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Water Treatment: Disinfection of Water by Chlorination as a Means of Water Diseases Elimination

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ABSTRACT: Though disinfection is also known as sterilization of water, but with a difference because sterilization is a process of complete killing or destruction of all sorts of bacteria in water not minding that they are harmful or useful to the health of end users but disinfection restricts its destructive effect to only harmful bacteria. Pathogenic microorganisms such as viruses, algae, protozoa. Therefore, by definition, disinfection of water is the process method of killing harmful pathogenic bacteria from water to make it safe for consumers. Disinfectant materials are expected to be harmless, unobjectionable, economical in use, available and easy application usage.

Chlorine is the universally accepted most used disinfectant material for disinfecting water. Chlorination is the method or process of chlorine application to water in order to destroy and kill all harmful microorganisms or pathogens such as viruses, fungi, algae, bacteria and all sorts of germs. Chlorine is always available in the form of sodium hypochlorite solution (NaOCl) or as solid calcium hypochlorite ($Ca(OCl)_2$) chlorine is acceptable/unobjectionable, economical and harmless (at the right dosage of use).

KEYWORDS: Residual chlorine, harmful pathogens, sodium hypochlorite solution, free chlorine, rate of kill, pH value, dose of chlorine, break point, hypochlorinous acid, chlorine demand.

I. INTRODUCTION

Chlorine is the disinfectant almost universally employed in water supply treatment. Chlorine use for the disinfection of water is referred to as chlorination and it indicates that water had been treated with a chlorine sterilizing agent. Chlorination is the final safe guard for the quality of the water, hence its application cannot be overemphasized. To ensure that only required amount of chlorine is fed into the chlorinator, the operation of the chlorine should be automatic and should be applied at such a point in the water supply system that a good mixing of chlorine with the water is ensured. Precaution in the mixing process is because too little chlorine is ineffective and too much may cause undesirable taste and odour.

The process of disinfection by chlorine in recent times is based on the enzymatic theory which says that the disinfecting agents react with certain enzymes needed for metabolic process of living cells which renders them inactive and hence causes the death of living cells contained in water.

Temperature, concentration, of organisms, amount of disinfectant, contact time, the pH value, the presence of various chemicals and the disinfecting action of chlorine are all factors that affects the disinfecting efficiency of chlorine but the efficiency of chlorine as a disinfectant agent on water will as well depend on dose of chlorine, which is by definition, the appropriate amount of chlorine dosage to be added to water which must be monitored continuously to ensure the levels are within the recommended limits because too little will not destroy the contaminants and too much is definitely bad for human health.

The principle of disinfection of water by use of chlorine in homes is that, when chlorine is added to water, the chlorine dissolves in the water and then converts to hypochlorous acid (HOCl) and hypochloricacic (HCl) that is, chlorine (Cl_2)+ (H_2O)=hydrochlorous acid (HOCl) and hydrochloric acid (HCl).

Chlorine is the disinfectant almost universally employed in water supply. The terminology used for chlorine disinfection of water is called chlorination and it indicates that water has been treated with a sterilizing agent. Chlorination is final safe guard for the quality of the water, application cannot be overemphasized. The equipment used for chlorine application is known as chlorinator. The operation of the chlorinator should be automatic so as to ensure that only required amount of chlorine is fed and should be applied at such a point in the water supply system that a good mixing of chlorine with the water is ensured. All these precaution is because too little chlorine is ineffective and too much may cause taste and odour. Contact period of chlorination is the period serving the double purpose of providing the time necessary to destroy the pathogenic organism in the water and reduction of the effect on consumers of possible overdose of chlorine. The point of mixing chlorine with water should be so located that there is a contact period between chlorine and water of about 20 to 30 minutes before it gets to end users destination, contact period so required is a function of the amount of residual chlorine being the chlorine remaining after initial contact with water. If the residual chlorine is low, then a longer contact period is required. Chlorine uses in water treatment is not limited to disinfection but also for control of algae, growths in reservoirs which at the end of time produces bacteria. Its other use is that coagulation with chlorinated copperas neutralizes taste and odour.

