Water Supply Engineering

Chapter 6

Water Treatment

Lecture 10 (Week 10)

Disinfection, Purpose, Methods of disinfection, Chlorination, Types of chlorine, Forms of chlorination, Factors affecting efficiency of chlorination

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Learning Objectives:

After studying this chapter, students will be able to:

- Understand the Purpose of Disinfection
- Identify Common Methods of Disinfection
- Explain the Process of Chlorination
- Differentiate Types of Chlorine Used in Water Treatment
- Understand the Various Forms of Chlorination
- Analyze the Factors Affecting Efficiency of Chlorination

6.7 Disinfection

- Filtration alone doesn't make water safe for drinking purpose
- Water disinfection means the removal, deactivation or killing of pathogenic microorganisms.
- The substance or agent used for disinfection is called Disinfectant.

6.7.1 Purpose

The **main purpose of disinfection** in water supply systems is to:

1. **Destroy or inactivate pathogenic microorganisms** (such as bacteria, viruses, protozoa, and fungi) that may be present in water.
2. **Prevent the spread of waterborne diseases** like cholera, typhoid, dysentery, and hepatitis.

3. **Ensure the microbiological safety of drinking water** before it is supplied to the public.
4. **Provide residual protection** in the distribution system so that water remains safe from recontamination during storage or transportation.

Essential Requirements of an Ideal Disinfectant

1. **Complete Elimination of Pathogens:**

   It should be capable of destroying all harmful disease-causing microorganisms, making the water completely safe for human consumption.

2. **Quick Action:**

   The disinfectant should act rapidly and achieve effective disinfection within a short contact time under normal temperature conditions.

3. **No Adverse Effect on Water Quality:**

   It should not alter the physical, chemical, or taste properties of the treated water.

4. **Non-Toxic:**

   The disinfectant and its by-products must not be harmful or poisonous to humans.

5. **Effective Across pH and Temperature Ranges:**

   It should remain effective across the normal variations in water pH and temperature found in real-world conditions.

6. **Economical and Easily Available:**

   It should be cost-effective and readily available for regular use, especially in large-scale public water supply systems.

7. It shouldn’t require high skill and capable of easily handling.

8. Concentration of disinfectant should be measurable.

9. It must be able to leave some residual concentration after the disinfection

6.7.2 Methods of disinfection

- Boiling
- Excess Lime Treatment
- Iodine Treatment
- Bromine Treatment
- Ozone Treatment
- Potassium Permanganate Treatment
- Silver Treatment
- Ultra Violet Ray Treatment

a. **Boiling**

- Most effective and conventional method of disinfection
- Boiling for 15 minutes kills all harmful micro-organisms
- Not economically feasible for public water supply in large scale
- Does not take care of future contamination and Suitable method of disinfection for individual household to safely fulfill domestic demand.
- Ideal to boil just before consumption.

b. **Excess lime treatment**

- Bacteria and e-coli cannot survive in water basic condition ($pH > 9.5$)
- Thus, adding excess lime to raise pH above 9.5 kills almost 100% of the bacteria.
- 10 – 20 ppm of lime is added to achieve this effect

- The lime needs to be removed after disinfection by decarbonation or other suitable method before supplying to consumers.
- This effect can also be reached by addition of acid in water (Ph < 3)

c. Iodine Treatment for Water Disinfection

- When iodine is added to water (at around pH 7), it forms hypoiodous acid (HIO). Both iodine and hypoiodous acid are effective disinfecting agents.
- Unlike chlorine, iodine can oxidize ammonia and remains more stable in water, making it reliable under certain conditions.
- The typical dosage of iodine for disinfection is around 8 mg/L, with a contact time of approximately five minutes to ensure effective microbial inactivation.
- However, iodine is more expensive than chlorine, so its use is usually restricted to special cases such as swimming pools, military operations, and field-level applications where portability and quick treatment are essential.

d. **Bromine treatment**

- Bromine(Br) when added to water forms hypobromous acid(HOBr).
- With ammonia, bromine forms monobromamine and dibromamine which are strong bactericide.
- Because of higher cost and less effectiveness it is not used in public water supplies.
- However it is used in small scale in disinfection of swimming pool water.

e. Ozone treatment

- Ozone breaks down to normal oxygen (O2) and nascent oxygen[O].
- Nascent oxygen is very effective in killing bacteria and oxidises organic matters.

