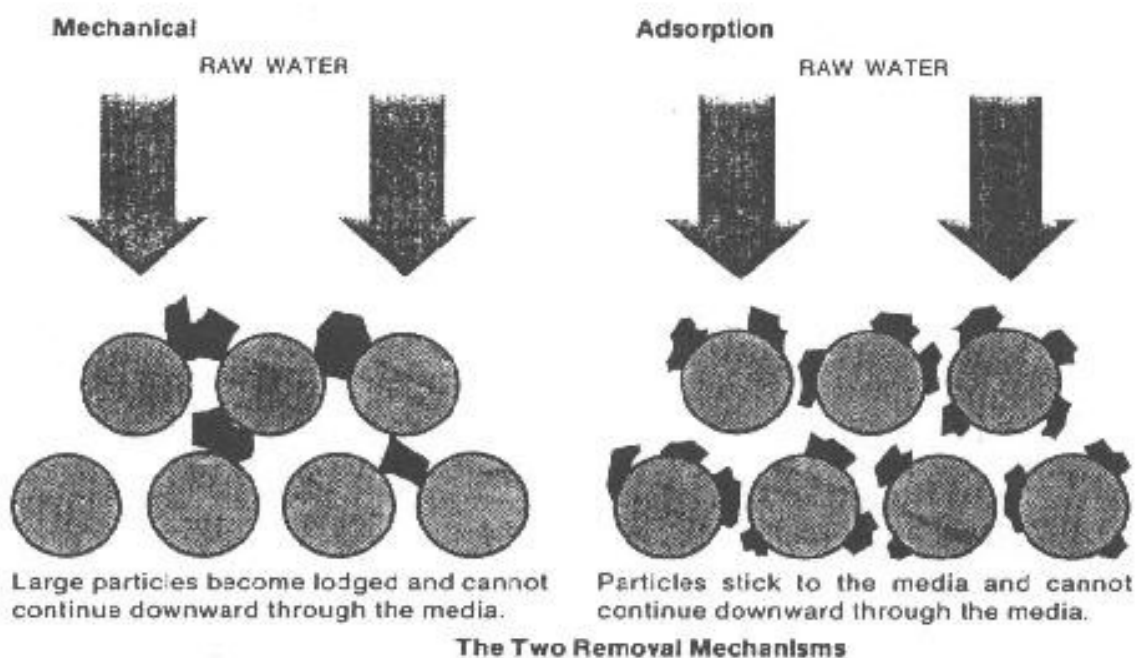


Filtration

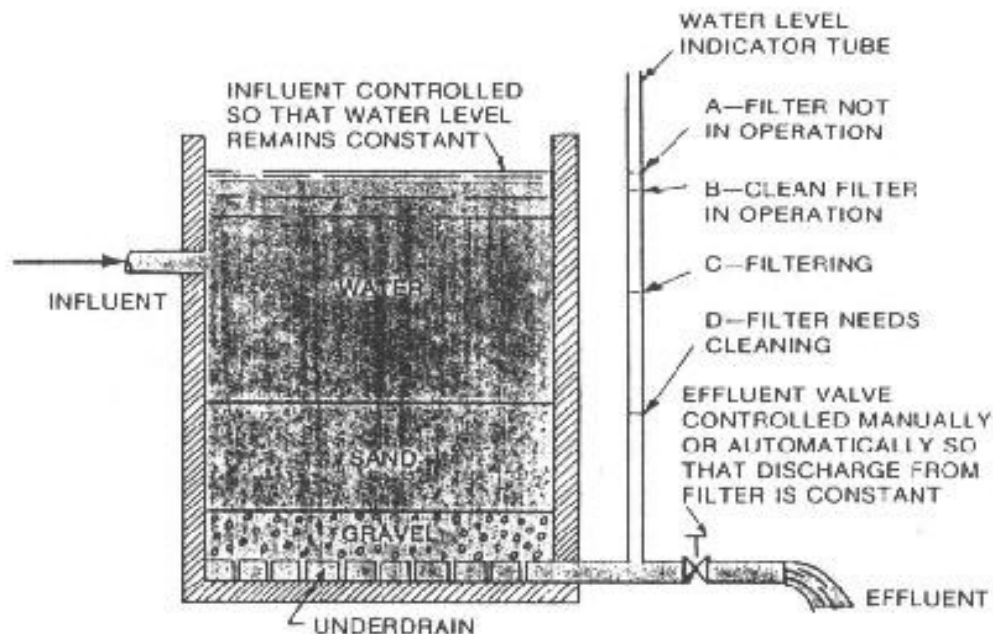
Filtration plays an important role in the natural treatment of groundwater as it percolates through the soil. It is also a major part of most water treatment. Groundwater that has been softened, or treated through iron and manganese oxidation, requires filtration to remove floc created by coagulation or oxidation processes. Since surface water is subject to run-off and does not undergo natural filtration, it must be filtered to remove particles and impurities.

Filtration can be compared to a sieve or micro-strainer that traps suspended material between the grains of filter media. However, since most suspended particles can easily pass through the spaces between grains of the filter media, straining is the least important process in filtration. Filtration primarily depends on a combination of complex physical and chemical mechanisms, the most important being adsorption. Adsorption is the process of particles sticking onto the surface of the individual filter grains or onto the previously deposited materials. Forces that attract and hold particles to the grains are the same as those that work in coagulation and flocculation. In fact, coagulation and flocculation may occur in the filter bed, especially if coagulation and flocculation before filtration was not properly controlled. Incomplete coagulation can cause serious problems in filter operation.



TYPES OF FILTERS

Several types of filters are used for water treatment. Early slow sand filters typically have filter rates of 0.05 gallons per minute (gpm)/ft² of surface area and require large filter areas. The top several inches of the sand has to be removed regularly—usually by hand—due to the mass of growing material “schmutzdecke” that collects in the filter. Sand removed is usually washed and returned to the filter. These filters are still in use in some small plants, especially in the western United States as well as in many developing countries. They may also be used as a final step in wastewater treatment.

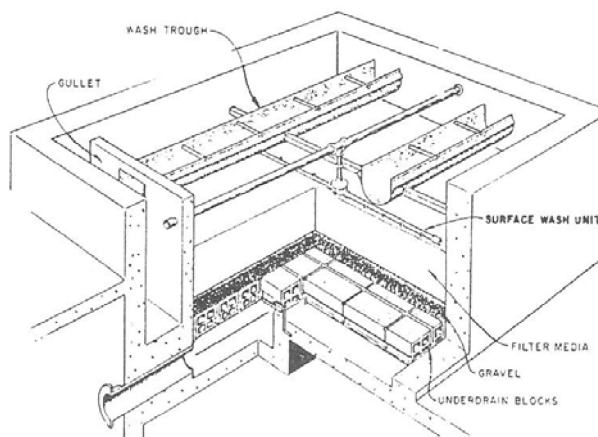


Modern filters are classified as Gravity Filters (Rapid Sand or High Rate-Dual media-Multimedia) and Pressure Filters (Sand or Multi-media).