THEORY OF DISINFECTION AND DISINFECTION OF CHLORINE

Theory of disinfection

Rate of kill is generally expressed by the application of chick's law which state that:

$$\frac{dN}{dt} = -KN \qquad \text{--------------------------------(1)}$$

Where

K= Reaction rate (it is constant for particular disinfectant)
N = Number of viable organisms
N_t= Number of organisms at any time **t**

If equation (1) is integrated,

Then

$$\int \frac{dN}{N_t} = -\int Kdt$$

$$\therefore \int \frac{dN}{N_t} = \int Kdt$$

$$\therefore \log e^{Nt} = K_t + C \qquad \text{--------------------(2)}$$

At t = 0 and N_t = N_o = number of initial organisms

$$\therefore \log e^{No} = C$$

Equation (2) becomes:

$$\log e^{Nt} = K_t + \log e^{No}$$

$$\therefore \log e^{\frac{Nt}{No}} = -K_t$$

Then,

$$t = \frac{1}{k}\left[\log e^{\frac{Nt}{No}}\right]$$

And changing to base 10

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$t = \frac{1}{k} \log_{10}\frac{N_t}{N_o}$

Knowing that N_t will not reach zero, so it is the usual practice to specify kill as a percentage.

Theory of disinfection by chlorine

Chlorine is the most popular disinfection of water. It does not obey equation I above of the theory of disinfectants. Rather, it definitely follows the relation given by:

$$\frac{dN}{dt} = KN_t t$$

$$\int \frac{dN}{d_t} = \int -K\, x\, td_t$$

$$\log e^{N_t} = -\frac{Kt^2}{2} + C$$

At $t = 0$, $N_t = N_0$

Then

$C = \log e^{N_o}$

$$\log e^{\frac{N_o}{N_t}} = \frac{Kt^2}{2}$$

$t^2 = \frac{2}{k} \log_{10}\frac{No}{Nt}$

$\therefore \quad t = \sqrt{\frac{2}{k}} \log_{10}\frac{No}{Nt}$

To explain the process of disinfection by chlorine, different theories have been developed. The enzymatic theory is the recent and widely accepted, the theory says that the disinfecting agents react with certain enzymes needed for metabolic processes of living cells which render them inactive. This inactiveness of the enzymes causes the death of living cells contained in water. Disinfection procedure is in two stages because the enzymes are developed within the cell plasma. The two ways are:

a) Penetration of disinfection agent through cell walls
b) Its reaction with enzymes

The theory is that the nascent oxygen liberated from the hypochlorous acid oxidizes essential constituents of the bacteria. To explain this, let's consider a situation that will allow us obtain a 99.7% kill of bacteria, where ozone is to be used in water with residual of 0.7mg/l. Assuming a reaction constant under these conditions to be 3 x 10^{-2}/sec, the contact time period can be computed as explained thus;
Bacteria in water = 100.0 – 99.7 = 0.3%
i.e 0.3% bacteria remains in water after ionization

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Concentration of bacteria which is 100mg/l after ionization = 0.3%mg/l
Milligram per litre of residual given = 0.7mg/l
Number of initial organisms (N_0) = $100 \times \frac{0.70}{0.30} = \frac{700}{3} = 233.3\text{mg/l}$
Number of organism at time **t** = 0.7mg/l

$$t = \frac{1}{k}\log_{10}\frac{No}{Nt} = \frac{1}{k}\log_{10}\frac{233.3}{0.7} = \mathbf{84.1secs.}$$

Also, if we compare the contact times necessary to obtain 99.98% kill of bacteria in water under the following conditions.

a) Free chlorine residual of 0.2mg/l when $k = 1.1 \times 10^{-2}$/sec
b) Combine chlorine residual of 1.5mg/l with $k = 1.2 \times 10^{-5}$/sec

Then,

a) For free chlorine residual, bacteria in water to be kill = 99.98%
Bacteria in water that will remain unkill = 100 – 99.98 = 0.02%
0.02mg/l bacteria remains from 100mg/l of its concentration,
0.2mg/l bacteria remain from $\frac{100 \times 0.2}{0.02}$ = 1000mg/l concentration

Hence N_0 = 1000mg/l, N_t = 0.2, $k = 1.1 \times 10^{-2}$/sec

$$\therefore\quad t = \sqrt{\frac{2}{k}}\log_{10}\frac{No}{Nt} = \sqrt{\frac{2}{1.1 \times 10^{-2}}}\log_{10}\frac{1000}{0.02} = 672.5 \text{ secs.}$$

b) Combined chlorine residual:

N_t = 1.5mg/l, $k = 1.2 \times 10^{-5}$/sec, $N_0 = 100 \times \frac{1.5}{0.02} = 7500\text{mg/l}$

$$t = \sqrt{\frac{2}{k}}\log_{10}\frac{No}{Nt} = \sqrt{\frac{2}{1.2 \times 10^{-5}}}\log_{10}\frac{7500}{1.5} = \mathbf{785.2\ secs.}$$

