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Chlorine as Disinfectant in Water Treatment Plant (WTP)

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Abstract

The supply of safe drinking water is most important for human health. Disinfection process is considered as one of the most significant water treatment processes. It is a process of destruction of microorganisms by chemical substance or compound. Though disinfectants are highly efficient killing agents, these are very toxic by their selves. However, they interact with natural organic matter (NOM), microorganisms, and algae to produce disinfection byproducts (DBP) which are poisonous. Therefore, the use of chemical disinfectants must be avoided or reduced as possible at the lowest level. There are several types of disinfectants that have been used such as chlorine, chlorine di-oxide, ozone, ultraviolet light etc. Due to its low cost, availability, ease of transportation and storage, chlorine is widely used as a disinfectant in most of the countries. In this review, we discuss about chlorination processes which are largely used in water treatment plant.

KEYWORDS: Aerator, Chlorine, Coagulation, Disinfection, Disinfection byproduct (DBP), Filtration

1. INTRODUCTION

Humans totally depend on water for their survival. Water is the most abundant and common substance on our planet, but clean water is essential for good public health. Humans cannot survive without water; in fact, our bodies are 67% water [1]. Water regenerates the shape of oceans, seas, rivers, lakes and forests, becoming part of the hydrological cycle that is important for the development of ecosystems and human life [2]. According to Rijsberman [3], it is estimated that a minimum of 7.5 litres of water is required for individual consumption, personal hygiene and preparing food. Available water resources in cities are scarce because of increasing population, changing precipitation patterns, and degradation of existing sources of water. The Conventional water treatment processes include several stages: aeration, coagulation, flocculation, particle separation (sedimentation/flotation), filtration, and disinfection.

Disinfection is a crucial water treatment method as it ensures that water is free of pathogenic micro-organisms causing water borne diseases [4]. It is worth noting that in the U.S. cholera incidence was reduced by 90%, typhoid by 80% and amoebic dysentery by 50% after introducing disinfection in water treatment [5,6]. Among the chemical reagents, chlorine and its derived compounds are the most widely used disinfecting agents worldwide. Many organisms regulate the residual chlorine values and they depend on the end use of the water. For drinking water, it is recommended that the residual free chlorine be between 0.2 and 1 ppm [7]. The most common chlorine family products for water treatment are chlorine gas, chloramines, sodium hypochlorite, and calcium hypochlorite. Chlorine (Cl_2) is a yellowish green, denser than air, toxic gas. Disinfectant is an essential treatment that safeguards consumers against pathogenic microorganisms in reclaimed water, and chlorine-based disinfectants are widely utilized disinfectants for drinking water and reclaimed water. Chlorine destroys target microorganisms by oxidizing cellular materials; it is the most widely used disinfectant for municipal water. DBP concentrations differ at the storage tanks and within the water distribution network and especially in their dead-ends. Reaction time is the key factor, as longer reaction time leads to higher consumption of residual disinfectant and results in more formation of DBPs [8]. This review concerns the killing agents most usually utilized in the water treatment industries focusing on their implied mechanisms and disinfection secondary reactions health concerns.

2. OVERVIEW OF WATER TREATMENT PLANT

Surface waters must be treated to remove turbidity, color and bacteria. The object of coagulation (and subsequently flocculation) is to turn the small particles of color, turbidity and bacteria into larger flocs, either as precipitates or suspended particles. A typical flow chart of water in water treatment plant is shown in figure 1.

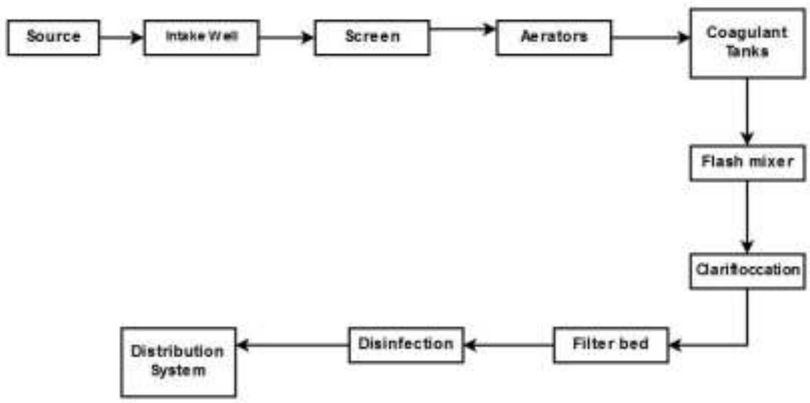

Figure 1: Schematics over conventional water treatment process [9]

The various steps involve in water treatment plants are discussed below;

2.1. AERATOR

Aeration is the process by which air is circulated through, mixed with or dissolved in a liquid or substance [10]. Aeration brings water and air in close contact in order to remove dissolved gases such as hydrogen sulphide, volatile organic chemicals and to oxidize dissolved metals, including iron, manganese.