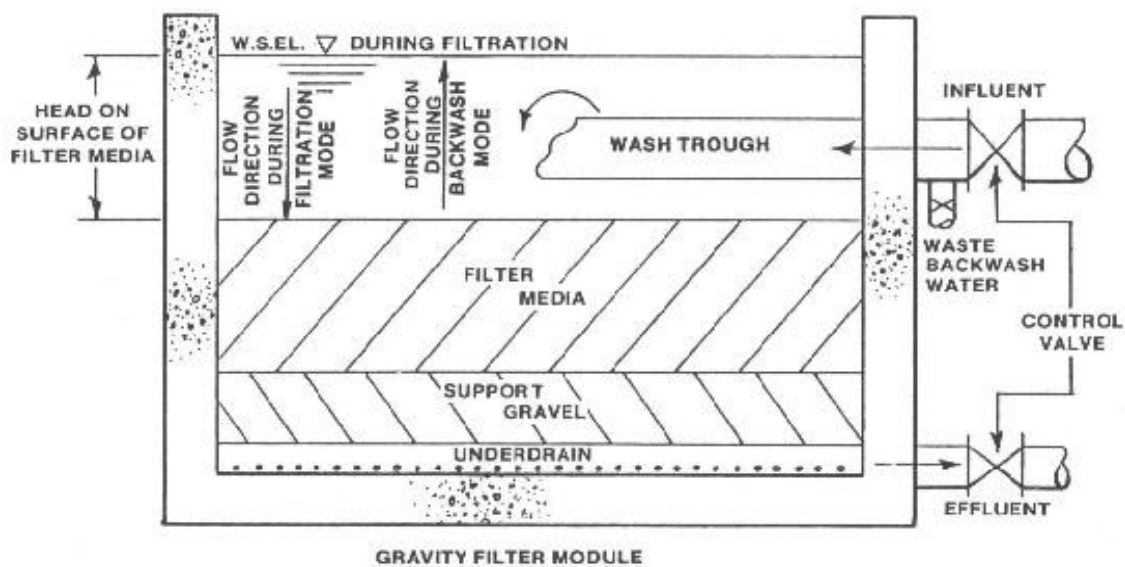
RAPID SAND FILTERS

Rapid sand filters have filter rates 40 times those of slow sand filters. The major parts of a rapid sand filter are:

- Filter tank or filter box
- Filter sand or mixed-media
- Gravel support bed
- Underdrain system
- Wash water troughs
- Filter bed agitators

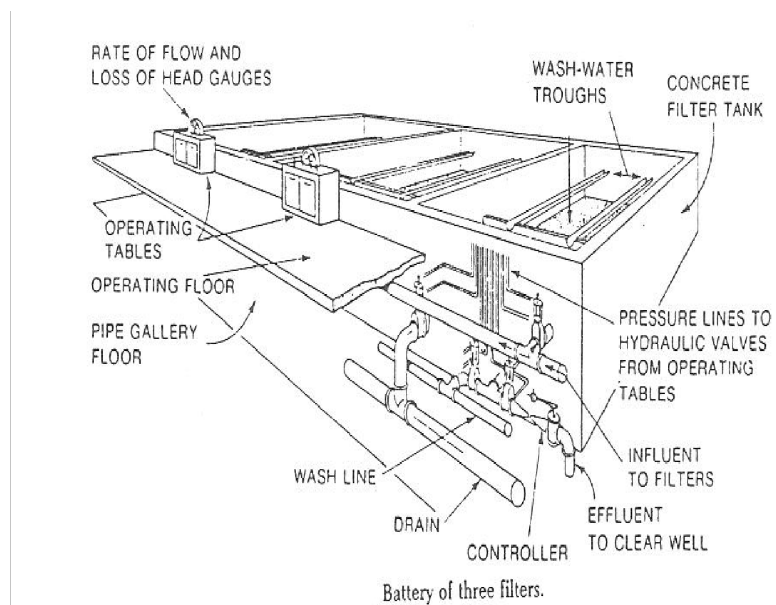
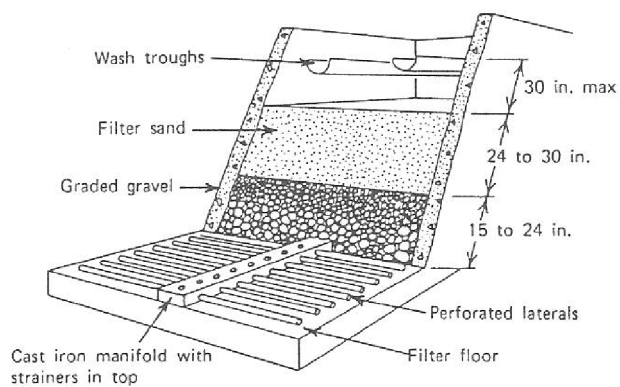
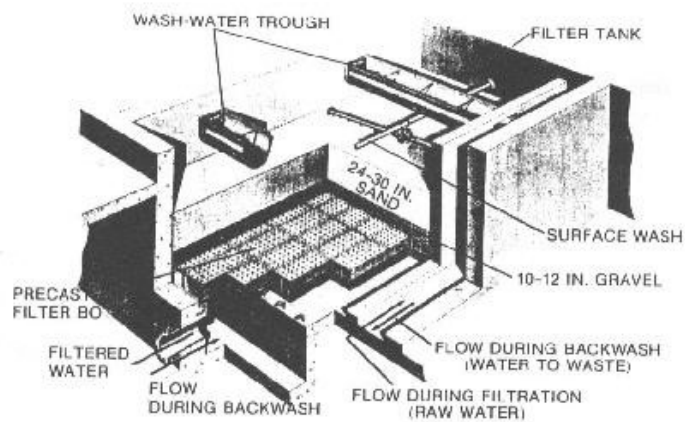


The filter tank is generally constructed of concrete and is most often rectangular. Filters in large plants are usually constructed next to each other in a row, allowing piping from the sedimentation basins to feed the filters from the central pipe gallery. Some smaller plants are designed with filters forming a square of four filters with a central pipe gallery feeding the filters from a center wall.



Filter Sand

The filter sand used in rapid sand filters is manufactured specifically for the purpose of water filtration. Most rapid sand filters contain 24-30 inches of sand, but some newer filters are deeper. The sand used is generally 0.4 to 0.6 mm in diameter. This is larger than the sand used in slow rate filtration. The coarser sand in the rapid filters has larger voids that do not fill as easily.