FACTORS AFFECTING EFFICIENCY OF CHLORINE

The disinfecting efficiency of chlorine is affected by the following factors:

a) Temperature
Rise in temperature increase the rate of reaction with enzymes and hence harmful bacteria death rate increases as well.

b) Concentration of organisms
The higher the concentration of the organisms, the greater the percentage destruction of the organisms

c) Disinfectant amount
Because different disinfectant have different germicidal value, therefore the higher the concentration of the disinfectant, more effective it will be.

d) Time of contact
Number of organisms killed by a disinfectant per unit time is proportional to the number of organism left alive. The rate of death of organisms in water decreases with time, therefore a minimum of 30 to 60 minutes contact period time should be provided before delivery water to the consumers.

e) pH value
Disinfecting process of chlorine is affected by the change in pH value of water. Hence at lower pH value, contact period required to kill the same percentage of the organism is smaller.

f) The presence of various chemicals

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When various impurities present in water react with the chlorine, chlorine that is available for disinfection purpose reduces.

g) Disinfecting action of chlorine

As chlorine is mixed or added to water, it forms hypochlorous acid or hypochlorite ions. These acid or ions so formed, have an immediate and disastrous effect on any form of microscopic organism. The reaction taking place is;

$$H_2O + Cl_2 \xrightarrow[pH>5]{} HOCl + HCl$$

(Hypochlorides acid)

The hypochlorous acid is unstable so it further dissociate or break into hydrogen and hypochloride ions

$$HOCl \underset{pH<7}{\overset{pH>5}{\rightleftharpoons}} \underset{\text{Hydrogen ions}}{H^+} + \underset{\text{Hypochloridesions}}{OCl^-}$$

The reaction is reversible thought it depends upon the pH value of water. Hypochlorous acid (HOCl) and the hypochlorite ions (OCl) are the agents which carry out disinfection of water. The dissociation of hypochlorous acid into ions is more effective at high pH values and vice versa.

DOSE OF CHLORINE

The appropriate amount to be added to water as chlorine dosage but it is not chlorine that remains. Appropriate proper dosage means that enough chlorine should be added to react with substances in the water but while still having some left over to disinfect. A chlorine dosing pump is usually used to carefully measure a recommended amount of diluted chlorine through the process of reverse osmosis water to the system. The amount of chlorine in the water must be monitored continuously to ensure the levels are within the recommended limits as tool little will not destroy the contaminants and too much is definitely bad for human health.

The quantity of chlorine required for a water treatment depends upon the inorganic and organic impurities present in it because it first react with the inorganic impurities reducing agents such as S^{--}, Fe^{++}, M^{++} and NO_2^- amongst others which converts the chlorine into chloride that have no residual oxidizing power. Excess chlorine after this point is consumed by ammonia to form chloramines (combined Cl_2). So also, it reacts with organic impurities present in water and some of which will completely oxidize chlorine, and some chloro-organics formed will have some oxidizing power. The chlorine demand of water is the consumed chlorine in all the above reactions of chlorine with inorganic and organic impurities. Free chlorine (the sum of hypochlorous acid, hypochlorite ions and the molecular chlorine existing in a given sample of water) as well as combined chlorine (which is also known as compounds of chlorine, is as a result of reaction of chlorine with organic impurities) which result to the formation of the combine chlorine (chloramines). While the free chlorine kills the pathogens, the combine chlorine will provide long term germicidal effect.

Generally, waters are satisfactory disinfected if the free chlorine residual is about 0.2mg/l at 10minutes after the chlorine is applied. The amount of chlorine to be added to water should be adjusted to accurate precision because if chlorine is insufficient, the disinfection of water will be incomplete and not relied on while excess application of chlorine to water will cause bad taste and as well emit bad offensive odour. Chlorine is most effective if the pH value of water is slightly less than 7.0, therefore the effectiveness of chlorine depends on the pH value of the water. The required optimum dose of chlorine for a given water is determined experimentally by adding varying amounts of chlorine to a given sample and observing the residual left after a contact period of about 10minutes. The chlorine dose which will leave a residual of 0.2mg/l or 0.2ppm is then selected. So the total dose in mg/l minus the free residual will then automatically represent the chlorine demand of water. However, in studies conducted by public Health services has confirmed that for effective disinfection of water, the following dosages with the conditions explained applied:

i. 0.2ppm (0.2mg/l) free residual chlorine is the minimum requirement under most favourable conditions.
ii. If conditions are adverse, 0.4 to 0.8mg/l should be the residual chlorine in disinfected water.
iii. For water that has a pH value nor greater than 7.0, there should be a free residual of 0.2mg/l after 10minutes or a combined residual of 1.0 to 1.5mg/l after 60 minutes.
iv. For water with a pH of 8.0, there should be a free chlorine residual of 0.5mg/l or a combined residual of 1.8mg/l
v. For a pH value of 9.0, the free chlorine residual should be 0.8mg/l
vi. For a combined residual to be effective, the pH value should be reduce below 9.0.

