Water Filtration (Grades 8-12)

This lesson covers Granulated Media, Slow Sand, Rapid Sand, Granulated Activated Carbon (GAC), and Diatomaceous Earth Filters

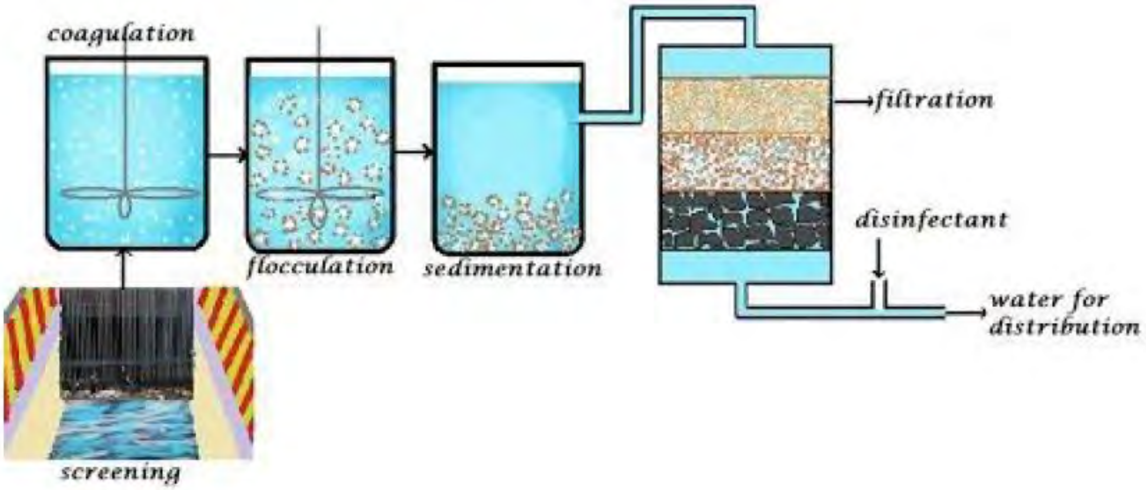
Objective

In this lesson we will answer the following questions:

- What are the different types of filtration processes?
- What are the different types of media that can be used during filtration?
- What problems can occur if filtration does not perform as needed according to design criteria?

Introduction

In the conventional water treatment process, filtration usually follows ***coagulation, flocculation and sedimentation.***

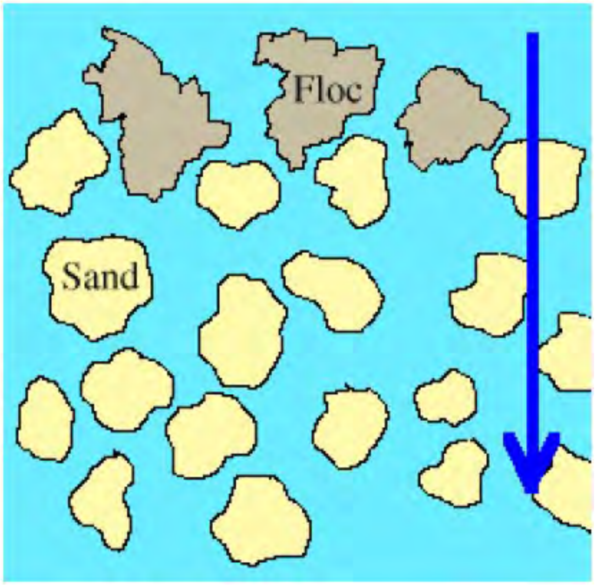


At present, filtration is not always used in small water systems, however, recent regulatory requirements under the USEPA Interim Enhanced Surface Water Treatment rules may make water filtering necessary at most water supply systems. Water filtration is a physical process of separating suspended and colloidal particles from water by passing water through a granular material. The process of filtration involves straining, settling, and adsorption. As floc passes into the filter, the spaces between the filter grains become clogged, reducing this opening and increasing removal. Some material is removed merely because it settles on a media grain. One of the most important processes is adsorption of the floc onto the surface of individual filter grains. This helps collect the floc and reduces the size of the openings between the filter media grains. In addition to removing silt and sediment, floc, algae, insect larvae, and any other large elements, filtration also contributes to the removal of bacteria and protozoa such as *Giardia lamblia* and *Cryptosporidium*. Some filtration processes are also used for iron and manganese removal. Filtration is the mechanical removal of turbidity particles by passing the water through a porous medium, which is either a granular bed or a membrane. Filtration's purpose is to remove all the turbidity particles carried over from the sedimentation phase, thus producing a sparkling clear water with almost zero turbidity.

