

Water Treatment

- It is desired that drinking water be:
 - Safe
 - Clean
 - Clear
 - Free of disagreeable smells and odours
 - Free of pathogens (Over 7000 people a day die due to waterborne diseases that could be prevented with water treatment.)
 - Free of dissolved solids or minerals
 - Conveniently and inexpensively available.
- Sources of drinking water:
 - Ground water
 - Surface water
- The advantages of ground water include:
 - Fewer contaminants (usually)
 - Clarity
- Disadvantages of ground water include:
 - Radon

- Hardness and alkalinity
- Finite capacity of aquifers. If an aquifer is depleted, the ground above may subside and become vulnerable to flooding.
- The advantages of surface water include:
 - Availability
- Disadvantages of surface water include:
 - What is upstream?
 - Dissolved organic matter.
 - Biological and chemical oxygen demand.
- Since it was recognized that ground water was better than surface water, the first attempts at water treatment in the 19th century was to “make” ground water.
 - Surface water was trickled through sand.
 - Surface water was used to “reinject” under-water aquifers.
 - This does lead to a decline in the incidence of waterborne diseases such as cholera, typhoid, and amoebic dysentery.

- Modern water treatment consists (typically) of four stages:
 - Settling
 - Aeration
 - Coagulation
 - Disinfection
- Depending on the water supply, one or more of the first three steps may not be necessary.

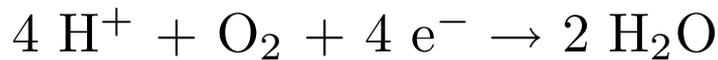
Settling

- Water brought into a large holding pond and particulate is allowed to settle.
- If the pH is too low, it is adjusted to be greater than 6.5

Aeration

- Aeration has the objective of removing oxidizable substances.
 - These include both chemical and biological species.
 - Fe^{2+} is removed at this stage to prevent rust stains ($\text{Fe}(\text{OH})_3$).

- Upon contact with air Fe^{2+} is quickly oxidized to Fe^{3+} .



Net reaction: $4 \text{Fe}^{2+} + 4 \text{H}^{+} + \text{O}_2 \rightarrow 4 \text{Fe}^{3+} + 2 \text{H}_2\text{O}$

- If $\text{pH} > 3$, then:



Coagulation (Secondary Settling)

- Coagulation has the objective of removing suspended solids such as:
 - Colloidal minerals
 - Bacteria
 - Pollen
 - Spores

resulting in water that is clear.

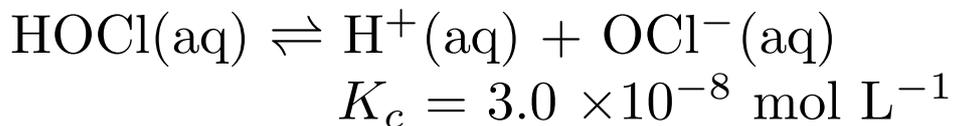
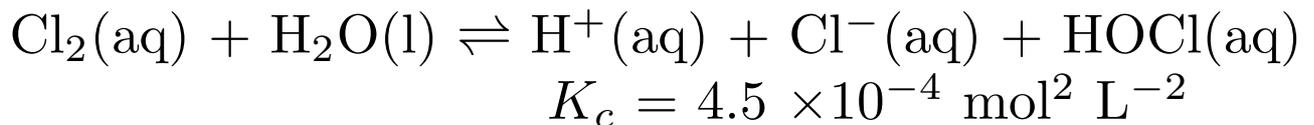
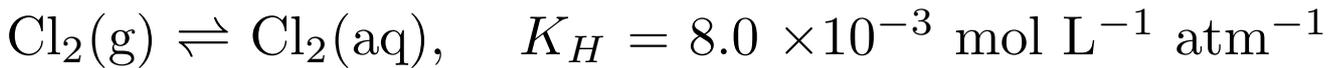
- Since in the settling step, the pH of the water has been adjusted to $\text{pH} > 6.5$.
 - Minimum solubility of Al^{3+} occurs in the pH range 6.5 to 8.

- Filter alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$) is used as a clarifying agent since it forms a gelatinous precipitate that settles slowly, carrying down the suspended solids.
- Alternative settling agents are $\text{Fe}(\text{OH})_3$ and activated silica, both of which form gelatinous precipitates.

Disinfection

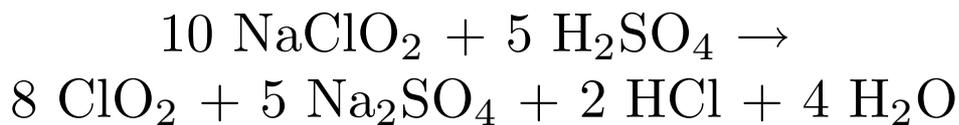
- Disinfection of drinking water is essential
 - To kill any pathogens that persist through the earlier stages of treatment.
 - To prevent the growth of bacteria in the distribution system (in which water can spend up to a week).
 - To prevent recontamination of the water in the distribution system due to leaks.
- Disinfection agents include:
 - Chlorine
 - Chlorine Dioxide
 - Ozone
 - Ultraviolet radiation