According to other studies, in the case of chlorine doses required for killing isolated virus of various types of organisms, the following quantities of chlorine doses are required for different viruses as shown in the table below.

Table 1: Quantity of chlorine doses required to kill different viruses

S/N	Types of virus to be killed	Quantity of free chlorine required in mg/l with about 30 minutes contact period for water of pH lower than 7.0
1.	Poliomyelitis virus	0.1 of free chlorine residual after 30 minutes at pH of 7.0
2.	Hepatitis virus	0.4 of free residual or 1.1mg/l of combined residual
3.	Cysts of E. histolytics, i.e the organisms causing amoebic dysentery	3.0mg/l or lower of free residual at 7.0 pH, though they are resistant to chlorine
4.	Tuberculosis organism	3.0mg/l with 3 minutes contact
5.	Coxsaickie virus	Very huge dose of chlorine residual varying from 21 to 138ppm (mg/l)

Chlorine Demand

Chlorine demand is defined as the difference between the amount of chlorine which is added to water or even wastewater and the amount of residual chlorine remaining after a specified given contact time. The chlorine demand changes with changes with dosage, temperature, time, nature and the amount of identified impurities in the water.

Before any disinfection is achieved, chlorine and chlorine compounds by virtue of their oxidizing power can be consumed by a variety of inorganic and organic materials present in water. The activity of chlorine is influenced by the water's pH value and temperature because reaction rate increase with higher temperature size and lowering of pH value. Hence it is necessary to provide sufficient time and dose of chlorine to satisfy the various chemical reactions and leave some amount of unreacted chlorine as residual either in the form of free or combined chlorine adequate for killing the pathogenic organisms. The definition of **chlorine demand** therefore is the difference between the amount of chlorine added to water and the amount of residual chlorine after a specified contact period and it varies with amount of applied chlorine, time of contact pH and temperature.

Types of chemical disinfectant and chlorine application

i. Action of chlorine with water having various impurities;

a) When water contains ammonia and organic nitrogen compound and chlorine is mixed with it, monochloramine $(NH_2Cl)_2$, dichloramine $(NHCl_2)$ and trichloramine $(NHCl_3)$ are formed. Distribution of all these three compounds depends on the pH value of water. $NHCl_2$ is not normally well formed at pH value normal unless **break point** of chlorination is not reached.
b) If water is reasonably free from organic impurities and chlorine is added to it, hypochlorous acid (HOCl) and hypochlorite ions (OCl) are formed. These two species, that is (HOCl) and (OCl) are known and called free available chlorine in practice and chemical disinfectants for the disinfection of water.
c) When water contains sewage and waste waters, complex organic chloramines are formed when chlorine is mixed to it or with it.

ii. Chlorine application and its associated chemical disinfection chlorine could be applied to water for the purpose of disinfection in any form of the following:

a) Free chlorine

This is the actual available concentration of residual chlorine in water present as dissolved gas (Cl_2), hypochlorous acid (HOCl), and hypochlorite

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ion (OCl^-). Hypochlorous acid and hypochlorite disinfect water but hypochlorous as acid is a more effective disinfectant. Free chlorine refers to all chlorine present in the water as Cl_2 (gas), HOCl (aq) and OCl (aq).

Free chlorine is also the total chlorine less combined chlorine.

After initial application of chlorine, the remaining low level of chlorine in water that has been treated is called residual chlorine. Chlorine residual is an important safeguard against the risk of possible subsequent microbial contamination after treatment. It is therefore a unique and significant benefit for public health. In drinking water, the presence of residual chlorine confirms that sufficient chlorine was added initially to the water and that the water is protected from recontamination.

Combined chlorine is the already used up chlorine. It is the chlorine that sanitizes the water. When chlorine is added to water, the water reacts with the chlorine to form hypochlorous acid and hypochlorite ion and the chlorine start to react with the contaminants in the water, such as nitrogen and ammonia, then combined chlorine is form.