Types of Filter Technologies

Granular Media Filtration

A granular media filter, generally, consists of a rectangular concrete structure with 4-feet-deep media formed of sand or a combination of sand, garnet, anthracite (crushed hard coal), and activated carbon. The media are supported by a layer of gravel. Under the gravel is a drain system for the drainage of filter effluent, called **filtrate**. Mostly, a small amount of cationic polymer is applied to the filter influent for micro flocculation. Polymer and turbidity particles form a very fine floc that accumulates on the top of the filter media and forms a straining mat (also called a surface cake) that removes the turbidity. Turbidity is removed by two mechanisms, straining and adsorption. Adsorption is acquiring the turbidity particles on the surface of micro floc. Most of the turbidity is removed in the top few inches of media.



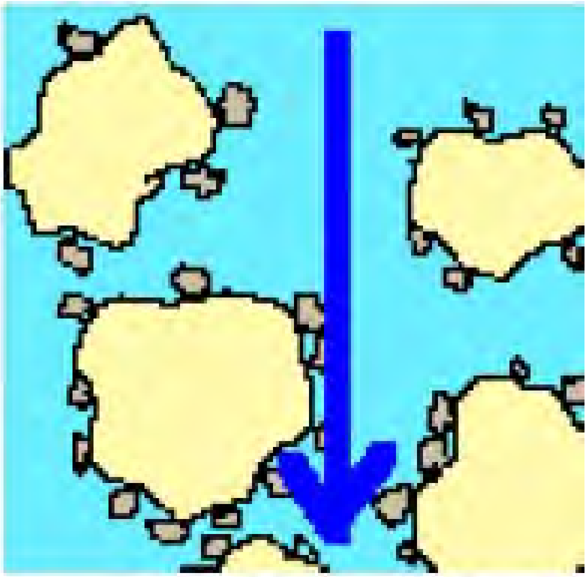
There is a slightly high turbidity during the first 10 to 15 minutes of the filtration because the mat is not effectively formed. This is known as the **ripening period**, after which filtration is adequate. When there is too much build-up of the surface mat and filter interstices are plugged up, the rate of filtration decreases, and turbidity starts going up. At this point, the filter needs backwashing. **Backwashing** is the removal of filtered-out turbidity by reversing the flow through the filter (i.e. from the bottom upward). The time period from beginning filtration to the filter wash is called a **filter run**. The period from the start of filtration to the end of the backwashing is called a **filter cycle**. Turbidity of filter effluent and the resistance to flow, called **head loss**, are monitored continuously to determine the backwashing time and the filter performance. Generally, a washed filter is taken out of service for at least 30 minutes for the proper settling of media before putting it back into operation. A good filter operation removes more than 99 percent of the feed water turbidity and produces a sparkling clear water with turbidity as low as 0.1 NTU or less.

Of these, all but rapid sand filtration are commonly employed in small water systems that use filtration. Each type of filtration system has advantages and disadvantages. Regardless of the type of filter, however, filtration involves the processes of straining (where particles are captured in the small spaces between filter media grains), sedimentation (where the particles land on top of the grains and stay there), and adsorption (where a chemical attraction occurs between the particles and the surface of the media grains).

Straining involves passing the water through a filter in which the pores are smaller than the particles to be removed. This is the most intuitive mechanism of filtration, and one which you probably use in your daily life. Straining occurs when you remove spaghetti from water by pouring the water and spaghetti into a strainer. The picture below shows an example of straining in a filter. As you can see, the floc cannot fit through the gaps between the sand particles, so the floc is captured. The water is able to flow through the sand, leaving the floc particles behind.

In the past, straining has been assumed to be very important in the filtration process. However, in many cases, the pores between sand particles in the filter are much larger than the particles captured by the filter. It has been suggested that small particles become wedged between sand grains as filtration occurs, making the pore spaces smaller and allowing the filter to strain out yet smaller particles. However, a clean filter will produce clean water before any of this pore size-reduction has occurred. Therefore, it is now believed that straining is not an important part of most filtration processes.