- Chlorine is the only one that leave a residual that can prevent recontamination.
- Chlorine dissolved in water establishes the following equilibria:

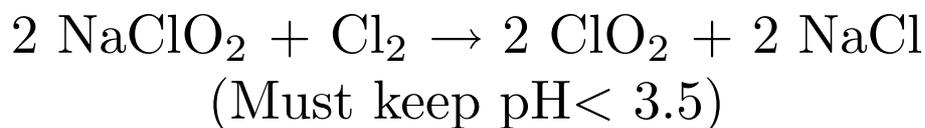


- It is HOCl that is effective in killing microorganisms since it can penetrate the cell membrane.
- Chlorine dose required depends on pH (need to keep pH below 2.5).
- Desire chlorine residual of about 1 ppm.
- Disadvantages of chlorine include:
 - Taste and odour.
 - Chlorination of organic compounds.
 - Concerns about toxicity.
- Advantages of chlorine include:
 - Inexpensive
 - Residual

- Chlorine dioxide is often considered as an alternative to chlorine.
- Chlorine dioxide has the advantages:
 - Oxidizes organic compounds instead of chlorinating them.
 - Can use a physical plant very similar to that required for chlorine.
 - Possible to easily switch from chlorine temporarily if chlorine is causing problems.
- Disadvantages of chlorine dioxide include:
 - Must be manufactured on site from NaClO_2 .



or



- The first reaction is preferred because it is chlorine free.
- There is no residual disinfection, therefore the water must be “finished” with chlorine before distribution.

- There is some concern about toxicity of ClO_2 .
 - At levels of 50 ppm NaClO_2 , hemolysis can occur.
 - Finished water has less than 1 ppm ClO_2 , which is shortlived.
- Ozone requires a completely different physical infrastructure than chlorine or chlorine dioxide.
 - Usually implemented in new facilities.
 - Economic only on a larger scale.
 - Generated by running a high voltage electrical discharge through air giving about 1
 - Ozone absorbed by water ($K_H = 1.3 \times 10^{-2} \text{ mol L}^{-1} \text{ atm}^{-1}$.)
- Advantages of ozone include:
 - Oxidizes organics
 - Air is the main raw material required.
- Disadvantages include:
 - pH control is necessary.
 - Finishing with chlorine is necessary.

- Ultraviolet radiation with $\lambda < 300$ nm damages pyridine base pairs in DNA sequences.
 - Causes cell death and thus death of microbes.
- Can be generated by mercury arc lamps ($\lambda = 254$ nm) with about 40% efficiency.
- Advantages of UV water treatment include:
 - Contact time is short (< 10 s).
 - No large reservoir required.
 - Low installation cost.
 - Do not need to control or monitor pH or temperature.
 - No toxic residues.
 - Cost competitive with chlorine treatment.
 - Possible to implement on a small or portable scale as an emergency or remote, stand alone system.
- Disadvantages of UV treatment include:
 - Water source must be clear of suspended matter and organic molecules that could absorb the UV.

- If suspended matter or organic molecules are present, then pretreatment with activated charcoal may be required.
- No residual disinfection. The water must be used immediately or be finished with chlorine.

Quality Control in Water Treatment and Distribution

- Before water treatment:
 - What are the potential contaminants in the watershed or aquifer?
 - What dissolved inorganic species are present?
 - What organic chemical species are present, especially those that can survive the treatment process and lead to unacceptable taste or smell?
 - For treatment with chlorine, chlorine dioxide, or ozone: what is the demand of the raw water for the disinfecting agent.

- For treatment with UV, is the clarity acceptable.
- Is the quality of the incoming water consistent with the capacity of the treatment facility.
- During water treatment:
 - Are the pH and temperature in the appropriate range for the treatment process?
- After water treatment:
 - Is there an appropriate level of residual chlorine?
 - Are any pathogens present?
 - Are there any undesirable chemicals present that formed during the treatment process or survived the treatment process?
 - Is further treatment (softening, deionization, filtering) required.
 - Are the taste, smell, and appearance acceptable.

Sewage Treatment

- Sewage treatment parallels water treatment.
 - Primary treatment consists of settling and skimming
 - Secondary treatment consists of reducing the biological oxygen demand.
 - Tertiary treatment reduces the concentration of particular contaminants, such as phosphorous.
 - Finishing consists of disinfection.
- Primary sewage treatment
 - Physical separation of solids and immiscibles.
 - Raw sewage enters a lagoon through one or more coarse screens that remove large objects.
 - A grit tank allows for the deposition of grit, sand, etc.
 - The sewage then moves slowly through the clarifier slowly enough for solids to settle.

- At the same time, greasy material is skimmed off.
- The result of primary treatment is clear effluent with a very high biological oxygen demand.
- Solids removed are landfilled.
- Some facilities use coagulating agents such as alum to aid the settling in the lagoon. This can reduce the BOD to the point that secondary treatment may not be necessary.
- Secondary treatment
 - Reduction of biological oxygen demand by at least 90%.
 - Usually done with either a trickling filter or an activated sludge reactor.
 - A trickling filter is a bed of sand of graduated particle size, ranging from coarse gravel on top to very fine sand on the bottom.
 - The trickling filter is colonized with microbes which reduce the BOD by utilizing the carbon compounds found in the sewage.

