CHLORINE EFFICACY

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Introduction

Chlorine is one of the most commonly used disinfectants for water disinfection. Chlorine can be applied for the deactivation of most microorganisms and it is relatively cheap. Chlorine is commercially available as gaseous Chlorine (CL_2) and as Sodium Hypochlorite liquid or powder (NaOCL).

Both gaseous Chlorine (CL_2) and Sodium Hypochlorite (NaOCL) have very limited disinfecting properties. It is the formation of chlorine by-products such as Hypochlorous Acid (HOCL), Hypochlorite Ion (OCL^-), Hydrochloric Acid (HCL) and Oxygen (O) that inhibit disinfecting properties.

Gaseous Chlorine

Gaseous Chlorine (CL_2) is commercially available and mostly used in disinfecting mains water.

When gaseous Chlorine (CL_2) added to water (H_2O) the following hydrolysis reaction takes place:

$$Cl_2 + H_2O = H^+ + Cl^- + HOCl$$

Sodium Hypochlorite

Sodium Hypochlorite is produced adding gaseous Chlorine (CL_2) to caustic soda (NaOH). When this is done, Sodium Hypochlorite (NaOCL), water (H_2O) and salt (NaCl) are produced according to the following r*eaction:*

$$Cl_2 + 2NaOH + \rightarrow NaOCl + NaCl + H_2O$$

Chlorine reacts with sodium hydroxide to Sodium Hypochlorite (NaOCl). Sodium Hypochlorite is known as Bleach. Bleach (NaOCL) cannot be combined with acids. When NaOCL comes in contact with acids the hypochlorite becomes instable, causing poisonous gaseous Chlorine (CL_2) to escape.

Hypochlorous Acid and Hypochlorite Ion formation

Hypochlorous Acid (HOCL) and Hypochlorite Ion (OCL^-) are the by-products of Sodium Hypochlorite (NaOCL) in water (H_2O)

NaOCL reacts with water (H_2O) to Hypochlorous Acid (HOCl) and Hypochlorite Ions (OCl^-).

$$NaOCl + H_2O \rightarrow HOCl + NaOH-$$

Hypochlorous Acid formation

Hypochlorous Acid (HOCL) is the by-product of gaseous Chlorine (CL_2) in Water. Gaseous Chlorine (CL_2) reacts with water to Hypochlorous Acid (HOCL).

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

Oxygen formation

Depending on the pH value, Hypochlorous Acid (HOCL) expires to Hypochlorite Ions (OCL^-).

$Cl_2 + 2H_2O \rightarrow HOCl + H3O + Cl^- \; HOCl + H_2O \rightarrow H_3O^+ + OCl^-$

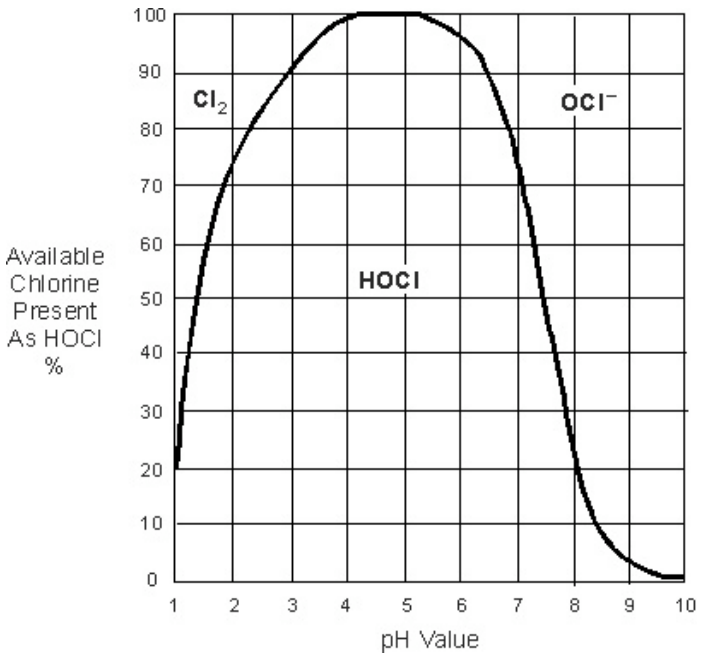
This falls apart to Chlorine and Oxygen atoms:

$OCl^- \rightarrow Cl^- + O$

The efficacy of disinfection is determined by the pH.

Disinfection will take place optimally when the pH is between 5 and 7, as then a maximum of HOCL is present.

HOCL reacts faster than OCl^- ; HOCL is 80-100% more effective than OCL^-. HOCL does not evaporate and does not cause severe corrosion like CL_2. CL_2 exposed in air can be very explosive and evaporation should be avoided. For this reason, the ideal pH is between 6 and 7, as no CL_2 is present.

