10. TURBIDITY THROUGH THE TREATMENT PROCESSES

10.1 Introduction

In the arena of public water supply, water treatment is provided to remove constituents from raw water which may pose a risk to public health or are undesirable in finished water. Turbidity is a characteristic related to the concentration of suspended solid particles in water and has been adopted as an easy and reasonably accurate measure of overall water quality. Turbidity can be used to measure the performance of individual treatment processes as well as the performance of an overall water treatment system. Common water treatment processes intended to remove suspended solids and reduce turbidity, or aid in this removal and reduction process, include:

- Raw water screening;
- Pre-sedimentation;
- Coagulation;
- Flocculation;
- Sedimentation; and
- Filtration.

This chapter provides a general description of each of these processes and information on the level of turbidity reduction that is commonly achieved through each. A typical water treatment system is shown schematically in Figure 10-1.

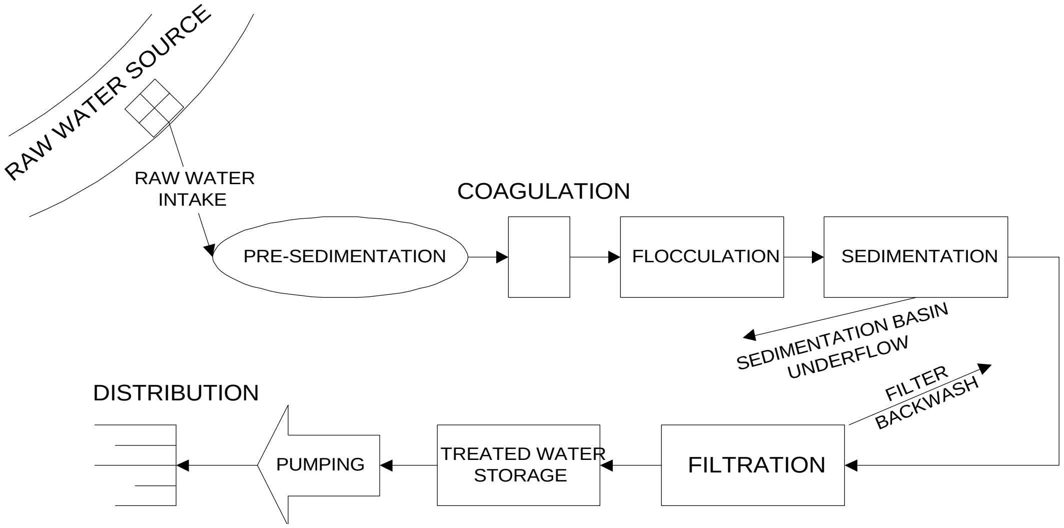


Figure 10-1. A Typical Conventional Water Treatment System

10.2 Intake Facilities/Raw Water Screening

Systems which obtain water from surface supplies such as lakes and rivers employ intake facilities to allow water to be withdrawn from the source. Most surface water intake facilities are equipped with some type of screening device to prevent large rocks, sticks, and other debris from entering the treatment system. Large bar racks with openings of 1 and 3 inches apart are commonly used for this purpose. They are designed specifically to prevent large materials that could damage the intake structure or downstream equipment from entering the treatment system. Bar racks are usually designed for manual cleaning. When the raw water source is a river and a bar rack is used, the rack is usually oriented to take advantage of the hydraulics of the river to keep the rack cleaned. Although trash racks have little effect on turbidity, they do serve an important function in keeping large solids out of the treatment system.

In other cases, intake screens are employed to perform the same function. Intake screens are generally similar to bar racks except they have smaller openings (typically 3/16 to 3/8 inch openings) and are usually equipped with mechanical or hydraulic cleaning mechanisms. Because intake screens remove particles much smaller than those generally removed with bar racks, screens may provide some turbidity reduction by removing larger solids that may be the source of smaller particles further in the treatment train.

10.2.1 Intake Location

Intake facilities are typically the very first process in the water treatment system. When the water source is a lake or reservoir, substantial "pre-sedimentation" may occur within the reservoir itself. This can serve to reduce the turbidity of water entering the treatment system as well as dampen the impact of fluctuations in source water turbidity resulting from storm events and other environmental phenomenon. If the intake facility is located away from the reservoir's water source (i.e., the river feeding the reservoir) this pre-sedimentation may substantially reduce the turbidity of the water entering the treatment system. On the other hand, if the intake facility is located near the point where the supply stream enters the reservoir, the benefit of the pre-sedimentation occurring within the reservoir can be significantly reduced or lost.

When the water source is a river, the quality of water withdrawn may be impacted by the location of the intake in relationship to sources of pollution entering the river. For example, an intake structure located upstream from a municipal or industrial wastewater discharge may supply substantially higher quality water than if it were located downstream from the discharge.

10.2.2 Intake Depth

For many lakes and reservoirs the water surface elevation varies seasonally due to environmental factors or reservoir management practices. In such cases, it is essential to be able to withdraw water from the source under a variety of different water surface level conditions. Even in cases where the source water surface elevation does not vary significantly, the intake structure may be designed to allow withdrawal from the surface, or from different levels beneath the surface. This capability can have a significant impact on the quality of water entering the treatment system. Many times stratification within a lake or reservoir exists continually or occurs on a seasonal basis. In these cases, the quality of water may vary significantly from near the surface to tens or hundreds of feet below the surface. For example, if algae growth is a problem, water withdrawn from several feet beneath the surface may have substantially lower turbidity than water withdrawn from the surface, as algae needs sunlight to survive and is typically found near the water surface.

10.2.3 Effect on Turbidity

Intake screens are not intended to reduce the turbidity of the water entering the treatment system. The solids removed by intake screens are large enough that they typically do not directly impact turbidity, though subsequent deterioration and break-up of these solids could contribute to increased levels of turbidity later in the treatment process. The physical location of the intake structure and the flexibility it provides for varying the depth from which source water is withdrawn can significantly influence the turbidity of the water entering the treatment system.

10.3 Pre-sedimentation

Pre-sedimentation is commonly used for water supplies where raw water turbidity is continually high, is high on a seasonal basis, or is high sporadically due to storms or other environmental events within the watershed. Pre-sedimentation may also be used in situations where substantial amounts of sand and gravel may be present in the source water. Depending on the purpose of the pre-sedimentation process, the pre-sedimentation basins may be relatively large settling ponds or small concrete basins. When ponds are utilized, they are generally designed to remove large quantities of silt from the raw water and typically provide hydraulic detention times ranging from a few hours to a few days. Smaller concrete basins that provide less than 20 minutes detention time are sometimes used to provide grit removal. The larger settling ponds are generally not equipped with mechanical sludge removal facilities and must be periodically cleaned by dredging or other means. The concrete pre-sedimentation basins may be equipped with mechanical equipment to remove solids from the basin bottom, or they may be designed to promote manual cleaning using a fire hose or other equipment.

When pre-sedimentation is intended to remove silt and other fine suspended solids, chemical addition is often used to enhance process performance. Organic polymers are the chemicals most commonly added prior to pre-sedimentation to enhance solids removal, but alum and ferric chloride are also sometimes used. The chemicals are added to the raw water as it enters the pre-sedimentation basin to promote solid separation.

10.3.1 Effect on Turbidity

Pre-sedimentation facility performance depends largely on facility design. Factors such as the ability to provide low velocity plug flow through the pre-sedimentation facility and the capability to add chemicals are critical to achieving optimal system performance. The characteristics of the suspended solids in the raw water also play a key role in facility performance. In cases where well-designed pre-sedimentation facilities are available and adequate hydraulic detention times are provided (generally greater than 12 hours), significant turbidity reduction can be achieved through the pre-sedimentation process.

In cases where pre-sedimentation is used primarily to remove grit from the raw water before it enters subsequent treatment processes, detention times are generally limited to 10 to 20 minutes and very little turbidity reduction is achieved.

10.4 Coagulation

Coagulation is the process of conditioning suspended solids particles to promote their agglomeration and produce larger particles that can be more readily removed in subsequent treatment processes. In many cases, dissolved organic substances are adsorbed on the surface of suspended solids particles and effective coagulation can be an effective step in their removal as well (AWWA and ASCE, 1990). The particles suspended in raw water typically vary widely in size. Typical sizes for different types of particles commonly found in water supplies can be seen in Figure 8-1.