The chlorine to be applied could be available either in gaseous or liquid form. If in gaseous form, it could be dissolved in little water to produce the concentration. Chlorine gas gets converted into liquid form due to external pressure. Liquid chlorine is available in cylinders which are commercially available and should be protected from corrosive effects because damp or liquid chlorine is highly corrosive. With the use of chlorinators or chloronomes, chlorine is then applied to water from the cylinders. Chlorine that is free chlorine is universally adopted as water disinfectant due to some of the following reasons:

1. It can be stored for a longtime without any deterioration in its quality and stability.
2. The pure chlorine gas is efficient in killing bacteria and very powerful.
3. It is economically available, results obtained are uniform and reliable and no sludge formation.
4. The chlorine dosage is precise and there is no likely overdose or underdose.
5. Chlorinators or chloronomes working are simple and skill supervision is not required.

b) Chloramines

It is to be noted that chlorine alone is not stable in water, so when mixed with ammonia, it then forms mono and di-chloramines which simply referred and called/known as chloramines. These chemical compounds are stable in water and also found to posses disinfecting properties but of a little lesser degree than chlorine alone. Its chemical reaction is as follows:

$H_2O + Cl_2 \rightarrow HCl + HOCl$

$NH_3 + HOCl \rightarrow H_2O + NH_2Cl$ (Mono chloramines)

$NH_2Cl + HOCl \rightarrow H_2O + NHCl_2$ (Di-chloramines)

$NHCl_2 + HOCl \rightarrow H_2O + NCl_3$ (Nitrogen trichloride or trichloramine)

The pH value of water and its temperature are the factors that determined the particular type of chloramines formation as shown in the table below:

Table 2: Factors that determine the particular type of chloroamine formation

S/N	Chloramines formed	pH value of water
1.	Mono-chloramine only (NH_2Cl)	More than 8.5
2.	Both NH_2Cl and $NHCl_2$ and their quantities depend upon pH value at pH value of 7 NH_2Cl and $NHCl_2$, both are equally formed	5 to 8
3.	Di-chloramines only ($NHCl_2$)	4.4 to 5
4.	Tri-chloramine only	Less than 4.4

Ammonia should be added to water at the rate of half to one-fourth of the chlorine amount and should be mixed with the aid and help of mechanical mixers because though it dissolves quickly in water, it does not diffuse easily. Chloramines should be allowed to reach end users after a lapse of about 1 to 2 hours after treatment. Chloramines has the advantages that it lasts for longer periods disinfection effect, more effective than chlorine alone, less amount of quantity is required, more useful for treatment of swimming pool water because it is less irritant to eyes and nose and finally it has no danger of overdose.

c) Bleaching powder and hypochlorites

Bleaching powder contains about 35% of chlorine and when mixed with water, hypochlorite ions separate or dissociates. Calcium and sodium hypochlorites could be used for chlorinating small public supplies. So when calcium and sodium hypochlorite are dissolved in water, it dissociate to hypochlorite ions.

$Ca(OCl)_2$ $\xrightarrow{H_2O}$ Ca^{++} + $2OCl^-$

$40 + (16+35)_2 = 142$ Calcium hypochlorite — Calcium ions — $2x\ (16+35) = 102$ Hypochlorite ions

The hypochlorite ions could further combine with the hydrogen ions present in water to form hypochlorous acid as in

$OCl^- + H^+$ $\underset{pH > 8}{\overset{pH < 7}{\rightleftharpoons}}$ $HOCl^-$

Hypochlorous acid

This is the hypochlorination process which enables the hypochlorous acid as well as the hypochlorite ions perfect disinfection of water. For a 100% pure hypochlorite, the free available chlorine that it contains should be equal to the hypochlorite ions (OCl^-) value of the compound. For instance, in the reaction;

$Ca(OCl)_2 \rightarrow Ca^{++} + 2OCl^-$,

The calcium hypochlorite should contain free available chlorine equal to twice the OCl^- value or that, 142 parts of calcium hypochlorite will contain 102 parts of free chlorine which is about 70%. High test hypochlorite (HTH) or perchloronis the commercial name of calcium hypochlorite, and contain 60 to 70 percent of available chlorine. They are available in small packets forms, its chlorine content does not decrease with storage time and can be used in dry condition or as in solution. Bleaching powder is another chlorine compound which is also use in disinfecting water. It is also known as chlorinated lime or calcium oxychlorite. Its molecular formula is $CaOCl_2$. It is a white amorphous powder having a pungent smell of chlorine. It is an unstable compound and on exposure to air, light or moisture, it rapidly loses its chlorine content but when freshly made, it contains about 30 to 35% of available chlorine. Therefore, before using bleaching powder for chlorination or disinfection of water, its strength should contain very low amount of chlorine and raises pH value of water, hence not too a treating method of water but could be use for small supplies.