- Ozone is produced by passing air between two high potential electrodes and is diffused to water.
- 2-3 ppm of ozone is required for residual ozone of 0.10 ppm
- In this treatment the contact period is about 10 minutes.

f. **Potassium Permanganate ($KMnO_4$) Disinfection**

- This method is **commonly used in rural areas**, especially where water is drawn from **wells** that generally contain a **lower concentration of bacteria**.
- In practice, **potassium permanganate is first dissolved in a bucket of well water**, and then this solution is **thoroughly mixed with the rest of the well water** to ensure even distribution.

- Potassium permanganate acts as a **disinfectant**, effectively **killing bacteria**, and also serves as an **oxidizing agent**, helping to remove **taste- and odor-producing organic matter**.
- The **recommended dosage** is about **1 to 2 parts per million (ppm)**, with a **contact time of 4 to 6 hours** for effective treatment.
- One noticeable feature of using $KMnO_4$ is that it imparts a **distinct pink coloration** to the water during treatment.

g. **Silver treatment**

- Silver treatment uses **metallic silver ions** to disinfect water. This is done by passing water through solid silver electrodes, with an electric current of about 100 volts applied. This process, known as the **electro-Katadyn method**, releases silver ions into the water.

- These silver ions are **powerful disinfectants** and can kill bacteria effectively. Typically, the silver concentration in the water is kept between **0.05 to 0.1 parts per million (ppm)**. The contact time needed for effective disinfection ranges from **15 minutes up to 3 hours** depending on conditions.
- However, this method is **quite expensive** and requires special equipment, so it is **rarely used in large-scale water treatment plants**. Instead, it might be applied in specialized or small-scale settings.

h. **Ultra-violet ray treatment**

- Ultra violet rays are invisible light rays having wave length of **0.49 µ to 0.149µ**.
- Sun rays have ultra-violet rays which can be utilized in the disinfection of water.

- In the laboratory they can be obtained by the ultra-violet ray equipment, which essentially consists of mercury vapors enclosed in quartz bulb and passing current in it.

- Depth of water should be 10 cm, and it should be colorless and turbidity should not exceed 20 NTU
- This rays penetrate in water and kill the bacteria
- This process is very costly and requires technical skill and costly equipment Therefore, it is not commonly used in public water supplies.

(Kansakar, 2015)

6.7.3 Chlorination (theory, chlorine demand, chlorine dose, residual chlorine, contact time

- Chlorine/compound used as disinfectant for disinfection
- Common: reliability/ease handling/affordability in cost
- Chlorine in water is unstable and rapidly decomposes on exposure to sunlight.
- Enzymatic hypothesis theory is most widely accepted, in which chlorine first penetrates cell wall then reacts with enzyme resulting death of microorganism.
- Nascent oxygen theory explains that bacteria are oxidized by nascent oxygen produced by chlorine in water

Action of chlorine

When chlorine is added to water above reactions

take place

- Hypochlorous acid and hypochloride ions are good disinfectant.
- The chlorine existing in water as hypochlorous acid, hypochloride ion and molecular chlorine is termed as free available chlorine

Chlorine demand

- Chlorine and its compounds are very reactive, it reacts with organic, inorganic matters and pathogens.
- The amount of chlorine consumed in reaction with chemicals present in water as well as in killing pathogens in the water is called chlorine demand of water.

Dosage of chlorine

- The amount of chlorine consumed in the oxidation of impurities is chlorine demand of water.
- After the chlorine demand is fulfilled, chlorine will appear as free chlorine.
- The dose of chlorine varies from trace to 1 ppm.

- The dose which leaves 0.2 mg/L of residual chlorine is the optimum dosage of chlorine.
- The difference between the total amount of Cl_2 added to water and the quantity of free available chlorine remaining at the end of a specified contact period is chlorine demand.

Residual chlorine

- The amount of chlorine remaining in water after chlorine demand is fulfilled is called residual chlorine
- Residual chlorine is required so that water is disinfected in the distribution system as well as prevention of pollution.
- Chlorine demand = total chlorine added – residual chlorine.