- The activated sludge reactor is more compact and can be enclosed in climates too cold for optimum biological activity.
 - The reactor is a large tank in which the waste water is aerated to provide sufficient oxygen for the biological removal of BOD.
 - Microbial sludge leaving the reactor is re-injected to maintain colonization of microbes.
 - Many issues involved in the disposal of sewage sludge.
- Tertiary treatment is usually focused on the removal of phosphorous.
 - Usually achieved by precipitation with lime (a source of Ca^{2+}) or Al^{3+} or Fe^{3+} . The latter two form gelatinous precipitates which can further remove any microorganisms left from secondary treatment.
 - Finishing usually involves a heavy dose of chlorine to kill remaining pathogens.
 - There is concern about chlorination of organics.

Sewage Sludge

- By-product of sewage treatment
 - High water content ($\sim 95\%$)
 - Difficult to handle
 - Needs to be digested to facilitate coagulation and dewatering.
 - Digestion of sludge produces methane, which can be used for co-generation of electricity or heat.
 - Dewatered sludge must be disposed of.
- Disposal of sludge may be by:
 - Landfilling
 - Incineration
 - Ocean dumping
 - Using as fertilizer.
- In using sewage sludge as fertilizer, there are a number of considerations.
 - High organic content with nitrogen and phosphorous can restore nutrients to soil in disturbed sites.

- Allows soils to retain water.
- Inexpensive alternative to other methods of disposal.
- Sludge is low in nutrients compared to conventional fertilizers, so cost of handling and shipping must be kept low. In practice, this means that only local use is practical.
- Sludge may contain toxic substances.
 - Both organic and inorganic toxins can survive sewage treatment.
 - Oxidation resistant organics such as organochlorine compounds.
 - Inorganics such as As, Cd, Pb, Hg, and Zn, which usually have industrial sources.
 - Pathogens
 - Toxins may be taken up by vegetation, therefore most jurisdictions have strict limits on the use of sludge on agricultural lands.
 - Transfer of pathogens avoided by waiting periods between application of sludge and harvest.

- Some metals are not harmful to human health, but can harm ruminants. (Cu is toxic to sheep.)
- Fate of metal from sludge depends on properties of the soil.
 - Porous, gravelly soils allow transport of dissolved metals to watershed.
 - High organic muck soils facilitate biological uptake.
 - Clay soils have ion exchange properties and bind metal ions tightly, greatly reducing their mobility.
 - pH affects speciation, solubility, biological uptake, and binding to clay.

Tertiary Sewage Treatment

- Focused on one or more specific elements in the sewage, including P.
 - P is usually the limiting element in biological systems.
- P in sewage.

- P can usually give rise to eutrophication.
- Anthropogenic sources include fertilizer and detergent.
- Phosphates removed by precipitation with Ca^{2+} , Al^{3+} , and Fe^{3+} .
- Tertiary treatment can also be used to further reduce BOD
 - Secondary treatment leaves a BOD of about 50 ppm O_2 .
 - This is usually in the form of suspended organic matter.
 - May be removed by microstraining or coagulation.
 - Very fine (μm) stainless steel screens are used for microstraining.
 - Filter alum is used for coagulation and has the advantage of simultaneously reducing phosphate.
 - Tertiary BOD reduction is desirable so that high doses of chlorine are not required for disinfection.

- Tertiary treatment may include disinfection with chlorine
 - High doses of chlorinated can lead to undesirable reactions between NH_3 and Cl_2 and between organic compounds and chlorine.
 - Production of chlorinated organics also an issue.

Other Aqueous Wastes

- The nature of the waste depends on the nature of the source.
 - Food processing
 - Pulp and paper
 - Metal finishing
 - Chemical manufacturing
 - Petroleum refining
 - Mining
 - Agriculture
 - Landfills

High Strength Aqueous Waste

- Very high BOD
- Come primarily from food processing and pulp and paper
- Contain naturally occurring organic compounds.
- If discharged into sewage system, can overwhelm the capacity of the sewage treatment facility.
 - Treatment required before discharge.
 - If municipalities allow discharge into sewage system, a commensurate levy is charged.
- Pulp and paper waste is primarily lignin.
 - Treated by biological degradation in vigorously aerated lagoons.
 - Alternative treatment involves closed bioreactors (which is less vulnerable to weather variation).
 - Resulting sludge needs to be digested, dewatered, and landfilled.

Low Strength Aqueous Waste

- Oily wastes generated by petroleum refining.
 - Interfere with oxygen transport across surface of water.
 - Broken down by long treatment in aeration lagoons or bioreactors.
 - Mechanical separation is difficult, especially if emulsifiers are present.
 - Water may be removed by evaporation.
 - Oily component may be combusted or ozonized.
- Landfarming is also used.
 - Oily waste is spread out on soil and microbes are allowed to degrade it.
 - Persistent organic compounds accumulate.
 - Volatile organics evaporate.
 - Environmental impact and land costs are issues.
- Treatment with activated charcoal may be considered.