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MANUAL OF WATER SUPPLY PRACTICES

# Precoat Filtration

AWWA M30

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# Foreword

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# Contents

**Foreword, iv**

**Chapter 1 Description and Applications** . . . . . . . . . . . . . . . . 1
- Description, 1
- Applications, 4
- Economic Considerations, 6

**Chapter 2 Filter Design** . . . . . . . . . . . . . . . . . . . . . . . . . 10
- Filter-Vessel Design, 10
- Filter-Element Design, 13
- Filter-Septum Design, 14
- Filtration Rate, 15
- Hydraulics, 15
- Design Capacity, 15

**Chapter 3 Filter Media** . . . . . . . . . . . . . . . . . . . . . . . . . 17
- Media Types and Grades, 17
- Precoating, 18
- Body Feed, 20
- Filter-Media Storage, 21

**Chapter 4 Spent-Cake Removal and Waste Handling** . . . . . . . . . . 22
- Spent-Cake Removal, 22
- Sludge and Waste Handling, 23

**Chapter 5 Auxiliary Equipment and Safety** . . . . . . . . . . . . . . 25
- Auxiliary Equipment, 25
- Safety, 26

**Chapter 6 Control and Instrumentation** . . . . . . . . . . . . . . . . 28
- Control, 28
- Instrumentation, 29
- Emergency Controls, 30

**Chapter 7 Operation** . . . . . . . . . . . . . . . . . . . . . . . . . . 31
- Operating Adjustments, 31
- Maintenance, 31
- Record Keeping, 32

**Glossary, 33**

**References, 35**

**Index, 36**

# Chapter 1

# Description and Applications

This manual provides general guidelines for the use of precoat filtration, commonly called diatomaceous-earth (DE) filtration, in potable-water treatment. The evaluation of appropriate applications for precoat filtration and the design of filtration units to economically serve those applications are covered in some depth, and an overview of operating practices is presented.

In this chapter, the basic operating principles of a precoat filter are described, followed by a guide to evaluating situations in which such a filter would be appropriate and a discussion of additional treatment processes that might be required. As a preface to the design and operation information in the remainder of the manual, the chapter concludes with a list of factors to consider for optimum economy in the design and operation of a precoat-filtration installation.

## DESCRIPTION

In precoat filtration, unclarified, turbid water is passed through a uniform layer of filtering material (filter media) that has been deposited (precoated) on a septum, a permeable material that supports the filter media. The septum is supported by a rigid structure called a filter element. As the water passes through the filter media and septum, insoluble particles of the semicolloidal size and larger are captured and removed.

The majority of the particles removed by the filter are trapped at the surface of the filter-media layer, with some being trapped within the layer. As the filter run proceeds, additional filter media, called body feed, is regularly metered into the influent water flow in proportion to the solids being removed. Without the regular addition of filter media as body feed, the head loss across the precoat layer would increase rapidly. Instead, the semicolloidal particles intermingle with the body-feed particles so that permeability of the cake is maintained as the thickness of the cake gradually

