SURFACE WATER TREATMENT

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities*.**

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **SURFACE WATER TREATMENT** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

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CHAPTER-1

1.1 A Brief History of Water Treatment

TIME	WATER TREATMENT TECHNOLOGY
3000 BC	Mohenjo-Daro (Pakistan) used a very extensive water supply. In this city there were public bathing facilities with water boiler installations and bathrooms.
2000 BC	Sanskrit and Greek writings say impure water should be purified by heating, boiling, or filtration through sand and gravel
1500 BC	Egyptians use alum(coagulation) to clarify cloudy water
1829	Slow sand filters constructed in London
1854	British scientist John Snow applied chlorine to purify the water
1906	Ozonation in Nice, France
1970s	Techniques such as aeration, flocculation, and active carbon adsorption were applied.

1.2 Water quality standards

Sr.No.	Organisms	PEQS Value	WHO GUIDELINES
1	Total Coliform ,Thermo tolerant/Fecal Coliform E-Coli	Must not detectable in any 100ml sample	Must not detectable in any 100ml sample
2	Colour	**<15TCU**	**<15TCU**
3	Odour	Nonobjectionable	Non objectionable
4	Taste	Nonobjectionable	Non objectionable
5	Turbidity, NTU, Max	**<5**	**<5**
6	pH value	6.5 to 8.5	6.5 to 8.5
7	Total Hardness ($CaCo_3$) mg/l,	**<500**	
8	Chlorides mg/l, Max	≤250	≤250

10	Total Dissolves Solids mg / l Max	**<1000**	**<500**
11	Nitrate (as NO3 −)	50	50
12	Fluoride (as F) mg/l/ Max	1.5	1.5
13	Mercury (as Hg) mg/l Max	0.001	0.006
15	Arsenic (as As), mg/l Max	≤0.05	0.01
16	Zinc (as Zn), mg/l Max	5	3

1.3 Main reasons for treating water

- Suspended and dissolved organics (plant or animal origin)
- Inorganic (mineral) material,
- Biological forms such as bacteria, spores, cysts and plankton
- Aesthetic Contaminants, taste (cloudiness or turbidity), or smell bad.
- Most are not directly harmful to human health,

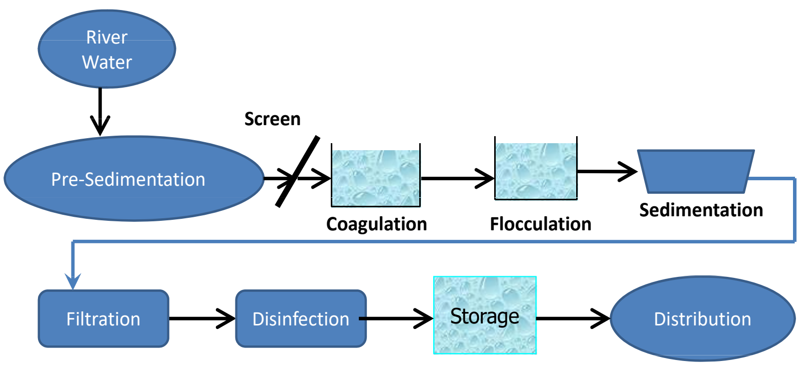
1.4 Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)

- TSS and TDS measure the amount of particulate matter. In lakes and rivers this can include particles from algae, other organic matter, silt and clay, and other inorganic substances (such as minerals, salts and metals).
- Divided into two types by passing the water through a filter.
- The particles that are large enough to be held back by the filter are called total suspended solids (TSS) and are closely related with turbidity,
- while the particles that pass through the filter are called total dissolved solids (TDS) and are smaller than 2 microns & include dissolved minerals and salts in the water.
- As a result, TDS is often closely related to conductivity, salinity, alkalinity, and hardness measures.

