The ABC's of Filtration

by Philip C. Olsen and Peter S. Cartwright, P.E.

Since before recorded history, humans have employed filtration as a means of improving the appearance and potability of water. These early peoples discovered that sand, charcoal and even porous pottery jars improved the aesthetic appearance (and often the taste) of water containing visible particles, color, and perhaps offensive odors. Without completely understanding the science behind their approaches, early "water engineers" were utilizing bed filtration as a water treatment technology.

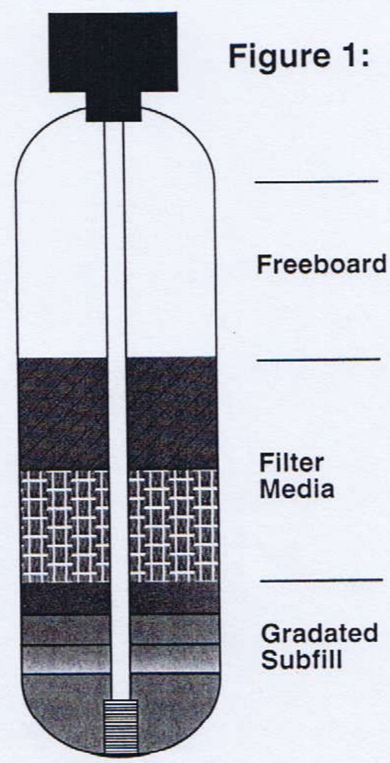
The WQA Glossary of Terms defines media as a "selected group of materials used in filters and filter devices to form barriers to the passage of certain solids or molecules which are suspended or dissolved in water. Media is a plural form of medium. When the medium is a granular material and is placed in a vessel, it becomes a bed of medium. Figure 1 illustrates a multimedia filter, which is a typical bed filter containing several media.

Typically, the line pressure in the water delivery system forces water through the various media from the top of the bed to the bottom, and from there into a distribution system which channels the filtered water into a discharge pipe and out of the filter. Other operational approaches are possible, such as gravity filters which allow the influent water to trickle down through the media under the force of gravity (typically used for large municipal filtration). Although bed filters can be used with special media to remove iron, manganese, chlorine and dissolved organic compounds, this article is devoted to the application of these filters to suspended solids removal only.

Filter Bed Construction

As most bed filters are designed to reduce turbidity (the suspended solids in a water supply), the selection of the particular media as well as the design and operation of the filter determine its overall effectiveness. Virtually all water supplies contain a soup of dissolved contaminants (organic, ionic and gaseous), as well as a myriad of suspended solids. These suspended solids vary in size, shape and chemical composition, ranging from very fine colloidal dispersions up to bits of debris, oxides or other contaminants visible to the naked eye (larger than 40 microns). The media are selected either to provide one or several layers of different porosities to segregate the suspended solids roughly by particle size or to provide a consistent gradation (coarse to fine) from top to bottom to achieve separation throughout the depth of the filter bed. The three methods of bed construction are referred to as single media, multimedia, and depth (see Figure 2).

Figure 1:



A typical bed filter containing several media is known as a multimedia filter.

Regardless of bed construction, 24" is considered the minimum bed depth required to achieve adequate performance. Filtration media typically includes such naturally occurring material as anthracite, garnet, and silica and quartz sand. These materials are crushed and sieved to provide filter grains within a range of sizes. Other important physical characteristics include the shape, surface smoothness and density.

Multimedia and depth filter bed designs will lengthen the service cycle of a filter relative to backwashing frequency. The actual length is largely dependent upon particle size disbursement of suspended solids and microbiological activity of the raw water.

Distribution System

A good distribution system provides an even flow across the horizontal plane of the filter bed. This prevents channeling of raw water through one area of the filter bed which will reduce both filter performance and service cycles between cycles. The distribution system also plays an important role in cleansing the bed during the backwash cycle. Inadequate design will prevent the circumference area of a filter bed from backwashing, eventually leading to solidification of media within this region (see Figure 3).