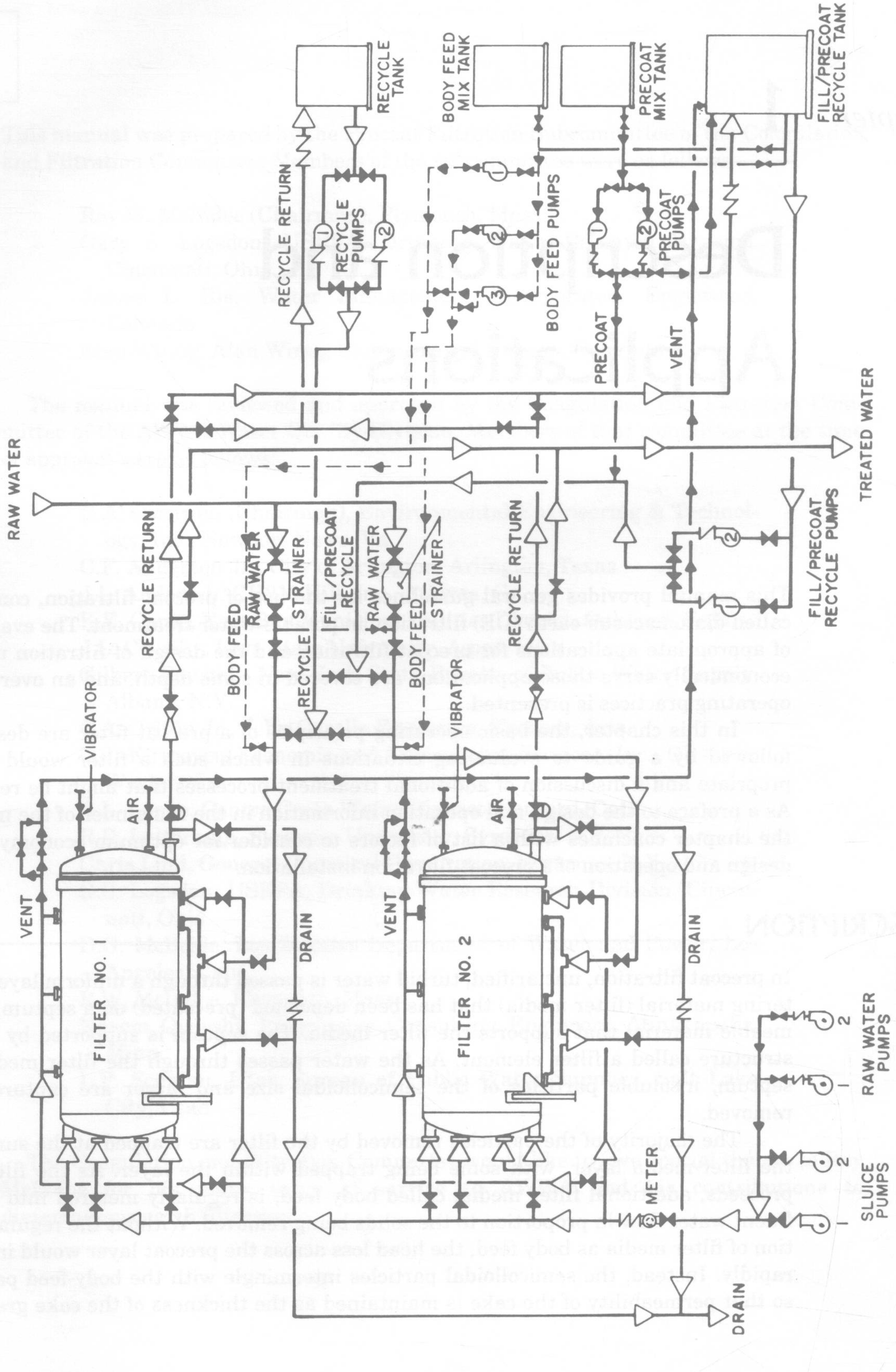



Figure 1-1 Schematic of filtration process.

increases. By maintaining cake permeability in this way, the length of the filter cycle is extended.

Ultimately, a gradually increasing pressure drop through the filter system reaches a point where continued filtration is impractical. The filtration process is stopped, the filter media and collected turbidity are washed off the septum, a new precoat of filter media is applied, and filtration continues. A typical flow schematic is shown in Figure 1-1.

The basic function performed by all water filters is to remove particulate matter from the water. Precoat filters accomplish this by physically straining the solids out of the water. Normally there is no chemical reaction involved in the process, unless a soluble contaminant must be precipitated prior to filtration. The thickness of the initial layer or precoat of filter media is normally $^1/_{16} - ^1/_8$ in., and the water passageways through this layer are so small and numerous that even very fine particles are retained.

There are five or six commonly used grades of filter media (sometimes called filter aid) available. They offer a range of performance with respect to clarity and flow characteristics. With an appropriate selection from among these grades, a large amount of particles as small as 1 μm can be removed by the precoat-filter cake. This includes most surface-water impurities. However, where colloidal matter or other finely dispersed particles are present, filtration alone may not be adequate to reduce turbidity to the required 1-NTU limit.[1]

Generally speaking, precoat filtration is most cost-effective, as is granular direct filtration, when raw-water turbidity is moderate to low (10 NTUs or less). Higher turbidity may be handled economically depending on the concentration of the solids to be removed and their physical characteristics. The next major section of this chapter discusses appropriate applications for precoat filtration in greater detail.

## History

Since 1949, more than 170 potable-water treatment plants utilizing precoat filtration with DE or other filter media have been designed, constructed, and operated. The largest existing plant is the 20-mgd San Gabriel, Calif., plant.