Chapter-2 Preliminary Treatment

2.1 Pre-treatment: Pre-settling Tanks

- Larger sized particles such as sand and heavy silts can be removed from water by slowing down the velocity of flow to allow for simple gravity settling.
- It is the process of removing solid particles heavier than water by gravity force.
- Hydraulic retention time is the primary variable used to settle large solids; to main treatment process that can reduce larger amounts of turbidity and organic matter.
- Smaller sized particles, such as spores, cysts, plankton, fine clays and silts with their associated bacteria, do not readily settle. These smaller particles are often called non settleable solids or colloidal matter.



2.2 Screening: General Rule

- Racks and screens are designed for removal of large suspended and floating material and should be designed to minimize head loss by providing sufficient flow-through area to keep velocities low.
- The total area of clear openings in a screen typically ranges between 150% and 200% or more of the area or channel protected by the screen.
- The velocity in approach channel is kept at 0.5m/s.
- The maximum head loss from clogging should be limited to between 2.5 and 5.0 ft (0.76 and 1.52 m), and the screen should be designed to withstand the differential hydraulic load.

Chapter-3 Turbidity Treatment

3.1 Turbidity Treatment

- Turbidity can come from suspended sediment such as
- silt or clay,
- inorganic materials,
- or organic matter such as algae,
- plankton and decaying material.
- Turbidity can also include colored dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM corresponds to total organic carbon (TOC) and other dyes.

3.2 Turbidity increase indicators

3.2.1 Erosion

- An increase in turbidity can also indicate increased erosion of stream banks, which may have a long-term effect on a body of water

3.2.2 Contamination

- Pollutants such as dissolved metals and pathogens can attach to suspended particles and enter the water .
- This is why an increase in turbidity can often indicate potential pollution, not just a decrease in water quality.
- Contaminants include bacteria, protozoa, nutrients
- Several of these pollutants, especially heavy metals, can be detrimental and often toxic to aquatic life. The addition of nutrients can encourage the development of harmful algal blooms.

3.3 Turbidity removal

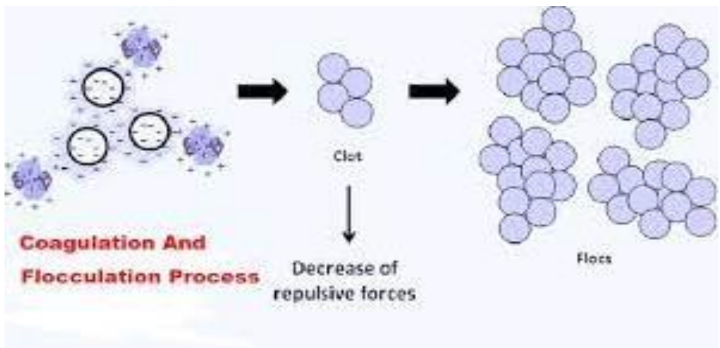
- Coagulation, Flocculation and sedimentation

b) Enhanced settling (Sand Ballasted settling/Filtration

c) Softening

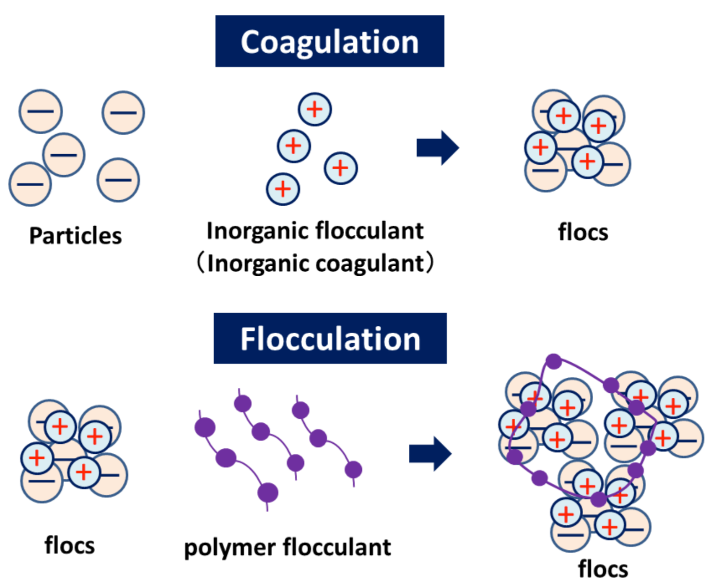
3.4 Coagulation, Flocculation and sedimentation

- The positive charge of the coagulant neutralizes the negative charge of dissolved and suspended particles in the water. When this reaction occurs, the particles bind together, or coagulate.
- Coagulation reactions occur rapidly, probably taking less than one second.
- The overall purpose is to form particles large enough to be removed by the subsequent settling or filtration processes.