Colloidal size particles typically carry an electrical charge (AWWA and ASCE, 1990). When the suspended particles are similarly charged, the resulting repulsive forces between particles tend to “stabilize” the suspension and prevent particle agglomeration. The process of coagulation is complex and may involve several different mechanisms to achieve “destabilization”, which allows particle agglomeration and enhances subsequent removal.

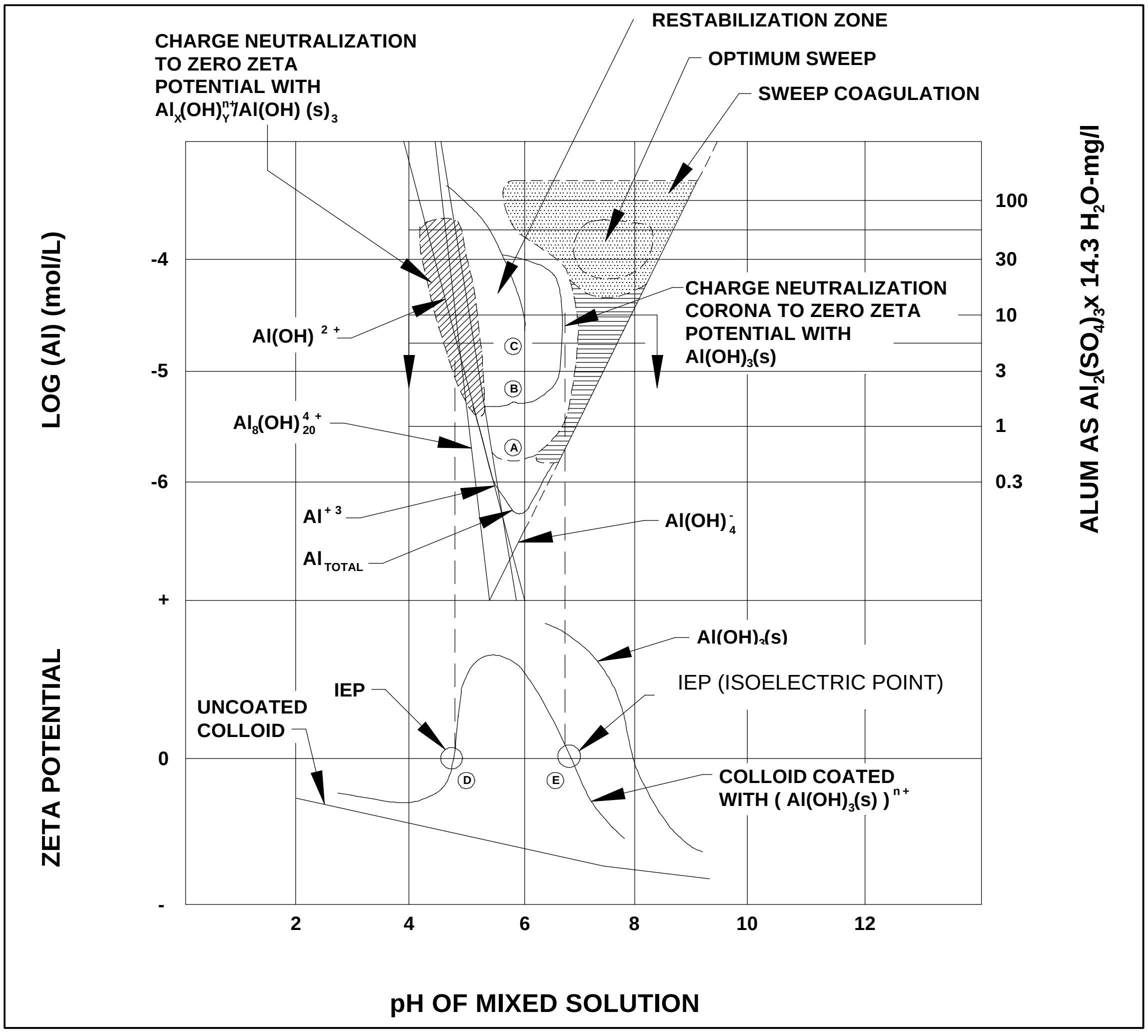
Coagulation is typically accomplished through chemical addition and mixing. Following coagulation, the processes of flocculation, sedimentation, and filtration are used to remove the “destabilized” particles from suspension.

10.4.1 Chemicals

Chemicals commonly used in the coagulation process include aluminum or iron salts and organic polymers. The most common aluminum salt used for coagulation is aluminum sulfate, or alum. Alum may react in different ways to achieve coagulation. When used at relatively low doses (<5 mg/l), charge neutralization (destabilization) is believed to be the primary mechanism involved. At higher dosages, the primary coagulation mechanism is entrapment. In this case, aluminum hydroxide ($Al(OH)_2$) precipitates forming a “sweep-floc” which tends to capture suspended solids as it settles out of suspension.

Solution pH plays an important role when alum is used for coagulation since the solubility of the aluminum species in water is pH dependent. If the pH value of a mixed solution is between 4 and 5, alum is generally present in the form of positive ions (i.e., $Al(OH)^{2+}$, $Al_8(OH)^{4+}$, and Al^{3+}). However, optimum sweep and sweep coagulation occur when negatively-charged forms of alum predominate, which occurs when the pH is between 6 and 8. Figure 10-2 depicts the solubility of some of these aluminum species present during a typical coagulation process. Figure 10-2 depicts some of the aluminum species involved in alum coagulation and the conditions of aluminum concentration and pH under which they occur (AWWA and ASCE, 1990).

When alum is used and charge neutralization is the primary coagulation mechanism, effective flash mixing is critical to the success of the process. When the primary mechanism is entrapment, effective flash mixing is less critical, and flocculation is the more important process.



Source: AWWA and ASCE, 1990.

Figure 10-2. The Alum Coagulation Diagram and Its Relationship to Zeta Potential

Ferric Chloride ($FeCl_3$) is the most common iron salt used to achieve coagulation. Its reactions in the coagulation process are similar to those of alum, but the relative solubility and pH ranges differ significantly from those of alum.

Both alum and ferric chloride can be used to generate inorganic polymeric coagulants that have been used for coagulation. These coagulants are typically generated by partially neutralizing concentrated solutions of alum or ferric chloride with a base such as sodium hydroxide prior to their use in the coagulation process (AWWA and ASCE, 1990). The resulting inorganic polymers may have some advantages over alum or ferric chloride in cold waters or in low alkalinity waters.

Organic polymers tend to be large molecules composed of chains of smaller “monomer” groups (AWWA and ASCE, 1990). Because of their large size and charge characteristics, polymers can promote destabilization through bridging, charge neutralization, or both. Polymers are often used in conjunction with other coagulants such as alum or ferric chloride to optimize solids removal.

10.4.2 Rapid Mixing

Mixing is utilized as part of the coagulation process to distribute the coagulant chemicals throughout the water stream. When alum or ferric chloride are used to achieve destabilization through charge neutralization, it is extremely important that the coagulant chemical be distributed quickly and efficiently because it is the intermediate products of the coagulant reaction that are the destabilizing agents. The life of these intermediate species is short and they must contact the solids particles in the water if destabilization is to be achieved. When other mechanisms are predominant in the coagulation process, or when organic polymers are being used as the coagulant chemical, immediate distribution of the coagulant chemical is not as critical and less intense mixing may be acceptable, or even desirable. In some cases, excessive mixing may serve to break-up coagulant molecules or floc particles, thereby reducing the effectiveness of subsequent solids removal processes.

Mixing intensity is typically quantified with a number known as the “velocity gradient” or “G value”. The G value is a function of the power input into the mixing process and the volume of the reaction basin. Typical G values for coagulation mixing range from 300 to 8000 sec^{-1} (Hudson, 1981).

The time required to achieve efficient coagulation varies, depending on the coagulation mechanism involved. When charge neutralization is the mechanism involved, the detention time required may be one second or less. When sweep floc or entrapment is the mechanism involved, longer detention times on the order of 1 to 30 seconds may be appropriate (Kawumara, 1991; AWWA and ASCE, 1998; Hudson, 1981).

10.4.3 Effect on Turbidity

Coagulation by itself does not achieve turbidity reduction, in fact turbidity may increase during the coagulation process due to the additional insoluble compounds generated through chemical addition. The subsequent processes of flocculation, sedimentation, and filtration are used in conjunction with coagulation to achieve suspended solids and turbidity reduction.