## Economic Benefits

Where the raw-water source and other conditions are suitable, precoat filtration can offer a number of economic benefits to the user, including the following:

- Capital cost savings may be possible because of smaller land and building requirements (Figure 1-2).
- Treatment costs may be 40–60 percent less than conventional coagulation/sedimentation/granular-media filtration when filterable solids are low.[2,3,4]
- The process is entirely a physical/mechanical operation and does not require operator expertise in water chemistry relating to coagulation. The use of chemicals, such as aluminum sulfate, iron salts, and polymers, in the manner associated with granular-media filtration, is not necessary.
- The volume of filtered water used for cleaning the filter is less than that with granular-media filtration. Normally, less than 1 percent total product water is required.
- Diatomaceous earth filter media is easily dewatered and, in some cases, the media may be reclaimed for other uses, including soil conditioning and land reclamation.

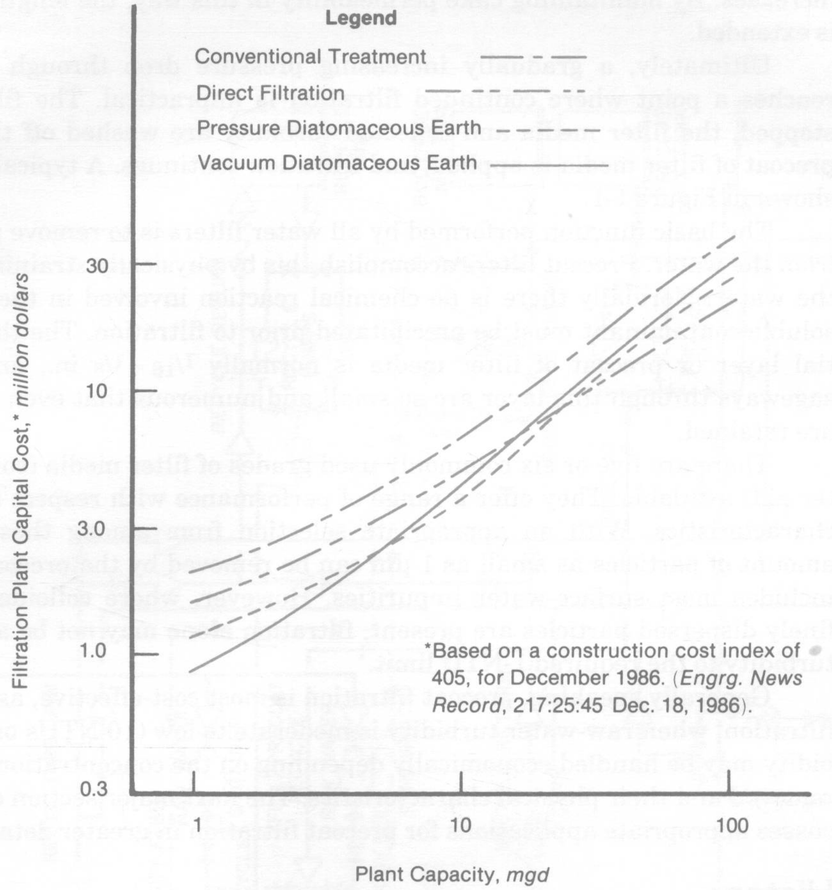



Figure 1-2 Filtration capital costs versus plant capacity for different filtration systems.

- Acceptable finished-water clarity is achieved as soon as precoating is complete and filtration starts. A filter-to-waste period is generally not necessary to bring turbidity of the finished water within acceptable limits.

# APPLICATIONS

The following discussion is intended to assist in determining when use of precoat filtration may be appropriate and in evaluating the equipment to be specified. Each proposed application should be examined to determine

- if the process reliably produces a satisfactory treated water, either with or without other treatment steps; and
- if the process is economically advantageous when compared with alternative types of treatment.

There are a number of factors that must be considered when selecting treatment and filtration processes to achieve effective and economical performance. Foremost among these are the quality of the raw water and the desired quality of the finished water. Raw-water qualities can vary widely, depending on their sources and types. Desired finished-water quality can also vary, depending on intended use and on what local contaminants must be removed.

## Raw-Water Quality and Source

As a general rule, raw waters that are relatively clean are good candidates for precoat filtration. Groundwaters and large surface-water impoundments that require only suspended-solids removal may be suitable for treatment by precoat filtration more economically than by conventional treatment.

**Turbidity**. In a workshop on filtration, disinfection, and microbial monitoring, the workshop participants proposed a definition, in part, of DE filtration as, "a filtration technique for relatively low turbidity waters, generally below 10 turbidity units [NTUs]."[5] The proposed definitions by the workshop participants for slow-sand and direct filtration also referred to low-turbidity waters under 10 NTUs. A survey of direct-filtration practice, including precoat-filtration plants, indicated that 80 percent of the plants had an average raw-water turbidity of 5 NTUs or less. The maximum turbidity at 80 percent of the plants was 40 NTUs or less.[6]

The efficiency and economics of pretreating waters of higher than 10 NTUs to obtain a precoat-filter influent water with less than 10 NTUs should also be evaluated.