3.5 Why Flocculation is required?

- Floc formed in many waters with alum is light and fragile and somewhat difficult to settle.
- Polymers and other additives can often help form a floc that is more efficiently removed by settling and filtration.



3.6 What is removed by coagulation, flocculation

- Particles in source water that can be removed by coagulation, flocculation, sedimentation, and filtration include:
- colloids,
- suspended material,
- bacteria,
- and other organisms
- The size of these particles may vary by several orders of magnitude.

3.7 Enhanced settling (Sand Ballasted settling/Filtration)

- Ballasted flocculation is a high-rate, physical-chemical clarification process involving the fixing of flocs, or suspended solids, onto ballast (sand) with the aid of a polymer.
- A combination of a metal-salt coagulant, micro-sand (or sludge recycle), and enhanced clarifier features (such as lamella settlers) increase settling velocities by a near factor of 10.
- Clarified water exits the system by way of a peripheral outlet launder.
- Separation: Settled floc and sand are collected and pumped to the hydrocyclone where the sand is separated from the solids. The solids are sent to waste and the separated sand is returned to the first flocculation tank.

3.8 Coagulation Process Aids/Improvements

3.8.1 Pre-Aeration

- To reduce the concentration of taste- and odor-causing substances and, to a limited extent, for oxidation of organic matter.
- To remove substances like carbon dioxide from water for corrosion control and before lime softening.
- To add oxygen to water, primarily for oxidation of iron and manganese so that they may be removed by further treatment.
- To remove gases such as radon, hydrogen sulfide, and methane.
- To remove ammonia from the water.

- To remove Volatile organic compounds (VOCs) considered hazardous to public health.

3.8.2 Pre-ozonation for oxidation and/or disinfection

- The coagulation process may, in some cases, be improved by pre-ozonation.
- Ozone may significantly reduce coagulant requirements to the point where low residual solids make direct filtration feasible.

3.8.3 Carbon addition

- Carbon addition, typically in the form of powdered activated carbon (PAC), may also improve coagulation, as it would remove a fair amount of organic matter prior to the coagulation process., thereby, reducing coagulant demand and the associated levels of sludge production.
- It is removed from the water during the coagulation process.
- PAC particle size typically between 10 and 100 μm in diameter.
- PAC can be applied for short periods, when problems arise, then ceased when it is no longer required. With problems that may arise only periodically such as algal toxins or tastes and odours, this can be a great cost advantage.
- It cannot be reused and is disposed to waste with the treatment sludge or backwash water.

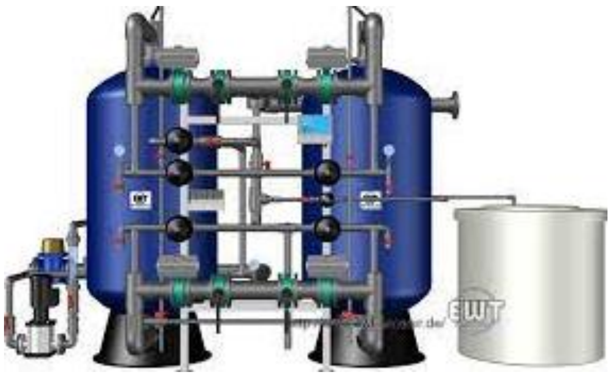
3.8.4 Adjustment of pH

- Control of pH and alkalinity is an essential aspect of coagulation. The optimum pH for coagulation varies but is generally within the following range for turbidity removal:
- Alum: pH 5.5 to 7.5; typical pH 7.0
- Alum and ferric chloride consume alkalinity and can lower pH; In some source waters with low pH or low alkalinity, it may be necessary to add caustic soda or lime to raise pH
- Typically, the optimum pH for organics removal with alum is between 6.0 and 6.5

