQUIRED**. Vendor A cartridge manufacturer recommends using 10 L/min. (2.5 gpm) per 250 mm (10 in.) cartridge filter length. The Vendor bulletin indicates that a 250 mm (10 in.) cartridge length has 0.5 m^2 (5.4 ft^2) of filter media. Similarly, the 500 mm (20 in.), 750 mm (30 in.) and 1000 mm (40 in.) cartridges have areas equal to 1.0 m^2 (10.8 ft^2), 1.5 m^2 (16 ft^2) and 2.0 m^2 (21.5 ft^2), respectively.

$$\text{Hydraulic Filter Loading} = \frac{10\ \text{L/min per 250 mm filter}}{0.5\ \text{m}^2\ \text{per 250 mm filter}} = 20\ \text{L/min m}^2$$

$$\text{Total Required Filter Area} = \frac{420\ \text{L/min}}{20\ \text{L/(min-m}^2)} = 21\ \text{m}^2 \text{(use 20)}$$

$$\text{No of 250 mm Filters} = \frac{21\ \text{m}^2}{0.5\ \text{m}^2\ \text{per element}} = 42\ \text{(use 40)}$$

$$\text{No of 500 mm Filters} = \frac{21\text{m}^2}{1.0\ \text{m}^2\ \text{per element}} = 20$$

$$\text{No of 750 mm Filters} = \frac{21\ \text{m}^2}{1.5\text{m}^2\ \text{per element}} = 14$$

$$\text{No of 1000 mm Filters} = \frac{21\ \text{m}^2}{2.0\ \text{m}^2\ \text{per element}} = 10$$

Selection of the filter cartridge lengths and number of filter cartridges selected may be based on space limitations, operating procedures for changing longer filter cartridges and limited overhead space, or filter suppliers standard housing configurations.

D-4 **HOUSING SELECTION**. The housing materials of construction must be suitable for the waste stream characteristic including temperature. The Vendor A product bulletin also discusses the use of PVC and CPVC housings which are compatible. From the Bulletin, the housing should be manufactured of CPVC (see Table D-2) to give added temperature protection and it should be the Vendor A model 12EFC (Figure D-1) which provide flow rates up to 450 L/min. (120 gpm) and it should contain 20–500 mm (20 inch) filters. The basic arrangement of the Vendor A unit is shown in Figure D-1.

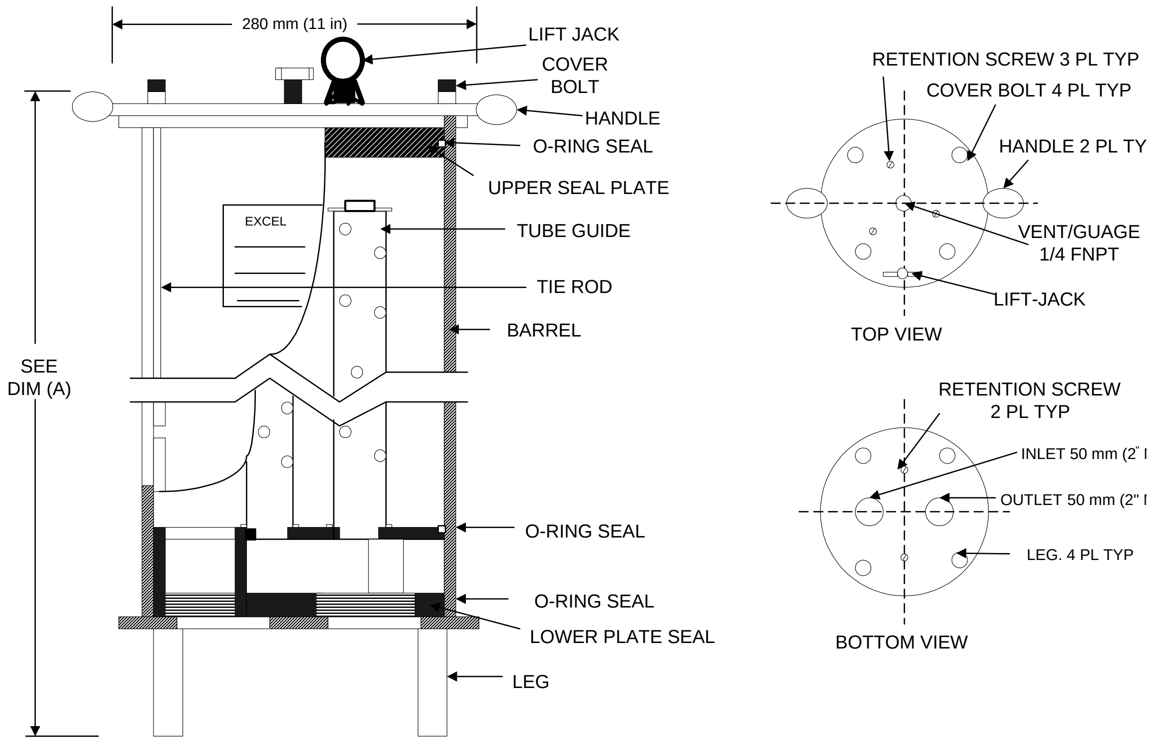
Table D-2. Vendor A General Chemical Resistance

Chemical	Temperature Degrees C (degrees F)				Chemical	Temperature Degrees C (degrees F)			
	21 (70)	38 (100)	60 (140)	82 (180)		21 (70)	38 (100)	60 (140)	82 (180)
Acetaldehyde	R	R	NR	NR	Ammonia, Liquid	R	R	NR	NR
Acetamide	R	NA	NA	NA	Ammonium, Acetate	R	NR	NR	NR