**Surface waters.** Surface raw-water sources must not only be evaluated on the basis of normal conditions that may prevail for most of the year, but should also be examined for the effect of increased suspended material on the filtration process during high-flow and runoff periods. Facilities for raw- and/or finished-water storage to provide adequate potable-water supply during adverse raw-water-quality periods may be needed. In general, when presettling of raw water at the plant site is required, some of the benefits of precoat filtration may be diminished by the increased capital and operating costs of the presettling facilities.

Many surface-water supplies, such as lakes or ponds, may have algae, color, or taste-and-odor problems that would generally require additional treatment in conjunction with precoat filtration. The use of a microstrainer before the precoat filter has been shown to be effective in removing microscopic material, including planktonic organisms and amorphous matter. This form of pretreatment has resulted in increased filtration-run length.[7]

Surface waters in some areas may also contain *Giardia lamblia* cysts, which the precoat-filtration treatment process is capable of removing. Where *Giardia* cysts are to be removed by precoat filters, a precoat layer of at least 1/8 in. is recommended.[1,8]

**Groundwater.** Groundwater supplies may require filtration to remove suspended material. In some cases, mineral impurities, such as soluble iron or manganese, require pretreatment prior to filtration to precipitate them from the raw water. The resulting precipitate can then be removed by the precoat filter. (See Supplementary Treatment Practices, later in this chapter.)

## Pilot Testing

The filterability of particulate matter is affected by both the amount and physical nature of the solids. Some particulates are nondeformable, discrete particles and do not often pose problems. Deformable particulates, however, tend to clog the media. While visual turbidity readings, weight measures of suspended solids, and other analytical measures, such as particle count and size distribution, may be helpful, they alone may not be sufficient indicators of whether precoat filtration could be applied successfully and economically. Where there is no prior practical experience, pilot testing on the water to be filtered is recommended before making a final judgment on process selection. Pilot testing of the precoat-filtration process on a given water involves the use of small-scale equipment similar in function and operation to the proposed full-size units. Pilot filters and ancillary supporting equipment are generally available from equipment manufacturers and producers of filter media. A pilot operation set up for the operating conditions required of a full-scale plant will help to determine process applicability, design criteria, and operating economics.[9]

## Supplementary Treatment

Additional treatment techniques can be used in conjunction with precoat filtration to ensure disinfection and to handle special problems, such as soluble iron and manganese, softening, color, taste, and odor.

**Disinfection**. Precoat filtration generally provides excellent clarification, and tests with the finest grades of filter media have given good to excellent removal of turbidity and coliform bacteria.[8,10] However, final disinfection with chlorine or other acceptable disinfectants must be provided, consistent with the multiple-barrier concept of public-health protection.

**Iron**. Iron can be precipitated from solution by mixing magnesite (MgO) with the raw water along with the body feed in a 10- to 15-min detention tank to provide sufficient reaction time. The resulting particulate matter is readily removed by the precoat filter. Iron could also be precipitated by preaeration or other oxidation methods with detention and then removed by the filter. Tests have shown that residual solids from the magnesite process are much easier to remove by filtration than are the aerated ferric oxide particles.[11,12] However, there may be cases where a combination of aeration and the magnesite process may be more cost-effective.

**Manganese**. When manganese alone is the principal contaminant to be removed, potassium permanganate may be used to oxidize and precipitate the manganese. In this case, a 5- to 10-min mixing/detention time is required ahead of the filter.[13]

**Iron and manganese**. Where iron and manganese are both present, there are several treatment options possible, depending on the relative levels of each that are present.[11,12,13,14]

**Hardness.** Where reduction of total hardness by lime and soda ash is required, residual calcium carbonate and magnesium hydroxide precipitate in the overflow effluent from the clarifiers has been shown to be removed with diatomite media.[15]

**Taste and odor**. Where taste and/or odor are problems, they may be handled by activated carbon in conjunction with precoat filtration. When preceding granular-carbon columns, the filters will reduce the particulate load on the carbon beds, preventing blinding and improving bed life. The filters may also be designed to incorporate powdered activated carbon along with the filter media as precoat and body feed, to achieve clarification and taste-and-odor removal within the filter.