3.8.5 Rule for pH adjustment

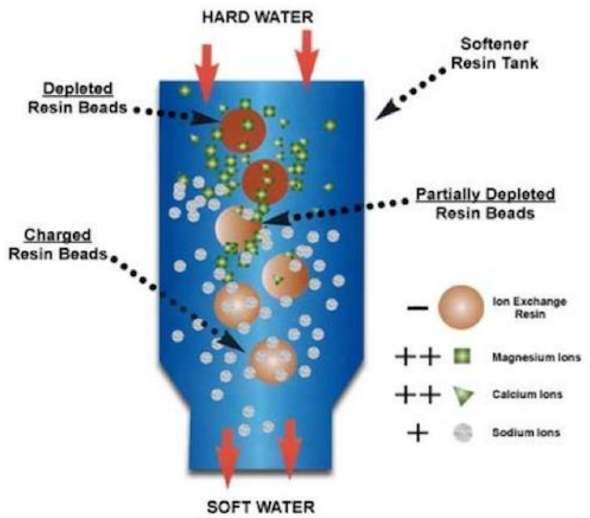
- If pH is lowered to improve coagulation, it is typically necessary to raise the pH in the final effluent from the plant as compared to pre- filtration :
- To provide a less corrosive finished water.
- This is due to the fact that some organic matter may be adsorbed onto the floc that may carry over from the clarification process, and any prefiltration pH adjustment may then result in the "release" of this organic matter, which could pass through the filters and contribute to subsequent DBP formation during chlorination.

3.8.6 Softening



- **Lime precipitation:** Water can be chemically softened on a large scale by the addition of just enough lime to precipitate the calcium as carbonate and the magnesium as hydroxide, whereupon sodium carbonate is added to remove the remaining calcium salts.

- **Ion exchange** is a common industrial method of water softening.



- It is accomplished by passing the water through columns of a natural or synthetic resin that trades sodium ions for calcium and magnesium ions.
- After the column has been in use for some time, calcium and magnesium begin to appear in the water leaving the column.
- the excess sodium ions displace the ions that produce the hardness so that, after flushing with water, the bed of exchanger is ready to be used again.

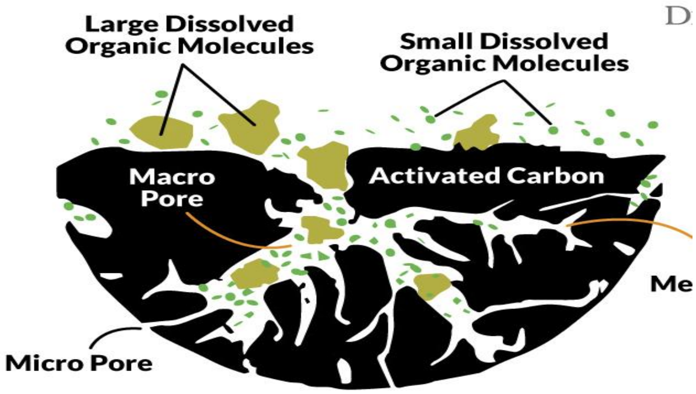
CHAPTER-4 Color Removal

4.1 Source of Color

- Color by itself is not toxic and does not pose a health concern
- leaves falling into water cause brownish color.
- Decaying aquatic plants & algae can create a green color in the water.
- Small particles of oxidized iron create red color and manganese create black.
- Runoff from eroding soil can contribute clay and silt particles that make water yellow, brown, red or grey.
- A brown, rusty color usually comes from rust in water pipes

4.2 Granular activated carbon (GAC) in the filtration process

- The pores of filter trap microscopic particles and large organic molecules,
- While the activated surface areas cling to, or adsorb, small organic molecules