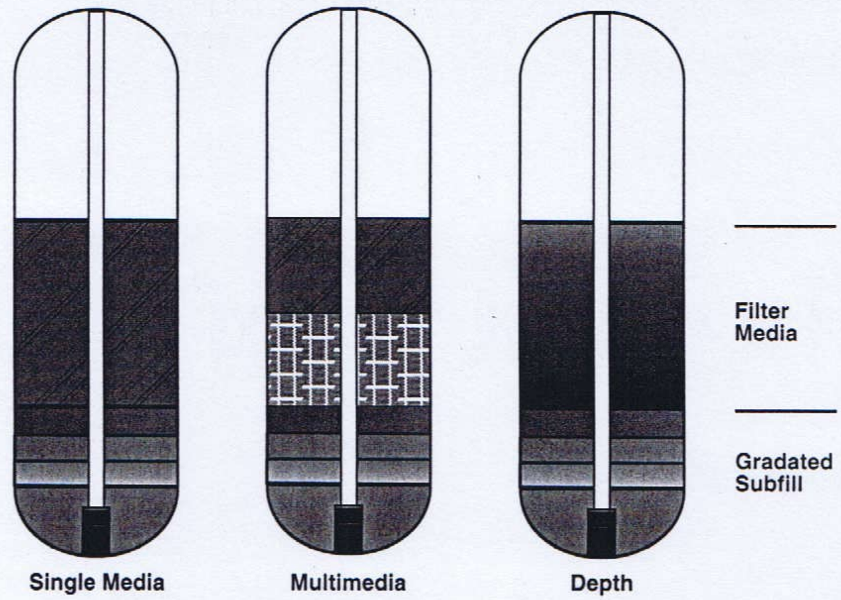


Figure 2: The three methods of bed construction are referred to as single media, multimedia and depth.

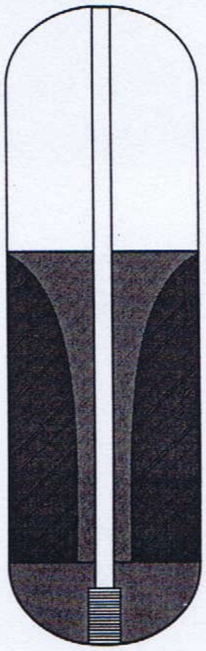
Distribution system design begins with a lower distributor. Several basic distributor designs are frequently used; manifold, hub and lateral, and basket (see Figure 4).

In residential installations, basket distributors are used exclusively due to the smaller diameter tanks required for such applications.

Around and above the distributor, gradated layers of washed gravel, quartz or garnet are placed to diffuse the direction of flow away from the distributor orifices and support the filter bed. This combination of layered, coarse media is generally referred to as subfill. A minimum of three layers should be used (fine to coarse) from top to bottom. The bottom layer should terminate one inch above the lower distributor and the second layer should extend up to the base of the sidewall of the filter vessel at a minimum depth of three inches above the second layer. Gradations of layers are primarily dependent upon mesh size of the filter media supported. A typical subfill load supporting a media bed of 45/55 mesh size material is shown in Figure 5.

Figure 3:

Inadequate design prevents the circumference area of a filter bed from backwashing, eventually leading to solidification of media within this region.



Control Valve Design

Control valve design is important to the process of filter bed construction. Incoming raw water must be offered as direct a route as possible to the filter bed. Each directional change provides an opportunity for oxides to accumulate and eventually inhibit flow. For this reason, it is important to be able to access the raw water side of the control valve for periodic cleaning.

For a basic filter only two cycles are required: backwash and fast rinse. The valve is required to switch from one cycle to the other and to control the duration of each. More elaborate control systems include multiple stage backwash and rinse cycles.

The valve must be capable of providing enough flow during backwash to thoroughly cleanse the filter bed.