10.5 Flocculation

Flocculation is the physical process of agglomerating small particles into larger ones that can be more easily removed from suspension. Flocculation is almost always used in conjunction with, and preceded by coagulation. During the coagulation process the repulsive forces between solids particles are reduced or eliminated. Flocculation is the process of bringing the destabilized particles into contact with one another to form larger "floc" particles. These larger particles are more readily removed from the water in subsequent processes.

Flocculation is generally accomplished by mixing the destabilized suspension to provide the opportunity for the particles to come into contact with one another and stick together.

10.5.1 Slow Mixing

Mixing is a key aspect of the flocculation process. Often the intensity of mixing is reduced as the water proceeds through the flocculation process to achieve optimum performance.

At the beginning of the process, the mixing is fairly intense to maximize the particle contact opportunities. Mixing intensity values (G values) in this area are typically in the range of 60 to 70 sec^{-1} (Kawamura, 1996).

Toward the end of the flocculation process, mixing intensity is generally reduced to minimize the potential for breaking up the floc particles that have begun to form. In this portion of the process, G values are commonly in the 10 to 30 sec^{-1} range (Kawamura, 1996). Many times mixing intensity is tapered through several different stages of the flocculation process to optimize process effectiveness.

A wide variety of flocculation mixing mechanisms have been used in water treatment. These include vertical shaft mechanical mixers, horizontal shaft mechanical mixers, and hydraulic mixing systems.

10.5.2 Detention Time

The amount of time the water spends in the flocculation process is a key performance parameter. Adequate time must be provided to allow generation of particles sufficiently large to allow their efficient removal in subsequent treatment processes. The optimum particle size may vary significantly depending on the downstream treatment processes utilized. For example, when sedimentation is used, large floc particles are typically desirable because they tend to settle out of suspension readily. If filtration directly follows the flocculation process, smaller floc particles may be the most desirable since they tend to be stronger and less susceptible to break-up by the shear forces encountered within the filters. Overall detention time in the flocculation process typically ranges from 10 to 30 minutes and is generally provided in several different basins or basin segments. This allows the mixing intensity to be varied through the process.

10.5.3 Effect on Turbidity

As with coagulation, the purpose of the flocculation process is not to directly reduce turbidity or suspended solids levels, but rather to prepare the solids for subsequent removal. The reduction in number of suspended solids particles in suspension is typically achieved in the flocculation process as the smaller particles are combined to form larger ones. This process may, or may not result in a reduction in turbidity.

10.6 Sedimentation/Clarification

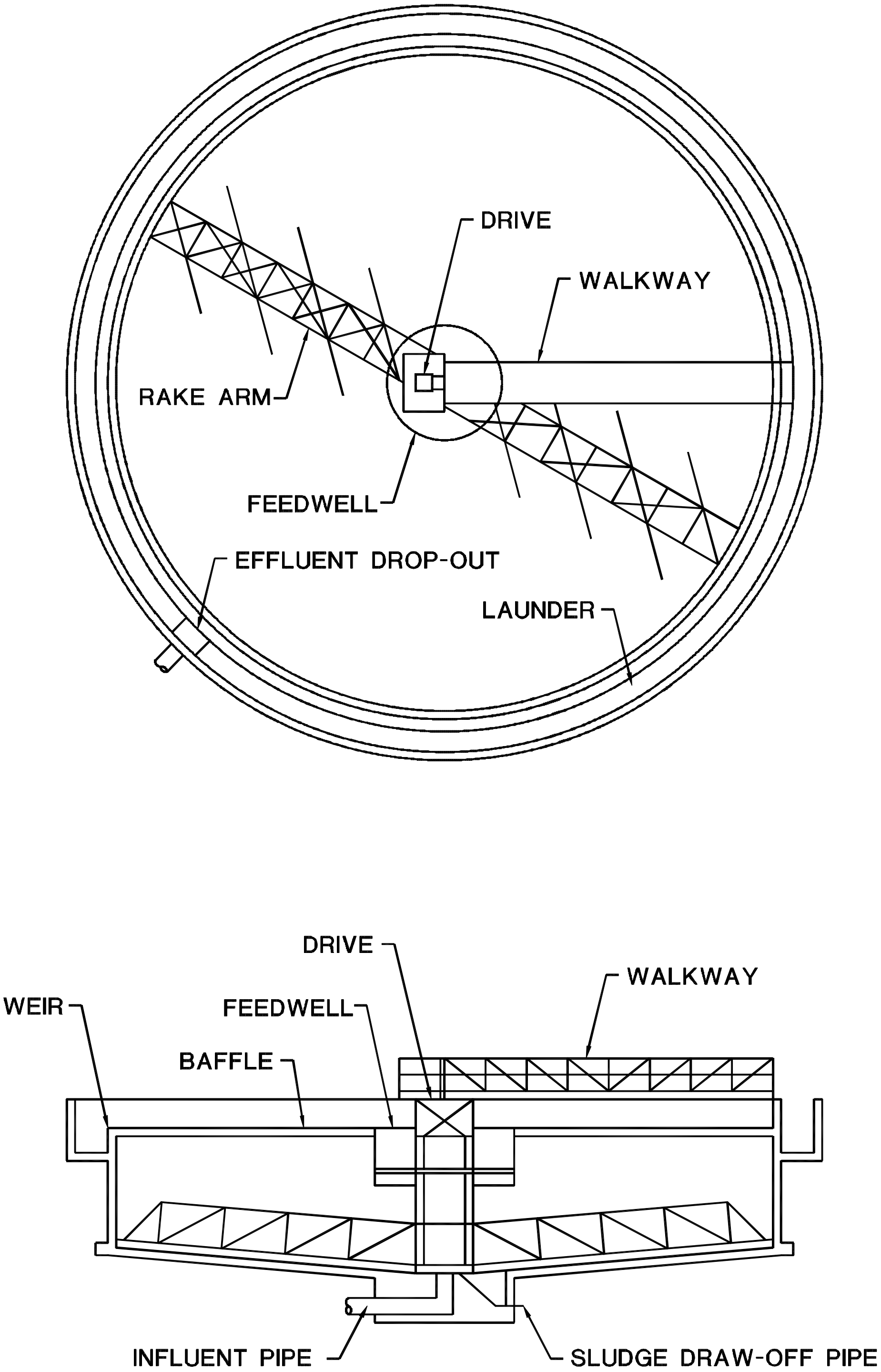
Sedimentation is the process by which solids are removed from the water by means of gravity separation. In the sedimentation process, the water passes through a basin in which relatively quiescent conditions prevail. Under these conditions, the floc particles formed during flocculation settle to the bottom of the basin while the “clear” water passes out of the basin over an effluent baffle or weir. As shown in Figure 10-3, the solids collect on the basin bottom and are removed, typically by a mechanical “sludge collection” device. The sludge collection device scrapes the solids (sludge) to a collection point within the basin from which it is pumped directly to disposal or to a sludge treatment process.

Conventional sedimentation typically involves one or more basins. These “clarifiers” are relatively large open tanks, either circular or rectangular in shape. In properly designed clarifiers, velocity currents are reduced to the point where gravity is the predominant force acting on the water/solids suspension. Under this condition, the difference in specific gravity between the water and the solids particles causes the solids particles to settle to the bottom of the basin.

High rate sedimentation is similar to conventional sedimentation except that the sedimentation basin has been modified through the addition of some mechanical or other device to aid in the settling process. These mechanical devices typically consist of plates or tubes intended to reduce the distance the solids particles must settle through the water before they reach the bottom of the basin and can be removed. Figure 10-4 illustrates a plate settler used for high rate sedimentation.