The second, and in many cases the most important mechanism of filtration, is adsorption. Adsorption is the gathering of gas, liquid, or dissolved solids onto the surface of another material, as shown below:



Coagulation takes advantage of the mechanism of adsorption when small floc particles are pulled together by van der Waal's forces. In filtration, adsorption involves particles becoming attracted to and "sticking" to the sand particles. Adsorption can remove even very small particles from water.

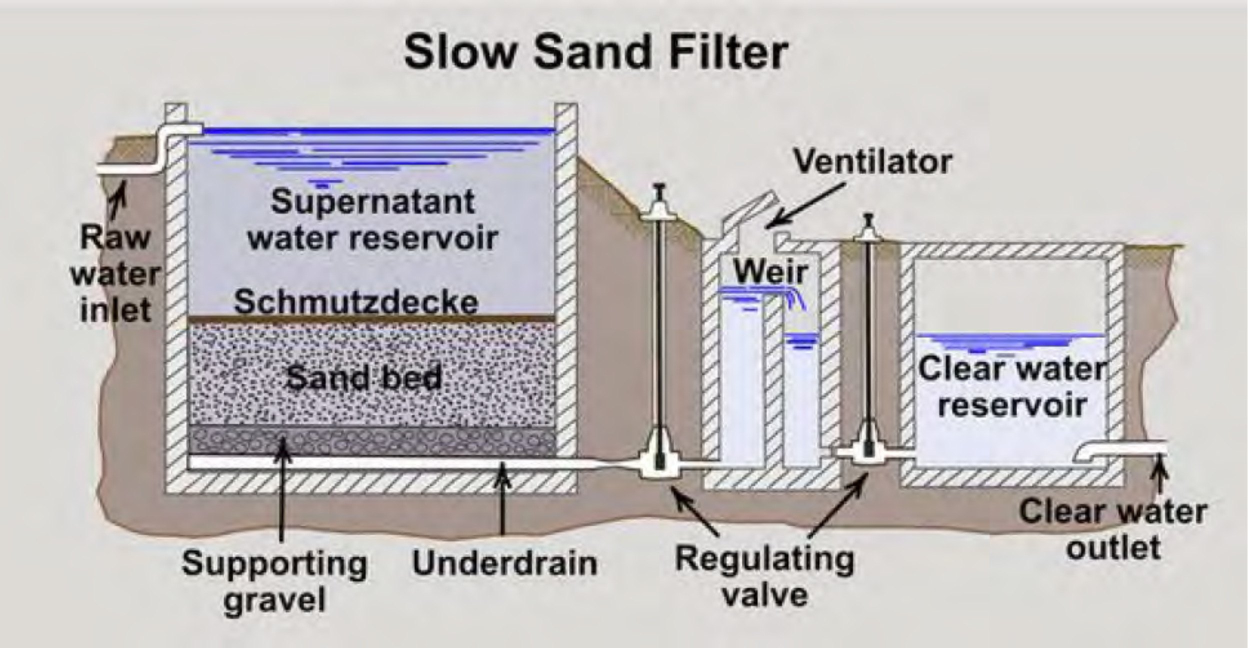
The third mechanism of filtration is biological action, which involves any sort of breakdown of the particles in water by biological processes. This may involve decomposition of organic particles by algae, plankton, diatoms, and bacteria or it may involve microorganisms eating each other.

Although biological action is an important part of filtration in slow sand filters, in most other filters the water passes through the filter too quickly for much biological action to occur.

Slow Sand Filters

Slow sand filtration is well suited for small water systems. It is a proven, effective filtration process with relatively low construction costs and low operating costs (it does not require constant operator attention). It is quite effective for water systems as large as 5000 people; beyond that, the surface area requirements and manual labor required to recondition the filters make rapid sand filters the more effective choice. The filtration rate is generally in the range of 45 to 150 gallons per day per square foot. Components of a slow sand filter include:

- A covered structure to hold the filter media
- An underdrain system
- Graded rock that is placed around and just above the underdrain
- The filter media, consisting of 30 to 55 inches of sand with a grain size of 0.25 to 0.35 mm
- Inlet and outlet piping to convey the water to and from the filter and the means to drain filtered water to waste



The area above the top of the sand layer is flooded with water to a depth of 3 to 5 feet, and the water is allowed to trickle down through the sand. An overflow device prevents excessive water depth. The filter must have provisions for filling it from the bottom up, and it must be equipped with a loss-of-head gauge, a rate-of-flow control device (such as an orifice or butterfly valve), a weir or effluent pipe that ensures that the water level cannot drop below the sand surface, and filtered waste sample taps. When the filter is first placed in service, the head loss through the media caused by the resistance of the sand is about 0.2 feet (i.e. a layer of water 0.2 feet deep on top of the filter will provide enough pressure to push the water downward through the filter). As the filter operates, the media become clogged with the material being filtered out of the water, and the head loss increases. When it reaches about 4 to 5 feet, the filter must be cleaned.

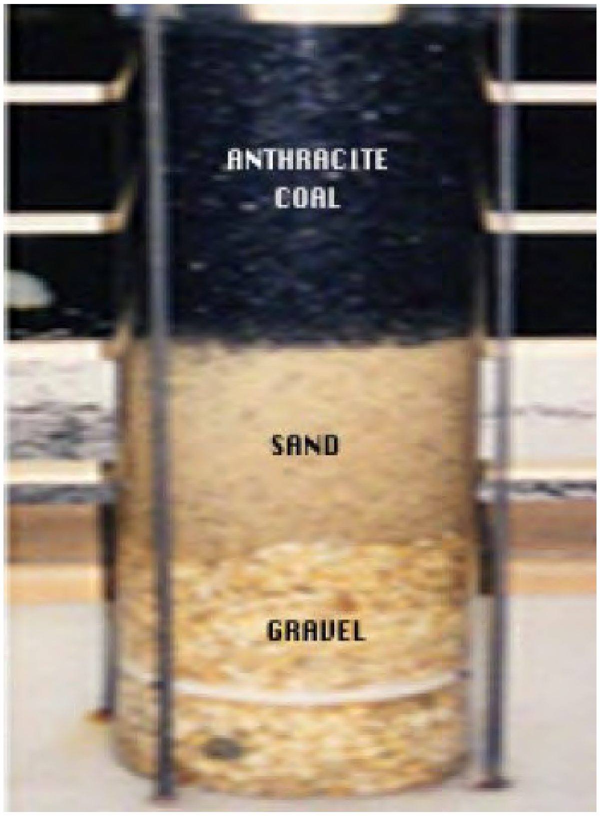
Turbidity particles form a surface mat that becomes sticky due to microbial activity. This mat is called **smutzdecke**, which is very effective to remove particles by straining, adsorption, and microbial metabolism. After the filter run, which could be several days or even weeks, the filter is taken out of service and cleaned. For cleaning, the top layer of sand is scraped, washed, and stored for replacement. The filter is cleaned several times by scraping the surface layer before replacing any sand. For an effective filtration, the minimum required depth of sand is 2 to 2.5 feet. There is no backwashing in these filters. These filters are effectively used for direct filtration of source water with very low (less than 1 NTU) turbidity such as pristine mountain streams or reservoirs.

Rapid Sand Filters

The rapid sand filter, which is similar in some ways to the slow sand filter, is one of the most widely used filtration units. The major difference is in the principle of operation; that is, in the speed or rate at which water passes through the media. In operation, water passes downward through a sand bed that removes the suspended particles. The suspended particles consist of the coagulated matter remaining in the water after sedimentation, as well as a small amount of uncoagulated suspended matter.

Some significant differences exist in construction, control, and operation between slow sand filters and rapid sand filters. Because of the design and construction of the rapid sand filtration, the land area required to filter the same quantity of water is reduced. Components of a rapid sand filter include:

- Structure to house media
- Filter media
- Gravel media support layer
- Underdrain system
- Valves and piping system
- Filter backwash system
- Waste disposal system



Usually 2 to 3 feet deep, the filter media are supported by approximately 1 foot of gravel. The media may be fine sand or a combination of sand, anthracite coal, and coal.