Contact time

- The time taken for chlorine to kill the pathogens after application of chlorine is called contact time of chlorine.
- For chlorine contact time = 10 minutes
- Due to poor diffusion, it generally requires 30 minutes for free chlorine and 60 minutes for combined chlorine

6.7.4 Types of chlorine (hypochlorites, chloramines, liquid/gas chlorine)

Chlorine may be applied to water for disinfection in following ways:

1. As bleaching power or hypochlorite

- Calcium hypochloride Ca(OCl)2 or beaching powder is a chlorinated lime.
- When it is added to water dissociates into Calcium Ca^{++} and hypochlorite OCl^{-}
- $Ca(OCl)_2 \;=\; Ca^{++} + 2OCl^{-}$
- The hypochlorite ions obtained above further combine with the hydrogen ions present in water and form hypochlorous acid as follows:

$OCl^{-} + H^{+} = HOCl$

- Commercially available bleaching powder contains approximately 30 **to 35**

percent of available chlorine.

- The value of chlorine content continuously decreases if the powder is exposed to the atmosphere

2. Chloramines

- Chloramines are compounds formed by **reaction between ammonia and chlorine**.

$$H_2O + Cl_2 \Leftrightarrow HOCl + H^+ + Cl^-$$

$$NH_3 + HOCl \Leftrightarrow NH_2Cl\,(monochloramine) + H_2O$$

$$NH_2Cl + HOCl \Leftrightarrow NHCl_2(dichloramine) + H_2O$$

$$NHCl_2 + HOCl \Leftrightarrow NCl_3(trichloramine) + H_2O$$

- The compounds are quite stable in water and **remains in water as residual for a sufficient time** so are more effective than chlorine alone.
- The reaction is slow hence water treated can only be supplied to consumer after 20 minutes to 1 hour of application.
- It **does not cause bad taste and odor when left at residual** but is **weaker disinfectant than free chlorine disinfectant.**

3.Chlorine gas or liquid chlorine or free chlorine

- Chlorine gas is **fed directly** to the point of application to the water supply in a pressure of 7 kg/cm^2 **or first dissolved in small flow of water** and the chlorine water solution is then applied to the system.

- Application of gas chlorine is **less expensive but less satisfactory** because of poor diffusion of chlorine and at lower temperature crystalline hydrates of Cl are formed and **possibility of choking of pipes.**
- Undissolved Cl may corrode pipes and valves.
- Chlorine gas or liquid chlorine dissolved in small quantities of water is normally used.

4.Chlorine dioxide

- In this method, chlorine dioxide gas is produced by passing chlorine gas through **sodium chlorite solution**.
- ClO_2 has oxidizing capacity **2.5 times than that of chlorine** and most effective for removal of taste and odour.

6.7.5 Forms of chlorination (plain chlorination, pre chlorination, post chlorination, double chlorination, multiple chlorination, breakpoint chlorination, super chlorination, dichlorination)

• Forms of chlorination depends upon chlorine application in different stage of treatment and the expected results of application:

a. **Plain chlorination or simple chlorination**

b. **Pre-chlorination**

c. **Post-chlorination**

d. **Double chlorination**

e. **Multiple chlorination**

f. Break point chlorination or free residual chlorination

g. Supper chlorination

h. De-chlorination

a. Plain chlorination

- Application of chlorine to plain or raw water is called plain chlorination.
- Only chlorine treatment & no other treatment is given
- Helps to remove bacteria & color from water
- Controls growth of algae
- Usual dose of chlorine is 0.5-1 ppm

b. **Pre-chlorination**

- Application of chlorine to raw water before any treatment (especially before filtration & sedimentation)
- Reduces the amount of coagulant because of oxidation of organic matter
- Reduce bacteria loads on filters
- Controls algae & planktons in basins & filters run
- Eliminate taste & odor
- For satisfactory disinfection, water should have residual chlorine of 0.1 to 0.5 ppm

c. Post-chlorine

- Application of chlorine to water after the treatment of water

- Standard form of chlorination where chlorine is added after it leaves filters & before distribution
- Water should have residual chlorine of 0.1 to 0.2 ppm

d. Break point chlorination or free residual chlorination

- ➢ It is a water treatment process where chlorine is added to water until the demand for chlorine is fully met and all undesirable compounds (like ammonia and organic matter) are oxidized. Beyond this point, any additional chlorine added remains as free chlorine, providing a residual disinfectant.
- ➢ If no chlorine demand, chlorine appear as residual chlorine and indicated by line A of slope of 45°
- ➢ Generally, due to some chlorine demand it is indicated by curve B due to the fact firstly it slightly kills bacteria but reacts with compounds such as ammonia, proteins, amino acids and phenols with formation of chloramines and chloro-derivatives

- With increase in applied chlorine, residual chlorine increases and curve B goes on rising till point C where amount of residual chlorine is maximum

Further increase in applied chlorine:

- Sudden decrease in residual chlorine due to break down of chloramines into nitrogen compounds
- Represented by curve CD
- At point D, bad smell/taste suddenly disappears and oxidation is completed.
- At point D, residual chlorine has its minimum value which indicates true residual free chlorine
- Point D is called break point and application of chlorine at or slightly higher than this point is called break point chlorination.