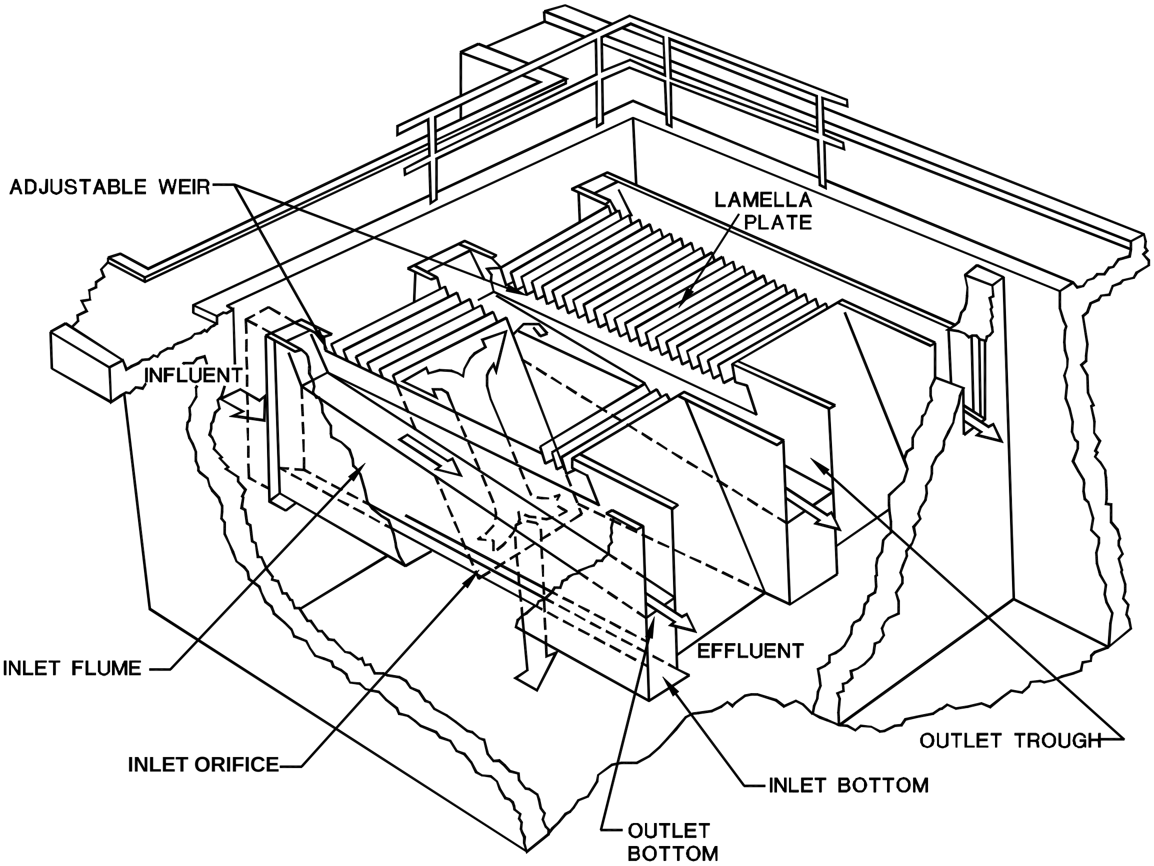
Another high rate clarification process employs an “adsorption clarifier” and is designed to provide flocculation and clarifications within a single process. These clarifiers consist of a basin filled with adsorption media, generally small particles of either plastic or rock, about the size of pea gravel. As the water passes through the media, hydraulic mixing promotes flocculation and the flocculated particles adhere to the surface of the media particles. The media is cleaned periodically using an air or air and water backwash process to remove the solids.

Solids Contact clarifiers represent an entirely different approach to high rate clarification. They consist of a basin similar to that used for a conventional clarifier but with a sludge recycle system to promote development of a dense sludge blanket as depicted in Figure 10-5.



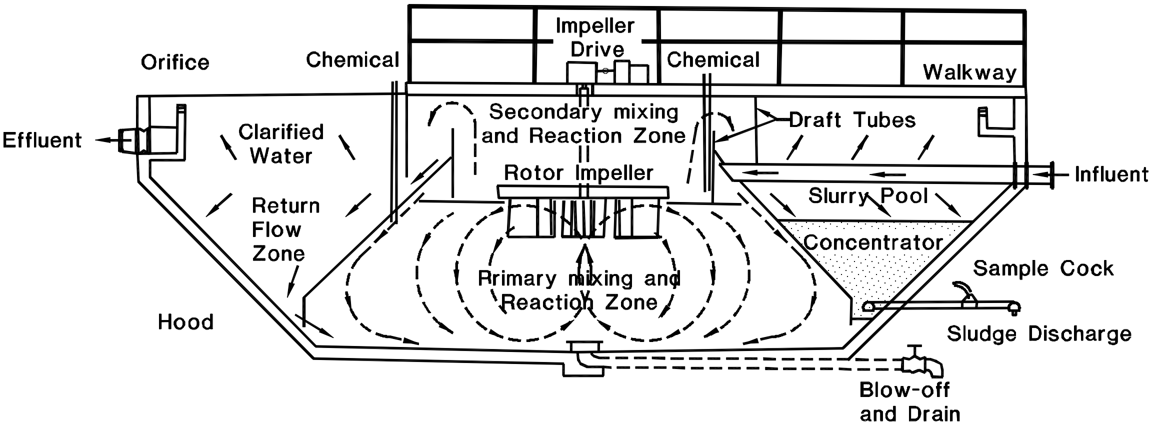
Source: AWWA and ASCE, 1990.

Figure 10-3. Circular Radial-flow Clarifier



Source: AWWA and ASCE, 1998.

Figure 10-4. Plate Settlers Used for High Rate Sedimentation



Source: AWWA and ASCE, 1998.

Figure 10-5. Accelerator Solids Contact Unit

As the water enters the bottom of the basin and passes upward through the sludge blanket, the flocculated solids in the blanket tend to contact and capture or adsorb the solids from the water.

10.6.1 Effect on Turbidity

Suspended solids removal and turbidity reduction rates achieved through sedimentation may range from about 50 to 90 percent, depending on the nature of the solids, the level of pretreatment provided, and the design of the clarifiers. Common values are in the 60 to 80 percent range (Hudson, 1981). A primary function of the sedimentation or clarification process is to reduce the load of solids going to the filters. Optimization of the clarification process will minimize the solids loading on the filters and contribute to enhanced filter performance and better overall treated water quality.

10.7 Filtration

Like clarification, filtration is a process in which solids are removed from water and substantial turbidity removal is achieved. Optimization used prior to the filtration process will control loading rates while allowing the system to achieve maximum filtration rates. In fact, filtration is the final step to achieve turbidity reduction in most water treatment operations. The water leaving the filtration process should be well within turbidity limits.

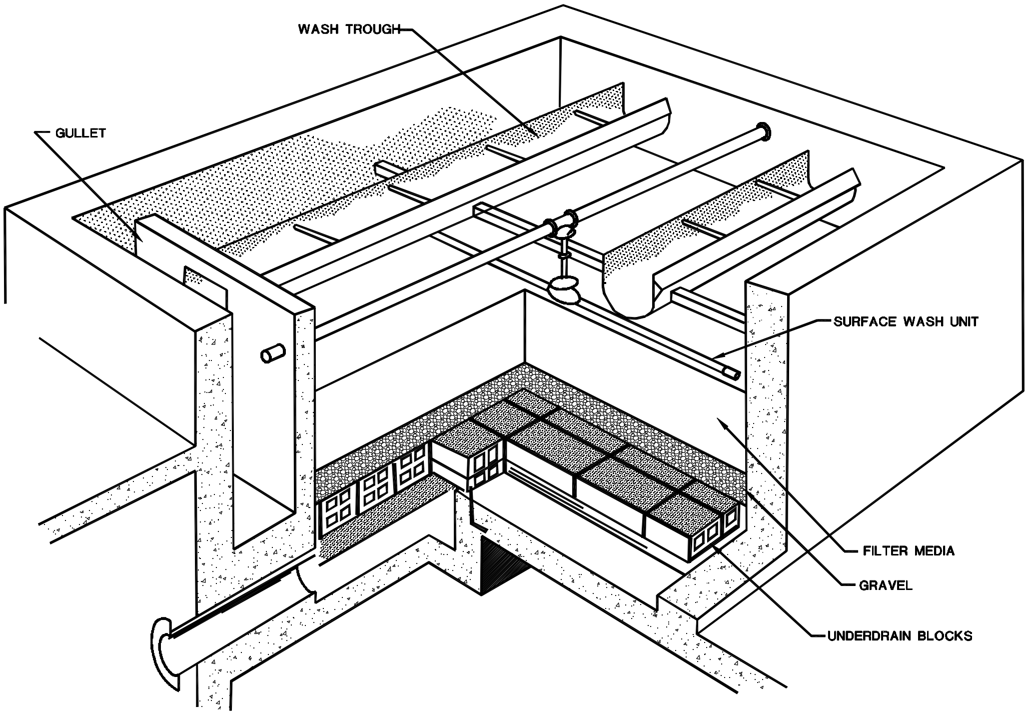
In the filtration process, the water passes through a bed of granular filter media or other filtering material and solids are physically retained on the media. After passing through the filter media, the “filtered” water is collected and removed from the filter. The solids retained on the media are also periodically collected and removed. As with the sedimentation process, the performance of most filters depends largely on the preparatory treatment processes of coagulation and flocculation. Without effective use of these processes, only marginal filter performance can be expected.