Graded Gravel

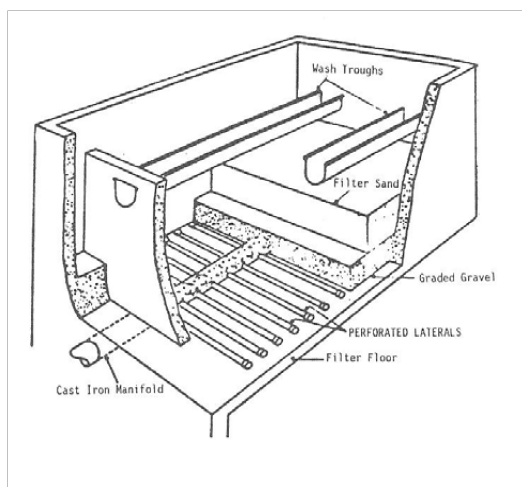
Gravel installed under the sand layer(s) in the filter prevents filter sand from being lost during filtration. The under-gravel also distributes the backwash water evenly across the total filter. This under-gravel supports the filter sand and is usually graded in three to five layers, each generally 6-18 inches in thickness, depending on the type of underdrain used.

Underdrain

The filter underdrain can be one of many types, such as:

- Pipe laterals
- False floor
- Leopold system
- Porous plates or strainer nozzles

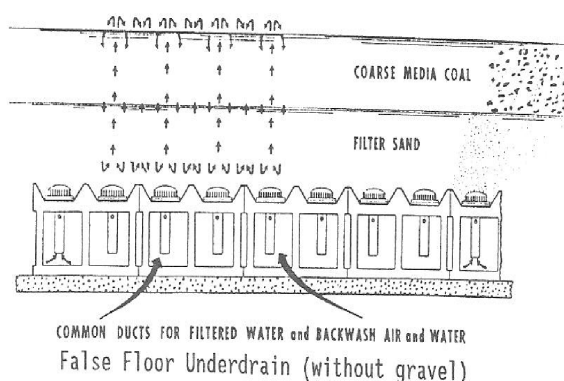
Pipe Laterals



A pipe lateral system uses a control manifold with several perforated laterals on each side. Piping materials include cast iron, asbestos cement, and PVC. The perforations are usually placed on the underside of the laterals to prevent them from plugging with sand. This also allows backwash to be directed against the floor, which helps keep gravel and sand beds from being directly disturbed by the high velocity water jets.

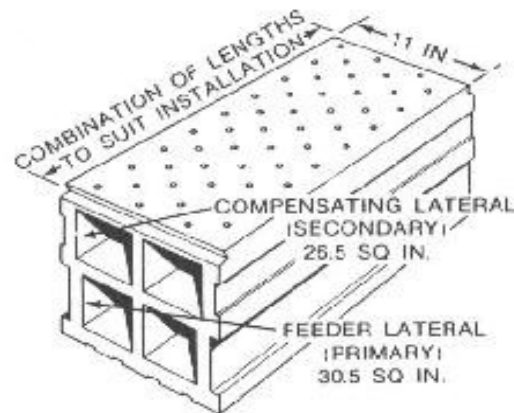
False Floor

The false floor design of a filter underdrain is used together with a porous plate design, or with screens that retain sand when there is no undergravel layer. This type of underdrain allows the open space under the floor to act as a collection area for the filtered water and distribution of backwash water.

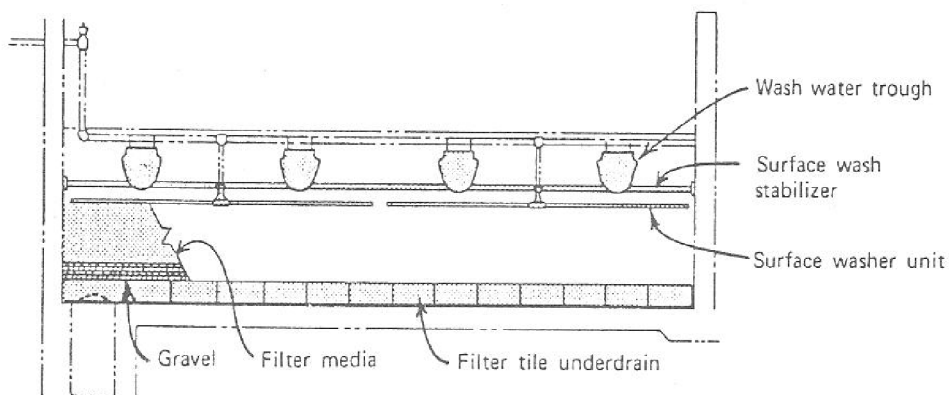


Leopold System

The Leopold system consists of a series of clay plastic blocks that form the channels to remove filtered water from the filter and distribute the backwash water. This type of underdrain is generally used with an undergravel layer, although some new designs allow for sand retention without gravel.



or
the



Washwater Troughs

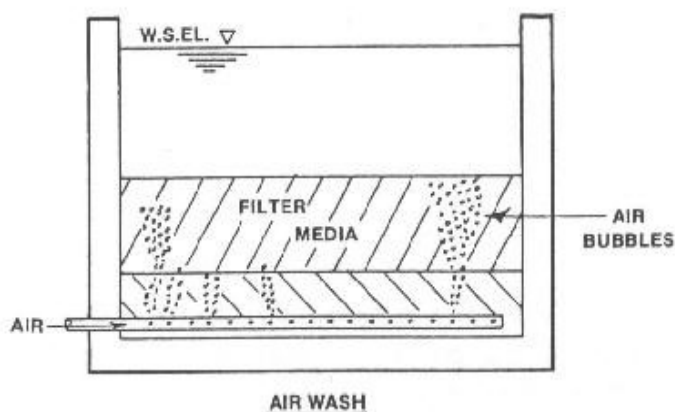
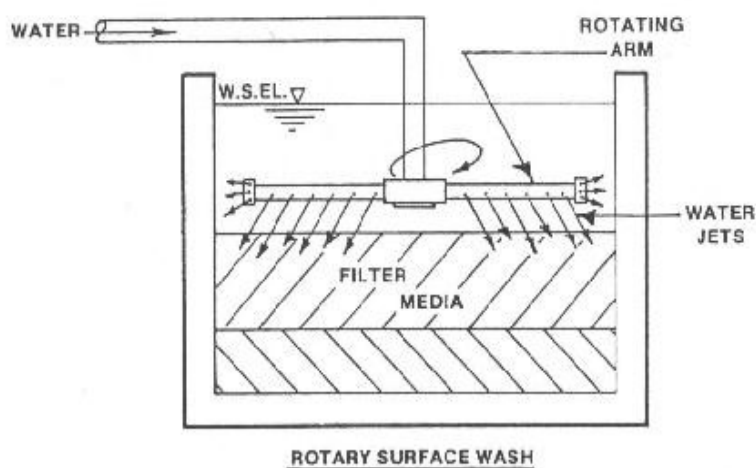
Washwater troughs above the filter media collect backwash water and carry it to the drain system. Proper placement of these troughs is important to ensure filter media is not carried into the troughs during the backwash and removed from the filter. Wash troughs must be installed at the same elevation, so they remove backwash evenly from the filter and an even head is maintained across the entire filter. These backwash troughs are constructed from concrete, plastic, fiberglass, or other corrosion-resistant materials.