For instance,if 0.3ppm of chlorine dose is required for disinfection at the water works, the amount of bleaching powder required annually to supply water to a population of 20,000 at per capital demand of 150litres per day can be determined if the disinfectant used for chlorination is bleaching powder that contains 30% of available chlorine. Hence;

Average daily water demand $\rightarrow$ population x per capital demand

= 20,000 x 150 litres

= 30,000,000litres

= 3 x 10,000,000

= 3×10^6litres

= 3×10^6litres (3 x 10,000,000)

= 30,000,000litres

∴ Amount of chlorine required daily (based on average annual consumption)

$0.3mg/l \ \times 3 \times 10^6 L = \frac{0.3mg}{L} \times 3x10^6 L = 0.3mg \times 3x10^6 = 0.9kg$

But the chlorine content in the bleaching powder is 30%, then it means 30kg of chlorine is contained in 100kg of bleaching powder.

So the amount of bleaching powder required daily based on average consumption is:

$$\frac{0.9 \times 100}{30} = 3kg$$

∴ Annual consumption of bleaching powder

= 3 x 365kg= 1095kg = 1.095 tonnes

Also, if Chlorine usage in the treatment of $20,000m^3$ per day is 8kg/day and the residual after 10min contact is 0.20mg/l. Then, the dosage in milligram per lire and chlorine demand of the water becomes;

Treated water/day = $20,000m^3$

= $20,000 \times 10^3$litres = 20 x 106 x0.001ml = 20ml

Chlorine consumed per day =8kg = 8M.mg

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∴ Chlorine used per litre of water

$$\frac{8\cancel{M}.\,mg}{20\cancel{M}.\,L} = 0.4mg/l$$

∴ the given chlorine dosage = 0.4mg/l
But residual chlorine left = 0.2mg/l(given)
Hence actual chlorine dosage which has reacted in water, i.e. chlorine demand of water:
= 0.4mg/l -0.2mg/l
= 0.2mg/l

d) Use of chlorine tablets

Though costly, chlorine tablets are sometimes used to disinfect small quantities of water and they available in the market with various trade names. A most used one is called halazone tablets. In some countries, most national environment engineering research institute have formulated new names types of chlorine tablets which are even 15times better than the known most available halazone tablets. These tablets are manufactured in various strengths but a single tablet of 0.5g is sufficient to disinfect 20litres of water. They are best for treating overhead water tanks or for ground water supplies. They could be as well be used for retreating the public supplies by end users during water borne disease epidemic or when public supplies are liable to be contaminated such as time of flood.

e) Use of chlorine – dioxide gas

Chlorine dioxide gas (ClO_2) is produced by passing chlorine gas through sodium chlorite

$$2NaClO_2 + Cl_2 \rightarrow 2NaCl + 2ClO_2\uparrow$$

Sodium chlorite
Chlorine dioxide gas

The chlorine dioxide gas is very powerful disinfectant which is about $2{}^1/_2$ times stronger than chlorine. It is advised that its use should be immediately after it is produced, because it is unstable. It is also costly. It may therefore not generally be suitable for treating ordinary public supplies but because of its stronger disinfecting powers, it could be used for treating waters containing larger amount of organic impurities and water containing phenolic compounds that may develop undesirable taste and odours when chlorine alone is used. Another of its advantageous use is that since the action of chlorine dioxide remains unaffected by the pH values of 6 to 10, it can be as well be advantageously used for treating highly alkaline waters with pH between 8 to 10. Its dosage normally is usually between ranges of 0.5 to 1.5mg/l.

FORMS AND TYPES OF CHLORINATION

Various technical terms regarding the chlorination process are used depending upon the quality of chlorine that is added to the raw water, or the stage of treatment at which it is added, or upon the expected results of chlorination. The following are some of such technical terms:

a) Plain chlorination
b) Pre-chlorination
c) Post-chlorination
d) Double chlorination
e) Break point chlorination
f) Super chlorination
g) Di-chlorination

a) Plain chlorination

This is the process in which only the chlorine treatment and no other treatment to the raw water before supplying to the consumers. It is recommended for the treatment of clearer waters that has turbidity less than 20 to 30mg/l. It could also be used during emergencies when complete treatment cannot be given (such as during war times). Chlorine's quantity required to be added to water for plain chlorination is about 0.5ppm (mg/l) or more.

