coal layers assuming that the pretreatment process is also improved by the addition of a new flash mixer and high-energy flocculators.

Solution

Set the design conditions as follows

1. New filter bed is to be reverse-graded dual-media bed with sand and coal grains.
2. Provide 200 mm of sand layer with 0.43 mm effective size (AWWA Standard classification—see B100.2.1) and 1.3 uniformity coefficient in order to ensure a good quality filtrate and a reasonable length of filter run. Coal layer, therefore, has 450 mm depth. Larger-size sand media cannot be used because of the limited maximum backwash rate. A specific gravity of 2.65 is used for the sand media.
3. Assume that overall porosity of the total filter media is 0.475. By use of Figure 21-33, d_e = 0.68 mm (weighted average d_e for both sand and coal grains) from the point of intersection between L = 650 mm and f = 0.475. Effective size of coal grains, therefore, may be computed through weighted average computation as follows:

$$\frac{450d_e + 200 \times 0.43}{650} = 0.68$$

Therefore, d_e = 0.79 mm, say, 0.8 mm for the coal media. To determine the uniformity coefficient of anthracite (specific gravity = 1.60) from Figure 21-34, draw a horizontal line from 0.6 m/min wash rate, drop a vertical line from the intersection of the horizontal and the anthracite line of s.g. 1.60, and read the 60 percent weight particle size on the horizontal axis. With an effective size of 0.8 mm, a uniformity coefficient of 1.4 should be used.

EXAMPLE 21-4

Problem

Assume that an average particulate volume in a raw water is 60,000 nL/L and filtered water should contain an average of 100 nL of particulates per liter or less. Also, assume that a pilot filtration study concluded that media constant, η, is 0.005, and 1.2 mm effective-size coal is the most efficient filter media size from the viewpoint of filter efficiency and head loss development during filtration. Determine the filter bed depth for 1.2 mm effective-size anthracite coal filter bed.

Solution

The equation describing filter collection efficiency can be rewritten as follows:

$$\frac{L}{d} = \frac{1}{\eta} \ln \frac{C_0}{C_L}$$

Since the values of η, C_0, and C_L are known, L/d can be obtained easily.

$$\begin{aligned} L/d &= \frac{1}{0.005} \ln \frac{60{,}000}{100} \\ &= 1280 \end{aligned}$$

Thus, $L = 1.2 \times 1280 = 1536$ mm or 60 in. media depth.

Wash Troughs

There are two distinct types of filter backwash systems: fluidized bed backwash (which is the most common system in the United States), and partial fluidized backwash with air scour (which is commonly used in Europe). Partial fluidized bed backwash with air scour is typically employed in filters with no backwash troughs. A single overflow weir or side channel weirs provide for discharge of backwash waste.

Spacing and elevation of troughs for fluidized bed backwash systems should be carefully determined so that (1) dislodged suspended matter will be washed away efficiently and (2) filter media will not be carried out. As a rule of thumb, the height and spacing of troughs can be determined based on the filter configuration as shown in Figure 21-35 on the following criteria:

Height of trough: $(0.75L + P) < H_0 < (L + P)$

Spacing of trough: $1.5H_0 < S < 2H_0$

Wash troughs are generally of two basic types: those with a shallow but wide cross section and a slight V-shaped bottom and those with a U-shaped cross section. The wide section troughs result in a

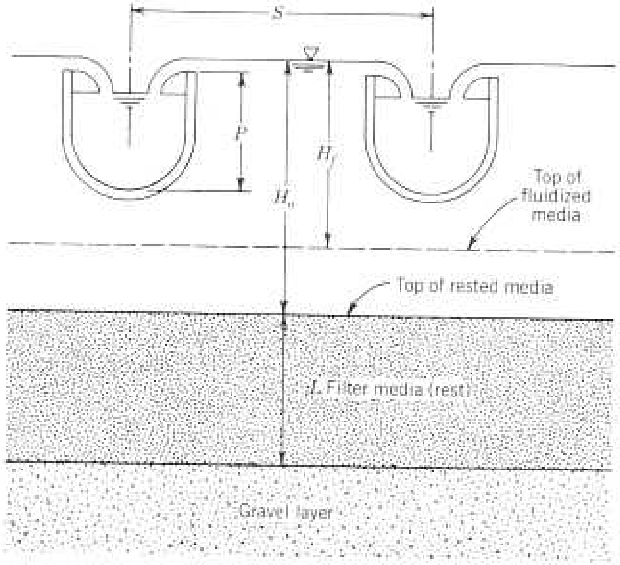

FIGURE 21-35. Height and spacing of wash troughs.

higher upflow velocity when flow gets above the trough bottom elevation and the U-shaped troughs allow for thinner walls because of a higher moment of inertia and greater structural integrity. The bottom of the wash trough should not be flat because froth and suspended matter is often trapped under the trough bottom and may never be washed out.

In either case, the troughs should be large enough to carry the maximum expected wash rate with 5–10 cm free-fall into the trough at the upper end. They should also provide a free-fall to the main collection outlet gullet at the lower end. The bottom of the trough may be either horizontal or sloping.

The required cross-sectional area of the wash trough for a given design flow can be quickly estimated from Figure 21-36. For troughs that have level inverts and rectangular cross section, required trough height can be computed by the following formula:

$$\text{Minimum trough height} = \left(\frac{Q}{1.4B}\right)^{2/3} + \text{free board}$$

where Q is the total flow rate of discharge (m^3/sec), B is the inside width of the trough (m), and, freeboard should be a minimum of 50 mm (2 in.).

Filter Underdrains

Filter underdrainage systems differ primarily due to the different filter-washing systems and filter types

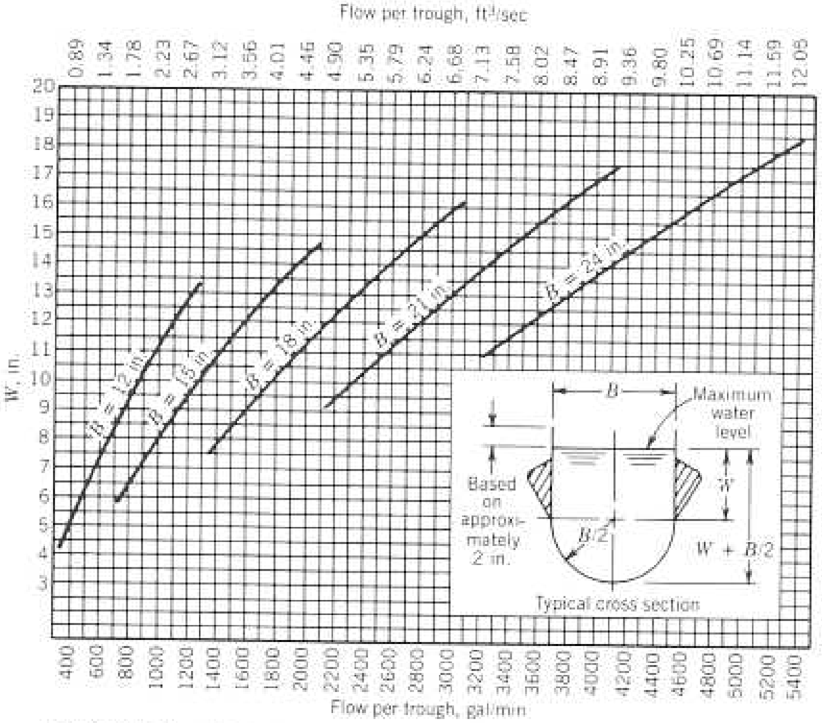

FIGURE 21-36. Wash-through sizing diagram. (Courtesy of Leopold Co.)