Surface Wash

The upper six-to-ten inches of filter media remove most of the suspended material from the water. It is important that this layer is thoroughly cleaned during the backwash cycle. Normal backwashing does not, in most cases, clean this layer completely, and agitation is needed to break up the top layers of the filter to help backwash water remove any material caught there.

The surface wash system consists of a series of pipes installed in the filter to introduce high velocity water or air jet action into the upper layer of the filter. This jet action is generally supplied by rotating arms activated during backwashing.

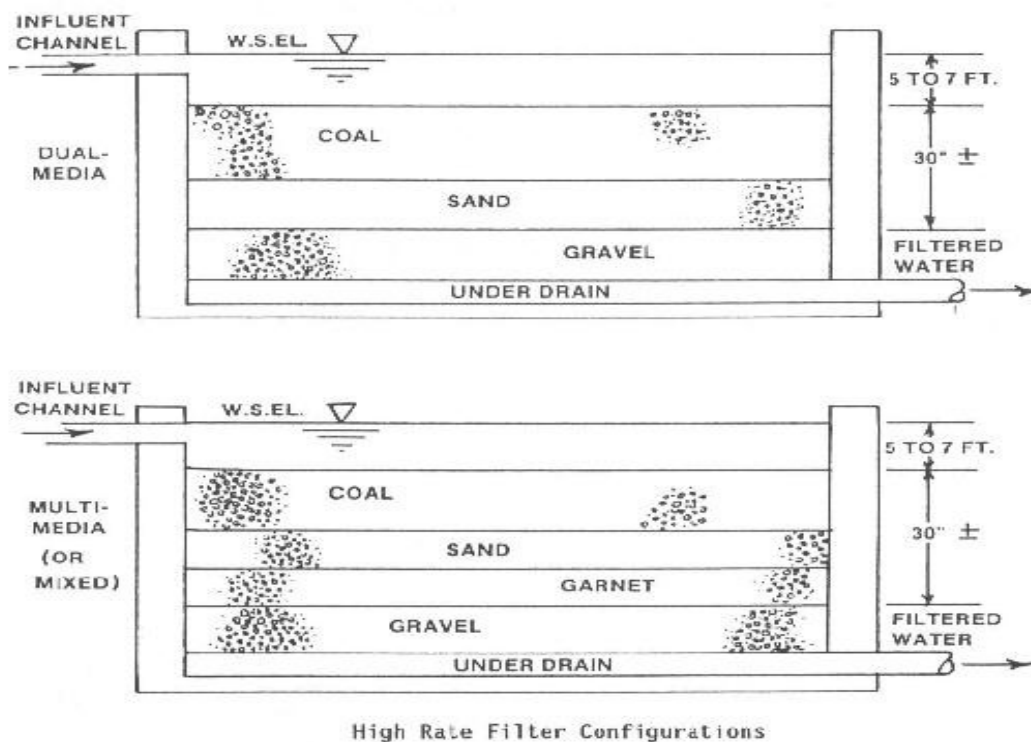
A newer design of surface wash uses compressed air to mix the upper layer and loosen particles from the sand, so backwash water can remove the particles more easily. This air wash generally is turned on before the backwash cycle. If both are used at the same time, some sand may be washed away. The compressed air rate can be two-to-five cubic feet per minute per square foot (cfm/ft²) of filter surface, depending on the filter.



HIGH RATE FILTERS

High rate filters, which operate at three-to-four times the rate of rapid sand filters, use a combination of filter media, not just sand. Media combinations are generally sand and anthracite coal. Multi-media or mixed-media filters generally use sand, anthracite coal, and garnet.

In rapid sand filters, fine sand grains are at the top of the sand layer with larger grains farther down the filter. As a result, the filter removes most suspended material in the first few inches of the filter. In the high rate filter, the media size decreases and the top layers consists of a coarse material with the finer material farther down, allowing the suspended material to penetrate deeper into the filter. This allows for longer filter runs at higher rates than is possible with rapid sand filters.



Filter media used in a high rate filter depends on the raw-water quality, raw-water variations, and chemical treatment used. Pilot studies help the operator evaluate which material, or combination of materials, will give the best result.

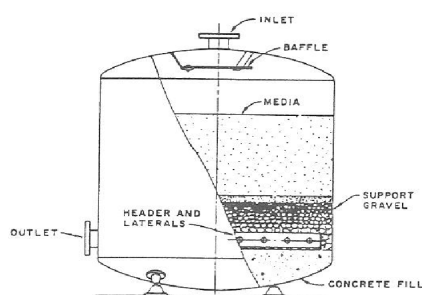
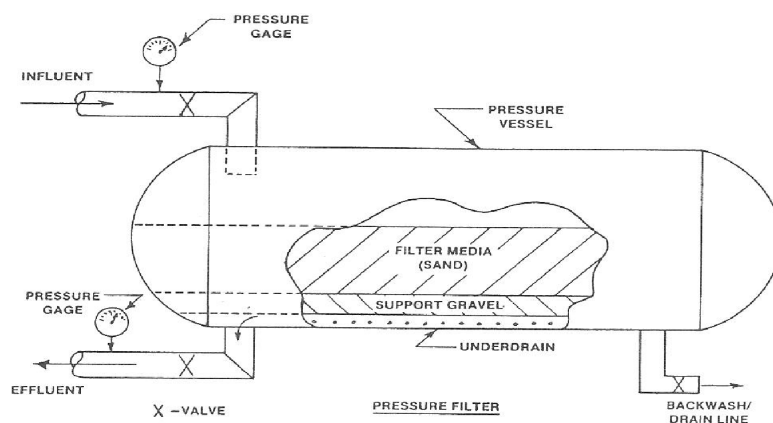
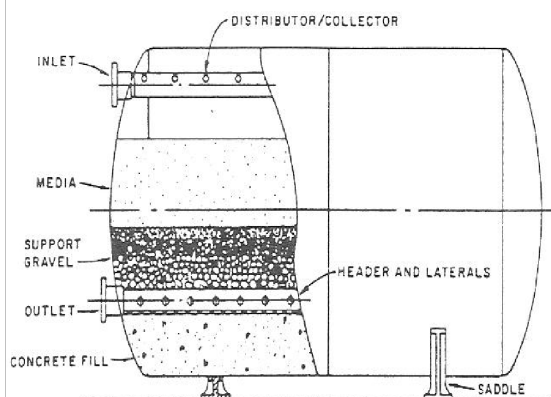
PRESSURE FILTERS

Pressure filters fall into two categories: pressure sand and diatomaceous earth filters. Pressure filters are used extensively in iron and manganese removal plants.