Calculation of Backwash Requirements

Although often underestimated, the backwash rate is essential for satisfactory performance of a bed filter. This basically involves a flow rate necessary to fluidize the media (separate each grain of filter medium in an envelope of water). This separation allows the backwash flow to completely remove the filtered contaminants trapped within the filter bed. In order to remove solids trapped throughout the filter bed, a backwash flow must be high enough to fluidize its entire depth. This is only achieved when the filter bed is expanded to 50 percent of its normal service depth. For example, a bed leveled at 24" deep during service should be expanded to 36" during the backwash cycle.

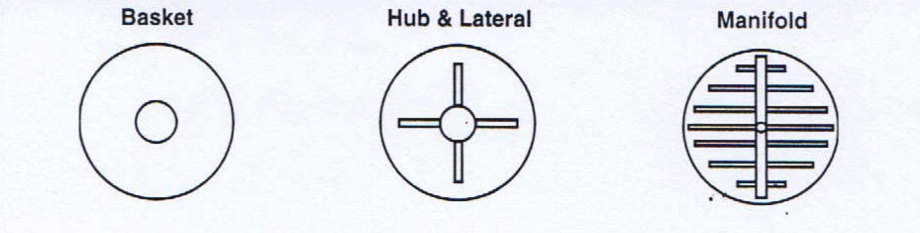


Figure 4: Aerial view of filters

Although backwash flow requirements can be calculated for any filter bed material by equation, it is recommended that unpainted fiberglass tanks be used so that the actual bed expansion during backwash can be measured by shining a spot light behind the freeboard area of the filter tank. It is also recommended that this be done upon installation and then again once the filter bed has seated (approximateley 4 weeks) and before the filter tank sides have become opaque with oxides. Depending upon the porosity of media used and the nature of contaminants being removed, the backwash flow rate may need to be increased to achieve the targeted 50 percent bed expansion. It has been observed that the flow rate required to achieve this target for both 45/55 filter sand and #1 anthracite is 18 GPM/Ft².

Filter Sizing

Three primary mechanisms can be used to reduce suspended solids: Straining, where particles are trapped within the filter bed based upon their size; sedimentation, where particles accumulate on top of the filter bed and effectively improve the micron rating of the filter; brownian attachment, where an electromechanical force attaches a particle to a filter grain. Of the three, straining and sedimentation (depicted in Figure 6) and how flow rate (and variation thereof) affect the performance of each are the most important.

A. Straining

Flow Rate: The ability of a filter bed to strain particles is inversely related to flow rate.

Flow Variations: Particulates which become strained (or trapped)

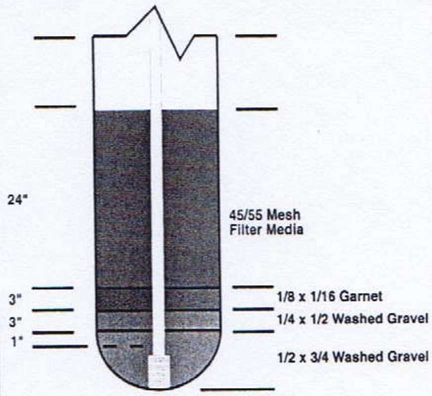


Figure 5:

A typical subfill load supporting a media bed of 45/55 mesh size.