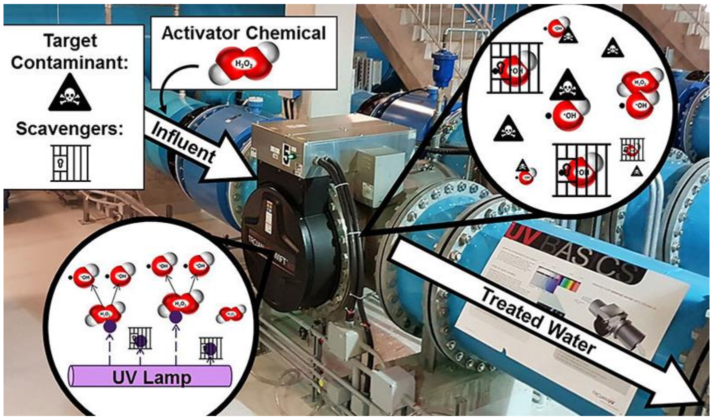
- Activated carbon created in a high-temperature process that creates a matrix of millions of microscopic pores and crevices extremely adsorbent used to remove organic contaminants
- Water treated by GAC needs about 2/3 less chlorine than without GAC.
- Adsorption on activated carbon is generally the most effective method for the removal of earthy or mouldy taste and odour.

4.3 Advanced Oxidation Processes

- Oxidizes iron, manganese, cyanide, phenol, benzene, nitrobenzene and other pollutants.
- A common use of conventional oxidation is to oxidize iron, manganese, which are soluble and become insoluble after oxidation. The insoluble species then precipitate and can be removed by sedimentation and filtration.
- Other common uses of conventional oxidation are taste and odor control, color removal, and hydrogen sulfide removal.
- kills bacteria and viruses (even the chlorine- resistant Polio-virus)

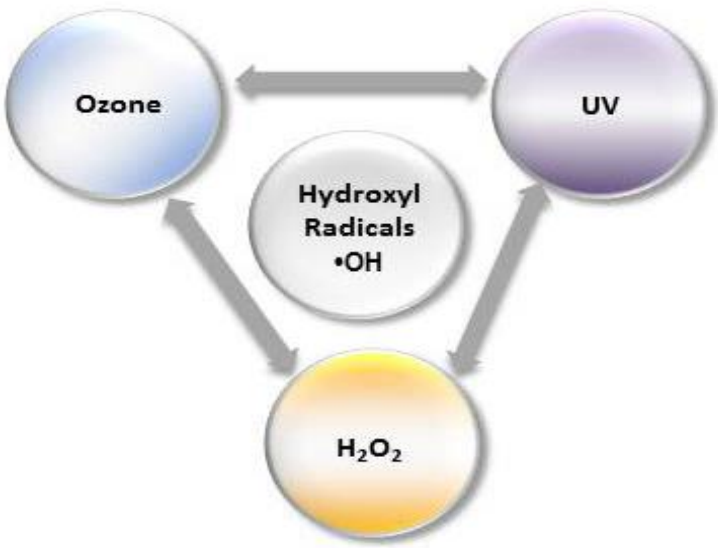
4.3.1 UV/Peroxide-UV AOP

- It utilizes UV in conjunction with Hydrogen per oxide(H_2O_2).
- Direct UV light breaks down contaminants directly and,
- oxidation of contaminants by radicals(OH) (generated via the chemical compound is broken down by photons (photolysis) of the oxidant Hydrogen per oxide(H_2O_2) .
- Generally, the most important factors impacting the efficiency of a UV AOP are UV transmittance (UV-T) of the water, pH, temperature and the activator chemical and dose.



4.3.2 Advanced Oxidation: Ozone/ Hydrogen per oxide (H2O2)

- The combination of UV with ozone/ H_2O_2 increased the degradation of micro pollutants MPs), including pesticides, herbicides, pharmaceuticals and endocrine disrupting compounds.
- Hydroxyl free radical (OH) is a 35% stronger oxidizing agent than O3