# ECONOMIC CONSIDERATIONS

Once it has been determined that precoat filtration and appropriate supplementary processes can produce an acceptable finished water, several interrelated design factors must be considered in preparing design and specification documents. Because all these factors will influence the total capital and operating costs of the system, it is important to evaluate them individually and in relation to one another, so that the final design will provide water at the most economic cost.

The general economic considerations in the following paragraphs should be kept in mind when applying the more detailed design and operating guidelines that comprise the remainder of the manual.

## Design Factors

The following facts should be considered during the initial design of the precoat-filtration installation:

**Filtration rate.** The filtration rate is expressed as gallons per minute per square foot of septum area (gpm/ft$^2$) and is sometimes called surface-loading rate. The higher the design filtration rate allowed, the smaller the amount of filter surface area required to produce the total volume of water to satisfy the demand. Lower filter area will lower the initial capital cost; and with less filter area, less precoat material will be used for each filter cycle. On the other hand, higher filtration rates are generally accompanied by a more rapid rise in pressure loss through the filter during the filter cycle, resulting in shorter cycles with more frequent precoating.

**Terminal pressure differential.** The terminal pressure differential is defined as the maximum difference in pressure between the inlet pressure to the filter and the outlet pressure at the end of the filter cycle. The higher the terminal pressure differential, the longer the filter cycle, and the longer the precoat is used. Another way to express this is that the longer the filter cycle, the more finished water produced per pound of precoat material used. As a trade-off, however, there will be a higher power cost associated with the additional pumping pressure required for the higher terminal differential if inlet feed pumps are used.

**Grade of filter media.** The coarser the grade of media used that still produces acceptable water clarity, the longer the filter cycle generally obtained and, hence, the greater the volume of water produced per pound of filter media. This gain may be offset by the added cost of the coarser grades relative to the finer grades (Table 1-1).

Table 1-1 Effect of Pore Size on Flow Rate and Clarity

| Diatomite Grade | Average Particle Size | Median Pore Size μm | Flow Rate | Clarity |
|---|---|---|---|---|
| FINE | SMALLEST | 1.5 | LOWEST | HIGHEST |
| ↑ | ↑ | 2.5 | ↑ | ↑ |
| | | 3.5 | | |
| | | 5.0 | | |
| | | 7.0 | | |
| | | 9.0 | | |
| | | 10.0 | | |
| ↓ | ↓ | 13.0 | ↓ | ↓ |
| | | 17.0 | | |
| COARSE | LARGEST | 22.0 | HIGHEST | LOWEST |

**Body-feed rate.** The body-feed rate is defined as the amount of media that is added to each gallon of raw water during filtration to ensure that the filter cake remains porous to water flow. In general, the higher the body-feed rate, the more porous the cake, resulting in longer filter cycles. In some cases, however, excessive amounts of body feed can introduce additional resistance to flow, due to cake thickness, and shorten the cycle. It is important to analyze body-feed rate in relation to filter-run length to see whether an extra body-feed amount more than offsets the

