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DEPARTMENT OF AGRICULTURAL ENGINEERING

CAI 334 IRRIGATION WATER QUALITY AND WASTE WATER MANAGEMENT

UNIT 3 WATER POLLUTION

3.3 WATER TREATMENT TECHNOLOGIES

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Water treatment technologies

Water treatment is any process that improves the quality of water to make it more acceptable for a specific end-use. The end use may be drinking, industrial water supply, irrigation, river flow maintenance, water recreation or many other uses, including being safely returned to the environment. Water treatment removes contaminants and undesirable components, or reduces their concentration so that the water becomes fit for its desired end-use.

Treatment systems are installed for two reasons: to remove those things that can cause disease and those things that create nuisances. The basic goal is to protect pub- lic health. However, the broader goal is to provide potable water that is safe to drink, pleasant in appearance, pleasant in taste and odor, and cost-effective to produce.

Reasons for Water Treatment

1 Aesthetics – With water, the term means pleasant in appearance, odor, and taste.

2 Health-related – Capable of influenc- ing health.

3 Odor – A quality that affects the sense of smell.

4 Turbidity – A condition in water caused by the presence of suspended matter, resulting in the scattering and absorption of light rays.

5 Color – Primarily organic colloidal

The two main reasons for treating water are

1) to remove those contaminants that are harmful to health and 2) to remove con- taminants that make the water look, taste, or smell bad. Since many contaminants harmful to health cannot be seen, smelled, or tasted, early water treatment efforts focused on mak- ing the water more appealing to the consumer or improving the aesthetic1 qualities of the water. However, with advances in modern science, our ability to detect microorganisms and very low levels of harmful chemicals

The chemical processes involved in potable water treatment include **oxidation**[15], **coagulation**[16] and **disinfection**[17]. The physical processes include **flocculation**[18], **sedimentation**[19], **filtration**[20], **adsorption**[21], and disinfection using ultraviolet light. The types of processes that are required and the order in which they are used depend on the types and concentrations of contaminants that must be removed. Examples of this include oxidation, followed by filtration or sedimentation, followed by filtration. In the first example, the oxidation process causes the dissolved contaminants to form a **precipitate**[22], which is then removed by filtration. In the second example, sedimenta- tion removes most of the solids by gravity and reduces the solids loading on the down stream filtration process.

Oxidation

Chemical oxidation is used in water treatment to aid in the removal of inorganic contaminants such as iron (Fe^{2+}), manganese (Mn^{2+}), and arsenic (As^{3+}) to improve re- movals of particles by coagulation or to destroy taste- and odor-causing compounds. Oxidation can also be used prior to coagulation, filtration, adsorption, or sedimenta- tion to improve the removal of inorganics, particulates, taste, or odor.

Oxidants

The most commonly used oxidants in small systems include chlorine (Cl_2) and potassium permanganate ($KMnO_4$). To a lesser extent, ozone and chlorine dioxide are also used for this purpose. Chlorine is supplied in gas, solid, and liquid forms; and potassium permanganate is usually supplied as a fine granular solid material that is dissolved in water. Ozone is a gas that is generated onsite using pure oxygen or air. The selection of the most desirable oxidant is dependent upon a number of factors, including process requirements, operational cost, chemical safety, and operational complexity.

Mixing

Oxidants are injected as a gas or a liquid. Mixing or diffusion of the gas or liquid into the water stream occurs very quickly; and therefore, mixing energy is rarely a sig- nificant issue for small systems. As a result, static or mechanical mixers are typically not required, although diffusers or injector assemblies are often used to enhance the diffusion of the oxidant into the water.

Coagulation

Most organic and inorganic material suspended in water and not dissolved will settle out if given enough time. However, the main materials that contribute to color and turbidity are either dissolved or too small to settle. The basic problem comes from material that is less than one micrometer (0.001 mm) in size, called colloidal material.

Colloids do not settle in a reasonable length of time due to electrical charges on their surface. At one micrometer (also stated as 1 µm) in size, the influence of the surface charges offsets gravity, and the particles stay suspended. For instance, a particle 0.01 mm in diameter will settle one foot in 33 minutes, but a particle 0.0001 mm in diam- eter (a colloid) will settle only one foot in 230 days.

There are two types of colloidal material:

- **Hydrophobic**[25] – Hydrophobic means water-fearing. Hydrophobic colloidal material is mostly inorganic material that contributes to turbid- ity and carries a negative electrical surface charge.
- **Hydrophllic**[26] –
- Hydrophilic means

water-loving. Hydrophilic colloidal material is mostly composed of organic material that is the common source of color in water. Hydrophilic compounds are surrounded by water molecules that tend to make these particles negatively charged as well.

Organic material that will pass through a 0.45 micrometer membrane filter is considered to be dissolved. These materials include humic and fulvic acids that can cause color in water and are mea- sured as **organic carbon**[27]. Total organic carbon (TOC) includes the materials that are both larger and smaller than 0.45 micrometers in size. Dissolved organic carbon (DOC) is the fraction of organic material that is smaller than 0.45 micrometers. These acids carry a negative charge.

Coagulants

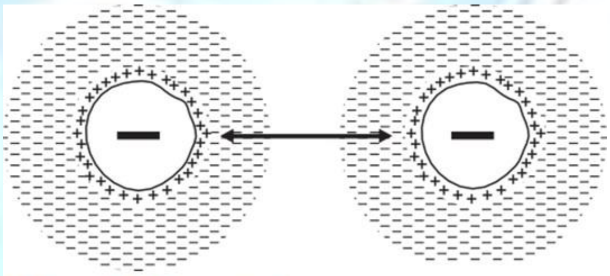
There are two opposing forces that impact the removal of colloidal material:

- Stability factors – Stability factors are those factors that help to keep colloids dispersed.
- Instability factors – Instability factors are those factors that contribute to the

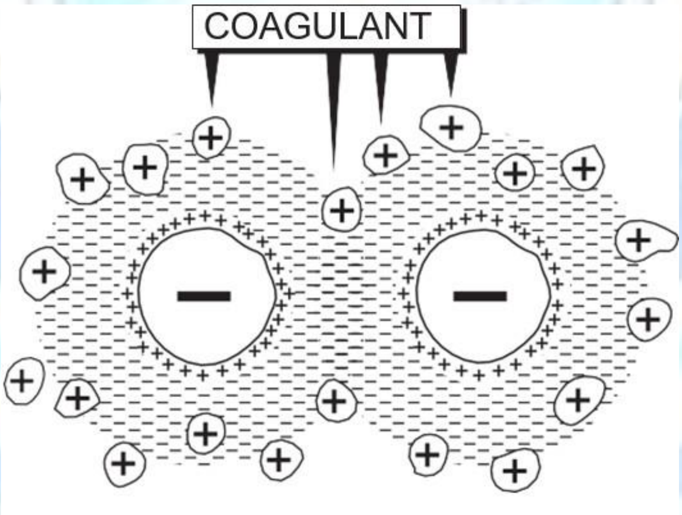
Natural removal of colloids.

The process of decreasing the stability of the colloids in water is called coagulation.

The addition of metal salts or polymers to water containing negatively charged contaminants may result in a process called coagulation. The simplest coagulation process to explain occurs between alum and water. When alum is placed in water, a chemical reaction occurs that produces positive charged aluminum ions. The posi- tively charged aluminum ions then become attached to the surface of the negatively charged colloid. The overall result is the reduction of the negative surface charges and the subsequent formation of **agglomerate**[30] (floc). This destabilizing factor is the major contribution that coagulation makes to the removal of turbidity, color, and microorganisms



Hydrophobic particles



Hydrophobic particles after coagulation

There are a number of factors that influence the coagulation process. Four of the most important are pH, turbidity, temperature, and **alkalinity**[31]. The degree to which these factors influence coagulation depends upon the type of coagulant used. When metal salts are used as the primary coagulant, these factors can have a significant affect on the performance of the chemical in removing contaminants. The performance of cationic polymers, however, is less influenced by these factors.

Polyelectrolytes, or polymers, as they are commonly called, can be used as a primary coagulant or as an aid to coagulation when metal salts are used. Polymers are long string-like (chain) molecules with charges placed along the string.

Flash Mixing/Rapid Mixing

Effective dispersion of the coagulant into the raw water stream ensures efficient and effective treatment. Flash mixing is very important when metal salts are used. Metal salts must be thoroughly dispersed into the stream within 1-2 seconds for effective treatment. The performance of polymers, on the other hand, is less influenced by flash mixing energy and is minimally affected by dispersion times as long as several seconds.

Detention Time

Appropriate detention times are required for the coagulation process to proceed to completion before the water is filtered or additional chemicals are added. The mixing energy that should be used during the reaction period depends of the type of water treatment process that is being used and the type of coagulant. Detention times on the order of 10-20 minutes are common.

Flocculation

Flocculation is a physical process of slowly mixing the coagulated water to increase the probability of particle collision. This process forms the floc. Floc is a snowflake- looking material that is made up of the colloidal particles, microorganisms, and precipitate.

Flocculants

Flocculation can occur with the addition of only the primary coagulant. However, additional chemicals can be added to improve the settling or filtering characteristics of the coagulated materials (floc). Anionic polymers are often used to aid in the forma- tion of good floc for settling. These polymers can increase the speed of floc forma- tion, the strength of the floc, and the weight of the floc. These polymers work through inter-particle bridging and rely on the presence of positive surface charges on the coagulated floc to create bonds with the negatively charged polymer chains. The op- timum dosage of the anionic polymer is directly related to the amount of coagulated material that is present in the water.

Mixing Energy

The two most common types of mixers that are used for flocculation include baffled channels or paddles. In some cases, pipelines are also used to provide flocculation.

- Baffled channel mixers rely on hydraulics to provide the necessary flocculation (mixing) energy. Flocculation energy in baffled channel mixers varies with changes in water flow rate or temperature.

- Paddle mixers provide the greatest level of operational control. The speed of the paddles can be changed to compensate for changes in water temperature, turbidity, or flow rate.

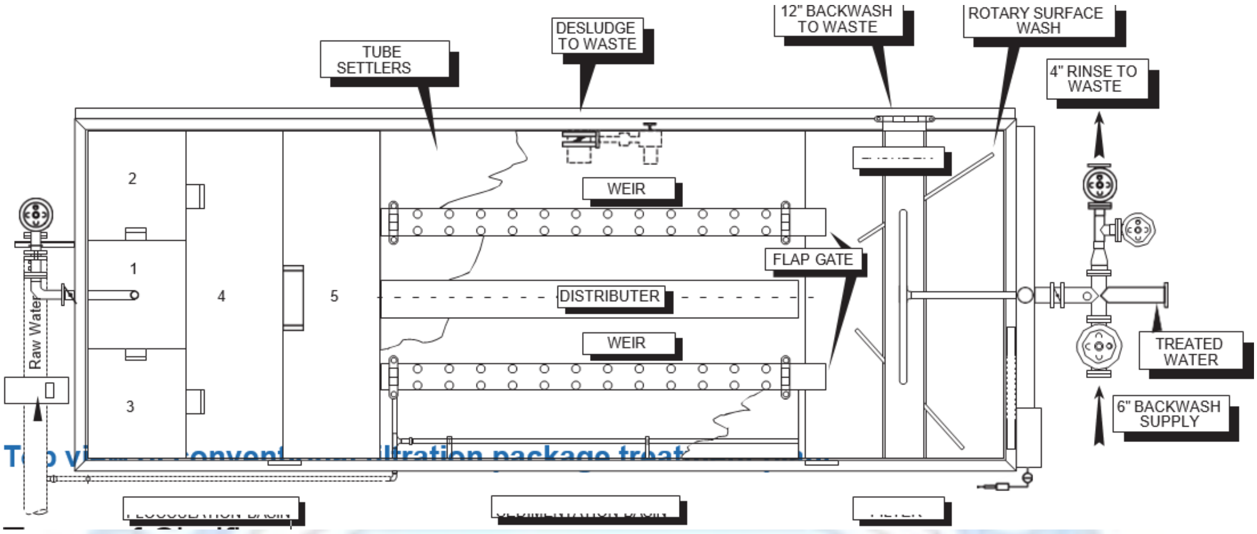
Tapered energy is critical in preparing the flocculated material for efficient filtration or sedimentation. The type of floc that is formed depends on the type of chemicals that are used and the mixing energy that is provided. Higher mixing energies form smaller denser floc that is ideal for filtering. In contrast, lower mixing energies form larger heavier floc that is ideal for settling.

Detention Time

The flocculation process requires 15 to 45 minutes of mixing. The time is based on the chemistry of the water, the water temperature, and the mixing intensity. The tem- perature is the key component in determining the amount of time required for good floc formation.

Clarification and sedimentation

Clarification of water involves removing contaminants through simple gravity sedimentation or through solids contact processes that operate in either a down-flow or up-flow configuration. The three most common types of clarifiers used in small systems include gravity sedimentation, up-flow sludge blanket clarification, or down- flow contact clarification. The down-flow contact clarification process uses large- diameter media, and the up-flow contact process may use floating media or simply the sludge blanket itself. In small systems, gravity sedimentation and sludge blanket clarification are generally proprietary systems designed and constructed as part of a conventional packaged water treatment system. Presently, contact clarifiers are more commonly custom-designed and resemble a roughing filter or prefilter in a two-stage filtration process.



Types of Clarifiers

Today, gravity sedimentation units generally incorporate tube settlers to improve removal efficiencies. Tube settlers are typically two-inch-square or oval-shaped tubes placed on a 7.5° to 60° angle in the top two feet of the gravity sedimentation basin.

The flow direction is up through the tubes. The angled tubes increase efficiency because a particle has to fall only a short distance in order to be intercepted by the sludge blanket. As water flows up through the tubes, the settled sludge moves down the tubes into the bottom of the basin.

One method of improving the efficiency of the sedimentation process is to use the sludge blanket itself as a solids contact media. In this type of clarification process, a sludge blanket is maintained in the bottom one third of the sedimentation basin. The flow of water is up through the sludge blanket. The sludge in the blanket increases the frequency of collision of the coagulated particles, and thus increases flocculation and improves solids removals. The sludge blanket works very much like a big net and is used to improve solids removals.

Aeration

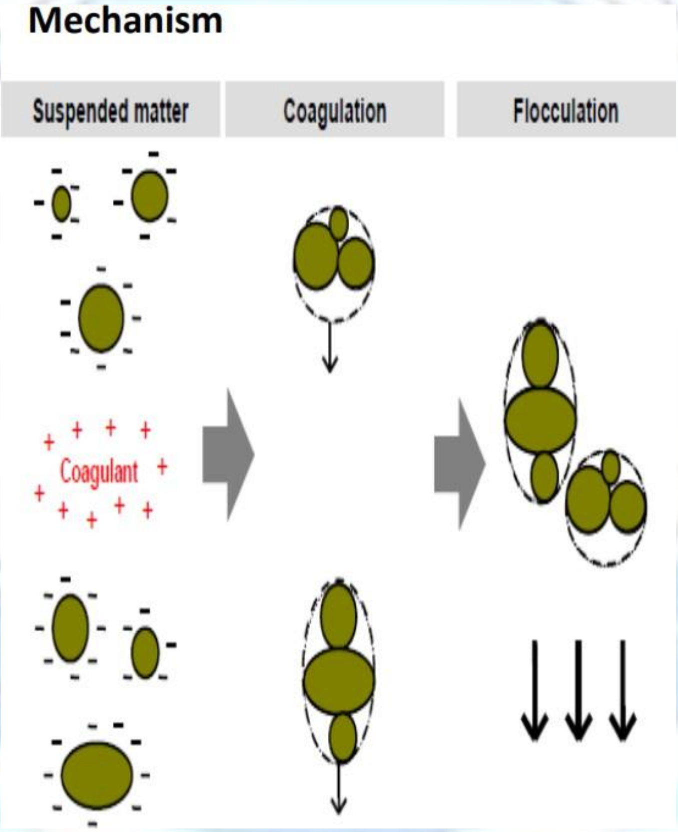
Aeration is a unit process that strips and oxidizes taste and odour causing volatile organics and gases. It also oxidises iron and manganese contained in the raw water. Some common examples are: spray aerator, diffuser, mechanical aerator and gravity aerator. Gravity aerator designs include waterfalls, weirs, cascade.

COAGULATION/FLOCCULATION

COAGULATION : A unit process. Destabilization of suspended solids and colloids neutralization of the negative charges that naturally surround these and keep them apart in order to favor the formation of micro flocs . Characteristics: ϖ Rapid mixing ϖ rapid injection ϖ short contact time (from a few seconds to ~ 2 minutes) ϖ use of coagulants (iron salts, aluminum salts).

FLOCCULATION :

A unit operation. Formation of larger flocs from colloids previously destabilized by coagulation; Aggregation of particles and colloids due to collisions induced by the motion of water (hydraulic or mechanical flocculation) Characteristics : ϖ slow mixing ϖ rapid injection ϖ contact time from 10 to 30 minutes.



SEDIMENTATION

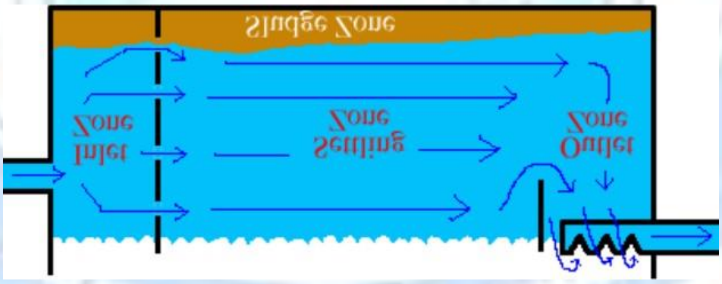
Sedimentation, or clarification, is the processes of letting suspended material settle by gravity. Suspended material may be particles, such as clay or silts, originally present in the source water. Suspended material or floc is typically created from materials in the water and chemicals used in coagulation or, in other treatment processes, such as lime softening (see Lime Softening chapter). Sedimentation is accomplished by decreasing the velocity of the water to a point which the particles will no longer remain in suspension. When the velocity no longer supports the particles, gravity will remove them from the water flow.

The process takes place in sedimentation basins that are either rectangular, square or circular. By increasing the volume of the flow channel, the flow velocity is slowed to the point where there is no turbulence and the suspended solids are allowed to settle out. This process follows the coagulation/flocculation process and is right before filtration and can effectively remove over 90% of the raw water turbidity if the coagulation/flocculation process are both functioning properly. An operator should expect the following regarding performance:

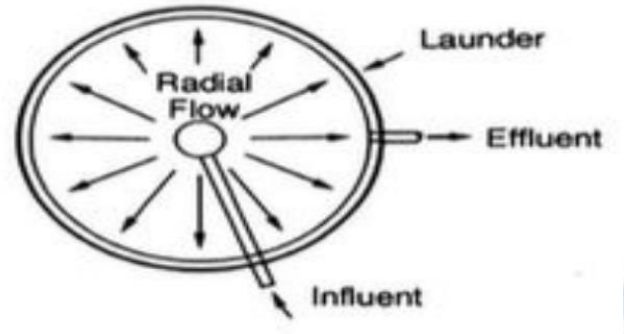
Primary Sedimentation Basins There are two main classifications for conventional sedimentation basins: rectangular and circular.

Conventional Basins

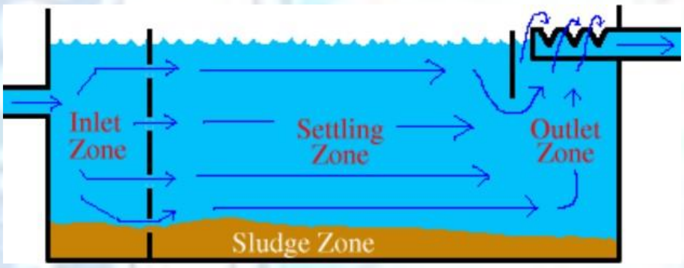
Conventional basins are rectangular or circular. Generally, they are 15 to 20 feet deep to allow proper sedimentation by keeping sludge, light floc (above the sludge), and clear water on the top well separated. Thus, carryover of the floc into the effluent is prevented. Detention time of water in these basins is 4 to 6 hours. A conventional rectangular basin is constructed of concrete or steel with a sloped floor towards the inlet. The sludge collector at the bottom scrapes sludge back to the inlet, while water flows end to end, known as rectilinear flow. Flow is evenly distributed across the basin to minimize eddies and currents that would prevent particle settling.



A circular basin has the radial flow from a central inlet. This type of basin can also be square, but operate the same. They are constructed of concrete or steel with the floor sloped towards the center where sludge is collected. Water enters the center and flows outward, this is known as a radial flow. Circular (or square) basins have inlet baffles to reduce the hydraulic energy entering the system, minimizing eddies and currents that would prevent settling.



Sedimentation Zones All sedimentation basins have four distinct zones - the inlet (influent) zone, the settling zone, the sludge zone, and the outlet (effluent) zone. Each zone should provide a smooth transition between the zone before and the zone after. In addition, each zone has its own unique purpose. Zones can be seen most easily in rectangular sedimentation basins, such as the one shown below:

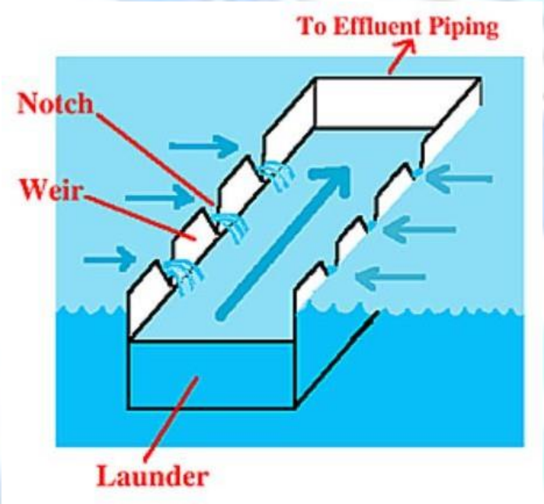


However, those same zones are in a circular clarifier as well. In a circular clarifier, water typically enters the basin from the center rather than from one end and flows out to outlets located around the edges of the basin; but the four zones can still be found within the clarifier. The effluent zone is on the outside of the settling zone, while the effluent weir goes around the entire circumference of the clarifier.

Inlet Zone The two primary purposes of the inlet zone of a sedimentation basin are to distribute the water and to control the water's velocity as it enters the basin. In addition, inlet devices act to prevent turbulence of the water. The incoming flow in a sedimentation basin must be evenly distributed across the width of the basin to prevent short-circuiting. Short-circuiting is a problematic circumstance in which water bypasses the normal flow path through the basin and reaches the outlet in less than the normal detention time. In addition to preventing short-circuiting, inlets control the velocity of the incoming flow. If the water velocity is greater than 0.5 ft/sec, then floc in the water will break up due to agitation of the water. Breakup of floc in the sedimentation basin will make settling much less efficient. Two types of inlets are shown below. The stilling wall, also known as a perforated baffle wall, spans the entire basin from top to bottom and from side to side. Water leaves the inlet and enters the settling zone of the sedimentation basin by flowing through the holes evenly spaced across the stilling wall.

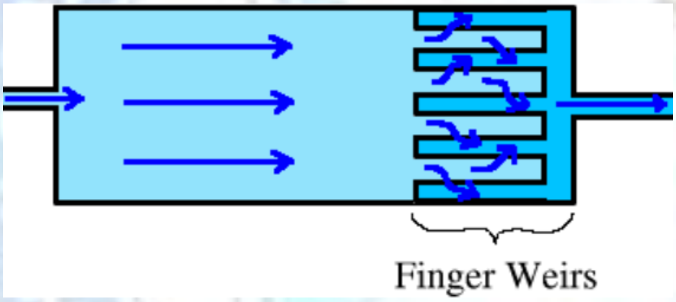
Settling Zone After passing through the inlet zone, water enters the settling zone where water velocity is greatly reduced. This is where the bulk of floc settling occurs and this zone will make up the largest volume of the sedimentation basin. For optimal performance, the settling zone requires a slow, even flow of water. The settling zone may be simply a large expanse of open water. But in some cases, tube settlers and lamella plates, such as those shown below, are included in the settling zone.

Outlet Zone The outlet zone controls the water flowing out of the sedimentation basin - both the amount of water leaving the basin and the location in the basin from which the outflowing water is drawn. Like the inlet zone, the outlet zone is designed to prevent short-circuiting of water in the basin. In addition, a good outlet will ensure that only well-settled water leaves the basin and enters the filter. The outlet can also be used to control the water level in the basin. Outlets are designed to ensure that the water flowing out of the sedimentation basin has the minimum amount of floc suspended in it. The best quality water is usually found at the very top of the sedimentation basin, so outlets are usually designed to skim this water off the sedimentation basin. A typical outlet zone begins with a baffle in front of the effluent. This baffle prevents floating material from escaping the sedimentation basin and clogging the filters. After the baffle comes the effluent structure, which usually consists of a launder, weirs, and effluent piping. A typical effluent structure is shown below:



The primary component of the effluent structure is the effluent launder, a trough which collects the water flowing out of the sedimentation basin and directs it to the effluent piping. The sides of a launder typically have weirs attached. Weirs are walls preventing water from flowing uncontrolled into the launder. The weirs serve to skim the water evenly off the tank.

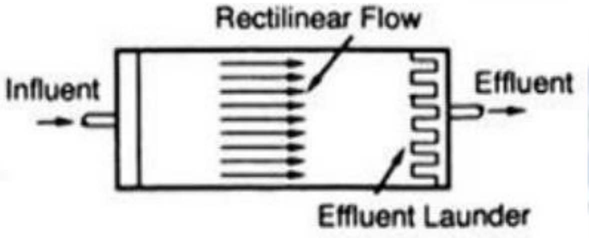
A weir usually has notches, holes or slits along its length. These holes allow water to flow into the weir. The most common type of hole is the V-shaped notch shown on the picture above, which allows only the top inch or so of water to flow out of the sedimentation basin. Conversely, the weir may have slits cut vertically along its length, an arrangement which allows for more variation of operational water level in the sedimentation basin. Water flows over or through the holes in the weirs and into the launder. Then the launder channels the water to the outlet, or effluent, pipe. This pipe carries water away from the sedimentation basin and to the next step in the treatment process, filtration. The effluent structure may be located at the end of a rectangular sedimentation basin or around the edges of a circular clarifier. Alternatively, the effluent may consist of finger weirs, an arrangement of launders which extend out into the settling basin as shown below.



Sludge Zone The sludge zone is found across the bottom of the sedimentation basin where the sludge collects temporarily. Velocity in this zone should be very slow to prevent resuspension of sludge. A drain at the bottom of the basin allows the sludge to be easily removed from the tank. Thank tank bottom should slope toward the drains to further facilitate sludge removal.

In some plants, sludge removal is achieved continuously using automated equipment. In other plants, sludge must be removed manually. If removed manually, the basin should be cleaned at least twice per year, or more often if excessive sludge buildup occurs. It is best to clean the sedimentation basin when water demand is low, usually in April and October. Many plants have at least two sedimentation basins so that water can continue to be treated while one basin is being cleaned, maintained, and inspected. If sludge is not removed from the basin often enough, the effective (usable) volume of the tank will decrease, reducing the efficiency of sedimentation. In addition, the sludge built up on the bottom of the tank may become septic, meaning that it has begun to decay anaerobically. Septic sludge may cause taste and odor problems or may float to the top of the water and become scum. Sludge may also become resuspended in the water and be carried over to the filters

The inlet valve evenly distributes the incoming water (influent) across the basin. The inlet baffle reduces the flow velocity to prepare the water for settling and to prevent short circuiting. Flow that moves from one end to the opposite end is called a rectilinear flow.



The collector drive unit moves the chain and flights in a circular manner, providing the power to move the sludge back to the influent end of the basin while also sending the surface scum to the scum trough. The scum trough is the collection point for any surface scum that the scum skimmer or flights collect. The flights are attached to a chain that rotates through the basin. The flights move the sludge to the influent end of the basin and surface scum towards the scum trough. The scum baffle prevents any floatable surface scum from passing and leaving the clarifier. The water leaving the clarifier flows over adjustable weirs which are attached to the effluent launder, which conveys the water to the next step in the process, filtration.

PARTICLE SIZE

The size and type of particles to be removed have a significant effect on the operation of the sedimentation tank. Sand or silt can be removed very easily because of their density. The velocity of the water-flow channel can be slowed to less than one foot per second and most of the sand and silt will be removed by simple gravitational forces. In contrast, colloidal material (small particles that stay in suspension and make the water seem cloudy) will not settle until the material is coagulated and flocculated by adding a chemical, such as iron salt or aluminum sulfate. The shape of the particle also affects its settling characteristics. A round particle, for example, will settle much more readily than a particle that has ragged or irregular edges. All particles also tend to have a slight electrical charge. Particles with the same charge tend to repel each other. This repelling action keeps the particles from congregating into flocs and settling.

WATER **TEMPERATURE**

When water temperature decreases, the rate of settling becomes slower. The result is that, as the water cools, detention time in the sedimentation tank must increase and the operator must make changes to the coagulant dosage to compensate for the decreased settling rate. In most cases, temperature does not have a significant effect on treatment. A water treatment plant has the highest flow demand in the summer when the temperatures are highest and settling rates are the best. When water is colder, the flow in the plant is at its lowest and, in most cases; detention time in the plant is increased so floc has time to settle in the sedimentation basin.

CURRENTS

Several types of water currents may occur in the sedimentation basin. Density currents are caused by the weight of solids, the concentration of solids, and the temperature of the water. Eddy currents are produced by the velocity and flow of the water coming into the basin and leaving the basin. Currents can be beneficial in that they promote sedimentation of the particles. However, currents also tend to distribute floc unevenly throughout the basin; as a result, do settle at an even rate. Current problems can be reduced by proper design of the basin and installation of baffles can help prevent currents from short circuiting the basin.

SEDIMENTATION BASIN ZONES

Most sedimentation tanks are divided into these separate zones:

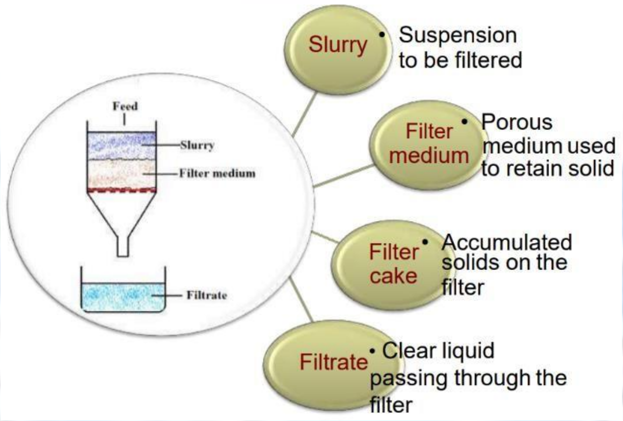
Inlet Zone The inlet or influent zone should distribute flow uniformly across the inlet to the tank. The normal design includes baffles that gently spread the flow across the total inlet of the tank and prevent short circuiting in the tank. (Short circuiting is the term used for a situation in which part of the influent water exits the tank too quickly, by flowing across the top or along the bottom of the tank.) The baffle is sometimes designed as a wall across the inlet, with holes perforated across the width of the tank.

Settling Zone The settling zone is the largest portion of the sedimentation basin. This zone provides the calm area necessary for the suspended particles to settle. Sludge Zone The sludge zone, located at the bottom of the tank, provides a storage area for the sludge before it is removed for additional treatment or disposal. Basin inlets should be designed to minimize high flow velocities near the bottom of the tank. If high flow velocities are allowed to enter the sludge zone, the sludge could be swept up and out of the tank. Sludge is removed for further treatment from the sludge zone by scraper or vacuum devices which move along the bottom.

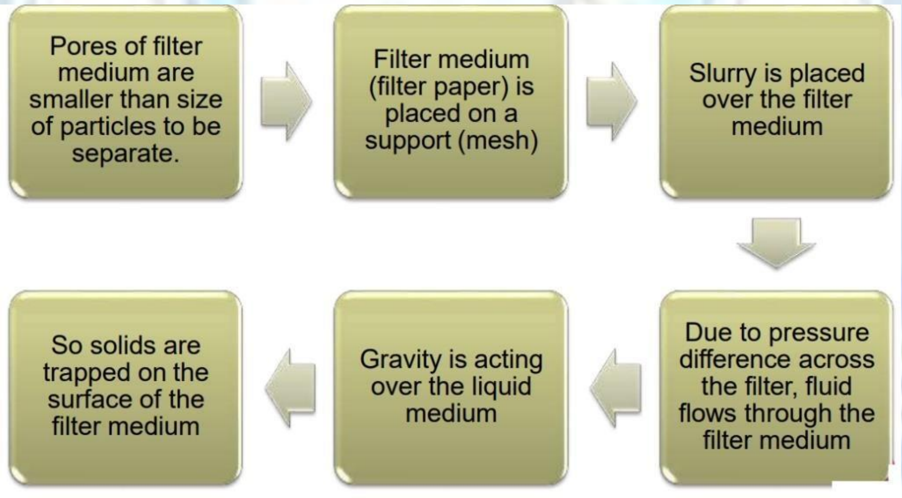
Outlet Zone The basin outlet zone (or launder) should provide a smooth transition from the sedimentation zone to the outlet from the tank. This area of the tank also controls the depth of water in the basin. Weirs set at the end of the tank control the overflow rate and prevent the solids from rising to the weirs and leaving the tank before they settle out. The tank needs enough weir length to control the overflow rate, which should not exceed 20,000 gallons per day per foot of weir.

Filtration: It may be define as a process of separation of solids from a fluid by passing the same through a porous medium that retains the solids but allows the fluid to pass through.

TERMS USED IN FILTRATION



PROCESS OF FILTRATION



TYPES OF FILTRATION

Surface/ screen filtration

➢ It is a screening action by which pores or holes of medium prevent the passage of solids.

➢ Mechanism involved : straining and impingement

➢ For this, plates with holes or woven sieves are used.

➢ Efficacy is defined in terms of mean or maximum pore size

Depth filtration

➢ In this slurry penetrates to a point where the diameter of solid particles is greater than that of the tortuous void or channel.

➢ Mechanism : Entanglement

DISINFECTION

Disinfection is a unit process that destroys disease-causing organisms in water. Disinfection can be achieved through the use of ultraviolet radiation or by application of oxidative chemicals such as ozone, iodine, and chlorine which is the most commonly used disinfectant. Granular media filtration is a process used in water treatment to remove suspended solids and other impurities from water. It involves passing water through a bed of granular media, such as sand, anthracite, or activated carbon. As water flows through the media bed, suspended particles are trapped and retained within the pores and void spaces of the media, resulting in cleaner water.

The process typically involves several stages:

1. **Coagulation/Flocculation**: Before filtration, chemicals are often added to the water to coagulate small particles into larger floc particles. These floc particles are easier to remove during filtration.
2. **Filtration**: The water passes through a bed of granular media. Depending on the size of particles to be removed and the specific requirements of the application, different media types and sizes may be used.
3. **Backwashing**: Over time, the media bed becomes clogged with trapped particles, reducing its effectiveness. Backwashing involves reversing the flow of water through the filter to dislodge and flush out trapped particles, restoring the media's ability to filter effectively.
4. **Rinse**: After backwashing, the filter is typically rinsed to remove any remaining debris and to settle the media bed before returning it to service.

Granular media filtration is commonly used in municipal water treatment plants, swimming pools, industrial processes, and in residential water treatment systems. It is an effective and widely used method for improving water quality by removing suspended solids, turbidity, and other impurities.

In the granular media filtration process, particles typically adsorb or attach to the grains of sand or anthracite in the filter. Below is a cross sectional drawing of a granular media filter. Solids removed from the water first accumulate at the surface and then penetrate into the filter bed. Water enters through the top, travels though the media, is collected in underdrain piping systems below, and eventually exits the filter and passes on to the clearwell or distribution system. As particles are removed in the media, loss of head occurs in the filter. Headloss increases due to accumulation of solids in the interstitial spaces and the corresponding increase in fluid velocity. Excessive headloss can lower the pressure within the bed allowing the release of gases from the water, `air binding'.

The fundamental system that removes particulate matter is filtration, the most common filters are composed of granular media of certain sizes and depths. The forces that typically remove particles in granular media filters include:

- Transport Mechanisms: Sedimentation--Density of particle is significantly greater than water and deviates particulate path from the water streamlines. Impaction--Inertia of particle is greater than hydrodynamic force. Interception--Particle remains in the fluid streamlines, but passes within a distance of half the particles diameter. Diffusion--Affects only colloidal particles (<1-micron) Dependent upon density, particle size, and flow velocity. Hydrodynamic--Not an important force with laminar (non-turbulent) flow, but basically particles are transported out the fluid streamlines to the surface of the media.
- Adsorption--collection of particulate matter on the surface or interface zone of media. Short range surface forces. Can only be realized if adequate destabilization has been accomplished (functions similar to coagulation).
- Absorption--taking in or absorbing contaminants. This mechanism is of little importance after the initial wetting.
- Straining--Removal of particulate by passing liquid through a media with smaller pore sizes than the particles. Relatively unimportant because most of the particles are too small to be effectively strained.

There are several types of granular media filters:

- Slow sand filters: These were the first filters used for treatment of public water supplies. They have a low loading rate (2 to 5 L/min /m^2). Most of the solids are removed by straining at the media surface and in clogged interstitial spaces in the upper layers of the sand bed (termed the Schmutzdecke by German investigators). Filter capacity is restored by removing media and replacing it.
- Rapid Sand Filters: These have a much higher loading rate of about 100 L/min /m^2. Two criteria for termination of a filter run are excessive headloss and solids penetration through the filter. At the end of the filter run the filter is taken off-line and the bed material is backwashed. The clean water is pumped back through the bed to dislodge trapped solids. There is additional cleansing of the filter media by abrasion

of particles on each other. The wash water is collected in troughs for removal and treatment or for removal and disposal.

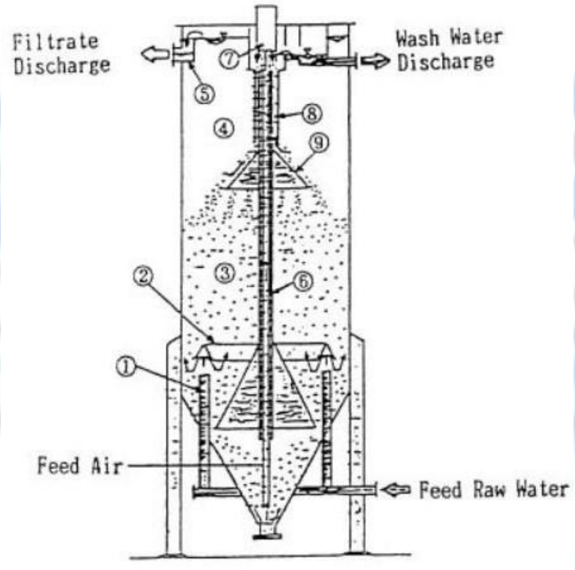
- Other filter types include: deep bed, upflow, pulsed bed dual and multimedia.

A slow sand filter consists of two or more filter beds containing 3 to 4 feet of sand placed over a gravel-supported underdrain. Most (if not all) of the materials of construction are often available locally, even in developing countries. As its name implies, a slow sand filter cannot filter a large flow of water in a small, contained filter assembly. Instead, it relies on a large surface area to filter a relatively slow flow of water (per square foot of filter area). Filtration rates of approximately 0.04 to 0.16 gallons per minute per square foot of filter surface area are typical. Therefore, a relatively large surface area is necessary to accommodate a realistic flowrate (for example, a 10-gpm flowrate requires between 60 and 250 square feet of filter surface area).

Slow sand filters can provide removal of suspended solids, turbidity, as well as microorganisms without the need for chemical addition or the use of electrical power. It will not remove all microorganisms, but removes a significant amount due to the formation of a rich biological matrix called a "Schmutzedecke." This layer consists of a wide assortment of life forms including algae, rotifers, and many other organisms. These organisms assimilate microorganisms (protozoans, bacteria and virus) thus reducing their numbers as water passes through the biologically active matrix. Slow sand filters are cleaned by draining the filter and scraping the top inch of sand (which includes the "Schmutzedecke"). However, this destroys the "Schmutzedecke" and requires a re-ripening period that can take weeks. While one filter is being cleaned, the other is on-line to continue the filtration process. In recent years, a new method of cleaning slow sand filters called "wet harrowing" has been developed that simplifies the cleaning process. Also, the creation and use of polyethylene filter vessel structures have made the task of building slow sand filters much easier.

Sand filters are used, first, for reducing the suspended solid content of the water before discharge. Secondly, they can also be used for bacterial and/or chemical removal of phosphorous and nitrogen. Carrying out these processes within the sand filter itself can do this or, if the processes are carried out earlier in the plant's process flow, the sand filter can be used to remove the flocs that they produce.

Advantages of continuous filters are: first, with the continuous filter you don't have the downtime required by backwashing. Secondly, the purchase prices of continuous filters are now competitive and, thirdly, the operating costs can actually be lower.



The filtration process begins as raw water ascends the filtration bed (3) via the raw water influent pipe (1) and raw water distributor (2). During this process, suspended solids are removed and the filtered water (4) collects at the filtrate through (5) and flows out as treated effluent.

The cleaning process is when the filter media which have caught suspended solids are sucked from the bottom of the air lift pipe (6) and cleaned while ascending together with air and water. The filter media is separated from the cleaning wastewater at the separation section (7), then further cleaned with the filtered water flowing opposite while it falls down through the special cleaner (8), and is uniformly scattered on the surface of sand layer by the sand distributor (9).

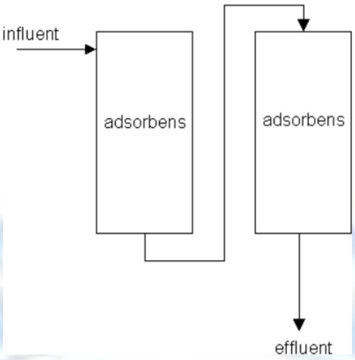
Rapid sand filter design considerations include size and uniformity of filter media which is specified using soils terminology. The effective size is the seize size in mm that permits only 10% of the media by weight to pass. The rationale for sizing filter media is as follows:

- Fine material - problems with loss during backwash - good solids removal, but excessive headloss
- Coarse material requires excessive backwash velocity, but little loss of materials during backwash

- Uniform materials deep penetration of the filter bed by solids, but a greater chance of solids break through

Adsorption is a process commonly used in water treatment to remove contaminants by attracting and adhering them to the surface of an adsorbent material. This process is particularly effective for removing dissolved organic compounds, heavy metals, and certain types of ions from water. Here's how it works:

1. **Adsorbent Material**: Adsorption typically involves using a solid material with a large surface area and high porosity, such as activated carbon, zeolites, or activated alumina. These materials have numerous pores and active sites on their surfaces where contaminants can attach.
2. **Contact Time**: The contaminated water is brought into contact with the adsorbent material, allowing the contaminants to come into contact with the surface of the adsorbent. The effectiveness of adsorption depends on factors such as contact time, concentration of contaminants, and the surface area and porosity of the adsorbent material.
3. **Chemical Interaction**: Contaminants in the water may undergo chemical interactions with the surface of the adsorbent material. This can include physical forces such as van der Waals forces or chemical bonding such as ion exchange or complexation.
4. **Adsorption Isotherms**: The relationship between the concentration of contaminants in the water and the amount of contaminants adsorbed onto the adsorbent material is described by adsorption isotherms. These isotherms help in understanding the adsorption process and optimizing treatment efficiency.
5. **Regeneration**: Eventually, the adsorbent material becomes saturated with contaminants and loses its effectiveness. At this point, the adsorbent is either replaced or regenerated. Regeneration involves desorbing the contaminants from the adsorbent material, often by washing with a desorbing agent or by heating, so that the adsorbent can be reused.



Method and installation description

Adsorption is a wastewater purification technique for removing a wide range of compounds from industrial wastewater. Adsorption is most commonly implemented for the removal or low concentrations of non-degradable organic compounds from groundwater, drinking water preparation, process water or as tertiary cleansing after, for example, biological water purification.

Adsorption takes place when molecules in a liquid bind themselves to the surface of a solid substance. Adsorbents have a very high internal surface area that permits adsorption.

Active carbon is by far the most commonly used adsorbent and is particularly suited to the removal of apolar compounds.

Other adsorbents are used for specific applications:

- Natural or synthetic zeolites (alumina-silicate-polymers)
  - Have a very homogenous pore distribution and polar bonding sites. Zeolites are a lot more selective than active carbon;
- Natural clay minerals
  - used for the adsorption of very polar organic and inorganic matter (ions);
- Silica gel and activated aluminium
  - Very polar adsorbents with large affinity for water – normally used to remove water from an apolar medium;
- Silicic acid

Active carbon can be made from wood, charcoal and coconut. Each type is characterised by a specific surface, grain size and pore diameter. Active carbon can be used in powder form, granular form or in impregnated form.

In powder form, active carbon is added to aerobic and anaerobic wastewater purification systems or is added to physico-chemical wastewater purification processes. In this case, the added active carbon is removed and treated together with the produced sludge.

Active carbon in grains or pellets is normally used in open or closed filters. Closed filters are used in most industrial applications. They are designed so that the to-be-treated liquid is pumped through the filter and over the active carbon under pressure. Open filters are primarily used in drinking water applications, where the water flows through the active carbon beds under the force of gravity. An industrial active carbon normally consists of two columns. Both columns feature a downward flow. In time, the carbon becomes saturated and reduces the effectiveness of the filter until it stops adsorbing. After saturation, the carbon can be thermally regenerated. This takes place in a reactivation oven at high temperature. The adsorbed organic compounds are destroyed during this process. Thereafter, the carbon can be redeployed.

Active carbon can be chemically impregnated to improve its activity. Impregnated carbon was specifically developed to capture chemical substances that are normally difficult to absorb with standard activated carbon. Impregnation can be done using COH, K_2CO_3, H_2SO_4 and sulphur for the removal of organic sulphides, ammoniac and amines.
An adsorption installation with adsorbents other than activated carbon normally consists of two columns, which also become saturated in time. Zeolites and adsorbents that adsorb inorganic matter are regenerated using chemicals (e.g. NaCl solution for zeolites).

Specific advantages and disadvantages

Active carbon adsorption is a proven and much used technique because of the low energy and maintenance costs, the simplicity and the reliability. An active carbon column requires a limited amount of supervision and maintenance.

There is less experience with adsorption using other adsorbents, than there is for active carbon adsorption.

The effectiveness of the adsorption treatment is determined by the type of substance to be removed. Substances with a high molecular weight and low water solubility are better adsorbed with active carbon. The concentration of the to-be-removed substance, the presence of other organic components, temperature, pH and the set-up design also influence the effectiveness of adsorption. Realistic load factors for active carbon vary between 10-30%. The load factor for other adsorbents is lower (1-5%). This means a large column and large adsorbent quantities are needed. This results in high investment and operational costs. An advantage of using other adsorbents is that they are more specific and remove other substances than active carbon.

Application

Active carbon filtration

Adsorption with active carbon is often used as tertiary purification for the removal of organic micro-pollutants and COD, and metals in organic complexes to a lesser extent, from wastewater.

Disinfection is a crucial step in water treatment processes aimed at killing or inactivating pathogenic microorganisms, such as bacteria, viruses, and protozoa, to make water safe for human consumption. Several methods are employed for disinfection, each with its advantages and limitations. Here are some common disinfection methods:

1. **Chlorination**: Chlorination involves the addition of chlorine-based compounds, such as chlorine gas (Cl2), sodium hypochlorite (NaOCl), or calcium hypochlorite (Ca(OCl)2), to water. Chlorine is highly effective at killing a wide range of microorganisms by disrupting their cellular functions. It is widely used in municipal water treatment due to its effectiveness, residual disinfection properties, and relatively low cost.
2. **Chloramines**: Chloramines are formed by the reaction of chlorine with ammonia. Monochloramine (NH2Cl) and dichloramine (NHCl2) are commonly used as disinfectants in water treatment. Chloramines provide longer-lasting residual disinfection compared to free chlorine and are less reactive with organic matter, reducing the formation of disinfection by-products (DBPs).
3. **Ozonation**: Ozone (O3) is a powerful oxidizing agent that is used for disinfection in water treatment. It is generated on-site using ozone generators and injected into water. Ozone destroys microorganisms by oxidizing cellular components, disrupting their structure and function. Ozone treatment is effective against a wide range of microorganisms and has the advantage of producing fewer harmful disinfection by-products compared to chlorination.

4. **UV Radiation**: Ultraviolet (UV) radiation is used to disinfect water by exposing it to UV light of specific wavelengths (usually around 254 nm). UV light damages the genetic material of microorganisms, preventing them from reproducing. UV disinfection is chemical-free, does not alter the taste or odor of water, and is effective against bacteria, viruses, and protozoa. However, it requires adequate contact time and does not provide residual disinfection.
5. **Chlorine Dioxide**: Chlorine dioxide ($ClO2$) is a highly effective disinfectant that is used in water treatment. It is usually generated on-site and applied to water as a gas or solution. Chlorine dioxide destroys microorganisms by oxidizing cellular components and disrupting their metabolic processes. It is effective over a wide pH range, produces fewer disinfection by-products than chlorine, and remains active in the presence of organic matter.

The choice of disinfection method depends on factors such as the nature of the water source, the level of contamination, regulatory requirements, and operational considerations. Often, multiple disinfection methods are used in combination to achieve the desired level of microbial control and ensure water safety.
Killing, removal, or deactivation of harmful microorganisms can be referred to as disinfection. Destruction or deactivation of pathogenic microorganisms results in stopping their reproduction and growth. People may fall ill by consuming the contaminated water containing the pathogenic microorganisms. Disinfection and sterilization are interrelated processes, but sterilization kills all the harmful and harmless microorganisms. Hence, disinfection is a more appropriate process.

Methods of disinfections

.Chlorine Gas

Chlorine is a greenish-yellow gas. By providing high pressure, the gas becomes liquid. It is toxic. Chlorine gas is mostly used as a water disinfectant. Introducing chlorine to water plays a very effective role for removing almost all pathogenic microorganisms. It can be used both as a primary and a secondary disinfectant. The gas is not applicable to be used in household system as it is very dangerous. It is lethal at concentrations as low as 0.1% air by volume

. Advantages

Chlorination is a cheaper source than UV or ozone disinfection methods used to treat water.

It is very effective against a wide range of pathogenic microorganisms.

Dosing rates are controlled easily as they are flexible.

The chlorine residuals left in the wastewater effluent can make the disinfection process longer even after initial treatment. They can be further used to evaluate the effectiveness

Limitations

Although chlorine gas is used in large-scale water distribution treatment plants and networks as a best method for treating water, still it have various limitations. These limitations might affect the applicability to a point of use (POU) treatment system. Objections against chlorination are because of the esthetic, logistic, and health-related concerns.

Regarding esthetic level, chlorination might be rejected as it imparts bad tastes and odors to the water. The developed countries might teach their people about the good impacts of chlorination; however, less-developed countries lack this ability.

Limitations in using chlorine gas in a household context might include the distribution, procurement/manufacturing, dosing of chlorine, and accurate handling. The health hazards caused by chlorine are not only confined to its volatile nature. A great concern might be the byproducts and incompletely oxidized compounds present in chlorinated water that increases its toxicity. The most notorious byproducts of chlorination are chloro-organics and trihalomethane (THMs). Humic and fulvic acids are present in the water. When chlorine reacts with these acids, trihalomethane are formed. It has been identified in many studies that some of these chloro-organics are mutagens, toxins, or carcinogens. The well-known THM chloroform is an animal carcinogen. Some guidelines have been set by USEPA (United States Environmental Protection Agency) that THMs should not be greater than 0.10 mg/l. The high concentrations of THMs will lead to health complications [1].

Process

Chlorine readily combines with all the water components, i.e., chemicals, small animals, microorganisms, plant material, odors, colors, and tastes. Sufficient quantity of chlorine is necessary to meet with the demand of chlorine in the water and provide residual disinfection.

Residual (free) chlorine is termed as the one that does not combine with other water components. The point at which free chlorine is available for continuous disinfection is termed as the breakpoint. The system at which free chlorine is supplied at a concentration of 0.3–0.5 mg/l is an ideal system. Simple test kits, most commonly the DPD (N,N-diethyl-p-phenylenediamine) colorimetric test kits are available for testing breakpoint and chlorine residual in private systems. The kit must test the amount of free chlorine, not total chlorine

Equipment

This consists of 908 kg (2000 lb) or 68 kg (150 lb) containers, weigh scales, chlorinator, injectors, switchover modules, vacuum lines, booster pumps, solution lines, diffusers, and a flow meter. Safety requirements are passive ventilation, mechanical ventilation, warning alarms and devices, showers, panic hardware for doors, and eye washes. A separate air tight room for chlorination equipment is mandatory. For disinfection process, 100% of chlorine gas is available .

Chemical

Chlorine can be used as liquid or gas form. It is a very strong, oxidizing agent. Both the forms (liquid and gas) can be stored and used from gas cylinders under pressure. The chlorine cylinders can be 150 pounds. Small drinking water systems commonly use cylinders of 150 pounds.

Hypochlorous and hypochlorite ions are formed when chlorine is mixed with water. The hypochlorous ion is a better disinfectant which is formed in greater concentration at low pH concentrations. The hypochlorite and hypochlorous ions will be present in equal concentrations at pH 7.3. At pH above 8.3, the hypochlorite ion predominates which is not a better disinfectant. So, better disinfection is achieved at low pH. To avoid the formation of trihalomethanes and haloacetic acids, chlorination should be applied after treatment

Chlorination by gas method.

Chlorination (sodium hypochlorite solution)

Sodium hypochlorite is used as a bleaching agent, mostly to bleach papers or textiles, and as a disinfectant in solution. The solution generally contains 10–15% of the available chlorine, but rapidly loses its force in storing process. Regular controlled environment is needed as the solution is affected greatly by the pH, light, heat, and heavy metals

Advantages

Sodium hypochlorite can also be used as a disinfectant.

Both sodium hypochlorite and chlorine gas shows similar disinfection effectiveness.

As compared to chlorine gas, sodium hypochlorite disinfection reduces the hazards in storing and handling.

No hazardous chemicals are used in onsite generation. Only softened water and high grade salt (NaCl) is used.

Limitations

NaOCl can be commercially supplied or generated on-site, the latter being the safer of the two methods for handling reasons. In on-site generation, salt is dissolved with softened water to form a concentrated brine solution that is subsequently diluted and passed through an electrolytic cell to form sodium hypochlorite. Hydrogen is also produced during electrolysis, and it needs to be vented because of its explosive nature

Process

These dosing systems are mostly simple, but there might be a concern regarding the design. The design might influence the control of gas release from the bulk hypochlorite in dosing pumps and piping and scale formation. Gasification (mostly produces oxygen) can lead to vapor or gas bubbles’ formation, specifically if sodium hypochlorite is below the atmospheric pressure, which leads to gas locking of the suction line in a diaphragm. Pumps should therefore be provided with flooded suction. Tanks must be properly vented out of all structures to the atmosphere.

Most commonly available dosing systems use diaphragm metering pumps. The pump action can lead to the development of vacuum. The vacuum causes the vaporization of the dissolved gases in the sodium hypochlorite, resulting in the pump losing its prime and a lower applied chlorine dose.

Consequently, to aid in the prevention of gasification, the dosing arrangements must have a positive head on the pump suction (with pump inlet always below the minimum tank liquid level). In addition, piping system configurations which will trap sodium NaOCl between two closed isolation valves or check valves should be avoided.

A calibration cylinder, a pulsation damper, a pressure relief valve, and a loading valve are the main components of a dosing system. Automatic auto-degas valves systems are also provided by some dosing pump suppliers. NaOCl is dosed either through a spreader bar submerged within an open channel or through an injection fitting (pressurized pipes). The pulsation damper and the dosing pump should be placed close to each other. Pulsation damping also helps in improving dispersion. A loading valve should also be provided in systems where the back pressure at the pump delivery side is not sufficient (<0.7–1.0 Bar), till a suction demand valve is installed on the suction side.

For protecting the diaphragm from rupturing, a PRV (pressure relief valve) should also be provided on the delivery side of the pump. PRV’s operation must be detected and alarmed: e.g., the outlet of the valve could be directed to a small “catch-pot,” equipped with a float switch. All the systems or pumps which are shut down should contain methods to relieve any pressure buildup.

As sodium hydroxide (NaOH) is used in its manufacturing, the pH of NaOCl is high. Extreme care is needed when using hard waters (or waters with CO2 present), as the highly alkaline product can lead to lower flow rates, reduced pipe diameter, reduce pump capacities, and scale formation at dosing points [8].

Equipment

NaOCl solution is a corrosive liquid with a high pH, i.e., 12. So, general precautionary measures for dealing with corrosive materials should be used such as avoiding metal contact, including stainless steel. These solutions might contain chlorate. Due do product degradation, chlorate can be formed during the processes of manufacturing and storage of sodium hypochlorite. The formation of chlorate and the degradation of NaOCl are directly related to each other. By reducing the degradation of NaOCl, the formation of chlorate can be minimized by avoiding high temperatures, reducing light exposure, and through limiting storage time. Spill containment should be provided for the NaOCl storage tanks. Typical spill containment structures include no uncontrolled floor drains, containment for the entire contents of the largest tank (along with the freeboard for rainfall/fire sprinklers), and separate containment areas for each incompatible chemical [9].

2.2.5. Chemicals

NaOCl solution (or liquid bleach) is a solution with 5–15% concentration of chlorine. It is used as bleaching and cleaning agent. It is also used extensively as water disinfectant, but it may not be the most economical solution as it is more expensive than gas. Being liquid, it can be handled easily than gas or calcium hypochlorite, but it is limited by its lack of stability and corrosive nature. It can be produced easily. Continuous supply of salt and electricity is needed for onsite generation of liquid bleach. Liquid bleach has a better POU application because of its availability and relative manageability [1] (Figure 2).

Chlorination by chlorine liquid method.

Chlorination (solid calcium hypochlorite)

Ca(OCl)2 (calcium hypochlorite) is an essential solid that can be used in replacement of NaOCl (liquid). As a disinfectant, it has similarity with NaOCl but it is much safer to handle. Almost 70% of chlorine is available in commercial grades of Ca(OCl)2. It has applications in both waste water and drinking water [7].

Advantages

Being solid, Ca(OCl)2 is more safer than chlorine gas and NaOCl.

It even has excellent stability when stored in dry place, maintaining its potency well over time .

Limitation

Contamination or improper use of Ca(OCl)2 may lead to explosion, fire, or the release of gases (toxic gases). Calcium hypochlorite should not be allowed to contact any foreign matter (including other water treatment products). If Ca(OCl)2 is exposed to even very small amounts of water, it can react violently to produce toxic gases, heat, and spatter. Product should be added to water instead of adding water into the product. Exposure to heat can cause Ca(OCl)2 to decompose rapidly, which may lead to explosion, intense fire, and the release of toxic gases. Dry, cool, well-ventilated area is needed for storing the product. Ca(OCl)2 is used as a strong oxidizing agent. It increases the intensity of fire. Ca(OCl)2 must be kept away heat, i.e., flame, heat, and any kind of burning materials .

Process

The calcium hypochlorite chlorinator contains a cylindrical polyvinyl chloride (PVC) tank with a height of 0.6–1.2 m and a diameter of 230–610 mm. A sieve plate is present containing holes that support the 80 mm diameter Ca(OCl)2 tablets. Tablet chlorinator systems can usually provide between 1 and 295 kg of chlorine per day. At the bottom, a side stream is piped into the chlorinator. The flow arises from the holes in the sieve plate that results in eroding the last layer of tablets. The amount of water entering the chlorinator is proportional to the rate at which the tablets erode. The rate of chlorine dosage can be calculated by controlling the water flow through the chlorinator. To meet the operational requirement, the chlorinator effluent is returned to the main stream, providing the desired level of available chlorine.

Variation in the dose and the contact time can be done to calculate the required disinfection. Different factors affect the chlorine dosage, i.e., wastewater characteristics, the demand of chlorine and discharge requirements. Mostly, the dose ranges from 5 to 20 mg/L. Different factors account for optimum disinfection that might include temperature, alkalinity, and nitrogen content. The pH of wastewater might affect the distribution of chlorine between hypochlorous acid and hypochlorite. A lower pH favors the hypochlorous acid: a better disinfectant. Higher concentrations of hypochlorous acid will lead to the formation of hazardous chlorine gas .

Equipment

$Ca(OCl)_2$ can be added to the wastewater by two ways, i.e.,

Either by mixing calcium hypochlorite powder in a mixing device and then injecting it into the wastewater stream;

By immersing chlorine tablets in the wastewater using a tablet chlorinator [2] (Figure 3).

Chlorination by calcium hypochloride method.

Chloramines

Chloramines are formed by reacting ammonia with free chlorine. They play an important role in providing residual protection in the distribution system. They are very stable. In comparison to chlorine, fewer halogenated by-products are formed .

Advantages

Chloramine is more stable but not a strong disinfectant as chlorine, providing long lasting residual disinfectant.

No by-products are formed in chloramination.

Chloramination equipment

Equipment for both the production of chloramines and chlorination systems are same. Both chlorine and ammonia might be introduced as a liquid or gas. Additionally, both chlorine and ammonia are available in liquid or granular form. Great care must be taken so that concentrated chlorine and ammonia are never mixed as they will form nitrogen trichloride, a potentially explosive compound

Ozonation

Ozone is an allotropic (unstable) formula of oxygen in which three molecules are combined to produce a new molecule. It quickly decomposes to generate highly reactive free radicals. The ozone’s oxidation potential (−2.7 V) is greater than that of the chlorine (−1.36 V) or hypochlorite ion (−1.49 V), substances widely used in wastewater treatment such as oxidants. Ozone is surpassed only by the hydroxyl radical (•OH) and fluoride in its oxidation capacity .

Advantages

Following are the advantages when ozone is used to treat water:

Ozone possesses strong oxidizing power

Short reaction time is needed so germs (including viruses) are killed in a few seconds

No change in color and taste occurs.

Requires no chemicals

Oxygen is provided to water after disinfection

Destroys and removes algae

Oxidizes iron and manganese

Reacts with and removes all organic matter

Limitation

Onsite generation is necessary as ozone is unstable at atmospheric pressure. It is toxic in high concentrations as it is a greenhouse gas. The three modules of an ozone plant are ozone destructor, ozone contact chamber, and generator. UV light or the corona discharge process is used for ozone generation. In contact chamber, ozone is added to water. The main purpose of the destructor is to limit the amount of ozone to be stripped out into the air. Three main processes affect the release of ozone after introducing ozone into water: decomposition, reaction with water impurities, and stripping into the atmosphere [14].

Process

Ozone is produced from a gas containing oxygen (usually ambient air or pure oxygen). The gas is then passed through an electric field. The air is treated to make sure that it is dry and free from dust impurities. Oxygen is converted to ozone in an electrical field. The ozone is then fed to the contact tank so that ozone is dissolved by water to proceed disinfection process

Equipment

The system consists of a combination of oxygen supply and high power electric supply systems: a high voltage electric current flow between electrodes and oxygen is discharged between the electrodes. Electrodes are separated with the help of a dielectric gap that contains the discharge chamber for oxygen flow. Electric field causes the breakdown of oxygen molecules and formation of ozone occurs. After generation, the ozone is directed toward the connection chamber, where the treated water is to be disinfected. The ozone produced will dissociate immediately so onsite generation of ozone must be done.

One of the important features is the contact time as well. So, the ballasting and the deballasting modes of very large ballast amounts of water will be much expensive in full-scale applications. One or several ballast water are equipped with ozone injection equipments that act as contact chambers. For achieving long contact time, that ballast water should be pumped into these contact tanks. In order to reduce the sediment formation and fine particles to enter the treatment process, the ozone treatment must undergo preliminary treatment (filter or cyclone).

The ballast treatment ensures that the all the water present in ballast tanks is exposed to ozone at the beginning of the voyage. Contact time plays an important role in the disinfection process. Disinfection is ensured if long contact is not required against the specific microorganism. If long contact time is required against specific microorganisms, treatment should be done during voyage to enable longer contact times.

Organic carbons are associated with sediment formation. These sediments settle down at the bottom of the ballast tanks during voyage. The sediments contain the microbes that are difficult to treat like bacterial colonies or viral clumps. Ozone treatment might not be efficient in the sediment. Ammonia might be produced as a result of biological activity during voyage. Bromines are produced by the reaction of ammonia and disinfectant residual. Bromines are weaker disinfectants, thus the efficacy is reduced [14].

2.5.5. Chemical

Ozone is produced by applying high voltage electricity to a gap (tube) containing pure oxygen or filtered dry air (corona discharge method).

The high voltage electricity results in the formation of ozone by recombining oxygen. The reaction is as follows:

$3O_2 \rightarrow 2O_3$

Ozone disinfects by oxidizing the cell walls of microorganisms, which then disintegrates (lyse), destroying the microorganism. This is a very different mechanism than with chlorine, which diffuses through the cell wall, making the cell susceptible to enzymatic attack [7] (Figure 4).

Ozone contacting.

. Ultraviolet light (UV)

UV treatment can be used for treating waste water, drinking water, and aquaculture. The UV light causes disinfectio by changing the biological components of microorganisms specifically breaking the chemical bonds in DNA, RNA, and proteins [14].

Advantages

It limits the regrowth potential within the distribution system so no increase in the concentration of biodegradable or assimilable organic carbon (AOC) occurs.

With respect to interactions with pipe material, there are no concerns.

No by-products are formed (e.g., hemoglobin-associated acetaldehydes (HAA), trihalomethanes (THM), aldehydes, ketoacidosis, and bromate).

By using UV light we can achieve the same log inactivation of Giardia and Cryptosporidium, less in cost either than chlorine dioxide and ozone techniques.

When used in relation with chloramines, no formation of chlorinated disinfection by-product (DBP) is noticed [14].

. Limitations

In underdeveloped countries, there are several limitations for UV disinfection. The major limitation is the energy requirement. In many systems, the electric power supply cannot be guaranteed.

A limitation might be that there is not even a single test available to examine the proper disinfection of the rays. It is only effective as a primary disinfectant as it does not leave any residues. It does not act as a secondary disinfectant as it does not work against reinfection in water.

A concern regarding the UV disinfection is chemical composition and the quality of microorganisms present in the influent water. Turbid, cloudy, or the water containing a large number of bacteria can be used to shield bacteria. Chemical composition is a basic problem as the water containing large amount minerals might cause coating on the lamp sleeve, thus reducing the effectiveness of the treatment. Phosphate injectors or water softeners can be used to prevent lamp coating. UV treatment is more effective on low turbid water or partially treated water, which may not be available in the field .

Process

UV disinfection units are used nowadays as water disinfection methods. The design is quite simple that consists of a UV light source that is enclosed in a transparent protective sleeve. The light source is mounted so that water can pass through a flow chamber so that UV rays can be both admitted and absorbed into the stream. No change in taste and color occur that is an advantage of this method. The contact time is also very short as these rays kill the pathogenic bacteria quickly .

Equipment

UV disinfection systems should be properly shut down if the treatment is not needed for few days. The lamp needs to be warm-up for few minutes before turning on. Moreover, the plumbing system should be properly flushed when not in use. The whole plumbing system should be disinfected by a chemical (preferably chlorine) before relying on the process.

UV lights loses effectiveness with usage, the lamp should, therefore be properly cleaned on regular basis and replaced once in a year. It should be noted that a new lamp might lose its 20% intensity in the first 100 h of operation. Properly calibrated UV detectors help the owner in alerting when the light intensity falls below a certain level.

Chemical

UV light can treat water without producing any major chemical or physical changes in the water. No negative effects have been noticed in utilizing UV-treated water. Fewer chances are there for the formation of DBPs as no new substance is added in this process. No change in the taste and color occurs. The dosage and frequency used for the disinfection do not produce any harmful substance. Even the overdosing of UV light does not lead to the formation of harmful products. To avoid exposure, protective clothing should be used by the operator

Disinfection by UV.

Photocatalytic disinfection

The acceleration of a photoreaction in the presence of a catalyst is referred as photocatalysis. In catalyzed photolysis, adsorbed substrate is used to absorb light. In photogenerated catalysis, electron–hole pairs are created by the photocatalytic activity (PCA) generating free radicals (e.g., hydroxyl radicals: •OH) that have the ability to undergo secondary reactions. Its practical application was made possible by the discovering the electrolysis of water by using of titanium dioxide.

Advantages

The followings are the advantages of photocatalytic disinfection

Photocatalysis uses capacity for renewable and pollution-free solar energy, thus it is a good replacement for the energy-intensive conventional treatment methods.

In comparison to the conventional treatment methods photocatalysis leads to the formation of harmless compounds.

Waste water contains different hazardous compounds. Photocatalytic process causes destruction of a wide range of these hazardous compounds in various wastewater streams.

These reactions are mild. Less chemical input is required and the reaction time is modest.

Process

Photocatalytic reaction depends mainly on light (photon) energy or wavelength and the catalyst. Generally, semiconductors are used as catalysts. These materials function as sensitizers for the irradiation of light-stimulated redox process because of their electronic structure. They have a filled valence band and a vacant conduction band.

The fundamental steps in the process of semiconductor photocatalysis are as follows:

When the light energy in terms of photons falls on the surface of a semiconductor and if the energy of incident ray is equivalent or more than the bandgap energy of the semiconductor, the valence band electrons move to the conduction band of the semiconductor.

The valance band of semiconductors is left with holes. These holes can react with water molecules to generate hydroxyl radicals by oxidizing donor molecules.

Superoxide ions are formed by reacting the conduction band electrons with dissolved oxygen species. These electrons induce the redox reactions.

These electrons and holes might undergo successive redox reactions with many species to form necessary products by absorbing on the surface of the semiconductor.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