2.2. COAGULATION

The alum is a very common chemical coagulant in water treatment plant. But due to its health hazard effect, natural coagulants are used as alternative coagulant [11]. During coagulation, chemicals with a positive charge are added to the water. The positive charge neutralizes the negative charge of dirt and other dissolved particles in the water. The coagulant dosing rate depends on the various parameters of raw water such as conductivity, turbidity, temperature, pH etc.

2.3. FLOCCULATION

Flocculation is the gentle mixing of the water to form larger, heavier particles called flocs. Often, water treatment plants will add additional chemicals during this step to help the flocs form [12].

2.4. SEDIMENTATION

Sedimentation is one of the steps water treatment plants use to separate out solids from the water. During sedimentation, flocs settle to the bottom of the water because they are heavier than water [13].

2.5. FILTRATION

Once the flocs have settled to the bottom of the water, the clear water on top is filtered to separate additional solids from the water. During filtration, the clear water passes through filters that have different pore sizes and are made of different materials (such as sand, gravel, and charcoal). These filters remove dissolved particles and germs, such as dust, chemicals, parasites, bacteria, and viruses. Activated carbon filters also remove any bad odors, dissolved gas and oil [14].

2.6. DISINFECTION

Disinfection is “any process in which most or nearly all microorganisms (pathogenic or not) in a given article are killed or inactivated to prevent or cease infection”. Disinfection treatments can be physical (gamma radiation, X-rays, ultraviolet radiation, thermal sterilization, etc.) or chemical (heavy metals, acids or bases, halogens, ozone, chlorine, permanganate, etc.) with the latter being the most common form of treatment [7]. Among the chemical reagents, chlorine and its derived compounds are the most widely used disinfecting agents worldwide.

3. CHLORINE AS DISINFECTANT

Disinfection of drinking water and wastewater is crucial to the protection of public health. All water and wastewater systems should use some form of disinfection process to remove or inactivate microorganisms (pathogens) that can cause disease in humans and animals. Disinfection is also used to remove micelles, dissolved solids and gases, algae etc.

3.1. CHLORINE CHEMISTRY

Chlorine is by far the far the most widely used disinfectant in water and wastewater treatment plants. Chlorine gas (Cl_2) introduced in water hydrolyzes according to the following equation:

$$\mathrm{Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-}$$

Hypochlorous acid dissociates in water according to the following equation:

$$\mathrm{HOCl \rightleftharpoons H^+ + ClO^-}$$

Figure 2 shows that the proportion of HOCl and OCl^- depends on the pH of the water. Chlorine, as HOCl or OCl^-, is defined as free available chlorine. HOCl combines with ammonia and organic nitrogen compounds to form chloramines.

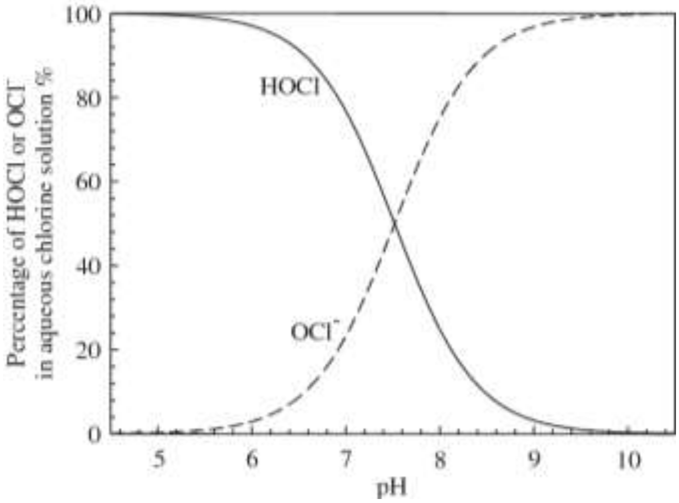

Figure 2: Distribution of HOCl and OCl^- in water as a function of pH [15].

3.2. INACTIVATION OF MICROORGANISM BY CHLORINATION

Of the three chlorine species (HOCl, OCl^-, and NH_2Cl), hypochlorous acid is the most effective for the inactivation of microorganisms in water and wastewater. Water treatment with ≤ 1 mg/L for about 30 min is generally efficient in significantly reducing bacterial numbers. Physical (heat, freezing, sunlight) and chemical agents (chlorine, sublethal levels of heavy metals) can cause injury to bacterial cells. Chlorine and copper appear to cause signifi cant injury to coliform bacteria in drinking water [16]. Injury by chlorine can affect a wide variety of pathogens, including enterotoxigenic *E. coli* , *Salmonella typhimurium* , *Yersinia enterocolitica* , and *Shigella* spp. The extent of injury by chlorine depends on the type of microorganism involved. Inactivation of *Cryptosporidium* oocysts with free chlorine can also be enhanced by ozone pretreatment. A 4 - to 6 - fold increase in free chlorine efficacy was obtained with ozone pretreatment. The sequential inactivation using ozone followed by free chlorine was shown to increase the inactivation of *Salmonella*, bacterial phage, poliovirus type 1, and parasites such as *Cryptosporidium* and *Giardia* [17].