Filters are classified according to the type of media used and the operational conditions employed. The primary types of filters used in domestic water treatment include:

- Rapid Sand Filters;
- Pressure Filters;
- Slow Sand Filters; and
- Precoat Filters.

10.7.1 Conventional Rapid Sand Filters

Rapid sand filters are the most commonly used type of filters in water treatment systems today. They get their name from the type of media employed (sand) and from the rate at which they are hydraulically loaded. A sectional drawing of a typical rapid sand filter is shown in Figure 10-6.



Source: AWWA and ASCE, 1998.

Figure 10-6. Typical Rapid Sand Filter

Water enters the filter unit above the media and flows by gravity downward through the filter media to the underdrain or collection system, where it is removed from the filter. When the filter media becomes clogged with solids it is cleaned through a “backwash” process. In the backwash process water, and in some instances, air is introduced to the filter at a relatively high rate through the underdrain system. The water and air flow upward through the media, expanding the media bed and creating a scrubbing or scouring action which removes solids accumulated on the media surface and in inter-particle sites within the media bed. After passing through the media bed, the backwash water and the solids it contains are removed from the filter with a series of collection troughs.

Media

A variety of different types of media are used in rapid sand filters. As the name implies, the primary media is sand. In some cases all of the sand is the same size, but more commonly the media consists of particles of varying composition, size, and density. Filters with more than one type and size of media are referred to as dual media, mixed media, or multi-media filters, depending on the media provided. As the backwashing process in these filters concludes and the media particles settle back into position in the filter bed, the particles become stratified due to their differing sizes and densities. The largest and least dense media particles accumulate near the top of the media bed and the smallest and most dense particles migrate to the bottom. With this media stratification, when the filter is placed back into service and the water passes down through the bed of media, it first encounters large particles and then finer and finer sand until it reaches the underdrain system. This stratification tends to minimize the “blinding” effect that occurs when solid particles accumulate at the very top of the media bed. It also provides a much greater volume for solids storage within the filter bed, which allows longer filter runs between backwash operations.

The top, or coarsest layer of media is often composed of anthracite coal rather than sand. The relatively light coal remains at the top of the filter bed after filter cleaning (backwashing), even though its particle sizes are relatively large. Conversely, high density garnet sand is used for the smallest layer of filter media. The high density of this material causes it to settle quickly to the bottom of the filter bed following backwash operations, even though its particles are relatively small.

Hydraulics

Filter performance is affected significantly by its hydraulic characteristics. Typical rapid sand filter loading rates range from 2 to 8 gallons per minute per square foot of filter bed surface area. As the filter bed becomes dirty and clogged with solids, the resistance to flow increases. Ultimately flow will cease when the resistance to flow is greater that the gravitational force compelling it. As the “head” required to push water through the filter increases, the rate of flow tends to decrease and solids particles are pushed further and further into the bed of media. Ultimately, if sufficient head is available, solids will be driven completely through the bed and appear in the filtered water, a condition known as “breakthrough”. The filter run should be terminated and backwash initiated before breakthrough occurs.

Controls

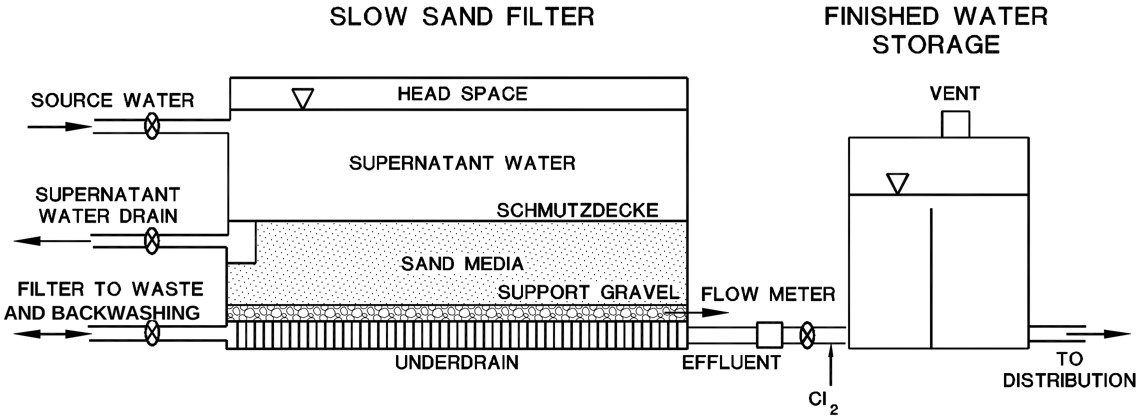
Typical filter control parameters include:

- Filter loading rate;
- Filter run length;
- Headloss;
- Filtered water turbidity;
- Backwash rate; and
- Backwash duration.

Control of these parameters gives the operator a great deal of influence in determining the performance of a filter. Often, however, there are conflicting objectives associated with filter operation. For example, the goal of maximizing water production may conflict with the objective of minimizing treated water turbidity. The operator must use good judgement in establishing operational goals and exercising process control to achieve optimal finished water quality and production.

10.7.2 Slow Sand Filters

Slow sand filters have been used for nearly two centuries and have been proven to an effective “low-tech” method of treating some waters (AWWA and ASCE, 1990). A slow sand filter consists of a bed of uniform, relatively fine grain sand underlain by an underdrain system as depicted in Figure 10-7.



Source: AWWA and ASCE, 1998.

Figure 10-7. Typical Covered Slow Sand Filter Installation

Water is introduced at the top of the bed and under the influence of gravity it passes downward through the bed to the underdrain system. Slow sand filters are loaded at much lower rates than rapid sand filters, with typical hydraulic loading rates ranging from 0.04 to 0.1 gallons per minute per square foot of filter bed area (AWWA and ASCE, 1998). Since the sand used in slow sand filters is relatively uniform in size and fine grained, most of the solids removal and turbidity reduction occurs at the very top of the sand bed. As operation of the filter continues, a layer of dirt and micro-organisms builds up at the surface of the bed. This layer is known as the “schmutzdecke” and contributes to the effectiveness of the filter in removing suspended solids and reducing turbidity. After a period of operation the headloss through the filter becomes excessive and the filter must be cleaned. Cleaning is accomplished by letting the water level drop below the top of the filter media and then physically removing the schmutzdecke along with the top 0.8 to 1.2 inches of sand. Typical slow sand filter runs between cleaning are one to six months (Kawamura, 1996).

Generally slow sand filters are not proceeded by coagulation or flocculation processes, making them one of the simplest water filtration processes available. However, relatively large land areas are required and, with their simplicity comes little operational flexibility. The only basic operational controls available to the slow sand filter operator are hydraulic loading and frequency of cleaning.