Unlike the slow sand filters, surface loading in these filters is 2 to 4 gpm/ft2, and there is backwashing after the filter run. Sand depth, in these filters, is 2 to 3 feet. The particles have an effective size of 0.35 to 0.55 mm. Medium is supported on 18 inches of gravel, which is graded from 4 inches to pea size. The under-drain system has a Leopold- or Wheeler-type false bottom for an effective drainage of the filter effluent. During filtration, there are about 30 inches of water above the medium. Free board, the distance between the surface of the medium and the lip of the backwash troughs, is 24 to 27 inches to prevent any loss of medium during the backwashing. Filtration takes place in the top few inches of the medium. These filters are used to filter water with influent turbidity up to 5 NTU.

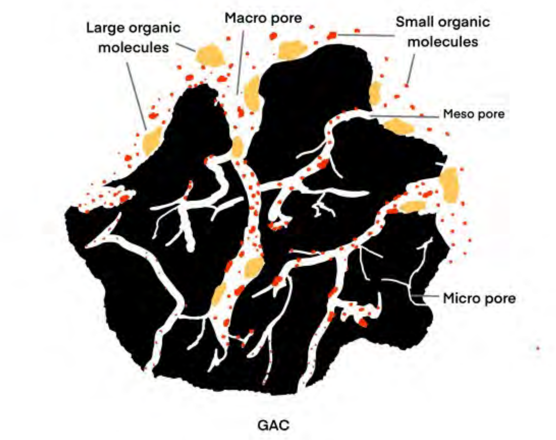
Water is applied to a rapid sand filter at a rate of 1.5 gallons per minute per square foot of filter media surface. When the rate is between 4 and 6 gpm/ft2, the filter is referred to as a high-rate filter; at a rate over 6 gpm/ft2, the filter is referred to as an ultra-high-rate filter. These rates compare to the slow sand filtration rate of 45 to 150 gallons per day per square foot. High-rate and ultra-high-rate filters must meet additional conditions to assure proper operation.

Generally, raw water turbidity is not that high; however, even if raw water turbidity values exceed 1000 NTU, properly operated rapid sand filters can produce filtered water with a turbidity of well under 0.5 NTU. The time the filter is in operation between cleanings (filter runs) usually ranges from 12 to 72 hours, depending on the quality of the raw water; the end of the run is indicated by the head loss approaching 6 to 8 feet. Filter breakthrough (when filtered material is pulled through the filter into the effluent) can occur if the head loss becomes too great. Operation with head loss too high can also cause air binding (which blocks part of the filter with air bubbles), increasing the flow rate through the remaining filter area.

Rapid sand filters have the advantage of lower land requirements, and they have other advantages as well. For example, rapid sand filters cost less, are less labor intensive to clean, and offer higher efficiency with highly turbid waters. On the downside, the operation and maintenance costs of rapid sand filters are much higher in comparison because of the increased complexity of the filter controls and backwashing system. When backwashing a rapid sand filter, the filter is cleaned by passing treated water backward (upward) through the filter media and agitating the top of the media. The need for backwashing is determined by a combination of filter run time (i.e. the length of time since the last backwashing), effluent turbidity, and head loss through the filter. Depending on the raw water quality, the run time varies from one filtration plant to another (and may even vary from one filter to another in the same plant). Backwashing usually requires 3 to 7% of the water produced by the plant.

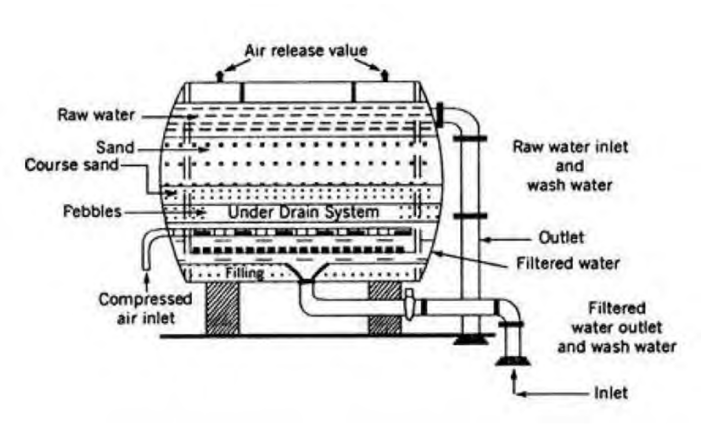
Granulated Activated Carbon (GAC) Multimedia Filters