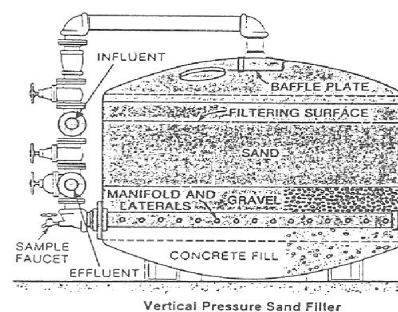
A pressure sand filter is contained under pressure in a steel tank, which may be vertical or horizontal, depending on the space available.

As with gravity filters, the media is usually sand or a combination of media, and filtration rates are similar to gravity filters.

Groundwater is first aerated to oxidize the iron or manganese, and then pumped through the filter to remove the suspended material.

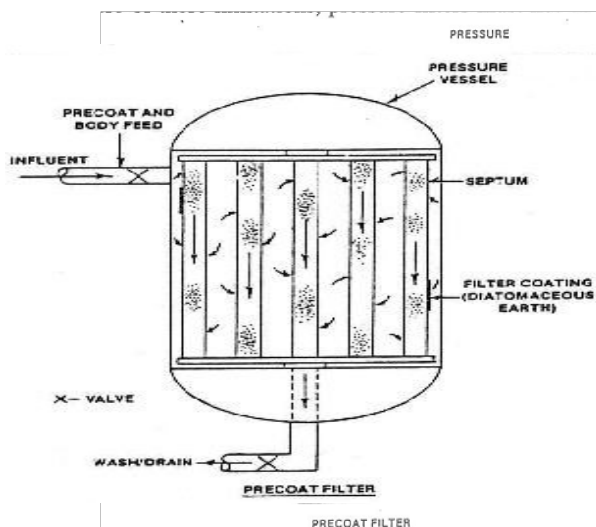


Typical horizontal and vertical pressure filters.



Vertical Pressure Sand Filter

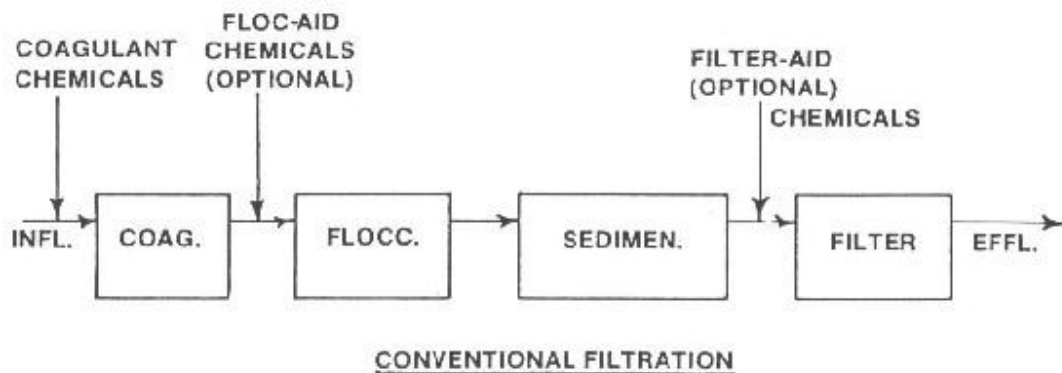
Because water is under pressure, air binding will not occur in the filter. However, pressure filters have a major disadvantage in that the backwash cannot be observed; in addition, cracking of the filter bed can occur quite easily, allowing the iron and manganese particles to go straight through the filter. When using pressure filters for iron and manganese removal, the operator must regularly measure the iron and manganese concentration of the filter effluent and backwash the filter before breakthrough occurs. Because of these limitations, pressure filters must not be used to treat surface water.



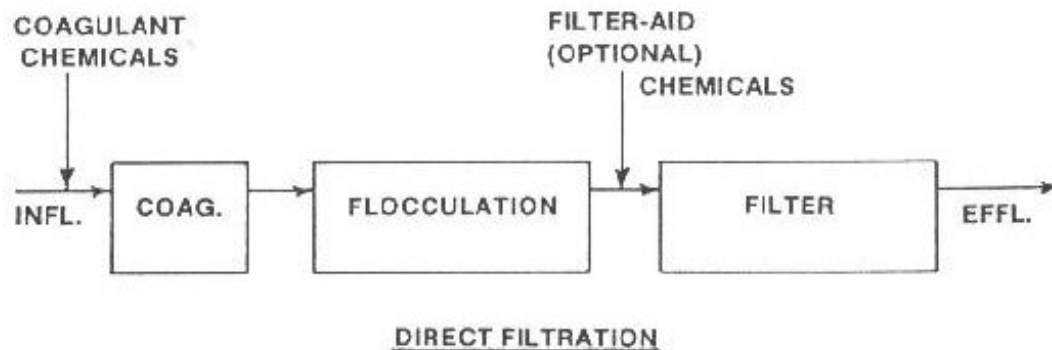
Diatomaceous earth filters are commonly used for the treatment of swimming pools. The process was developed by the military during World War II to remove microorganisms that cause amoebic dysentery from water used in the field.

FILTRATION

Conventional filtration, the traditional design for many years, provides effective treatment for just about any range of raw-water turbidity. Its success is due partially to the clarification that precedes filtration and follows coagulation and flocculation. Clarification (or flocculation/sedimentation) includes any solid/liquid separation process following coagulation, where accumulated solids are removed. Clarification, if operated properly, should remove most of the suspended material. After clarification, the water passing through to the filters should not have any turbidity higher than 10-15 Nephelometric Turbidity Units (NTUs).



In direct filtration, no clarification follows the coagulation phase. Direct filtration is designed to filter water with an average turbidity of less than 25 NTU. Dual and multi-media filters are used with direct filtration. They are able to remove more suspended material per cubic foot of filter media than sand filters. Direct filtration plants have a lower capital cost. However, the process cannot handle large variations in raw water turbidity.