b) Pre chlorination

When chlorination of water is done before treatment is given such as filtration or even sedimentation-coagulation treatment process, it is called pre-chlorination. It assist in improving coagulation and reduces the bacteria load on the filters. It also reduced undesirable taste, odour, algae's growth in the tank and other organisms. It is well used for prevention of putrefaction of sludge in setting basins. There should be no pre-chlorination without post chlorination, pre-chlorination should always be followed by post chlorination in order to ensure the final safety of the water. Normal dosages needed are as high as 5 to 10mg/l but the chlorine dose should be such that about 0.1 to 0.5mg/l of residual chlorine comes to the filter plant.

c) Post chlorination

This is the normal standard practice which is the process of applying chlorine to the water after all treatment of purification have been completed. The post chlorination is adopted after filtration and before the water enters the distribution system when treating normal public supplies. The chlorine dose should be such that a residual chlorine of about 0.1 to 0.2ppm is maintained until it enters the distribution system after a contact period of about 20 minutes.

d) Double chlorination

The terminology, double chlorination is used to indicate that the water has been chlorinated twice if chlorine is added once before filtration and once after filtration of water. In double chlorination, the pre-chlorination and post chlorination are generally used but post chlorination is a more generally used but when the water is highly turbid and contaminated, pre-chlorination is preferred. Again, when the raw water contains large amount of bacteria, colloidal and organic impurities, double chlorination becomes necessary, that is, the adoption of pre-chlorination and post chlorination process of treating raw water. Double chlorination has the same advantage as those of pre-chlorination.

e) Break point chlorination

Break point chlorination is a water treatment process term which gives an idea of what will take place regarding the extent of chlorine that is added to water. It represents what happened to much dose of chlorination, beyond which any further addition of chlorine will equally appear as free residual chlorine.

Wholesome water does not have any need for chlorine disinfection, this means that any chlorine added to such water will not be in any way utilized, so it will come out as residual chlorine. It therefore (residual chlorine) acts as safeguard against post chlorination. This is shown by line Q in figure 6 below.