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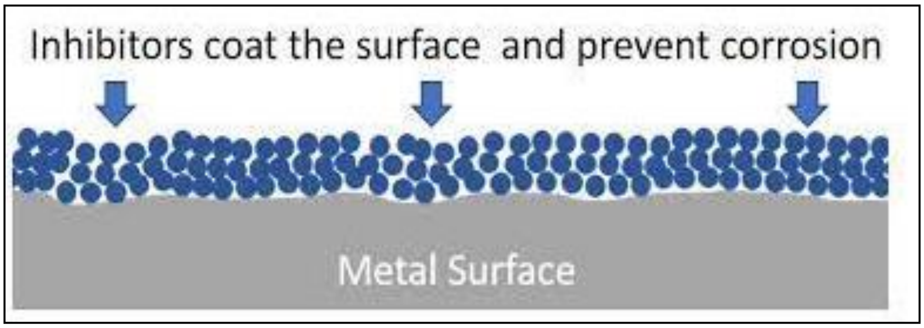
CHAPTER-5. CORROSION CONTROL

- The tendency of water to be corrosive is controlled principally by adjusting the pH.
- If a water is "hard," it is less likely to "leach" metals from plumbing pipes but often leaves a deposit on the inside of the pipe, while if a water is "soft" it has less of a tendency to leave deposits on the inside of plumbing pipes.

5.1 Corrosion inhibitors



- Chemical additives used for corrosion control include phosphates, silicates, and those affecting the amount of carbonate in the system, such as calcium hydroxide, sodium hydroxide, sodium bicarbonate, and sodium carbonate.

CHAPTER-6 Heavy metals removal

Heavy metals removal by precipitation

Type of precipitation	Metal removal
Hydroxide precipitation: calcium hydroxide (lime) or sodium hydroxide (caustic)	Cadmium, copper Nickel, Zinc
Sulphide precipitation solid (FeS, CaS, and Na2S),	Arsenic, Mercury, Copper, Cadmium
Co precipitation with hydroxide	Arsenic, Mercury

CHAPTER-7. High-Rate Granular Media Filtration

- Filtration is needed for most surface waters, to provide a second barrier against the transmission of waterborne diseases.
- Filtration can assist significantly by reducing the load on the disinfection process, increasing disinfection efficiency, and aiding in the removal of precursors to disinfection by-product (DBP) formation.
- The Surface Water Treatment techniques:
- Rapid sand
- Slow sand
- The term rapid sand includes not only sand, but also other types of filter media such as crushed anthracite coal and granular activated carbon (GAC).

7.1 Design Considerations

A number of interrelated components are involved in the overall design of a high-rate granular media filtration system:

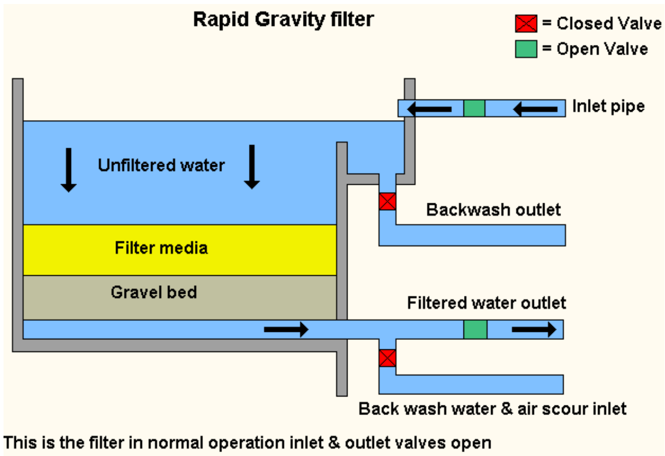
- Regulatory requirements
- Pretreatment systems
- Filter media
- Filtration rates
- Depth of the filter box
- Mode of operational control
- Filter washing system
- Filter arrangement
- Underdrain system
- Filter performance monitoring

7.2 Granular Media

- Granular media have been traditionally described in terms of effective size (ES) and uniformity coefficient Common practice in Europe is to express media sizes as the upper and lower limits of a range expressed either as linear dimensions or as passing and retaining sieve sizes.

- The sand medium typically has an ES of 0.35 to 0.60 mm (generally 0.5 mm). Bed depths are typically 24, 30, or 36 in. respectively.
- A typical dual-media bed contains 6 to 12 in. of silica sand (ES 0.45 to 0.55 mm) overlaid by 18 to 30 in. of anthracite (ES 0.8 to 1.2 mm).