employed. For instance, small size filters, including steel plate fabricated filters, are usually equipped with a fixed-pipe grid-type underdrainage system because of simplicity and cost-effectiveness. Filters for most municipalities are usually large in size and a variety of underdrainage systems are used including false bottoms with strainers, underdrain blocks, precast concrete underdrains, teepee-type underdrains, and porous plates. For large filters, the uniform distribution of flow becomes the most important factor in selecting the type of underdrain. Individual designer preference based on experience with past installations is frequently a deciding factor. The majority of underdrains installed are of the proprietary, underdrain block-type due, perhaps, to the availability of a manufacturer's warranty for performance of the underdrain system. Pipe grid systems are seldom used in large filters despite the fact that they are cost-effective and easy to install. Their lack of use is perhaps attributable to the perception that fixed-grid pipe underdrainage systems are outdated and outmoded. Figure 21–37 shows examples of underdrains commonly used in water treatment facilities.

Selection of proper underdrain is also affected by the size and type of filter media as well as the type of filter wash system adopted. For air-scour washing filters, false bottoms with long leg strainers have been the most popular and accepted type of underdrainage system. However, debris remaining in pipes and conduits can clog the strainers from inside during backwash and filter underdrain can be loosened and lifted unless rather large slits are used in the strainers. A thin gravel layer may also be necessary to prevent media from clogging the strainer openings. Orifice sizing, spacing, and underdrain gravel layers depend on backwash rates, type of underdrain system used, media size, and hydraulic conditions.

Uniform backwash flow distribution, durability, and cost are the three most important factors in selecting filter underdrains. In order to achieve an even distribution of flow, (1) the orifice openings should be small enough to introduce a controlling loss of head and (2) the flow velocity in the pipe or channel in the underdrainage system should be reasonably low and uniform throughout the entire filter area.

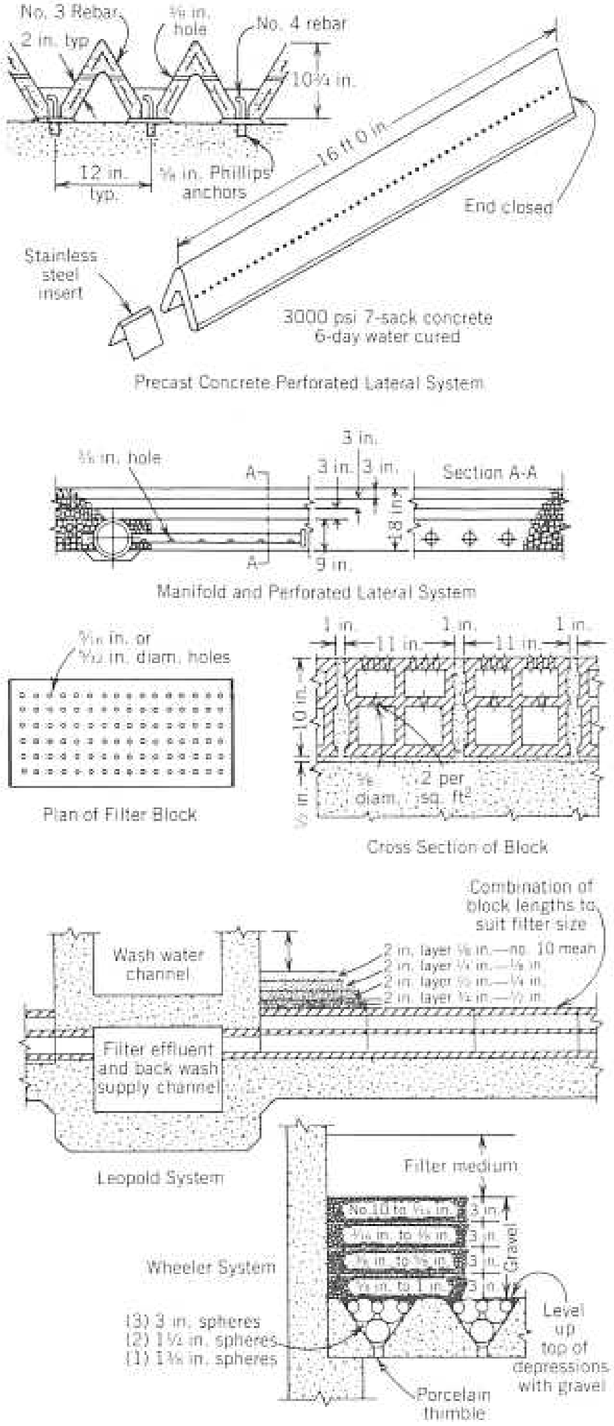

FIGURE 21-37. Filter underdrain systems.