Water (either from the source or, more commonly, from pre-treatment processes) is applied to the top of the filter; it then flows downward. The water level above the filter bed is usually kept at two-to-six feet. When the filtration is started after being backwashed, there will be little head loss. In filters with a control valve installed on the filter effluent pipe, the filter flow is restricted during this time. The control valve also has the important function of preventing filter surges, which could disturb the media and force floc through the filter.

The rate of flow on a filter depends on the type of filter. A rapid sand filter will have a flow of 23 gallons per minute (gpm)/square foot of filter area. The high rate filter may have 4-6 gpm/square foot applied to the surface. A constant rate flow valve is almost fully closed when a filter is clean so that the desired water level on top of the filter is maintained. As the filter becomes dirty with suspended material, the valve opens gradually until the increase in the water level above the filter indicates that the filter needs backwashing.

In filters with variable declining rate flow control, filters are allowed to take on as much water as they can handle. As the filters become dirty, the head loss and the depth of the water on the surface increase until the filters need backwashing. This method is generally preferred because it requires less operator attention. With this method, a filter accepts as much flow as it can handle. As the filter becomes dirty, the flow through the filter becomes less and, if the plant has more than one filter, additional flow redistributes across the other filters. A flow restrictor is placed in the filter effluent pipe to prevent a filter inflow that is too great for the filter.

Regardless of the method of control, the filter eventually fills with suspended material. At some time, usually after 15 to 30 hours, it will need to be backwashed to clean the media.

Control of filter operations requires a rate of flow controller, loss of head indicator, and in-line turbidimeter, as described below.



Rate of Flow Controllers

Flow rates through filters are controlled by one of two different methods:

Declining Rate

This method of control is used where the head loss through the plant is quite large. It allows the filter head to increase until the filter becomes plugged with particles and the head loss is too great to continue operation of the filter. The rate through the filter is much greater in the beginning of a filter run than at the end when the filter is dirty. This method tends to be the most commonly installed in new filter plants.

Constant Rate

This type of control monitors the level of water on the top of the filter and attempts to control this level from the start of the operation to the end. This is accomplished by the controller operating a valve on the effluent of the filter. The valve will be nearly closed at the start of the filter run and fully open at the end. This design is used when the head or pressure on the filter is limited.

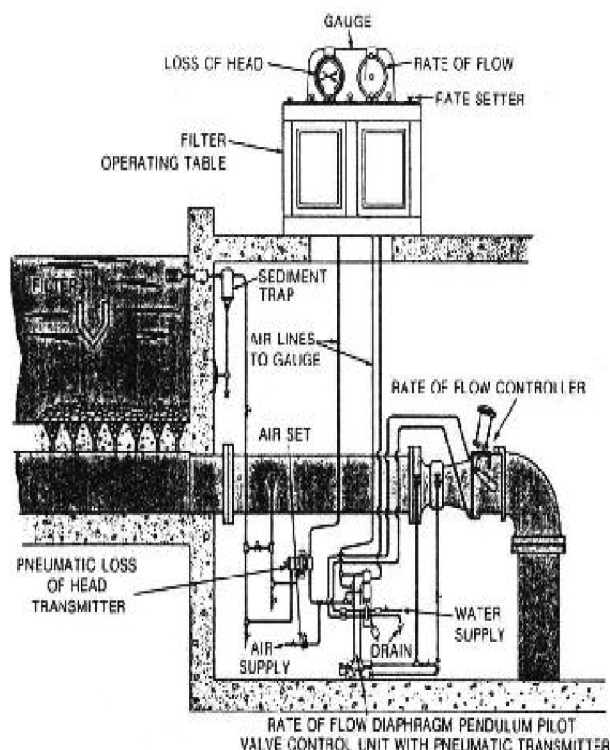
Both controllers consist of a venturi tube or some other type of metering device as well as a valve to control the flow from the filter. In most cases, the valve is controlled by an automatic control device, often an air-actuated type valve that is controlled by the flow tube controller.

Loss of Head Indicator

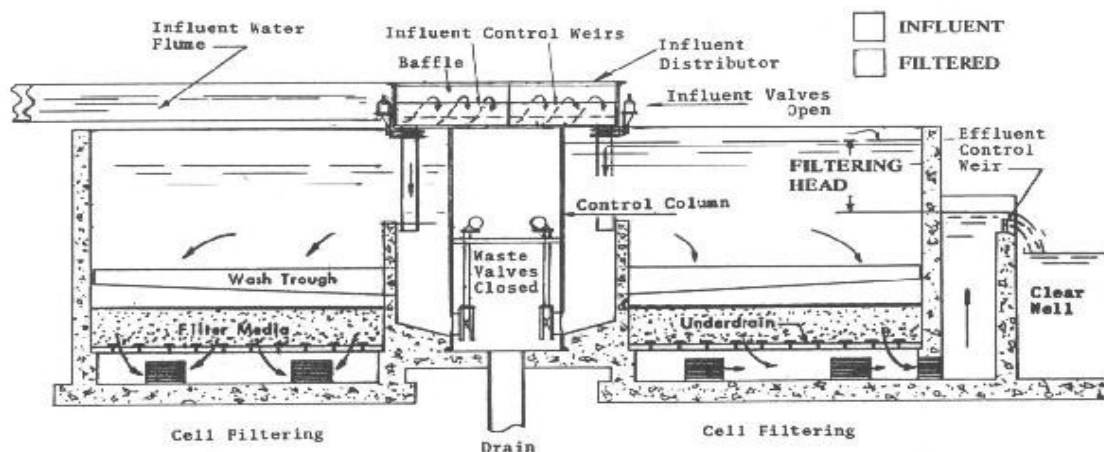
As filtration proceeds, an increasing amount of pressure, called head loss across the filter, is required to force the water through the filter. Head loss should be continuously measured to help determine when the filter should be backwashed. Usually the difference in the head is measured by a piezometer connected to the filter above the media and the effluent line.

In-line Turbidimeter

Turbidity in water is caused by small suspended particles that scatter or reflect light so that the water appears to be cloudy. Turbidity of the filtered water may shelter bacteria, preventing chlorine from reaching it during the final disinfection process. The turbidity of the filtered water is one of the factors that determines the length of a filter run. At some point, the suspended material will start to break through the filter media and increase the turbidity of the filter effluent. At this time, the filter should be backwashed. Continuous turbidity monitors provide information about when the filter is approaching this point so that the operators can start the backwash before the turbidity is too great. Turbidity measurements will also indicate whether the coagulation and other treatment processes are operating properly.



FILTER CYCLE



BACKWASH CYCLE

Proper backwashing is a very important step in the operation of a filter. If the filter is not backwashed completely, it will eventually develop operational problems. If a filter is to operate efficiently, it must be cleaned before the next filter run. Treated water is used for the backwash cycle, and is generally taken from elevated storage tanks or pumped in from the clear well.