7.3 Filtration Rates



- How much water passes through a certain sized filter over a specific time
- Dual- and mixed-media filters to operate successfully at rates from 8 to 20 m/h
- Uniformly graded anthracite filters have been operated reliably at rates of 24 to 37 m/h.
- Average filtration rates of roughly 5 to 17 m/h are reported for the upflow, biflow, and deep-bed filters
- Filtration rates are impacted by water temperature. Generally, when water temperatures drop below 8° C, water quality and filter run length deteriorate in high-rate filters (Kawamura, 1999).
- Many regulatory agencies will not approve rates in excess of 10 m/h without successful pilot-scale testing.

7.4 Filter Operational Control

- Two basic modes of gravity filter control are commonly found:

Constant-rate

- A rate-of-flow controller in the filtered water piping controls the rate of filtration;

Declining-rate.

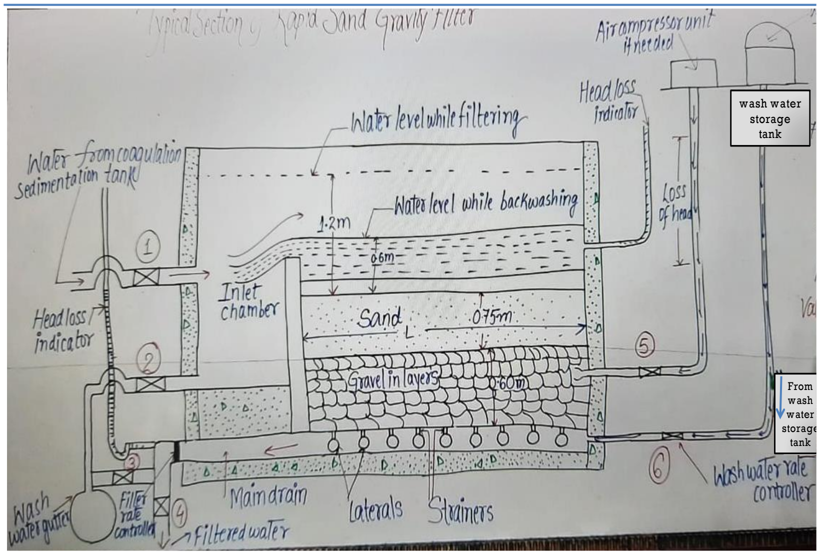
Filter control is predicated on head loss through the filter bed

- Declining-rate filters are equipped with effluent weirs rather than rate controllers.
- The filtration rate then becomes the highest in the cleanest bed and lowest in the dirtiest bed.
- In each bed, the filtration rate decreases as solids accumulate.
- To determine which bed is in greatest need of washing, some type of effluent rate indication is provided.

7.5 Number & Size of Filters

- Kawamura (1999) recommends the following formula as a guide to determining the required number of filters:
- $N = 1.2Q^{0.5}$
- where N is the number of filters and Q is the plant design flow rate in US million gallons per day.
- The size of individual gravity filters is determined by plant capacity, filtration rate, and the number of filters desired.
- Large filters may be divided into two sections by using a central gullet, permitting one-half of the filter to be washed at a time, although influent and effluent piping is usually shared.
- In general, the practical maximum size of a filter is 90 m2 provided the plant is not exceptionally large.

7.6 Back washing

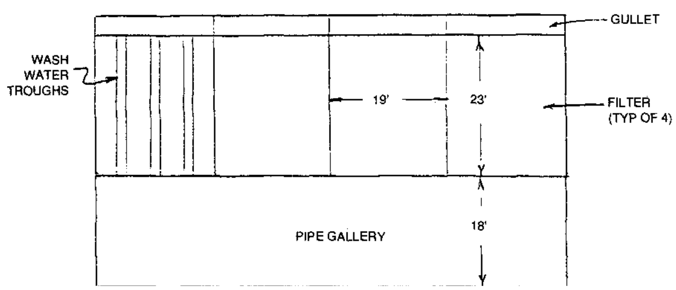


- Normally, when water wash is applied exclusively, an expansion of 20% to 50% is used.
- Air scour provides effective cleaning action, especially if used simultaneously with water wash.
- On the other hand, air wash has substantial potential for media loss and gravel disruption if not properly controlled.
- Use of air scour can significantly reduce the quantity of water required for backwashing filters.
- If air scour occurs simultaneously with water wash, airflow must usually be stopped before washwater overflow into the washwater collection troughs to prevent media loss. For this reason, the permissible duration of air washing is short.
- Water viscosity decreases with increasing temperature.
- Consequently, as washwater temperature rises, drag forces on media grains are reduced, and higher wash rates are required to achieve bed expansion.
- Each degree Celsius increase in water temperature requires roughly a 2% increase in wash rate to prevent a reduction in bed expansion.

- Filter wash systems should be designed for the warmest washwater temperature that will be encountered.
- A minimum rate of 37 m/h is recommended, with typical rates ranging from 37 to 56 m/h.
- Upflow Water Wash with Air Scour.
- The first--air scour alone followed by low-rate water wash--is commonly applied in Great Britain to single-medium sand filters with 0.6- to 1.2-mm ES media.

7.7 Configuration of Filters

Hemlock Water Filtration Plant; Rochester, NY (48 mgd)

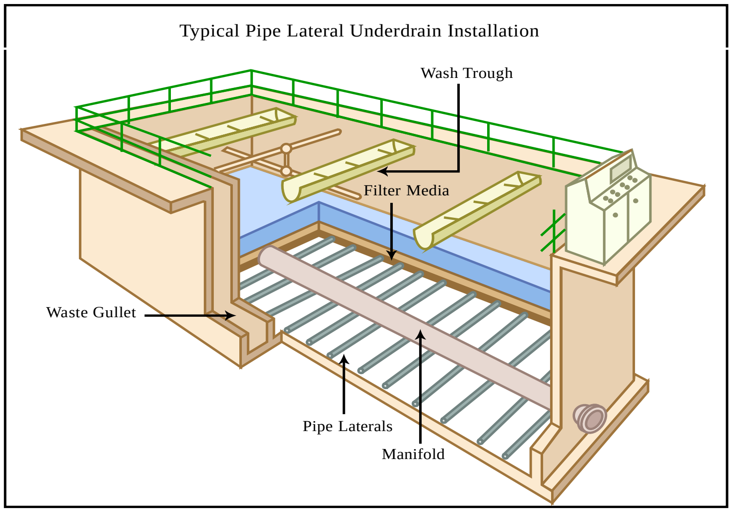


- Filters are normally placed next to one another along one or both sides of a pipe gallery.
- If possible, areas for future expansion should be provided at one end of the row (or rows) of filters, and piping in the gallery should be installed with blind flanges at the ends to make future filter additions easier.
- In larger plants, placing filters in rows on opposite sides of a pipe gallery is common practice.

7.8 Under drain System

- An underdrain system has two purposes:
- to collect water that passes through the filter media
- and to distribute washwater (and air, if used) uniformly across the filter bed.
- Support gravel is required when openings in the underdrain system are larger than the filter medium directly above it.

- Uneven distribution of washwater can displace support gravel, eventually requiring removal of the filter media to be regarded or replaced.



CHAPTER-8. Conventional Surface Water Treatment Processes

- Main processes
- Slow Sand Treatment
- Rapid Sand Treatment
- Disinfection;
- Chlorination
- Ozonation
- Ultraviolet Radiation

References:

- *AWWA & ASCE: Water Treatment Plant Design*
- *MWH,s Water Treatment principles and design 3rd edition*
- *AWWA: Water quality and treatment 5th edition*
- *US EPA: WATER TREATMENT MANUALS. COAGULATION, FLOCCULATION & CLARIFICATION*
- *https://www.dtkhydronet.com/post/introduction-to-commonly-used-methods-for-removal-of-colour-odour-and-taste-from-the-water*
- *https://www.britannica.com/technology/water-softening*

Irish EPA: Water Treatment Manual: Disinfection