Chemical	Temperature Degrees C (degrees F)				Chemical	Temperature Degrees C (degrees F)			
	21	38	60	82		21	38	60	82
	(70)	(100)	(140)	(180)		(70)	(100)	(140)	(180)
Acetic Acid 10%	R	R	R	R	Ammonium Bifluoride	R	R	R	NA
Acetic Acid 20%	R	R	R	R	Ammonium Bisulfide	NA	NA	NA	NA
Acetic Acid 50%	R	R	R	R	Ammonium Carbonate	R	R	R	R
Acetic Acid 80%	R	R	R	R	Ammonium Chloride	R	R	R	R
Acetic Acid, Glacial	R	R	NR	NR	Ammonium Dichromate	NA	NA	NA	NA
Acetic Anhyride	R	R	R	R	Ammonium Fluoride, 10%	R	R	R	NA
Acetone	R	NR	NR	NR	Ammonium Fluoride, 25%	R	NA	NA	NA
Acetonitrite	NA	NA	NA	NA	Ammonium Hydroxide	R	R	R	R
Acetophenone	R	R	NR	NR	Ammonium Metaphos-phate	R	R	R	NA
Acetyl Chloride	NR	NR	NR	NR	Ammonium Nitrate	R	R	R	R
Acetyl Nitrite	NA	NA	NA	NA	Ammonium Persulphate	R	R	R	R
Acetylene	R	NA	NA	NA	Ammonium Phosphate	R	R	R	R
Acrylic Emulsions	R	R	R	NA	Ammonium Sulfate	R	R	R	R
Acryionitrite	R	NR	NR	NR	Ammonium Sulfide	R	R	R	NA
Adipic 105 Acid	R	NR	NR	NR	Ammonium Thiocyanate	R	R	R	NA
Alcohol, Allyl	R	NA	NA	NA	Amyl Acetate	NR	NR	NR	NR
Alcohol, Amyl	R	R	R	R	Amyl Chloride	NR	NR	NR	NR
Alcohol, Benzyl	R	R	R	NA	Aniline	R	R	R	R
Alcohol, Butyl, Primary	R	R	R	R	Aniline Chloro-hydrate	NR	NR	NR	NR
Alcohol, Butyl Secondary	R	R	R	NA	Aniline Dyes	R	R	R	R
Alcohol, Diacetone	R	NR	NR	NR	Aniline Hydro-chloride	NR	NR	NR	NR
Alcohol, Ethyl	R	R	R	R	Anthraquione	NR	NR	NR	NR
Alcohol, Hexyl	R	R	NA	NA	Anthraquione Sulfonic Acid	NR	NR	NR	NR
Alcohol.	R	R	R	NR	Antimony	R	R	R	R

Chemical	Temperature Degrees C (degrees F)				Chemical	Temperature Degrees C (degrees F)			
	21	38	60	82		21	38	60	82
	(70)	(100)	(140)	(180)		(70)	(100)	(140)	(180)
Isopropyl					Trichloride				
Alcohol, Methyl	R	R	R	R	Apple Juice	R	R	R	R
Alcohol, Propargyl	NR	NR	NR	NR	Aqua Regis	R	NR	NR	NR
Alcohol, Propyl	R	R	R	R	Arsenic Acid	NR	NR	NR	NR
Allyl Chloride	R	NA	NA	NA	Aryl Sulfonic Acid	NA	NA	NA	NA
Alum	R	R	R	R	Asphalt Liquid	NA	NA	NA	NA
Alum, Ammonium	R	R	R	NA	Barium Carbonate	R	R	R	R
Alum, Chrome	R	R	R	NA	Barium Chloride	R	R	R	R
Alum, Potassium	R	R	R	NA	Barium Hydrate	NA	NA	NA	NA
Aluminum Chloride	R	R	R	R	Barium Hydroxide	R	R	R	R
Aluminum Fluoride	R	R	R	R	Barium Nitrate	NA	NA	NA	NA
Aluminum Hydroxide	R	R	R	R	Barium Sulfate	R	R	R	R
Aluminum Nitrate	R	R	R	R	Barium Sulfide	R	R	R	NA
Aluminum Oxychloride	R	R	NA	NA	Beer	R	R	R	R
Aluminum Sulfate	R	R	R	R	Beet Sugar Liquors	R	R	R	R
Ammonia, Aqua. 10%	R	R	R	R	Benzaldehyde, 10%	R	NR	NR	NR
Ammonia, Gas	R	R	R	NA	Benzaldehyde, above 10%	R	NA	NA	NA

Figure D-1. Vendor A Cartridge Filter Housing



PART No.	DIM (A)
6EFC1	480 mm (19 in)
12EFC2	740 mm (29 in)
18EFC3	1000 mm (39 in)
24EFC4	1250 mm (49 in)

NOTE: 50 mm (2") NPT STANDARD INLET AND OUTLET
NOTE: 50 mm or 75 mm (2" OR 3") FLANGE OPTIONAL
NOTE: ALL DIMENSIONS ARE NOMINAL UNLESS OTHERWISE NOTED

D-5 **HEAD LOSS CALCULATIONS**. Vendors A and B were evaluated to determine the Head loss characteristics of their 500 mm (20 inch) filter elements. Both indicate similar results, so Vendor B data was included for this example. The calculated loss per filter is equal to:

7 (L/s)/20 filters = 0.35 (L/s)/filter (5.6 gpm)

Based on the second chart of Figure D-2, for a flow of 0.35 L/s (5.6 gpm), the Head loss per clean filter is approximately 1.4 kPa (0.2 psi). In addition the Vendor A literature (not provided) indicates the Head loss through the filter housing is approximately 12 kPa (1.7 psi) at a flow rate of 7 L/s (110 gpm). Optional arrangements such as that shown in Figure D-2 indicate several housings containing fewer filters can be placed in parallel to increase operator flexibility, and maintain a constant flow rate to the downstream process. To ensure the constant operational flexibility, and to keep the process on line, three filter housings will be installed, two operational and one in standby mode, each housing containing 10 filter cartridgess each. Head loss calculations from the pump discharge to the downstream holding tank were performed, resulting in an additional head loss including differential water surface elevations equal to 22 kPa (3.2 psi). Total head loss through the entire clean system equals

1.4 + 12 + 22 kPa = 35.2 kPa

0.2 + 1.7 + 3.2 psi = 5.1 psi.

After evaluating differing pump curves, the maximum recommended Head loss through the system with dirty filters equals 138 kPa (20 psi). The estimated loading per filter based on the manufacturers recommendations, is 0.15 kg (0.33 lb). Calculating the solids loading based on 1 mg/l (1ppm) and 7 L/s (110 gpm) results in a loading rate of 0.6 kg/day (0.44 lb/day).

$7 \text{ L/s} \times 1 \text{ mg/L} \times 86{,}400 \text{ s/day} \times 10^{-6} \text{ kg/mg} = 0.6 \text{ kg/day}$

The resulting change out frequency is:

$\frac{0.15 \text{ kg/filter} \times 20 \text{ filters}}{0.6 \text{ kg/day}} = 5 \text{ days} < 2 \text{ times/week.}$

In addition, evaluate the capacity of upstream and downstream tanks based on the operating characteristics of the pumps during clean and dirty filter operations.

Figure D-2. Vendor B Operating Characteristics

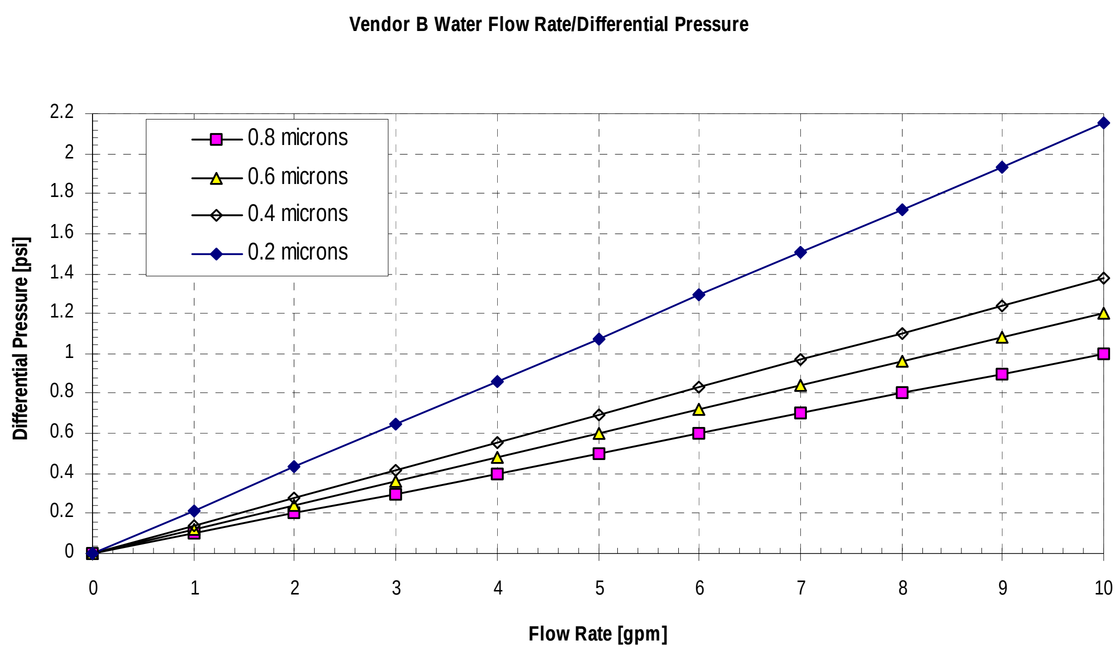


Figure D-2(cont'd). Vendor B Operating Characteristics

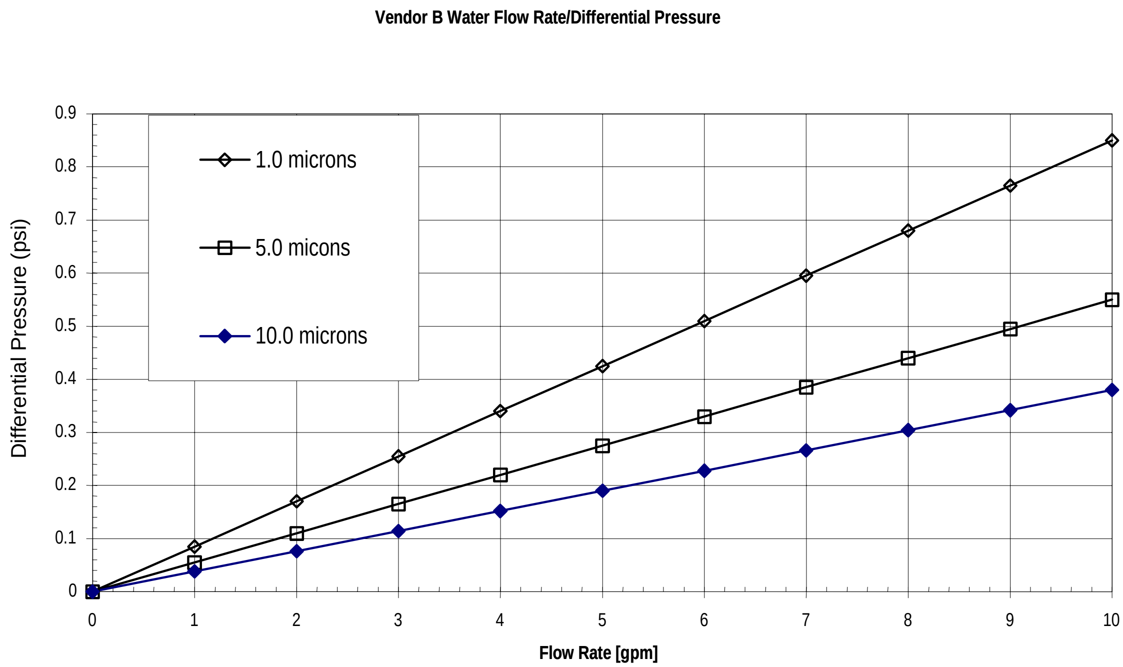


Figure D-3. Cartridge Filter Schematic

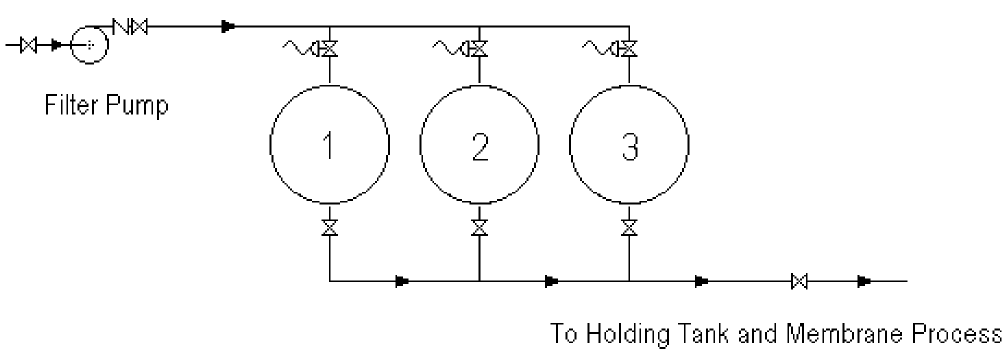


Figure D-4. Pleated Cartridge Filters

SPECIFICATIONS

Utilizes 10- to 40-in.cartridge filters.

Flow rate capacities:

6 EFC—up to 60 gpm
12 EFC—up to 120 gpm
18 EFC—up to 180 gpm
24 EFC—up to 240 gpm

1. Vessels are designed to meet or exceed ASME Code, Section X ,and conform to California Barclays Code.

2. Operating Conditions:
   (a) Pressure: 150 psi
   (b) Temperature: 150 degrees F
   (c) Fluids with a pH of 2–13

3. Each housing is pressure tested at 300 psi.

4. The vessel barrel is fabricated using Dow Derakane 411-45, a flexible, fatigue resistant vinylester.

5. All wetted materials meet the requirements of FDA CFR Title 21.

6. Vent connection is standard on all housing.

STANDARD SERIES

- 6 EFC—10-in. cartridge filter
- 12 EFC—20-in. cartridge filter
- 18 EFC—30-in. cartridge filter
- 24 EFC—40-in. cartridge filter

- 2 in. NPT Inlet/Outlet
- Buna O-ring Seals
- Anodized Aluminum/300 ss Series
- Externals

Figure D-5. Vendor A - Pleated Cartridge Filters Housings

SPECIFICATIONS

Utilizes 10- to 40-in. cartridge filters.

Flow rate capacities:

6 EFC—up to 60 gpm
12 EFC—up to 120 gpm
18 EFC—up to 180 gpm
24 EFC—up to 240 gpm

1. Vessels are designed to meet and/or exceed ASME CODE, Section X and conform to California Barclays Code.

2. Operating Conditions:
   (a) Pressure: 150 psi
   (b) Temperature: 150 degrees F
   (c) Fluids with a pH of 2–13

3. Each housing is pressure tested at 300 psi.

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STANDARD SERIES

- 6 EFC—10 in. cartridge filter
- 12 EFC—20-in. cartridge filter
- 18 EFC—30-in. cartridge filter
- 24 EFC—40-in. cartridge filter

- 2 in. NPT Inlet/Outlet
- Buna O-ring Seals
- Anodized Aluminum/300 ss Series
- Externals

APPENDIX E

BAG FILTER

E-1 WASTE STREAM CHARACTERISTICS

- Maximum Flow: 7 L/s (110 gpm).
- Maximum operating Temperature: 60 degrees C (140 degrees F).
- Design Influent Suspended Solids: 1 mg/L (1 ppm).
- Design Effluent Particle Size: 10 microns.
- Filter change out frequency: twice weekly (maximum).
- Influent pH: 8.0.
- The waste stream to be treated also contains residual soluble alum from upstream treatment process and aluminum nitrate(s) and barium chloride(s), which is to be treated by a downstream membrane process. Trace amounts of amyl alcohol are also present in the waste stream (s = soluble).

E-2 **SELECTION OF FILTER MATERIALS OF CONSTRUCTION**. The chemicals in the waste stream are compared to the General Chemical Resistance Chart, Table D-1 (cartridge filter example) and manufacturer data like that presented for Vendor A in Table E-1. The chemical resistance chart is compared to polypropylene filter material and based on the comparison polypropylene is compatible with the chemicals in the waste stream.

Table E-1. Vendor A Filter Fabric Properties

Fabric	Specific Gravity	Tensile Strength	Abrasion & Flex	Weak Acids	Strong Acids	Weak Alkali	Strong Alkali	Solvents	Temperature Degrees F
Cotton	1.55	44–109	Fair	Poor	Poor	Excellent	Excellent	Good	200–240
Polyester	1.38	64–124	Very Good	Very Good	Good	Good	Poor	Good	275–325
Glass	2.56	200–215	Poor	Excellent	Good	Fair	Poor	Excellent	500–600
Nylon	1.14	58–128	Excellent	Fair	Poor	Excellent	Excellent	Good	275–300
Nomex	1.14	58–128	Very Good	Fair	Poor	Excellent	Excellent	Good	400–450
Polypropylene	0.91	50–85	Very Good	Excellent	Excellent	Excellent	Excellent	Fair	200–220
Saran	1.69	15–44	Good	Excellent	Excellent	Excellent	Excellent	Poor	160–185
Teflon	2.30	47	Poor	Excellent	Excellent	Excellent	Excellent	Very Good	450–500

A review of Table D-1 shows that polypropylene is also compatible with the maximum operating temperature and its resistance to alkalis indicates that the pH of 8 will not impact filter performance. Therefore, filter materials of construction can be polypropylene. The Vendor A and B bag filter bulletins (not attached) show that the bag filter and bag filter core are all constructed of polypropylene. The Vendor bulletins also indicate these filters are available in a 10-micron rating.

E-3 **NUMBER OF FILTERS REQUIRED.** Use Vendor B literature to illustrate, and reference Table E-4, Table E-6, Table E-7, and Figure E-1. Refer to Table E-7 which indicates 1 – No. 1 bag, model FSP-40 has a maximum capacity of 5.7 L/sec (90 gpm), and 1 – No. 2 bag, for standard filter vessel model FSP-85, can handle a maximum flow of 12.6 L/s (200 gpm). Select the larger bag which will afford a much greater capacity in a single unit. The filter hydraulic loading based on the bags surface area of 0.41 m^2 (4.4 ft^2) is calculated below:

$$\text{Hydraulic Filter Loading} = \frac{12.6\ \text{L/s}}{0.41\,\text{m}^2\ \text{filter surface area}} = 30.8\ \text{L/s}\ \ \text{m}^2$$

E-4 **HOUSING SELECTION**. The materials of construction must be suitable for the waste stream characteristics including temperature. The Vendor B product bulletin has housings, which are compatible. According to the Vendor B data, the FSP-85 unit would be suitable for this application with a number 2-size bag. A typical bag filter system is shown in Figure E-2.

E-5 **HYDRAULIC CONSIDERATIONS**. The procedure for calculating Head loss through the unit is similar to the cartridge filter example. Refer to Appendix D and manufacturer ‘s literature for additional information and calculation procedures.

E-6 **COMPARISON TO CARTRIDGE FILTER DESIGN**. The bag filter requires only one bag as opposed to the 20 filter cartridges required to treat the same waste stream. This significantly reduces disposal cost when a bag filter is used versus filter cartridges.

The bag filter operates at approximately 90 times the hydraulic loading rate for the same throughput.

One additional consideration is that provisions could made to clean the bag filter for reuse and that systems are available in flow rates beyond the scope of this document.

E-7 **FILTER BAGS**

Table E-2. Vendor A Bag Media And Micron Ratings

1 Fibers & Media	2 Micron Rating
PECG - polyester/cotton	1, 3
PEIF - polyester inserted	1, 3, 5, 10, 15, 25, 50, 75, 100, 200
PENF - polyester non-inserted	5, 10, 15, 25, 50, 75, 100
PEIG - polyester inserted glazed	1, 3, 5, 10, 15, 25, 50, 75, 100, 200
PENG - polyester non-inserted glazed	5, 10, 15, 25, 50, 75, 100

1 Fibers & Media	2 Micron Rating
V-rayon-viscose felt	3, 5, 10, 15, 25
TFE - teflon felt	10, 25, 50
N - nylon felt	5, 10, 25, 50, 100
POIF - polypropylene inserted	1, 3, 5, 10, 25, 50, 100
POIG - polypropylene inserted glazed	1, 3, 5, 10, 25, 50, 100
PONG - polypropylene non-inserted glazed	5, 10, 25, 50, 100
POMF - polypropylene micro-fiber	2A, 10A, 25A, QA
HT - nylon nomex felt	5, 10, 25, 50, 100
PEM - polyester multifilament mesh	75, 100, 125, 150, 200, 250, 400, 600, 800
PEMO - polyester monofilament mesh (special order)	5, 10, 25, 50, 75, 100, 150, 200, 250, 400, 600, 800
NM - nylon multifilament mesh	100, 150, 800
MNO - nylon monofilament mesh	5, 10, 25, 35, 50, 65, 75, 90, 100, 125, 150, 175, 200, 250, 300, 400, 600, 800
PMO - polypropylene monofilament mesh	250, 300, 400, 600, 800
S - saran monofilament mesh	300, 600, 800

Table E-3. Vendor A - Bag Cover And Design Data

3 Bag Cover	4 Bag Size Number
P -plain (no cover) PEM - polyester multifilament cover G - fiber free finish NMO - nylon monofilament cover NM - nylon multifilament cover Carex - spun bonded nylon M - muslim cover	1 - #1 size bag 2 - #2 size bag 3 - #3 size bag 4 - #4 size bag 5 - #5 size bag 6 - #6 size bag 7 - #7 size bag 8 - #8 size bag 9 - #9 size bag

5 Bag Design	6 Suffix
P - polyloc S - metal retaining ring-snap collar design PC - 1 - fits #1 cuno housing PC -2 - fits #2 cuno housing CO - fits Commercial filter housing RP - fits Ronnigen-Petter housing RP - P - Plastic ring for above	SS 316 ss ring PVC PVC coated ring R reverse collar TN triple needle seam A adapter head AUTO inside seams CH cotton handle L loops

Table E-4. Vendor B Bag Media And Micron Rating

		Micron Range											
Fiber	Material	1	3	5	10	15	25	35	50	65	75	90	100
Polyester/cotton	Felt	x	x										
Polyester	Felt	x	x	x	x	x	x		x		x		x
Rayon-Viscose	Felt		x	x	x		x						
Nylon	Felt			x	x		x		x				x
Polypropylene	Felt	x	x	x	x		x		x				x
Teflon	Felt				x		x		x				
Nylon (Nomex)	Felt			x	x		x		x				x
Polypropylene	Micro-Fiber		x		x		x						
Nylon	Multifilament Mesh												x
Nylon	Monofilament Mesh			x	x		x	x	x	x	x	x	x
Polypropylene	Monofilament Mesh												
Polyester	Multifilament Mesh										x		x
Polyester	Monofilament Mesh			x	x		x		x		x		x
Saran	Monofilament Mesh												

Table E-4(cont'd). Vendor B Bag Media And Micron Ratings

		Micron Ratings											
Fiber	Material	125	150	175	200	250	300	400	600	700	800	1200	1500
Polyester/cotton	Felt												
Polyester	Felt				x								
Rayon-Viscose	Felt												
Nylon	Felt												
Polypropylene	Felt												
Teflon	Felt												
Nylon (Nomex)	Felt												
Polypropylene	Micro-Fiber												
Nylon	Multifilament Mesh		x								x		
Nylon	Monofilament Mesh	x	x	x	x	x	x	x	x		x		
Polypropylene	Monofilament Mesh					x	x	x	x		x		
Polyester	Multifilament Mesh	x	x		x	x		x	x		x	x	x
Polyester	Monofilament Mesh		x		x	x		x	x		x		
Saran	Monofilament Mesh						x		x		x		

Table E-5. Comparative Particle Size Vendor B

U.S. Mesh	Inches	Microns
10	0.0787	2000
12	0.0661	1680
14	0.0555	1410
16	0.0489	1190
18	0.0394	1000
20	0.0331	341
25	0.0280	707
30	0.0232	595
35	0.0197	500
40	0.0165	420
45	0.0138	354
50	0.0117	297
60	0.0098	250
70	0.0083	210
80	0.0070	177
100	0.0059	149
120	0.0049	125
140	0.0041	105
170	0.0035	88
200	0.0029	74
230	0.0024	63
270	0.0021	53
325	0.0017	44
400	0.0015	37

Table E-6. Filter Bag Data Vendor B

Bag size Number	1	2	3	4	5	6
Surface area per bag ft^2/m^2	2.0/0.19	4.4/.41	0.5/.05	1.0/.09	5.0/.46	2.5/.23
Volume Per Bag gal./liter	2.1/.19	4.6/17.3	0.37/1.4	0.67/2.5	5.3/20.1	2.5/9.3
Bag Diameter in./cm	7/17.8	7/17.8	4/10.2	4/10.2	7/17.8	7/17.8
Bag Length in./cm	16.5/41.9	32/81.3	9/22.9	15/38.1	32.5/82.6	15.75/40.0
FSI Filter Model Number	FSP-40 FS-40	FSP-85 FSP-250 and all multi-hole vessels	FSP-20 FS-20	FSP-35 FS-35	FS-90PVC	FS-50PVC

Table E-7. Vendor B - Standard Vessel Models.

Model No.	No. of Bags	Bag Size No.	Surface Area Per Bag (ft^2)	Surface Area per Filter (ft^2)	Inlet & Outlet Size (in.)	Max. Flow Rate (gpm)*
B-1	1	3	0.5	0.5	1	25
B-2	1	4	1.0	1.0	1	45
B-3	1	1	2.0	2.0	2	90
B-4	1	2	4.4	4.4	2	200
B-5	2	2	4.4	8.8	3-4	400
B-6	3	2	4.4	13.2	3-6	600
B-7	4	2	4.4	17.6	4-6	800
B-8	5	2	4.4	22.0	4-8	1000
B-9	6	2	4.4	26.4	4-8	1200
B-10	7	2	4.4	30.8	6-8	1400
B-11	8	2	4.4	35.2	8-10	1600
B-12	10	2	4.4	44.0	8-10	2000
B-13	12	2	4.4	52.8	8-10	2400
B-14	14	2	4.4	61.6	10-12	2800
B-15	16	2	4.4	70.4	10-12	3200
B-16	18	2	4.4	79.2	10-14	3600
B-17	20	2	4.4	88.0	10-14	4000
B-18	22	2	4.4	96.8	10-14	4400
B-19	24	2	4.4	105.6	10-14	4800

*Note: The maximum flow rate column is the maximum flow rate recommended through the vessel without filter bags installed using water as a base. Any increase in fluid viscosity, or the Installation of filter bags, will reduce the max. gpm figures significantly.

Figure E-1. Vendor B Single Bag Filter Vessels

SPECIFICATIONS

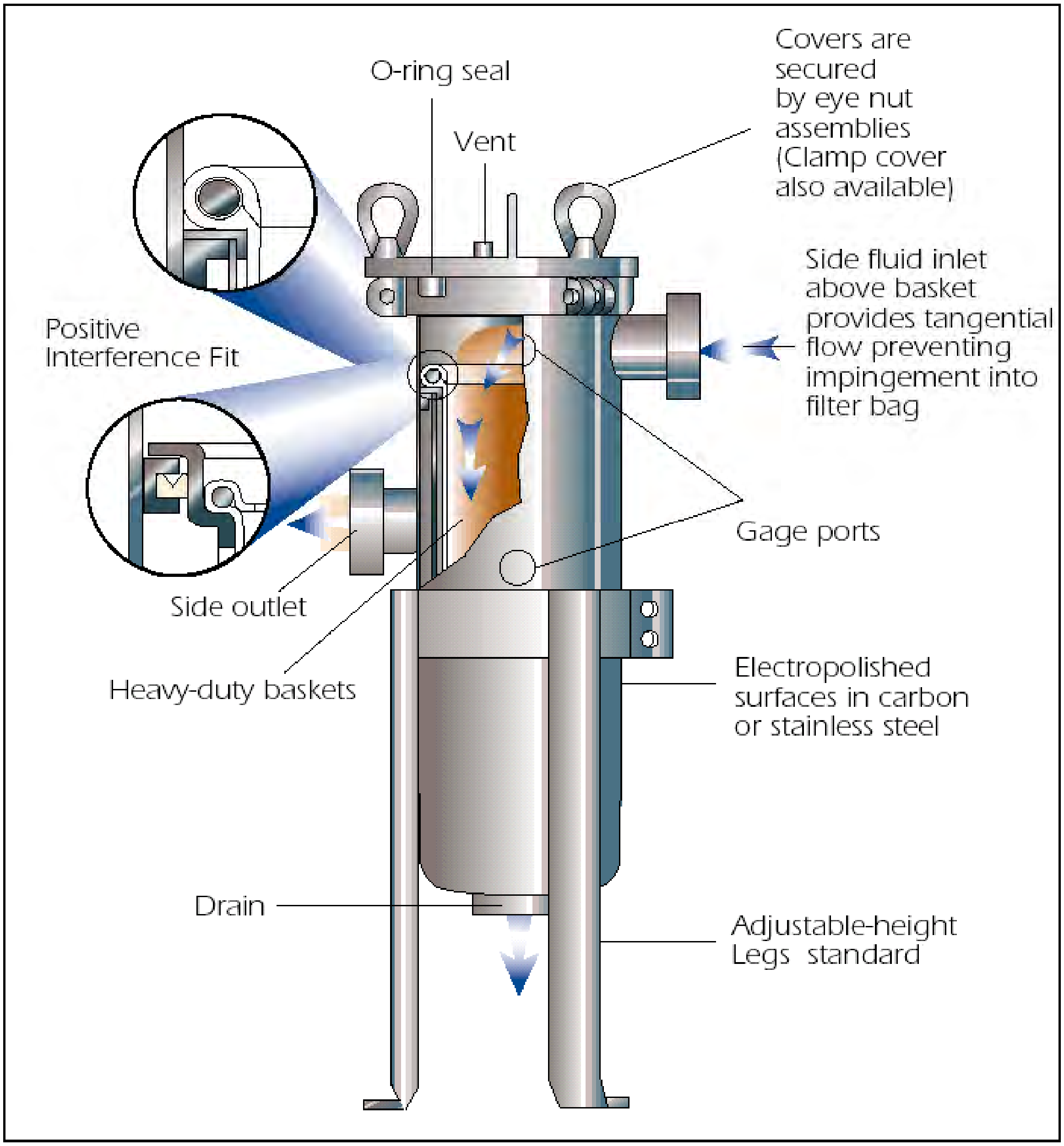
Model No.	No. of Filter bags	Bag Size No.	Surface area per bag, ft.^{2}	Surface area per filter, ft.^{2}	Inlet and Outlet Size	Max. flow rate, gpm
1	1	1	2.0	2.0	1–4 in.	90
2	1	2	4.4	4.4	1 –4 in.	200

- Standard 2-in. inlet and outlet.
- Specific locations and sizes up to 4 in. available on request.
- Four standard styles.
- Stock vessels available in:
  1. Carbon steel.
  2. 304 stainless steel.
- 316 stainless steel and electrolytic nickel plated carbon steel vessels available on request.
- Standard 150 or 300 PSI ASME code stamp (meets OSHA requirements) or customer specification.
- Filter bags available rated 1 to 1500 microns.
- Gasket materials include Buna N, Neoprene, EPR, Viton, Teflon.

ADDITIONAL FEATURES

- Single gasket seal.
- Positive bag sealing.
- Heavy-duty baskets (standard).
- Can be supplied with steam jackets, extra-length legs and corrosion allowance.
- Mesh lined baskets available for straining applications.

Figure E-2. Typical Single Bag Filter



APPENDIX F

GLOSSARY

The terminology used in describing filtration systems is not always consistent. Different manufacturers and filtration professionals may use the same term to describe different concepts and filtration functions. When discussing a particular application with different equipment manufacturers, the design professional should verify that the terms being used have the intended meaning. Terms used in this design guide and the filter industry include:

Adsorption—The process of transferring a substance from a liquid to the surface of a solid where it is bound by chemical or physical forces. (See DG 1110-1-2 Adsorption Design Guide.)

Backwash—A high-rate reversal of flow for the purpose of cleaning or removing solids from a filter bed or screening medium.

Bed volume—The volume occupied by filter media in a filter.

Capacity refers to a filtration system's ability to perform at acceptable levels until it is economical to end the filtration cycle and remove the accumulated solids. *Capacity* can be expressed as units of time, volume of liquid fed, or solids collected before terminating the cycle.

Coagulation—The destabilization and initial aggregation of finely divided suspended solids by the addition of a polyelectrolyte or a biological process. (See EM 1110-1-4012 Precipitation/Coagulation/Flocculation)

Effluent—Partially or completely treated water or wastewater flowing out of a basin or treatment plant.

Filter, as a technical term can be used as a verb or as a noun. As a verb it means to pass a mixture of particles suspended in a fluid through a permeable medium. As a noun, *filter* refers to equipment or hardware (e.g., the canister or vessel that holds the filter medium or directs the liquid flow through the medium). *Filter* does not refer to the medium itself. Instead the medium may be referred to as the *filter medium*, the *filter fabric*, the *filter cloth*, etc. *Filtration system* may be used to refer to the totality of the equipment, hardware, structure, permeable medium, piping, controls, etc., encompassing the filtration process.

Filter aid is a material added to the filtration process to prolong the useful life, or capacity, or improve the retention of the filtration system. It is often added as a precoat either with the influent liquid or with a pre-applied clear liquid where it deposits on the filter medium or the septum to then act as a filter medium collecting finer sized particles in the influent liquid.

Filter press—A dewatering device where water is forced from the sludge under high pressure. (See ETL 1110-3-457 Plate and Frame Filter Press).

Filtrate—The liquid that passes through the filter medium.

Filtration Costs refer to the totality of costs associated with one filtration treatment option over another. These costs include capital costs for equipment and design, including the cost of floor space and equipment housing. Filtration costs also include operating costs such as power, labor, maintenance and the costs associated with solids disposal. The designer should be careful to include all costs associated with installing and operating a filtration system when comparing solids removal options.

Filtration rate means a measurement of the volume of water applied to a filter per unit of surface area in a stated period of time.

Head loss is the difference in water level between the upstream and downstream sides of a treatment process attributed to friction losses. Sometimes called pressure drop.

HTRW means hazardous, toxic and radioactive waste, which is intended to include everything from petroleum contaminated soils and groundwater, to RCRA hazardous wastes, to munitions waste and unexploded ordinance (UXO), to radioactive wastes. It does not usually include domestic wastes or sanitary wastewater. However, HTRW can become mixed with sanitary waste, in which case the filtration systems described in this Design Guide can lend themselves to those applications as well. Code of Federal Regulations Title 40 PART 261- Sec. 261.3 (40 CFR 261.3) defines hazardous and toxic waste. Radioactive waste is any waste material that spontaneously emits measurable quantities of ionizing radiation.

Influent means water or wastewater flowing into a basin or treatment plant.

Launder means a trough used to transport water.

Micron means one millionth of a meter. Another term meaning the same thing is a micrometer. These terms will often be used to describe either particle size in a particular waste stream or the filtering capabilities of a filter cartridge. The smaller the size, however, the less likely the described particle or medium is to be uniform with respect to the dimension quoted and the harder it is to accurately measure that particle or pore size. Therefore, when someone refers to a 5 micron particle, or a 5 micron cartridge, it is important to verify what exactly that dimension is intended to convey, how it was measured, and whether it is given as an absolute or nominal dimension.

Permeability is a measure of a liquid flow rate through a filter medium or a filtration system. When manufacturers refer to a rated permeability they are often referring to the permeability of that medium tested under laboratory conditions. The permeability of a filtration system will not only vary under actual field conditions but will also change over time during the filtration cycle as solids collect on the filter medium. Some manufacturers may incorrectly report permeability as porosity.

Porosity is, strictly speaking, how much of a specific material is comprised of void space. It is the ratio of the non-solid volume to the total volume of a material. However, among filtration professionals, porosity may be used to describe the filter medium's retention. For example, a cartridge may be described by its manufacturer as having a porosity of 5 microns when what they mean to say is that the filter will retain some percentage (e.g., 90% or 95%) of particles 5 microns or larger. Other manufacturers may be used porosity when the correct term is permeability. For example, a certain filter fabric may be described as having a porosity of 10 cubic feet per minute at a certain pressure drop. The designer should be aware, therefore, that whenever porosity is being discussed in terms other than as a percentage or as a ratio, it is likely that some property other than porosity is being described.

Retention is a measure of the efficiency of removal. It describes how much of what sized particle is removed. For example a manufacturer may refer to the retention of a filter being 95% of particles 5 microns and larger. As with permeability, these numbers are generally derived in the laboratory and may vary with application and over the cycle life of a filter during operation.

Septum is used to describe either the filter medium on which a filter aid collects as a precoat or as the actual interface between the flowing liquid and the stationary particles. In this Design Guide *septum* will be used to describe the filter medium on which the filter aid collects or the filter cake forms as it becomes the filter medium. Often the *septum* will be a rigid medium, such as a wire mesh, whose purpose is not so much to act as a filter medium as it is to act as a structure on which the filter medium can form.

Suspended solids—(SS) milligrams of dry solids per liter of solution captured by a standard glass-fiber filter. Determined by Method 2540 D AWWA, 1998.

Total dissolved solids (TDS) is the weight per unit volume of all volatile and non-volatile solids dissolved in a water or wastewater after a sample has been filtered to remove colloidal and suspended solids.

Total solids (TS) is the sum of dissolved and suspended solids in a water or wastewater. Matter remaining as residue upon evaporation at 103 to 105 degrees C.

Total suspended solids (TSS) is the measure of particulate matter suspended in a sample of water or wastewater. After filtering a sample of a known volume through a glass wool mat or 0.45-micron filter membrane, the filter is dried and weighed to determine the residue retained. (EPA Test Method 160.2)

Turbidity means a qualitative measurement of water clarity that results from suspended matter that scatters or otherwise interferes with the passage of light through the water.

Ultrafiltration (UF) means a low pressure, 200-700 kPa (20-100 psi), membrane filtration process that separates solutes in the 20 to 1000 angstrom (up to 0.1 micron) size range.

Underdrain—Flow collection and backwash water distribution system used to support the filter bed in most granular media filters. Also called filter bottom.

Weir means a baffle over which water flows. Used for flow control.

Weir overflow rate means a measurement of the volume of water flowing over each unit length of weir per day.

APPENDIX G

ABBREVIATION AND ACRONYMS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CPVC	chlorinated polyvinyl chloride
DG	Design Guide
DOE	double open ended
EM	Engineer Manual
ES	effective size
ETL	Engineer Technical Letter
EPR	ethylene propylene rubber
FS	feasibility study
FTW	filter to waste
gpm/ft^2	gallons per minute per square foot
gpm	gallons per minute
HTRW	Hazardous, Toxic, and Radioactive Waste
HQUSACE	Headquarters, United States Army Corps of Engineers
HQ	headquarters
L/s	liters per second
MGD	million gallons per day
mg/L	milligrams per liter
MLD	million liters per day
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
O&M	operation & maintenance
psi	pounds per square inch
psid	pounds per square inch differential pressure
PVC	polyvinyl chloride
PVD	polyvinylidine
RCRA	Resource Conservation and Recovery Act
SOE	single open ended
TM	Technical Manual
TSS	total suspended solids
U. C.	uniformity coefficient
UIC	underground injection control
USACE	United States Army Corps of Engineers