During filtration, the filter media becomes coated with floc, which plugs the voids between the filter grains, making the filter difficult to clean. The media must be expanded to clean the filter during the backwash. This expansion causes the filter grains to violently rub against each other, dislodging the floc from the media. The filter backwash rate has to be great enough to expand and agitate the filter media and suspend the flocs in the water for removal. However, if the filter backwash rate is too high, media will be washed from the filter into the troughs and out of the filter. A normal backwash rate is between 15 to 23 gpm per square foot of filter surface area.

In most cases the filter backwash rate will not break up the mass on the top of the filter. The design engineer will recommend the installation of a surface wash of some type, the most common being a set of rotary arms that are suspended above the media during filtration. During filter backwash, the media expands upwards and around the washing arms. A newer method of surface wash involves using air scour before the water wash. This is a very efficient method but requires the installation of a large air blower to produce the air. The normal design for the air wash will be 2-5 cubic feet of air per square foot of filter area.

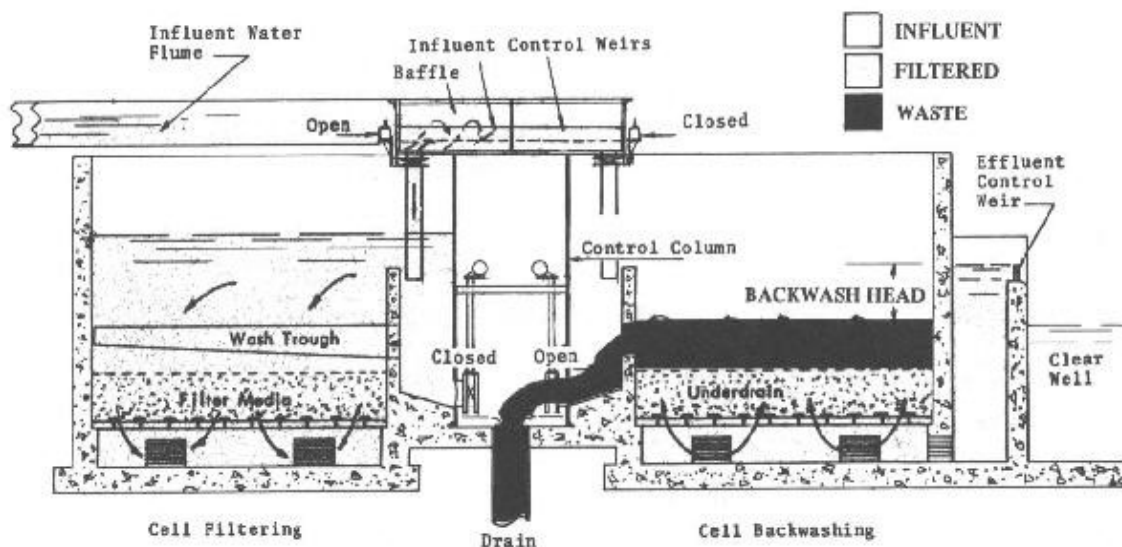
The filter should be backwashed when the following conditions have been met:

- The head loss is so high that the filter no longer produces water at the desired rate; and/or
- Floc starts to break through the filter and turbidity in the filter effluent increases; and/or
- A filter run reaches a given hour of operation.
- If a filter is taken out of service for some reason, it must always be backwashed prior to being put back on-line.

The decision to backwash the filter should not be based on only one of the above conditions. If a filter is not backwashed until the head loss exceeds a certain number of feet, the turbidity may break through and cause the filter to exceed the standard of 0.5 NTU of turbidity. Similarly, depending on filter effluent, turbidity alone can cause high head loss and decreased filter flow rate, which can cause the pressure in the filter to drop below atmospheric pressure and cause the filter to air bind and stop filtering.

If the water applied to a filter is very good quality, the filter runs can be very long. Some filters can operate longer than one week before needing to be backwashed. However, this is not recommended as long filter runs can cause the filter media to pack down so that it is difficult to expand the bed during the backwash.

The normal method for backwashing a filter involves draining the water level above the filter to a point six inches above the filter media. The surface wash is then turned on and allowed to operate for several minutes to break up the crust on the filter. After that, the backwash valve is opened, allowing backwash water to start flowing into the filter and start carrying suspended material away from the filter. For a filter with an air wash instead of a water-surface wash, the filter backwash water and the air wash should not be used together. This would be possible only if some means of controlling the media carryover is installed.



The time elapsed from when the filter wash is started until full flow is applied to the filter should be greater than one minute. After a few minutes, the filter backwash valve should be fully opened to allow full expansion of the filter media. Generally, this expansion will be 20-40 percent over the normal filter bed volume. The expansion needed will depend on how much agitation is needed to suspend the filter media to remove to suspended material trapped in the filter.

With a multi-media filter, the rate must be high enough to scrub the interface between the coal and the sand, where the highest amount of suspended solids will be removed from the media. The filter will be washed 10-15 minutes, depending on the amount of solids that must be removed. The best way to determine how long the filter should be washed is to measure the turbidity of the backwash water leaving the filter. In some cases, a filter is washed too long. This could be costly. Too much backwash water is used, and it must be treated after use. Backwash valves must be opened slowly. Opening the valves too rapidly can cause serious damage to the filter underdrain, filter gravel, and filter media.

Water from the filter backwash cannot be returned directly to the environment. Normally the water is discharged into a backwash tank and allowed to settle. The supernatant, or cleared liquid, is then pumped back to the head of the treatment plant at a rate not exceeding ten percent of the raw water flow entering the plant. The settled material is pumped to a sewer or is treated in the solids-handling process of the plant. This conserves most of the backwash water and eliminates the need to obtain a pollution discharge permit from the Minnesota Pollution Control Agency for the disposal of the filter backwash water.

Since backwash is a very high flow operation, the surges that are created from the backwash coming from the filter must not be allowed to enter the head of the plant. Therefore, the spent backwash water must be stored in storage tanks and returned slowly to the treatment process.



FILTER TO WASTE

When filtration is started after backwash, the filtered water should be wasted until the turbidity in the effluent meets standards. Depending on the type of filter, this may last from two to 20 minutes. This wasting is needed as some suspended material remains in the filter media following the backwash. The media needs to become somewhat sticky again to start to capture the suspended material. Also, the filtration rate is higher in a clean filter, causing more material to be swept from the filter during the start-up. Filtration should always be started slowly after a backwash to prevent breakthrough of suspended material.

FILTER AIDS

When water passes through a filter, the floc sometimes is torn apart into smaller particles that penetrate deeply into the filter media, causing premature turbidity breakthrough. This requires more frequent filter backwashing of the filter and large volumes of backwash water to be able to remove the floc that has penetrated deeply into the filter bed.