Loss of head in the underdrainage system during backwash ranges from 0.1 to 3 m (0.3–10 ft) depending on the type of underdrain and backwash rates. For a false-bottom-type underdrain system, the required head loss could be small (0.1 m for some systems) because the unbalance of pressure underneath is self-compensating in the plenum if the inlet is properly designed. Perforated pipe grid systems and other perforated lateral systems without a plenum underneath usually require smaller orifices to create a controlling head loss of at least 0.6 m (2 ft).

The ratio of orifice area to bed area varies from 0.2 to 1.5 percent depending on the type of filter underdrain, backwash rate applied, and type of filters. Pipe grids with strainer type systems usually have a small orifice opening ratio (less than 0.5 percent), but false-bottom-type systems generally have a higher opening ratio (over 1 percent) without sacrificing a uniform distribution of flow. A few modern high-rate filters (especially for nondomestic use) apply up to a 900-m/d (15 gpm/ft^2) filtration rate. The underdrainage system for these filters should be a low-head-loss type or the excessive initial head loss in the filtration cycle will significantly reduce the available head for gravity filtration.

Filter Washing and Related Systems

Selection of the filter-washing system depends on the characteristics of the raw water, the type of filter selected, the size and material of the filter media, and the type of auxiliary media scouring selected for filter washing.

Most physical factors of filter design are related to the filter-washing process. The major factors include (1) the size and specific gravity of the media, (2) the type and arrangement of the filter underdrainage system, (3) the washwater trough design, (4) the size and elevation of the washwater tank (if necessary), (5) the wash rate control system, and (6) the type and capacity of auxiliary scour. Although numerous papers have discussed many variations of the filter-washing process, there are three basic types of washing systems: (1) complete fluidization of filter media by a high backwash rate with or without surface washing; (2) air-scouring wash with partial fluidization of the media by backwash; and (3) combinations of 1 and 2.

Although most water treatment plants provide more than 10 m (33 ft) of static head for backwash by elevated tanks, most filters only require 1.2–2 m (3.9–6.6 ft) static head at the filter bottom. More than 80 percent of the available head is dissipated by delivery piping, the throttling valve, and flow controller in order to ensure a relatively constant backwash rate.

In the case of low-head backwash systems, such as valveless or monovalve filters which utilize filtered water from other filters or from their own storage, a slight change in the available static head will affect the backwash rate quite significantly. For instance, a drop of 1 m (3 ft) water level in an elevated backwash tank results in about a 15 percent reduction of backwash rate for a conventional-type filtration plant without a flow controller, but the same condition will create almost a 75 percent reduction of the backwash rate for most low-head-type backwash filters.

Certain filters such as multicell-type pressure filters and automatic backwash gravity filters require

TABLE 21-12. Typical Design Criteria for Various Backwash Systems

	Fixed-Jet-Type Surface Wash	Rotary-Jet-Type Surface Wash	Air Scour Type
Pressure at discharge point			
kPa	100–200	420–680	28–50
kg/cm^2	1–2	4.2–6.8	0.28–0.5
psi	15–30	60–100	4–7
Flowrate			
Water			
m^3/m^2 · min	0.12–0.17	0.03–0.06	0
gpm/ft^2	2.9–4.1	0.7–1.5	0
Air			
m^3/m^2 · min	0	0	0.5–1.3
cfm/ft^2	0	0	1.5–3.5
Duration of washing, min	4–8	4–8	8–15
Backwash rate			
m^3/m^2 · min	0.55–1.0	0.55–1.0	0.25–0.70
gpm/ft^2	13.5–22.5	13.5–22.5	6–17