3.3. CHLORINATION MECHANISM

Chlorine causes considerable damage to cells. The destruction of microorganism by the action of chlorine are discussed one by one.

3.3.1. EFFECTS ON VIRUSES

The mode of action of chlorine on viruses may depend on the type of virus. Nucleic

acid damage is the primary mode of inactivation for bacterial phage or poliovirus type 1 [18]. The protein coat appears to be the target site for other types of viruses (e.g., rotaviruses).

3.3.2. DISRUPTION OF CELL PERMEABILITY

Free chlorine disrupts the integrity of the bacterial cell membrane, thus leading to loss of cell permeability and to the disruption of other cell functions. Exposure to chlorine leads to a leakage of proteins, RNA, and DNA [19]. Permeability disruption was also implicated as the cause of damage of chlorine to bacterial spores [20].

3.3.3. DAMAGE TO NUCLEIC ACIDS AND ENZYMES

Chlorine also damages bacterial nucleic acids as well as enzymes (e.g., catalase, dehydrogenases). Whole genome analysis of *Staphylococcus aureus* exposed to HOCl has shown that the disinfectant leads to repression of the transcription of genes controlling cell wall synthesis, protein synthesis, membrane transport, and primary metabolism. However, HOCl induces genes encoding for virulence factors in *S. aureus* [21].

3.3.4. OTHER EFFECTS

Hypochlorous acid oxidizes sulfhydryl groups, damage iron-sulfur centers, disrupts nutrient transport, inhibits cell respiration, and impairs the ability of cells to maintain an adequate adenylate energy charge to remain viable [22].

3.4. TOXICOLOGY OF DISINFECTION BYPRODUCTS (DBPs)

Disinfection byproduct are formed following the reaction of chlorine with precursors such as natural organic matter (NOM; mainly humic and fulvic acids) and microorganisms such as algal cells (e.g., diatoms) as well as cyanobacteria and their extracellular products [23]. DBPs include THM such as chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and bromoform ($CHBr_3$), haloacetic acids (HAA; e.g., monochloroacetic acid, monobromoacetic acid, dichloroacetic acid, dibromoacetic acid, trichloroacetic acid), and halocetonitriles.There is evidence of an association between chlorination of drinking water and increased risk of bladder, kidney, and colorectal cancers. This association is stronger for consumers who have been exposed to chlorinated water for more than 15 years. Some DBPs are suspected mutagens/carcinogens or teratogens, and some, like chloroform, cause cytotoxicity in liver and kidneys. Exposure to high HAA levels in drinking water is associated with increased cancer risks in animals and humans. There is also the possibility of an association of water chlorination with increased risk of cardiovascular diseases [24].

3.4.1. CONTROL OF DISINFECTION BYPRODUCTS (DBPs)

There are several approaches for reducing or controlling DBP in water. Removal or reduction of DBP precursors (e.g., NOM, including humic substances, algae, and their extracellular products) before disinfection. Organic carbon concentrations can be reduced by enhanced coagulation, granular activated carbon (GAC), or membrane fi ltration [25]. In homes, THMs can be volatilized upon boiling tap water. HAA and THM concentration can also be reduced via adsorption to activated carbon. Pre-ozonation reduces the formation of THMs, HAAs.

3.5. DISADVANTAGE OF CHLORINE AS DISINFECTANT

Breathing problems, Lungs problem. Burning and Irritation of Eyes and loss of vision. Tissue damage, Burns and Irritation of skins. Safety and liability concerns have also been a key reason for facilities to switch to alternative technologies. Chlorine is an extremely volatile and hazardous chemical and requires specific precautions for it to be shipped, stored, and used safely. Systems using chlorine gas also have the disadvantage of producing toxic disinfection products. Most wastewater treatment systems using chlorine gas must use a dechlorinating technology to remove residual chlorine prior to discharge, increasing the cost of treatment.

3.6. ADVANTAGE OF CHLORINE AS DISINFECTANT

Chlorine is a good bacterial disinfectant requiring short to moderate contact times. Chlorine gas has a very large established base, and its design and operating characteristics are easily understood. Chlorination helps to prevent the spread of infections such as E. coli, it destroys bacteria, algae etc. It removes unpleasant tastes and odors from drinking water. Chlorine remains in the water while it's distributed, hence retaining its ability to continue killing microorganisms.

4. ALTERNATIVE DISINFECTANT

The alternative disinfectants are Bromine, Iodine, Silver, Ozone gas, Chlorine dioxide, Chloramine etc.

5. FUTURE STUDY

As quality drinking water is an important part of living organism, therefore much more research work will have to be done on the disinfection process . Modern study such as SEM, TEM, ultra-microscopic study etc may be implemented to study health hazard.

6. CONCLUSION

This paper evokes the chlorination of water treatment plant, effect of chlorine, suitable pH value, effectiveness of Chlorine, advantage and disadvantage of chlorine and usage of alternative disinfectants.

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