A filter aid is a material that adds strength to the floc and prevents its breakup. Generally, a polymer is used as a filter aid because it creates strong bonds with the floc. Polymers are water soluble, organic compounds that can be purchased in either wet or dry form.

Polymers have very high molecular weight and cause the floc to coagulate and flocculate quickly. Polymers can have positive or negative charges, depending on the type needed to cause attraction to the specific floc filtered.

When used as a filter aid, the polymer strengthens the bonds and prevents the shearing forces in the filter from breaking the floc apart. For best results, the polymer should be added just ahead of the filter. A normal dose of polymer for filter aiding will be less than 0.1 ppm, but the exact dose will be decided by the result of a jar test and by experimentation in the treatment plant. Too much polymer will cause the bonds to become too strong, which may then cause the filter to plug, especially the top few inches of the filter media.

FILTER OPERATING PROBLEMS

There are three major types of filter problems. They can be caused by chemical treatment before the filter, control of filter flow rate, and backwashing of filters.



Chemical Addition before Filter

Coagulation and flocculation stages of the water treatment must be monitored continuously. Adjustments in the amount of coagulant added must be made frequently to prevent the filter from becoming overloaded with suspended material. This overload may cause the filter to prematurely reach its maximum headloss.

If there is early turbidity breakthrough in the filter effluent, more coagulant may have to be added to the coagulation process. There may be a need for better mixing during the coagulation or the addition of more filter aid. If there is a rapid increase in filter head loss, too much coagulant may be clogging the filter. Less coagulant or less filter aid should be used. The operator needs to learn to recognize these problems and choose the proper corrections.

Control of Filter Flow Rate

When a filter is subjected to rapid changes in flow rate, the turbidity of the effluent may be affected, and the dirtier the filter media, the greater the effect.

When a plant flow changes, the filter flow also has to change to produce the water needed. If an increase is necessary, the flow should, if possible, be increased gradually over a ten-minute period to reduce the impact on the filter. Addition of filter aids may also reduce the impact on the filter effluent.

During backwashing, one of the filter cells will be temporarily out of service, and the remaining filter cells must pick up the additional flow. This can cause an abrupt change in flow that will cause turbidity breakthrough. This problem can be avoided by keeping one filter in reserve to accept this additional flow. If the plant has a backwash storage basin, this will also prevent surges to the filters.

Many plants are not operated continuously, and the start-up at the beginning of the day will cause a surge to the filter(s). The filters should be backwashed before putting them back into operation or operated to waste until the effluent meets the standards.

Backwashing of Filters

Backwashing of the filters is the single most important operation in the maintenance of the filters. If the filter is not backwashed effectively, problems may occur that may be impossible to correct without totally replacing the filter media. These problems could be caused by improper backwashing procedures:



Mud Balls

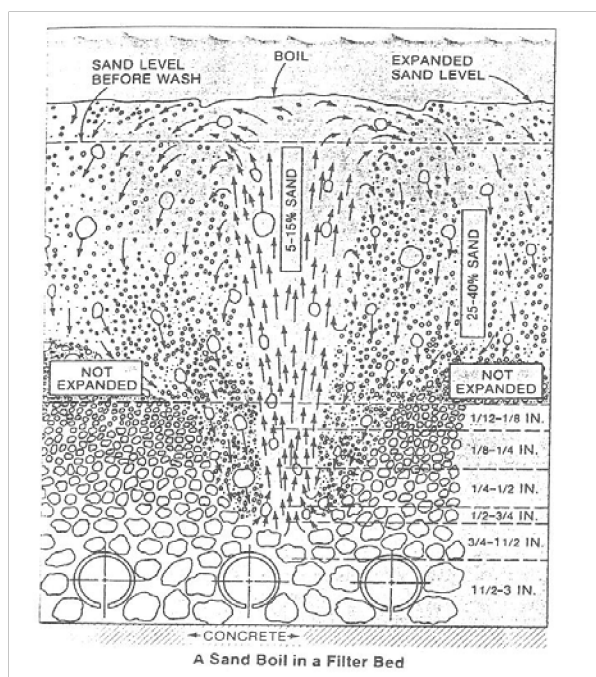
Mud balls are formed by the filter media cementing together with the floc that the filter is supposed to remove. If the filter is backwashed effectively, the mud balls are broken apart and removed. As the balls gain weight, they will settle to the bottom of the filter and occupy valuable filter volume. This will cause the flow to increase in the areas of the filter that have not been plugged. Additional problems, such as filter cracking and separation of the media from the filter walls may also be the result of mud-ball formation.

Filter Bed Shrinkage

Filter bed shrinkage or compaction can result from ineffective backwashing. Media grains in a clean filter rest directly against each other with very little compaction. Filter media in a dirty filter are surrounded by a soft layer which causes it to compact. This causes filter bed cracking and separation of the filter media from the walls of the filter. When the filter is cracked, it is obvious that the filter will short circuit. The flow will seek the crack and go straight through, resulting in excessive turbidity in the effluent.

Separation of Gravel

Separation of the gravel is caused by the backwash valve opening too quickly; as a result, the supporting gravel is forced to the top of the filter. This could also be caused by the filter underdrain being plugged, causing uneven distribution of the backwash water. When this happens, a boil occurs from the increased velocity in the filter. The filter media will start washing into the filter underdrain system and be removed from the filter. If displacement has occurred, the filter media must be removed from the filter and the filter rebuilt by the placement of each grade of media in its proper place.



Air Binding

Air binding of the filter is not common as long as the filter is washed regularly. Air binding is the result of pressure in the filter becoming negative during operation. This causes the air dissolved in the water to come out of the solution and become trapped in the filter, resulting in resistance and short filter runs. This negative head generally occurs in a filter that has less than five feet of head above the unexpanded filter bed. If a filter head of five feet is not possible, filter backwash should be started at a lower head loss than normal.

Air binding can also be caused by the water being cold and super-saturated with air. This air bubbles out as the water warms up. It is not possible for the operator to control this situation. If it happens, the filter must be backwashed more frequently to correct the filter air binding.

Media Loss

Media loss is normal in any filter. Some are lost each time the filter is backwashed, especially if the filter surface wash is used. If a large amount of media is being lost, the method of washing should be inspected and corrected. The bed should not have to be expanded more than 20 percent during the backwash cycle. It may help to turn off the surface wash approximately two minutes before the end of the backwash. If this does not correct the problem, the filter troughs may have to be raised to prevent the excessive media loss.

After a well-operated filter backwash, the filter should be level and smooth with no cracks or mud balls at the surface. A good bed will appear to move laterally during the backwash and there will be no boils at the surface. The filter should clear up evenly cleaning. If some areas are not clean, there could be an under-drain problem.