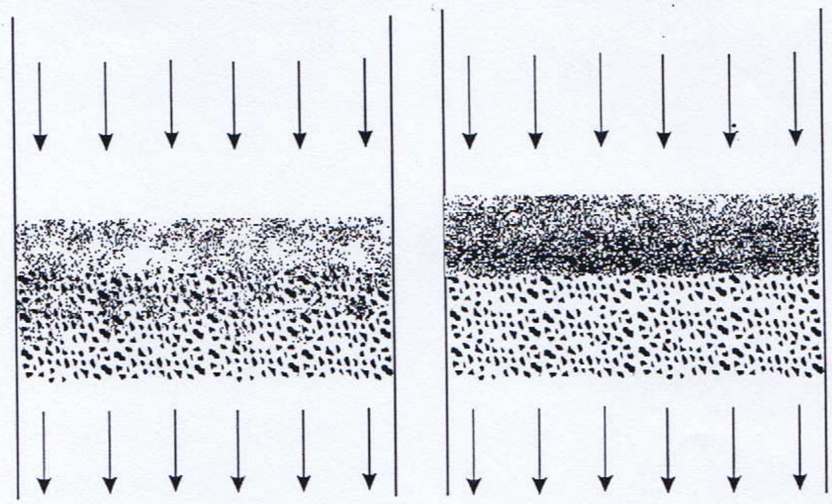


Figure 6: **Media bed filtration includes three primary mechanisms for the reduction of suspended solids**

within the bed at one flow rate will be dislodged when exposed to a higher flow rate. This action is often referred to as shearing.

B. Sedimentation

Flow Rate: The pressure differential between the top of the sediment layer and the media bed is directly related to flow rate. At higher flow rates, the pressure exerted against the sediment layer may cause portions of it

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Table 1
Flow Rates per Ft^2 for Various Size Tanks

Tank Diameter (in inches)	Surface Area (FT^2)	(GPM/FT^2) 2	4	6	8	10	12	14	16	18	20
8	0.350	0.699	1.399	2.098	2.798	3.497	4.197	4.896	5.596	6.295	6.995
9	0.443	0.885	1.770	2.656	3.541	4.426	5.311	6.197	7.082	7.967	8.852
10	0.546	1.093	2.186	3.279	4.372	5.464	6.557	7.650	8.743	9.836	10.929
12	0.787	1.574	3.148	4.721	6.295	7.869	9.443	11.016	12.590	14.164	15.738
13	0.923	1.847	3.694	5.541	7.388	9.235	11.082	12.929	14.776	16.623	18.470
14	1.071	2.142	4.284	6.426	8.568	10.710	12.852	14.995	17.137	19.279	21.421
16	1.399	2.798	5.596	8.393	11.191	13989	16.787	19.585	22.383	25.180	27.978
18	1.770	3.541	7.082	10.623	14.164	17.705	21.246	24.787	28.328	31.869	35.410
20	2.186	4.372	8.743	13.115	17.486	21.858	26.230	30.601	34.973	39.344	43.716
22	2.645	5.290	10.579	15.869	21.158	26.448	31.738	37.027	42.317	47.607	52.896

Other examples of slow and consistant flow rates

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or the entire layer itself to migrate through the media bed.

Flow Variations: The same action as described above occurs with variations in flow.

A slow, consistent flow rate will enhance filter performance.The recommended municipal water treatment plant design standard for service flow through a bed filter is 3 GPM per ft^2 of bed area ($0.122M^3$ per M^2). Coupled with this, a filter must backwash at an average flow rate of 18 GPM per ft^2 of bed area to achieve 50 percent bed expansion. For example, a 10 inch diameter filter operates at a service flow of 1.6 GPM, and must be backwashed at 9.8 GPM. Refer to Table 1 for other examples.

A POE residential application, where water is used intermittently rather than continuously, is difficult to achieve "ideally". However, much can be done to meet service and backwash flow rate requirements. Multiple filter vessels in parallel can satisfy service flow and backwashing sequentially will satisfy backwash flow requirements. The maximum output of the well pump will dictate the diameter of the filter vessels as based upon backwash flow rate.

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Summary

As a rule of thumb, bed filters are not effective at removal of suspended solids below the 10 to 20 micron range.

Compared with other filtration technologies such as cartridge and bag filters, bed filters represent a high capital cost. However, they require lower operating costs if they are properly designed and operated. The suspended solids can be removed by backwashing and the media will last almost indefinitely.

Because of its simple design, low maintenance operation and extremely low operating cost, media bed filtration is an important component available to the water systems design engineer. ❑

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