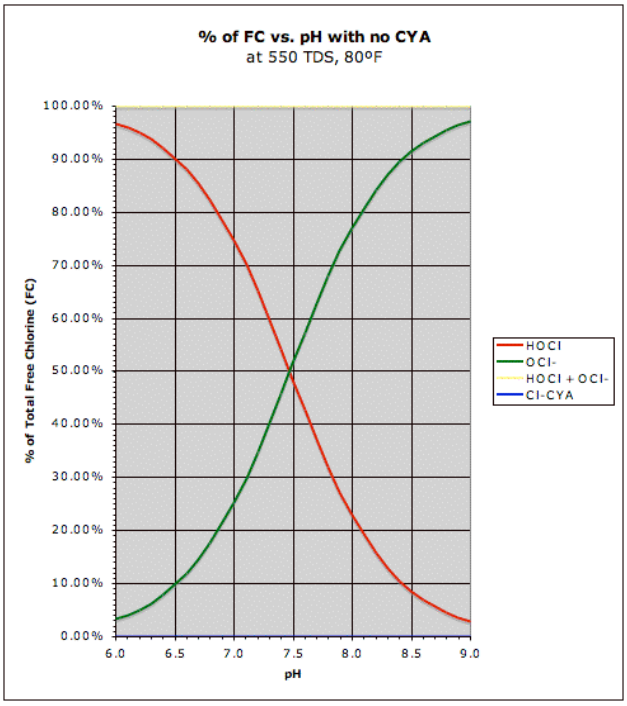


The level of HOCL will decrease when the pH value is higher than 5. The level of HOCL will decrease when the pH value is lower than 5. With a pH value of 6.5 the level of HOCL is more than 90%, whereas the concentration of OCL^- is less than 10%.

Free Available Chlorine

Free Available Chlorine (FAC) is chlorine that is present in the form of Hypochlorous Acid, hypochlorite ions or as dissolved elemental chlorine. FAC includes all chlorine species that are not combined with ammonia (or other nitrogenous compounds) to form chloramines. It is 'free' in the sense that it has not yet reacted with anything, and 'available' in the sense that it can and will react if needed.

A pH value of 6 to 7 is the most effective and the safest pH-range, due to absence of chlorine gas. Therefore when Free Available Chlorine is mentioned, it is assumed that Free Available Chlorine solely consists of HOCL and OCL^-



Free Available Chlorine compounds with regard to pH .Hypochlorous Acid (red) and Hypochlorite Ion (green)

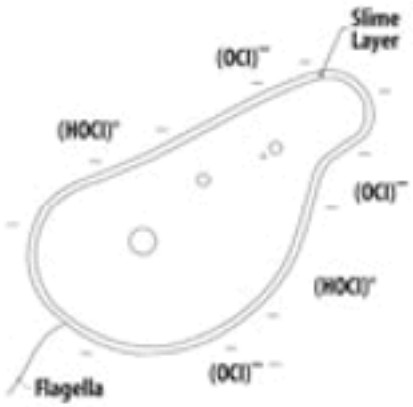
Superiority of Hypochlorous Acid compared to Hypochlorite Ion

Hypochlorous Acid (HOCl, which is electrically neutral) and Hypochlorite Ions (OCl^-, electrically negative) will form Free Available Chlorine (FAC) when bound together. This results in disinfection. Both substances have very distinctive behavior.

The cell wall of pathogenic microorganisms is negatively charged by nature. As such,

the negatively charged Hypochlorite Ion (OCL-) can only penetrate it by the neutral Hypochlorous Acid (HOCL), rather than.

HOCL can penetrate slime layers, cell walls and protective layers of microorganisms and effectively kills pathogens as a result. The microorganisms will either die or suffer from reproductive failures.



The pH neutral Hypochlorous Acid (HOCL) *can penetrate cell walls of pathogenic microorganisms whereas the negatively charged Hypochlorite Ion* (OCL^-) *cannot penetrate cell walls.*

Besides the neutrality of HOCL, it is a much more reactive and is a much stronger disinfectant than OCL^-, as HOCL is split into hydrochloric acid (HCl) and atom air Oxygen (O). Oxygen is a very powerful disinfectant.

HOCL guarantees optimal disinfecting

The disinfecting properties of Chlorine in water are based on the formation and oxidizing power of Oxygen and HOCL. These conditions occur when the pH is between 6 and 7.

HOCL produced onsite from AQUAOX ECS-200 and ECS-400 Systems has a pH of 6.5. At this pH more than 90% of the free available chlorine is HOCL, less than 10% OCL^- and no CL_2 are formed.

The strength of Free Available Chlorine (FAC) in HOCL is pre-set to 200ppm. To make a solution with 200ppm FAC from commercially available bleach (NaOCL), it is diluted in water (H_2O).

<u>The problem with diluting bleach in water is twofold:</u>

1) The volume to dilute bleach is very small. Small differences in the volume of bleach added to water causes significant differences in terms of pH and Free Available Chlorine (FAC).

2) The fact that water has naturally different pH levels, causes that addition of the same volume of bleach still result in a different pH. Although at each dilution 200ppm FAC can be measured, the pH of the mixture and consequently the amount of active compounds HOCL and OCL^- may vary considerably.

Therefore, disinfecting properties using bleach vary whereas the disinfecting properties of HOCL are kept stable. As a result HOCL may exceed the disinfecting properties of bleach by **300** times.

Safety

When producing HOCL by acidifying NaOCL, relatively high prices and possibility of side reactions limit the use of weak organic acids; use of cheaper inorganic acids provokes gaseous chlorine discharge and a raise of toxicity level. Because of it, the method above is only used for water treatment, where residual chlorine concentration values do not exceed 0.5-5mg/l.

Dilution of gaseous chlorine in water to produce HOCL according to equation demands special safety measures and is only used for disinfecting large volumes of water, where active chlorine concentration is below 10-15mg/l. Nowadays all the companies that manufacture gaseous chlorine stopped gaseous chlorine production and started NaOCL manufacture exclusively because of safety considerations.

HOCL onsite produced by AQUAOX Systems is a unique method of non-reagent synthesis of HOCL. We would like to point out once more that the unique quality of the AQUAOX System is the possibility of directed pH regulation in the 6.0-7.0 ranges, while working with solutions of any mineralization, whereas electrolyses of sodium chloride solutions have identical biocidal activity if pH and FAC concentration are equal.