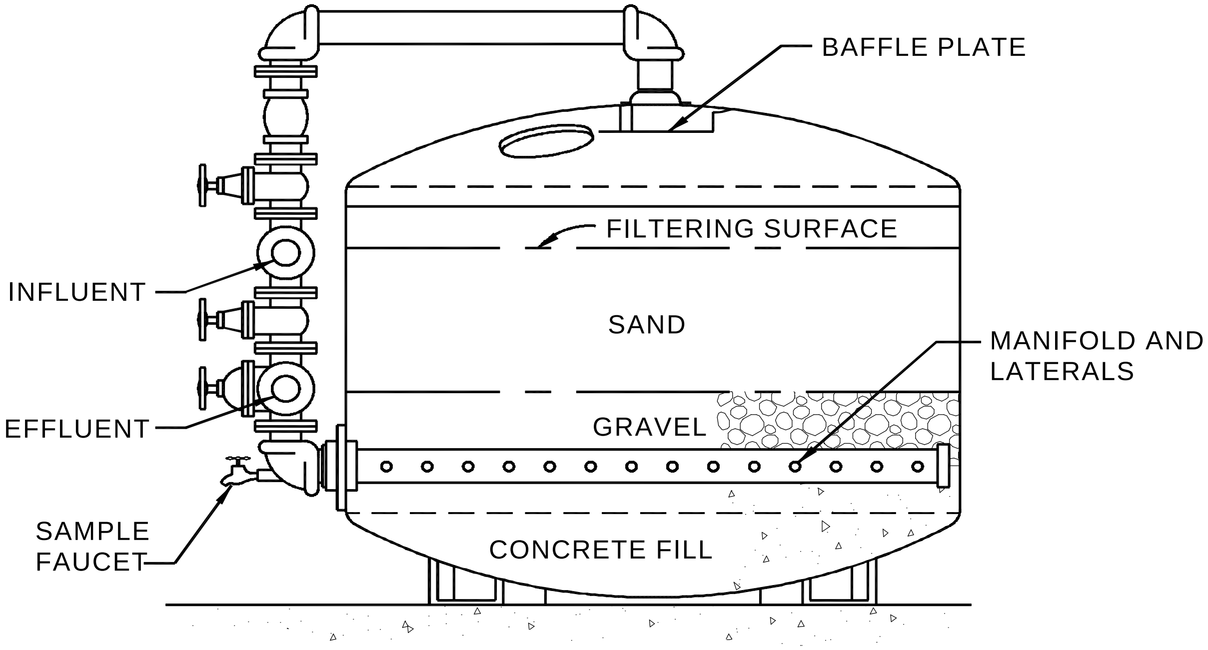
Slow sand filters can be very effective in removing suspended solids and reducing turbidity, depending on the nature of the solids particles involved, however, they have been found to be limited in their capability to remove clay particles and color (AWWA and ASCE, 1990).

10.7.3 Pressure Filters

Pressure filters are essentially a variation of the conventional rapid sand filter. They employ the same types of media and function in much the same way. The primary difference is that pressure filters are contained within a pressurized vessel, usually made of steel, and pressure is used to push the water through the filter bed rather than gravity as depicted in Figure 10-8.

Since pressure filters function much like conventional rapid sand filters, their capability to remove suspended solids and reduce turbidity is similar.

The primary advantage of pressure filters is that they do not require the vertical space for several feet of water above the filter bed and the water leaves the filter under pressure, thus eliminating the potential for air binding associated with conventional rapid sand filters. Disadvantages include the lack of access for visual observation of the filter bed and the possibly greater potential to experience turbidity "breakthrough" due to the higher pressure of force driving the filtration process.



Source: AWWA and ASCE, 1990.

Figure 10-8. Cross Section of a Typical Pressure Filter

10.7.4 Precoat/Diatomaceous Earth Filters

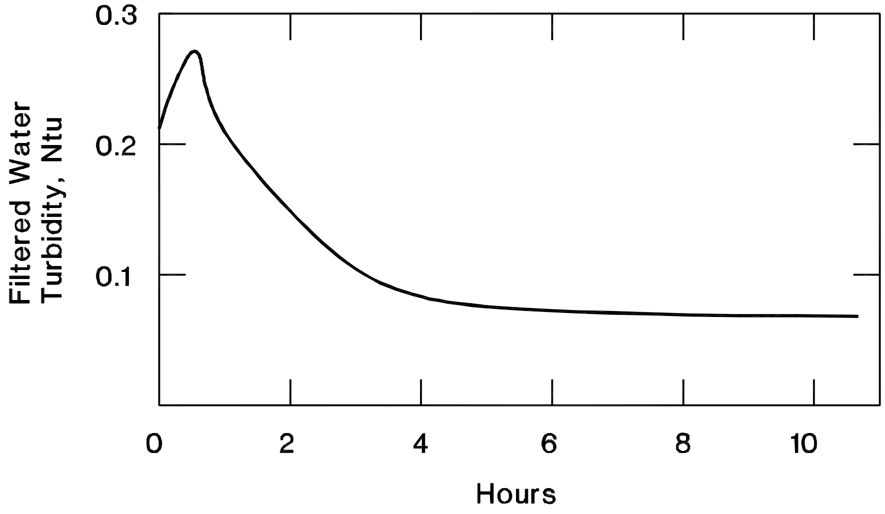
Precoat filters represent an entirely different kind of filtration mechanism. Instead of using sand or other granular material as the filtration medium, precoat filters use a thin layer of "diatomaceous earth" or similar material to form a thin layer of filter media over a supporting fabric or "septum", which in turn is supported by a rigid filter support structure. The filter coat material is applied in a slurry before the filtration cycle begins. When water passes through the filter under pressure, usually supplied by a pump but sometimes by gravity, the solids in the water are captured on the surface of the filter media. As the filtration process proceeds, additional filter media is added to the water going to the filter. This supplemental media or "body feed", like the suspended solids in the water, accumulates on the surface of the filter coat, increasing the depth of the media and preventing the surface blinding effect that would otherwise occur. When the pressure loss through the filter becomes excessive, filtration is discontinued and the filter media coat is washed off through a backwash process, a new pre-coat is applied, and the filtration process begins again.

Precoat filters have the capability to remove particles down to about one micron in size. Hydraulic loading rates are typically in the range of 0.5 to 2 gallons per minute per square foot of coated filter surface (ASCE, 1990). Advantages include relatively low capital cost and no need for the preliminary processes of coagulation and flocculation. Disadvantages include the inability to handle high turbidity water, the potential for particle pass-through if the precoat process is not effective or cracking occurs during filter operation, and the relatively poor capability to remove color and taste and odor causing compounds.

10.7.5 Effect on Turbidity

Conventional and direct filtration processes have the capability of producing water with turbidity below the proposed SDWA turbidity of 0.3 NTU and even below the 0.1 NTU Partnership for Safe Water finished water optimization goal if properly operated and maintained.

Filter performance depends largely on the characteristics of the solids particles entering the filter and on the characteristics of the filter itself. Generally treated water turbidity will be relatively high for a short period immediately following the backwash cycle of rapid sand filter operation, commonly known as post backwash turbidity spiking, but will then improve rapidly to a level near the highest quality level the filter can produce. The filter will then operate at or near this level for an extended period. Figure 10-9 shows typical filtered water turbidity as a function of filter run time.



Source: Hudson, 1981.

Figure 10-9. Typical Filter Run Showing Progress of Floc Penetration and Effluent Turbidity

A variety of strategies may be used to minimize the impact of post backwashing turbidity spikes on finished water quality. These include routing the post backwash, high turbidity, water to waste or adding organic polymers to the backwash water during the final stages of the backwash process.

The performance of other types of filters is similar to that of rapid sand filters, except that some may not experience the higher turbidity levels following filter cleaning operations.

A filter run is typically terminated after a pre-set period of time, when a certain pre-established headloss is reached, or treated water turbidity deteriorates to a set level.

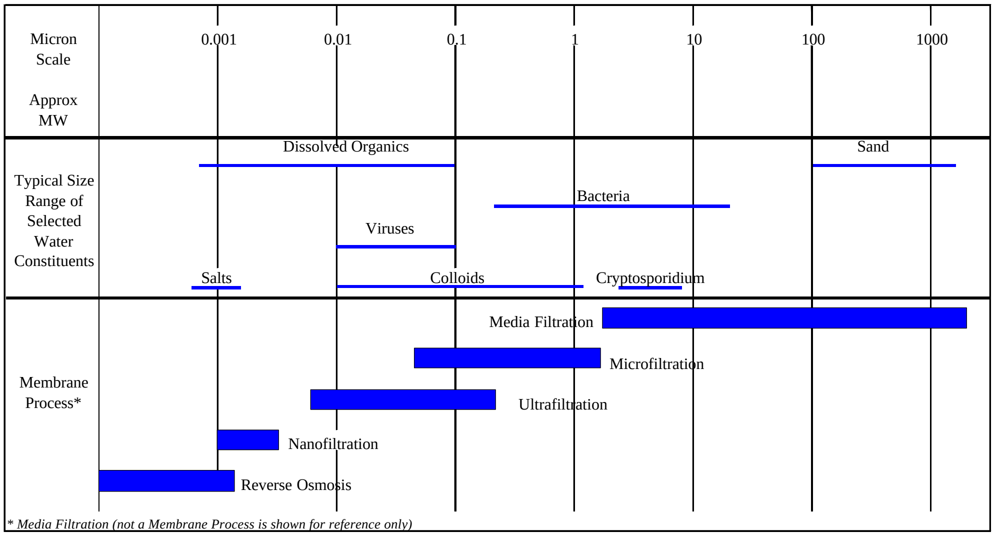
10.8 Membrane Processes

Membrane processes are processes in which the water is passed through a semi-permeable membrane to accomplish solids removal. They are much like other filtration processes except the membrane is used in place of the filter media. An additional benefit that may be realized with membrane processes is the removal of dissolved organic or inorganic constituents. Membrane technology has been in use for many years but recent technological advances coupled with increased concern for particulate removal have brought its use to the forefront of potable water treatment technology.