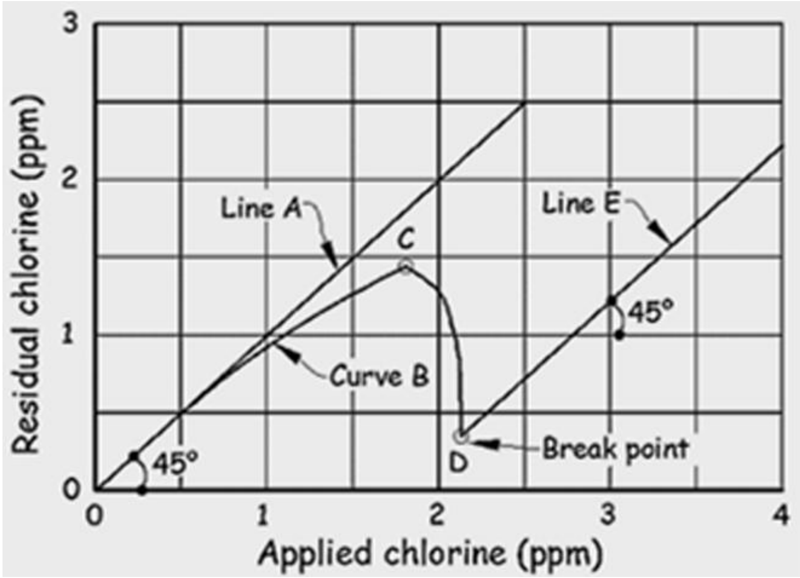

Figure 1: Residual chlorine Vs Applied Chlorine(©Sunil Rakhal,2024)

- Beyond break point, all applied chlorine appears as residual chlorine represented by a line E with 45° slope

e. Super Chlorination

- Application of chlorine beyond the break point chlorination.
- It is addition of large doses of chlorine to the water and removal of excess of chlorine after disinfection

f. De-chlorination

•Removal of excessive chlorine in water or due to super chlorination because it imparts unpleasant taste and odour

•By:

- ➢ Aeration
- ➢ Adding sodium thiosulphate, sodium metabisulphate, sodium sulphite, sodium bisulphate, ammonia and sulpherdioxide
- ➢ Treating water with magnesium metal.

6.7.6 Factors affecting efficiency of chlorination

Several factors influence the effectiveness of chlorination in water disinfection:

1. Turbidity

High turbidity can shield microorganisms from chlorine, reducing disinfection efficiency. It also increases chlorine demand, reducing residual levels (WHO, 2017).

2. Presence of Metallic Compounds

Compounds of **iron and manganese** consume chlorine during oxidation, forming insoluble oxides, and reducing the amount available for microbial disinfection.

3. Ammonia Compounds

Ammonia in water reacts with chlorine to form chloramines, which are less effective disinfectants.

Combined chlorine requires **25 times more quantity** and **100 times more time** than free chlorine to achieve the same bacterial kill rate (Kowal & Andrews, 1991).

4. pH Value

Chlorine is most effective at a pH of **6.5 to 7.5**, as it favors the formation of **hypochlorous acid (HOCl)**, the most active disinfectant form. Higher pH reduces its effectiveness.

5. Temperature

Lower water temperatures **slow down disinfection**, as the chemical reaction rate decreases.

Higher temperatures enhance the disinfecting action of chlorine.

6. Contact Time

The longer the chlorine remains in contact with water, the more effective the disinfection. Contact time requirements depend on factors like pH, temperature, and microbial load (WHO, 2017).

7. Type and Concentration of Microorganisms

Some microorganisms, like **viruses**, are more resistant to chlorine than bacteria. Clumped or high-concentration microbial populations require **higher chlorine doses** and **longer contact time** for complete disinfection.

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Thank You!!!