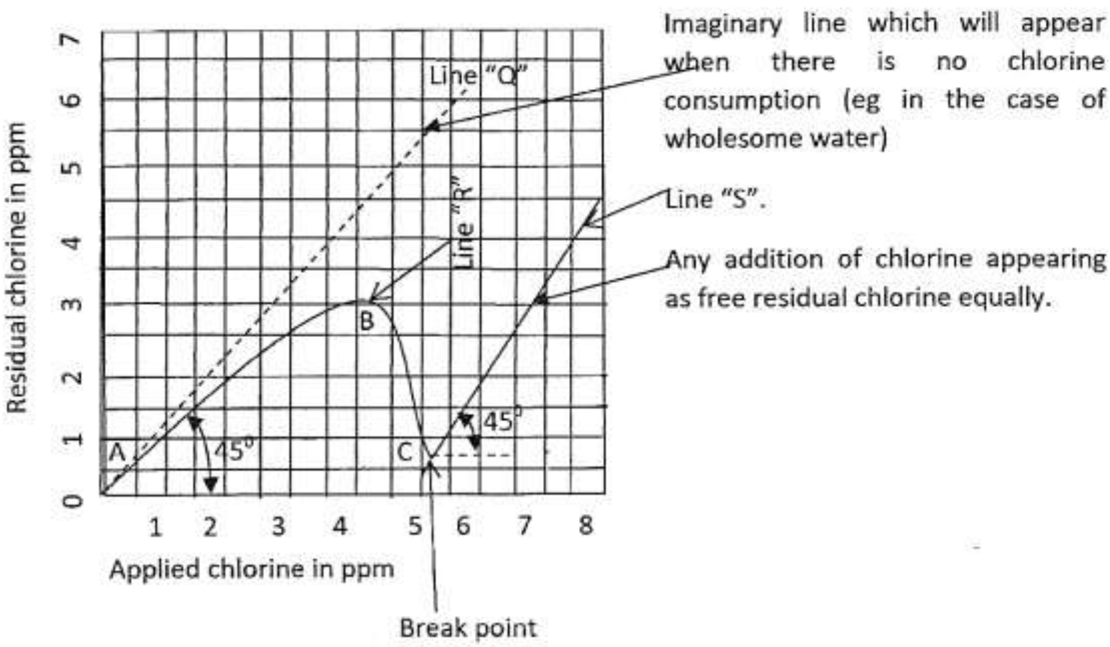

Figure 1: Break point chlorination in graphical detail explanation

But when chlorine is applied to water, that contains organic matter and bacteria, it first react to remove these impurities, and after the removal of the bacteria impurities, chlorine starts accumulating up to a certain point which is represented by point B on line R of figure 6. Here at point B, if more chlorine is added in water, it is followed by a sudden decrease in residual chlorine content in which sometimes, bad smell and objectionable taste are experienced. This indication means that the extra quantity of chlorine added after point B on line R has been used completely for the second function of chlorine which is oxidation of organic matter present in the water. On application of more chlorine to the water, a point C is reached on line R where all observation and experience of bad smell and undesirable taste disappears. Point C on line R therefore indicates that oxidation of all the organic impurities have been achieved. So any more chlorine that will be added to water beyond point C tends to accumulate as shown in line "S" of figure 6. This point C on line R is known as the **"break point"** since any more chlorine that is added to water beyond point C breaks through the water and appears as residual chlorine. Hence by definition; the practice in water treatment process of adding chlorine dose beyond break points is called **"Break point chlorination".** It is a deliberate general practice to add chlorine beyond the break point and this is to ensure a residual chlorine of 0.2mg/l to 0.3mg/l of free chlorine. This residual of free chlorine is highly persistent and very powerful disinfectant which can kill cysts of amoebic dysentery at a concentration of 0.2ppm. Residual chlorine beyond the break point can only be consumed by photo chemical reactions causing its distribution in the presence of sunlight and by the very slow continuous demand exerted by water until it is consumed. This is why the residual chlorine is readily available to destroy any pathogenic micro-organism that may enter into the distribution system of water. The residual chlorine so produced after break point, provides a safeguard against post contamination, it is very important to note that in all public water treatment plants, the system of break point chlorination is usually adopted to bring about the disinfection of water to be needed for domestic purpose because the residual free chlorine which is as a result of the break point chlorination treatment takes care of the future recontamination of water in the distribution system.

f) Super chlorination

Super chlorination is the process of chlorination beyond the stage of break point. It is evidently in excess than that necessary for adequate bacterial purification of water. The residual chlorine which under normal conditions is about 0.1ppm is raised to 0.5ppm or even up to 2ppm in contact by the super chlorination treatment process. During epidemic when water is likely to contain high amount of organic impurities, supper chlorination of water is highly desirable though with a very high disadvantage of strong odour and undesirable taste of chlorine but can be removed by de-chlorination. Relatively resistant organisms such as virus and amoebic cysts can be effectively destroyed by super chlorination treatment. Chlorine dose could be as high as 10 to 15mg/l with contact period of 10 to 30 minutes but the resultant excess chlorine will have to be de-chlorinated.

g) De-chlorination

As discussed in (6) above, the partial or complete reduction of residual chlorine after treatment is called de-chlorination. In practice, it is desired that some free residual chlorine remains in water even after dechlorination is completely done. Dechlorination may be carried out by adding certain chemicals to water or by just simply aerating the water. These chemicals are called dechlorinating agents. The common dechlorinating agents are:

i. Sulphur dioxide

This is mostly used in bigger plants. The chemical reaction is

$$SO_2 + Cl_2 + 2H_2O \rightarrow H_2SO_4 + 2HCl$$

The acid which is formed by the above reaction is neutralize by the natural alkalinity present in water. Up to near 1ppmsulphurdisoxide is required for removal of each mg/l of chlorine.

ii. Sodium bisulphate ($NaHSO_3$)

This is used in small plants. Apart from it is cheaper, it is more suitable than sodium sulphate. Its chemical reaction is

$$NaHSO_3 + Cl_2 + H_2O \rightarrow NaHSO_4 + 2HCl$$

iii. Sodium thiosulphate ($Na_2S_2O_2$)

This dechlorination agent is mostly use in laboratory test. The chemical reaction is:

$$2Na_2S_2O_3 + Cl_2 \rightarrow Na_2SO_6 + 2NaCl$$

iv. Activated carbon

Activated carbon is used in small plants. The process involves the filtering of superchlorinated water through the activated carbon bed thereby leading to the absorption of chlorine in its pores.

II. CONCLUSION

Before the routinely treatment of water with the use of chlorination technique, cholera, hepatitis, typhoid and dysentery has killed millions of people all over the world annually but with drinking water chlorination, these diseases are eliminated through and by the help of drinking water chlorination. Over the years, chlorination of drinking water has remained the most popular technique method for water disinfection. Chlorination method of treating water has shown to be effective enough for killing bacteria and some protozoa, cysts, algae and viruses. Though chlorination do have some negative drawbacks, it did not only remained the most dependable, it is also cost effective and most popular method of water treatment for cost-effective method of water disinfection.

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