Membranes are made of a variety of different materials and membrane processes are typically classified according to the driving force involved and the size of particles that pass through the membrane (AWWA and ASCE, 1998). For most systems commonly used in larger water treatment operations, the water is forced through the membrane by applying pressure to one side creating a pressure differential across the membrane. The four general classifications of pressure membrane process are:

- Microfiltration;
- Ultrafiltration;
- Nanofiltration; and
- Reverse Osmosis.

Figure 10-10 shows the size of particles generally removed by these different membrane processes.



Source: AWWA and ASCE, 1998.

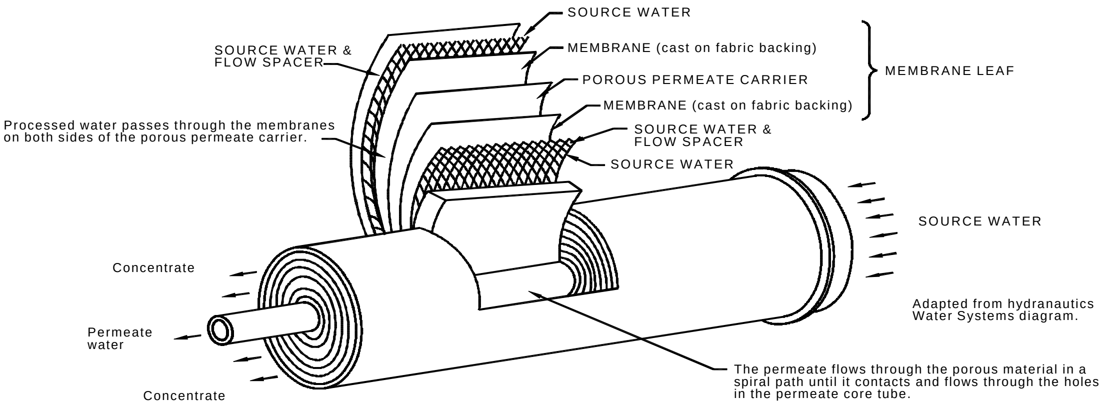
Figure 10-10. Pressure-Driven Membrane Process Application Guide

Table 10-1 provides information on the typical pressure operating ranges for the different types of pressure-driven membrane processes. Most pressure driven membrane processes utilize either cellulose acetate or synthetic organic polymer membranes (AWWA and ASCE, 1998). Standard pressure membrane configurations include spiral wound membrane units and hollow fiber membrane units. Figures 10-11, 10-12, and 10-13 show the standard membrane configurations commonly used for potable water treatment systems.

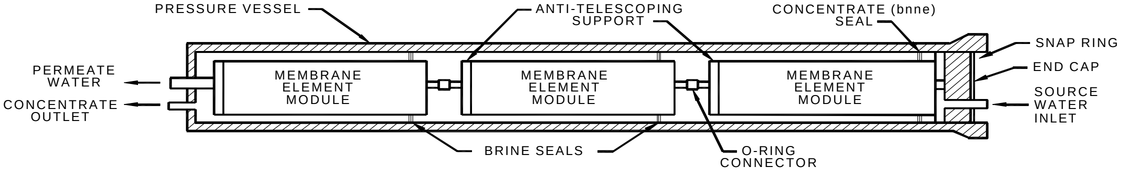
Table 10-1. Typical Feed Pressures for Pressure Driven Membrane Processes

Membrane Process	Typical Feed Pressure (psi)
Reverse Osmosis - Brackish Water Application	
Low Pressure	125 to 300
Standard Pressure	350 to 600
Reverse Osmosis - Seawater Application	800 to 1,200
Nanofiltration	50 to 150
Ultrafiltration	20 to 75
Microfiltration	15 to 30

Source: AWWA and ASCE, 1998.



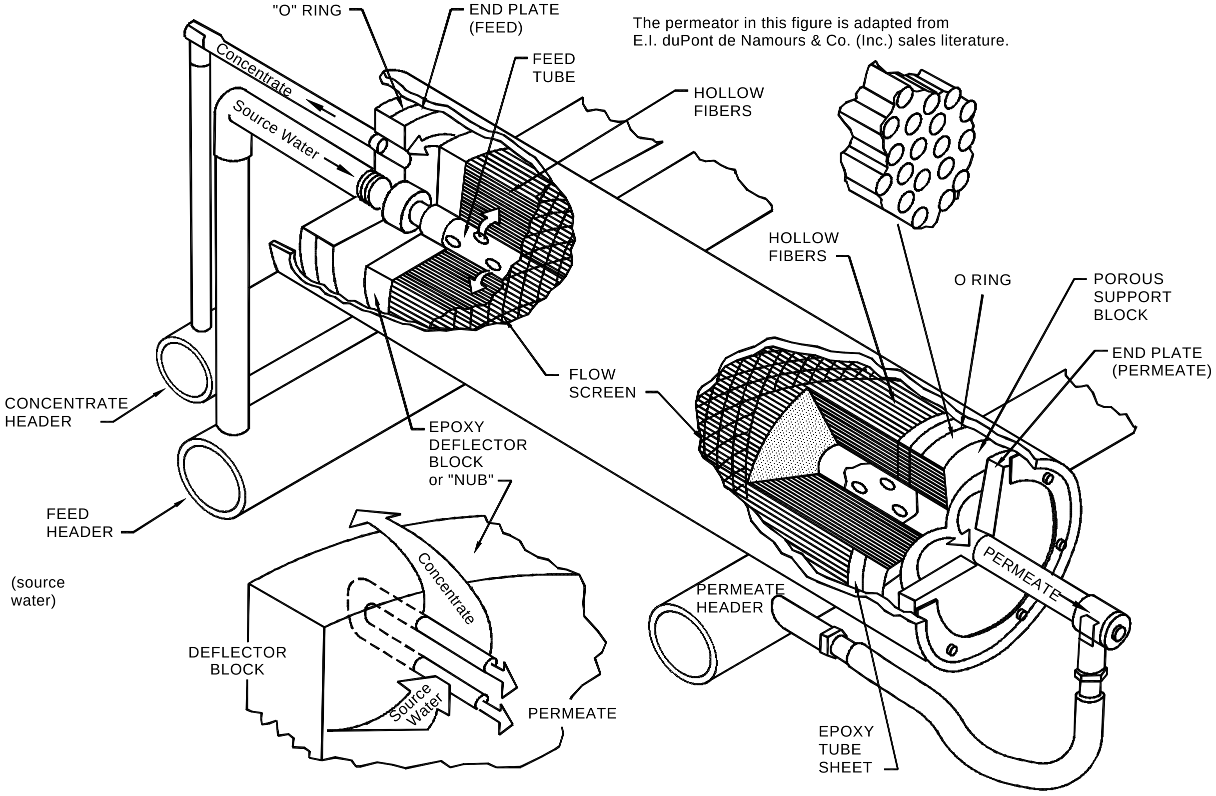
Cutaway view of a spiral membrane module



Cross section of pressure vessel with 3 membrane modules

Source: AWWA and ASCE,1998.