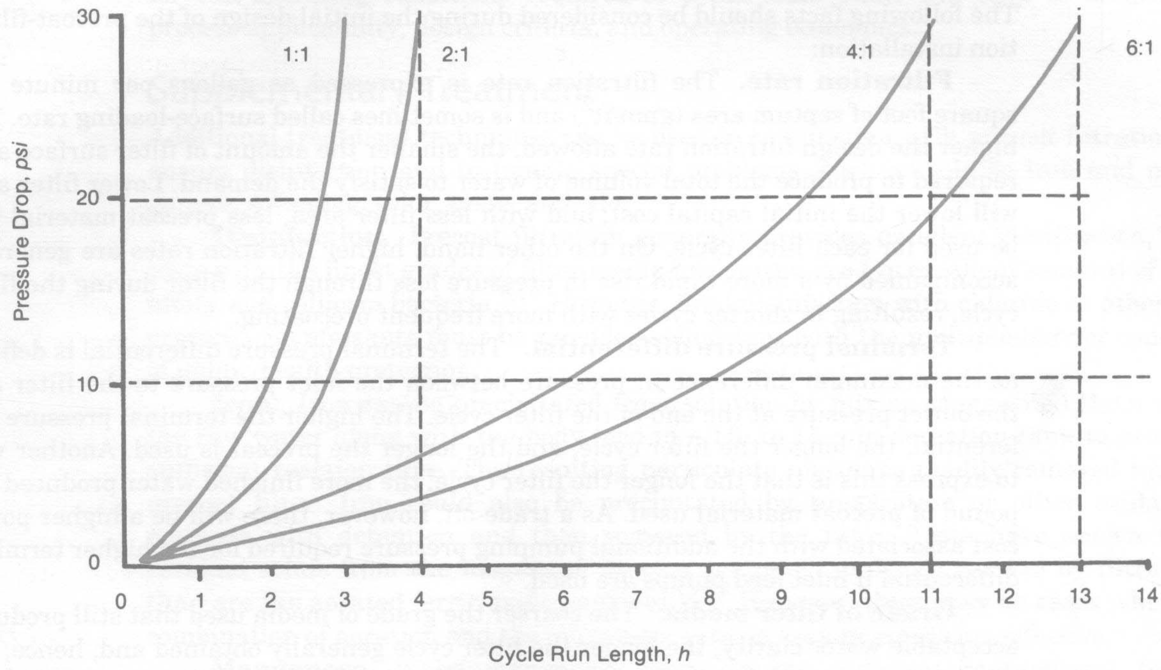
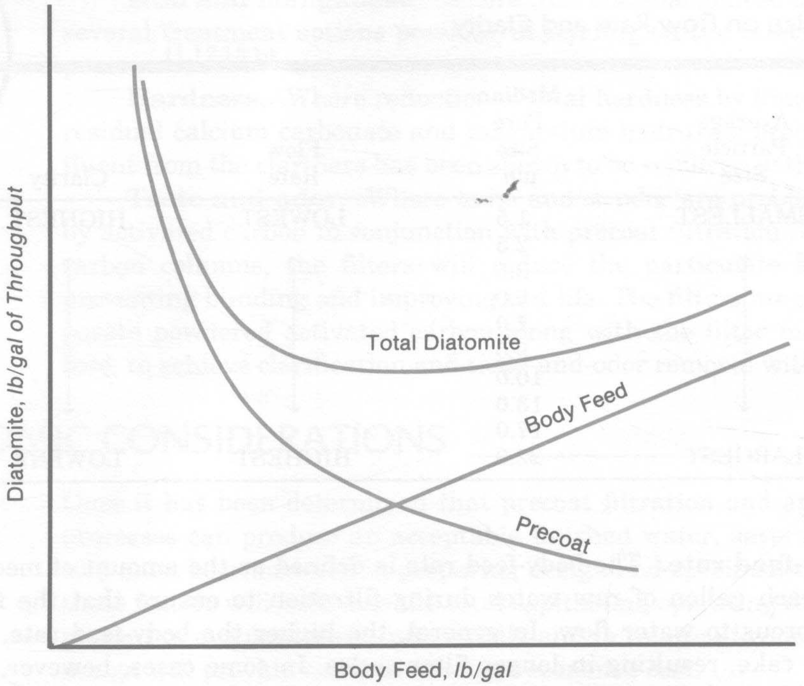



**Figure 1-3** Cycle run length as a function of body feed for DE plants.




Note: Relationship is typical. Exact figures will vary from water source to water source.

**Figure 1-4** Effect of body feed on total diatomite usage.

prorated cost of precoat material initially applied. Table 1-1 and Figures 1-3 and 1-4 depict typical interrelationships of these factors.

Extensive work on development of mathematical models for predicting head loss as a function of filtration rate, water viscosity, septum shape, and body-feed usage has been done.[16,17] Subsequent work resulted in a computer program that assists in the design of new plants and the optimization of operation of new and existing plants.[18]

## Operating Costs

Once facilities are in place, the major variables affecting operating costs are filter media and pumping requirements.

**Filter-media and pumping costs**. The target objective of the operating plant is to deliver the maximum volume of finished water to the distribution system at the lowest combination of filter-media and pumping costs. Even though pilot tests may have been run, a series of simple tests conducted with the full-scale plant equipment will be helpful in establishing optimum operating routines. Under controlled conditions, the flow rate and body-feed rate should be varied and the resulting effect on pressure rise, filter-run length, and clarity noted. Filter-media usage, including both precoat and body feed, should be carefully observed and analyzed for the lowest-cost compromise of all factors. These factors must be interrelated with the influent raw-water quality to accommodate any seasonal variations.

**Materials-handling costs**. In addition to the media and power costs associated with filtration, there are the added costs in receiving and storing filter media, moving material into the process stream, and finally the costs of dealing with and disposing of the waste slurries of water and filter media.

# Chapter 2

# Filter Design

In designing precoat-filtration systems, decisions must be made concerning the type of filter to be used (pressure or vacuum), the design of the filter element and septum, the filtration rate, and the hydraulics of the system. Each of these areas is important in ensuring effective, economical operation.

## FILTER-VESSEL DESIGN

As shown in Figures 2-1 and 2-2, there are two basic types of precoat filters: vacuum and pressure. In designing the precoat-filter vessel, the first decision to be made is whether the filter will be of the pressure or vacuum type. The construction features of the vessel can then be specified.

### Vacuum Filters

In vacuum filters, the vessel containing the filter elements and their septa is an open tank at atmospheric pressure. A filter discharge pump or a vacuum discharge leg downstream of the filter creates a suction. This suction enables the available atmospheric pressure to move water through the precoat and filter-media cake as the cake builds up. The open filter tanks permit easy observation of the condition of the septa and elements and general condition of the filter during filtration and cleaning.

In vacuum filters, the maximum available differential pressure across the filter is limited to the net positive suction head of the filter pump or the vacuum leg. This limitation influences the length of filter cycles. When a vacuum filter is used, any pressure of water entering the plant must be dissipated; the pressure cannot be used for filter operation.

The effect of any entrained air or dissolved gases coming out of solution due to a decrease in pressure must also be considered with vacuum filters. Gas will have an adverse effect on the filter cake, tending to disrupt the integrity of the filter media on the septum. At any given time, the amount of gas coming out of solution is directly related to the dissolved-gas concentration, water temperature, and vacuum.

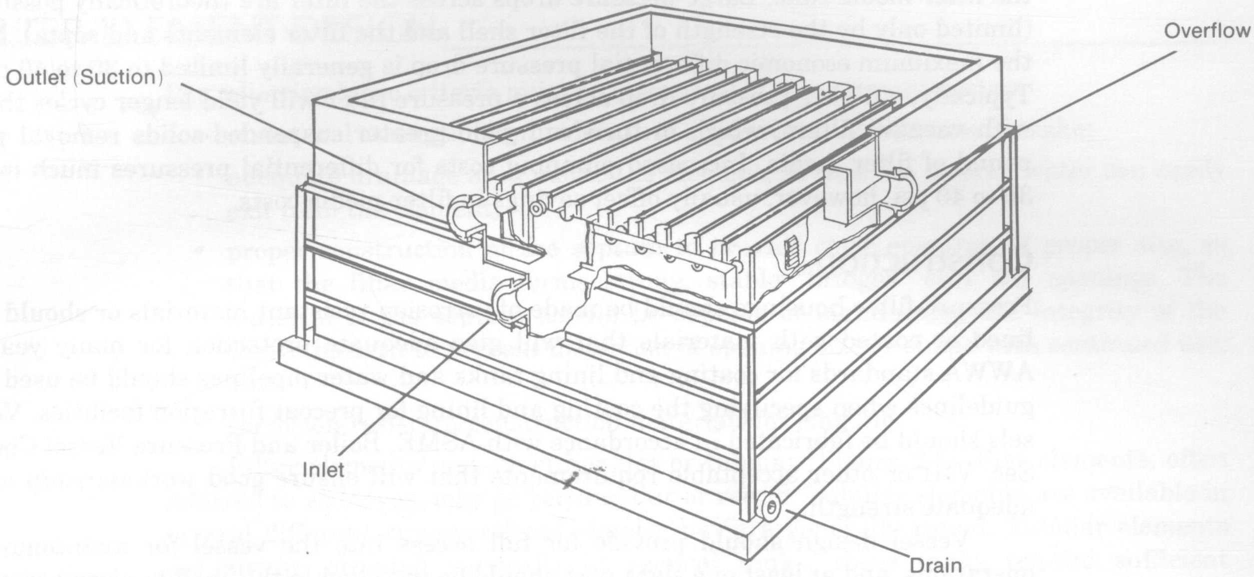



Figure 2-1 Vacuum leaf filter.

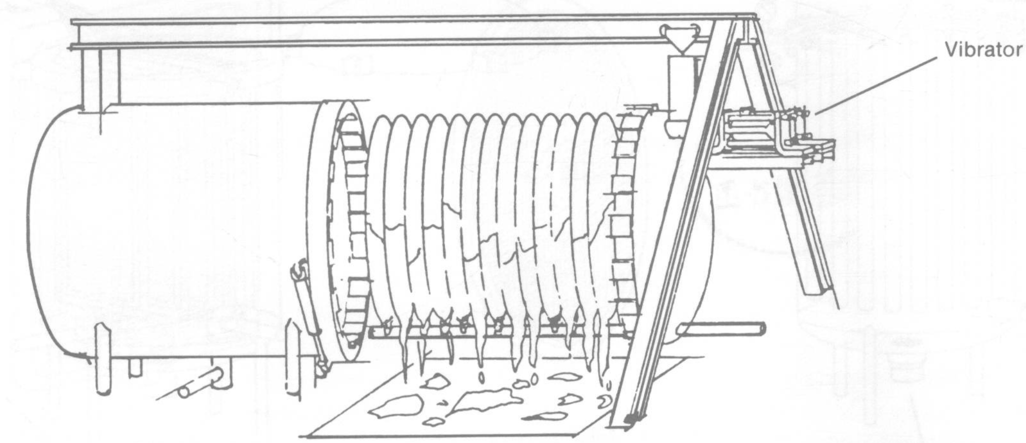



Figure 2-2 Horizontal-tank pressure leaf filter.

## Pressure Filters

In pressure filters, a filter feed pump or influent gravity flow produces higher-than-atmospheric pressure on the inlet (upstream) side of the filter, forcing liquid through the filter-media cake. Large pressure drops across the filter are theoretically possible (limited only by the strength of the filter shell and the filter elements and septa), but the maximum economic differential pressure drop is generally limited to 30 to 40 psi. Typically, a higher pressure drop across a pressure filter will yield longer cycles than with vacuum filters, which in turn will yield greater suspended-solids removal per pound of filter media. Increased pumping costs for differential pressures much over 30 to 40 psi, however, usually offset savings in filter-media costs.

## Construction

Pressure-filter housings should be made of corrosion-resistant materials or should be lined or coated with materials that will give adequate protection for many years. AWWA standards for coating and lining tanks and water pipelines should be used as guidelines when specifying the coating and lining for precoat filtration facilities. Vessels should be fabricated in accordance with ASME, Boiler and Pressure Vessel Code, Sec. VIII or other acceptable requirements that will ensure good workmanship and adequate strength.

Vessel design should provide for full access into the vessel for maintenance operations, and at least one sight port should be installed in the shell to permit visual observation of the filter during operation. Some pressure-filter vessels require bolt-circle disassembly to provide access for inspecting and maintaining the internal filter elements (Figure 2-3). Other filters are designed with quick-opening heads so that the filter can be opened within a few minutes to inspect the filter septa or to carry out maintenance functions (Figure 2-4).

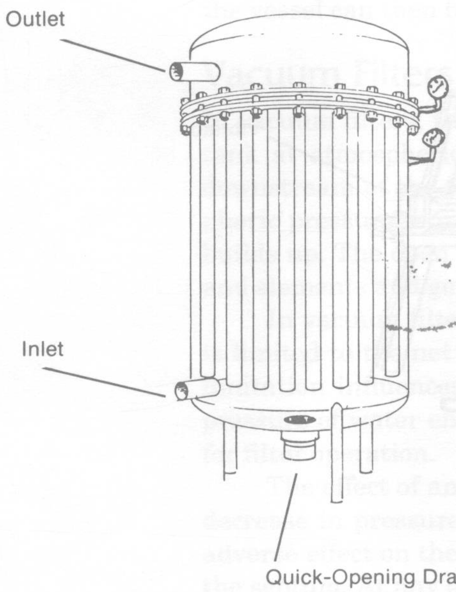



Figure 2-3 Pressure tubular filter.

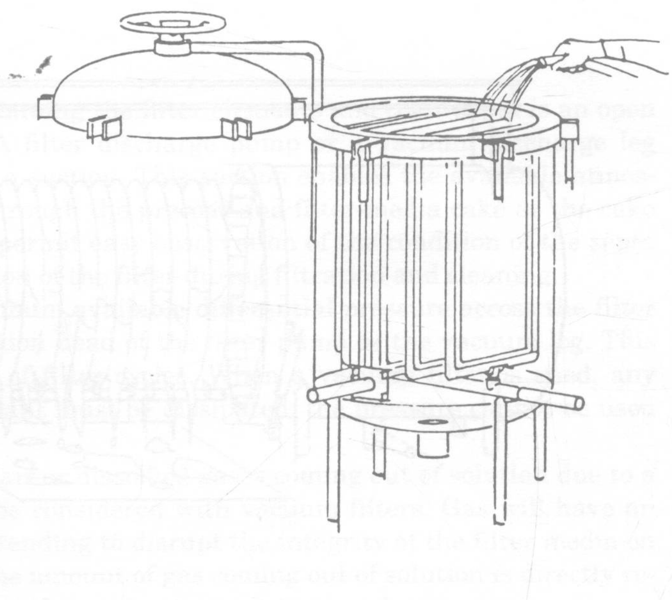


Figure 2-4 Vertical-tank pressure leaf filter.