Granulated Activated Carbon (GAC) filters have a layer of activated carbon on top of anthracite or sand. Activated carbon adsorbs various contaminants, such as tastes and odor-causing organics, THMs, and synthetic organics. GAC is lighter than sand or anthracite and has an effective size of 0.55 to 0.65 mm. These filters have the problem of losing some carbon during the backwashing; therefore, backwashing is properly controlled to prevent the excessive loss of GAC. Commonly, backwashing causes 1 to 6 percent GAC loss per year.



Pressure Filter Systems

In pressure filters, media are enclosed in a cylindrical steel tank and the water is forced under pressure through the filter. Media are either sand or diatomaceous earth.



When raw water is pumped or piped from the source to a gravity filter, the head (pressure) is lost as the water enters the floc basin. When this occurs, pumping the water from the plant clearwell to the reservoir is usually necessary. One way to reduce pumping is to place the plant components into pressure vessels, thus maintaining the head. This type of arrangement is known as a pressure filter system. Pressure filters are also quite popular for iron and manganese removal and for filtration of water from wells. They may be placed directly in the pipeline from the well or pump with little head loss. Most pressure filters operate at a rate of about 3 gpm/ft2.

Operationally the same, and consisting of components similar to those of a rapid sand filter, the main difference between a rapid sand filtration system and a pressure filtration system is that the entire pressure filter is contained within a pressure vessel. These units are often highly automated and are usually purchased as self-contained units with all necessary piping, controls, and equipment contained in a single unit. They are backwashed in much the same manner as the rapid sand filter. The main advantage of the pressure filter is its low initial cost. They are usually prefabricated, with standardized designs. A major disadvantage is that the operator is unable to observe the filter in the pressure filter and so is unable to determine the condition of the media. Unless the unit has an automatic shutdown feature on high effluent turbidity, driving filtered material through the filter is possible.

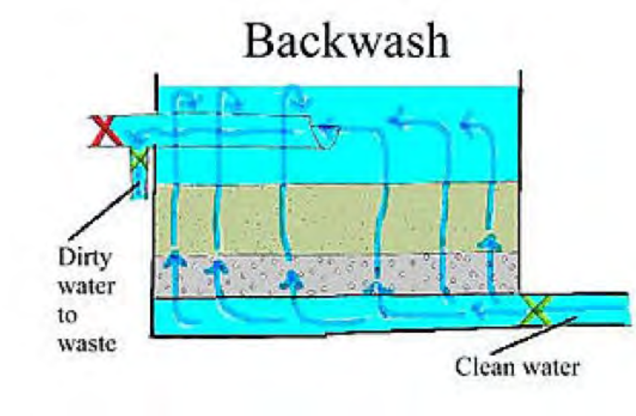
Diatomaceous Earth Filters

Diatomaceous earth is a white material made from the skeletal remains of diatoms. The skeletons are microscopic and, in most cases, porous. Diatomaceous earth is available in various grades, and the grade is selected based on filtration requirements. These diatoms are mixed in water slurry and fed onto a fine screen called a septum, usually made of stainless steel, nylon, or plastic. The slurry is fed at a rate of 0.2 lb/ft2 of filter area. The diatoms collect in a precoat over the septum, forming an extremely fine screen. Diatoms are fed continuously with the raw water, causing the buildup of a filter cake approximately 1/8 to 1/5 inch thick. The openings are so small that the fine particles that cause turbidity are trapped on the screen. Coating the septum with diatoms gives it the ability to filter out very small microscopic material. The fine screen and the buildup of filtered particles cause a high head loss through the filter. When the head loss reaches a maximum level (30 psi on a pressure-type filter or 15 inches of mercury on a vacuum-type filter), the filter cake must be removed by backwashing.

A slurry of diatoms is fed with raw water during filtration in a process called **body feed**, which prevents premature clogging of the septum cake. These diatoms are caught on the septum, increasing the head loss and preventing the cake from clogging too rapidly by the particles being filtered. Body feed increases head loss, but the head loss increases are more gradual than if body feed were not used. Diatomaceous earth filters are relatively low in cost to construct, but they have high operating problems if not properly operated and maintained. They can be used to filter raw surface waters or surface-influenced groundwaters with low turbidity (< 5 NTU) and low coliform concentrations (no more than 50 coliforms per 100 mL) and may also be used for iron and manganese removal following oxidation. Filtration rates are between 1.0 and 1.5 gpm/ft2.

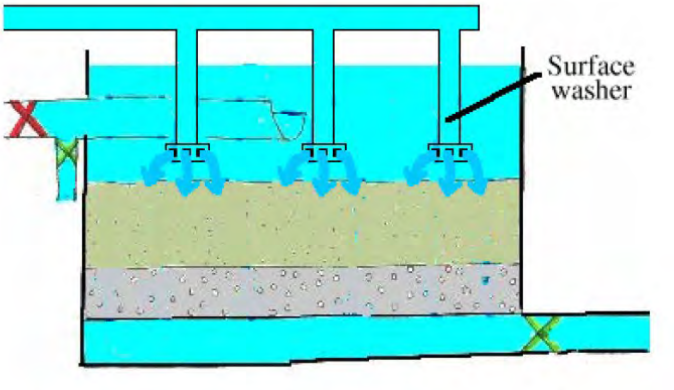
Backwashing

There is no standard criterion for backwashing of a filter. Mostly, it is decided by the performance of the filter from effluent turbidity, head loss, and filter run. For example, turbidity should not be more than 0.1 NTU, head loss should not be more than 6 ft (pressure as water height in feet), and filter run no longer than 24 hours. These are general guidelines, which vary from plant to plant. Rapid sand filters, pressure filters, and diatomaceous earth filters can all be backwashed. During backwashing, the flow of water through the filter is reversed, cleaning out trapped particles.



In order to backwash a filter, the influent valve is closed and a waste line is opened. A backwash pump or tower forces treated water from the system back up through the filter bed. The dirty backwash water is collected by the wash troughs and can be recycled to the beginning of the plant or can be allowed to settle in a tank, pond, or basin. Backwashing should begin slowly. If begun too quickly, backwash water can damage the underdrain system, gravel bed, and media due to the speed of the water. Beginning backwashing too quickly will also force air bound in the filter out, further damaging the filter. After a slow start, the backwash rate should be accelerated to reach around 10 to 25 gpm/ft.2 The backwash water must have enough velocity and volume to agitate the sand and carry away the foreign matter which has collected there. Backwashing normally takes about 10 minutes, though the time varies depending on the length of the filter run and the quantity of material to be removed. Filters should be backwashed until the backwash water is clean.

At the same time as backwashing is occurring, the surface of the filter should be additionally scoured using surface washers. Surface washers spray water over the sand at the top of the filter breaking down mud balls.



Factors Affecting Granular Media Filtration

Factors that affect granular media filtration include:

- Turbidity. The less the turbidity in the filter influent, longer the filter run, and better is the performance.
- Media form. The coarser the media the less is the head loss, the longer is the run, and vice versa.
- Depth. The deeper the bed, the better is the filtration.
- Backwashing. Proper backwashing is an important factor in the proper operation of a filter. Improper washing can cause the loss of media, mixing of media, formation of mud balls, cracks, and craters. All these factors cause an inadequate filtration and a high-effluent turbidity.
- Filtration rate. The higher the loading, the shorter the filter runs, and less efficient is the filter.
- Temperature. The higher the temperature, the better is the performance.
- Water stability. In the lime softening plants, higher pH (above 9.3) and higher calcium carbonate content of water can cause deposition of calcium carbonate on the media particles. This build-up of calcium carbonate causes swelling of media and the formation of mud balls.

Water needs to be stabilized by lowering the pH below 9.3. A controlled small amount of a polyphosphate, such as sodium hexametaphosphate, is applied as a sequestering agent to further correct this situation. Too much of a polyphoshate can cause excessive sloughing of calcium carbonate from the media particles, which causes higher turbidity, and too little may not be enough for an adequate sequestering.

Polymer dose. A small dose (0.5 - 0.75 mg/L) of a polymer is helpful in forming a microfloc mat to aid the filtration. A higher dose causes cracks in the filter mat, and a lower dose not form an effective microfloc.