Figure 10-11. Typical Spiral-Wound Reverse Osmosis Membrane

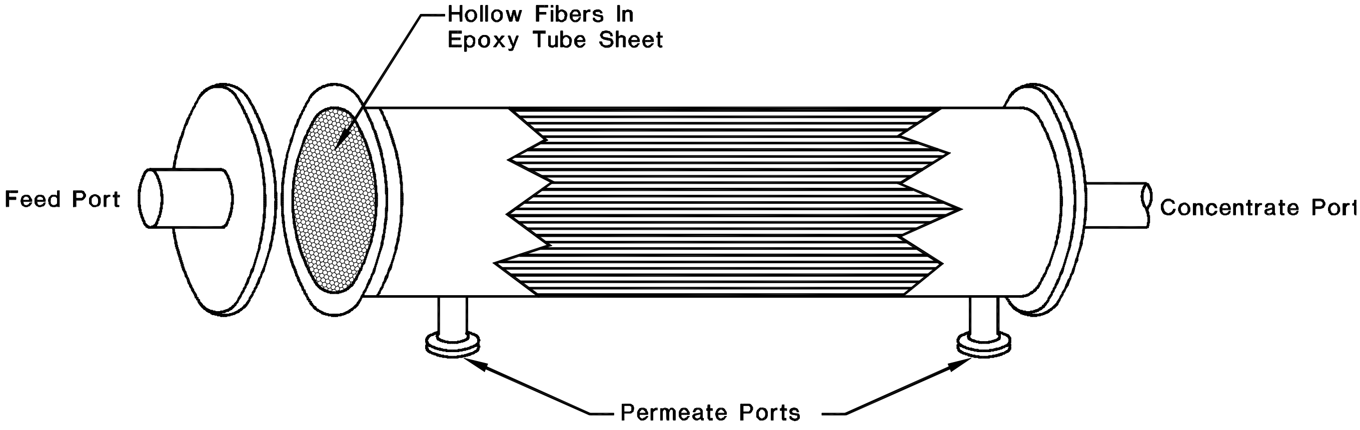


The permeator in this figure is adapted from
E.I. duPont de Namours & Co. (Inc.) sales literature.

Module Driven

Source: AWWA and ASCE, 1998.

Figure 10-12. Typical Hollow Fine-Fiber Reverse Osmosis Membrane Module



Source: AWWA and ASCE, 1998.

Figure 10-13. Representation of Hollow-fiber UF Module

10.8.1 Effect on Turbidity

Membrane systems provide a positive barrier to particles of a size larger than will pass through the membrane. Consequently, the turbidity of water produced by membrane treatment systems is usually well below 0.3 NTU. The size of particles that will pass through the membrane depends on the structure of the membrane itself. Figure 10-10 contains information on the sizes of particles removed by different types of membrane systems. As shown in Figure 10-10 all conventional membrane processes will effectively remove bacteria and other large organisms such as *Giardia* and *Cryptosporidium*. Only the more restrictive membranes are effective for removing viruses, small colloids, and dissolved constituents. Many times membrane system performance is determined not by treated water turbidity but by the level of other constituents such as total dissolved solids that may be of concern in a particular situation. Please note that this assessment is based on absolute pore sizes outlined in Figure 10-10. It does not reflect microbe pass-through resulting from nominal pore size membranes or membrane failures (e.g., rupture, seal leakage).

10.9 Recycle Streams

Recycle streams are waste streams generated during the water treatment process that are returned to the treatment train with or without prior treatment. Though they are not related to one particular treatment process, recycle streams may have a deleterious impact on treated water quality, including turbidity. Consequently, proper management of recycle streams is an important part of optimizing turbidity reduction in water treatment. Any discharges of recycle streams must comply with Federal and State regulations, including the National Pollution Discharge Elimination System (NPDES) program (40 CFR 122) and the Pretreatment program (40 CFR 403).

Waste streams may be handled in several different ways. Historically it was a common practice to discharge waste streams directly to surface waters. In some cases this may still be acceptable but state or federal regulations have largely curtailed the practice of discharging water treatment waste streams directly to surface water. If a waste stream is to be discharged to a surface water, an NPDES permit must be obtained from the appropriate permitting authority prior to any discharge occurring. Due to these new regulatory requirements, or to conserve water and reduce wastes, waste streams are now recycled by many systems, with or without treatment, or discharged to a sanitary sewer system.

10.9.1 Sources of Recycle Streams

The most common recycle streams found in potable water treatment systems include:

- Filter backwash water;
- Sludge thickener supernatant;
- Filter to waste flow; and
- Sedimentation basin underflow.

These recycle streams can represent concentrated waste flows and contain high levels of contaminants. The continued recycle of these contaminants may affect treated water quality. Impacts may include higher turbidity as well as higher concentrations of pathogens and other contaminants in the plant influent. Because of its potential impact to finished water quality, the handling of recycle streams should be carefully considered during design and upgrade of all water treatment systems.

10.9.2 Recycle Stream Quantity and Quality

The quantity and quality of recycle streams varies considerably depending on the quality of the raw water, the treatment processes employed and their efficiencies, and the type and amount of chemicals used during treatment. Generally, the composite of all waste streams generated in a conventional complete treatment system employing coagulation, flocculation, sedimentation, and filtration will be in the neighborhood of 2 to 10 percent of the total volume of water treated. Contaminants present in recycle streams may include:

- Suspended solids;
- Organics;
- Inorganics; and
- Microorganisms.

Reported quality parameters associated with sludges generated from alum coagulation include (Culp and Culp, 1974):

- BOD – 40 to 150 mg/l
- COD – 340 to 5000 mg/l
- TSS – 1100 to 14,000 mg/l
- VSS – 600 to 4000 mg/l
- pH – near neutral

Levels of *Cryptosporidium* oocysts ranging from 2,900 to 47,000 counts per mL have been reported in recycle streams from sedimentation and filtration processes after settling (Cornwell and Lee, 1994). Reported values of spent filter backwash water turbidity typically range from 30 to 400 NTU (Kawamura, 1991; Cornwell and Lee, 1993).

Waste streams generated from membrane processes such as reverse osmosis may also contain significant levels of other contaminants such as dissolved solids and salts.

10.9.3 Point of Recycle Stream Return

The point at which a recycle stream is introduced to the treatment train is also important. Recycle streams should be introduced at the plant headworks or as close to the beginning of the treatment system as possible to provide the maximum level of recycle stream treatment. The point of introduction should also be one where effective mixing is provided to thoroughly disperse the recycled flow in the raw water stream before it enters subsequent treatment processes. Studies have shown that the timing or regularity of the recycle stream introduction is also very important in determining it's impact on the performance of the treatment process (Goldgrabe-Brewen, 1995). The continuous and steady introduction of an equalized recycle stream will have much less negative impact on the water treatment process than sporadic introduction of larger volume recycle flows that vary in quantity and quality.

10.9.4 Effect on Turbidity

When waste streams are recycled they may have an impact on the amount of solids loaded to the treatment system. A model, developed by Cornwell and Lee (1993) to predict the impact of recycled spent filter backwash water on the concentration of *Giardia* cysts and *Cryptosporidium* cysts on water entering a treatment system, demonstrates the significant impact recycle streams can have on water quality, even when a relatively high level of treatment is provided for the recycle flow before it is returned to the main flow stream. The model predicts a greater than three-fold increase in cyst concentration in the water entering the treatment process as a result of the recycle practice, even when 70 percent of the cysts initially present in the recycle stream are removed through treatment. Similar impacts on turbidity can be expected.

10.10 References

1. AWWA. 1990. *Water Quality and Treatment.* Fourth Edition. McGraw-Hill, Inc.
2. AWWA and ASCE. 1998. *Water Treatment Plant Design.* Third Edition. AWWA and ASCE, McGraw-Hill, Inc, New York, NY.
3. AWWA and ASCE. 1990. *Water Treatment Plant Design*. Second Edition. ASCE and AWWA, McGraw-Hill, Inc, New York, NY.
4. Cornwell, D.A. and R.G. Lee. 1994. "Waste Stream Recycling: Its Effect on Water Quality." *J. AWWA*, 86(11): 50-63.

5. Cornwell, D.A. and R.G. Lee. 1993. *Recycle Stream Effects on Water Treatment*. AWWARF and AWWA.

6. Culp, G.L. and R.L. Culp. 1974. *New Concepts in Water Purification.* Van Nostrand Reinhold Environmental Engineering Series, Litton Educational Publishing, Inc.

7. Goldgrabe-Brewen, J.C. 1995. “Impacts of Recycle Streams on Water Quality.” Conference proceedings, AWWA Water Quality Conference, Anaheim, CA.

8. Hudson, H.E. Jr. 1981. *Water Clarification Processes, Practical Design and Evaluation*. Van Nostrand Reinhold Environmental Engineering Series, Litton Educational Publishing, Inc.

9. Kawumara, S. 1991. *Integrated Design of Water Treatment Facilities*. John Wiley & Sons, Inc.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES