

# DISINFECTION

Three basic strategies to keep microbiological contaminants out of drinking water.

1. Keeping microbiota out of water source.
2. Treating water to remove contaminants.
3. Maintaining safe water distribution system.

Disinfection has two components

1. Primary disinfection – inactivation of microorganisms in the water.
2. Secondary disinfection – maintaining disinfecting residual in distribution system.

## HISTORY

Source water protection and filtration used in second half of 1800's

1880 – Koch showed chlorine could inactivate bacteria.

1902 – First use of chlorination for disinfecting water in Belgium.

1908 – First use in U.S. Jersey City, NJ with calcium hypochlorite.

1913 – First use of chlorine gas-Philadelphia

1941 – 85% of public supplies chlorinated.

Mid 1970s – Formation of THMs demonstrated

1980 – Giardia identified as important pathogens Cryptosporidium identified more recently

## Disinfection methods

1. Free Chlorine –most common
2. Combined chlorine
3. Ozone – strongest oxidant
4. Chlorine dioxide
5. UV light

## Chemical disinfection kinetics

Chick's Law – Harriet Chick ,1908

Documented microorganism inactivation by phenol, mercuric chloride, silver chloride

$$\frac{dN}{dT} = -kN$$

$N$  = number of organisms per volume [ $L^{-3}$ ]

$k$  = Chick's law constant [ $T^{-1}$ ]

Integrate to get ,

$$\ln \frac{N}{N_0} = -kt$$

$N_0$  = starting number of organisms

$N/N_0$  = survival ratio

Chick –Watson Model – Herbert Watson, 1908

$C^n t = K$  achieves particular level of disinfection (i.e.  $N/N_0$ )

$C$  = concentration of disinfectant

$n$  = empirical constant called ‘coefficient of dilution’

$K$  = constant ( function of microorganisms)

If  $n > 1$  , disinfectant efficiency decreases with dilution –concentration is more important than time.

$n < 1$  time is more important than concentration.

$n = 1$  time and concentration equally important

$N$  is slope of  $\log C$  vs  $\log t$ , by convention, 9970 inactivation is plotted.

If  $n=1$ , then Chick Watson model is

$$\ln \frac{N}{N_0} = -\Lambda_{CW} C t$$

$\Lambda_{CW}$  = Chick Watson coefficient of specific lethality [ L/mg.min]

$C_t$  is specified by US EPA rules for Giardia and Cryptosporidium for different disinfectants and pH unlike bacteria, no easy tests for Giardia and crypto, so regulation focuses on technology (expressed as  $C_t$ ) rather than monitoring.

Note : Chlorine is relatively ineffective against Cryptosporidium (C. Parvum) UV is particularly effective against Giardia and Crypto.

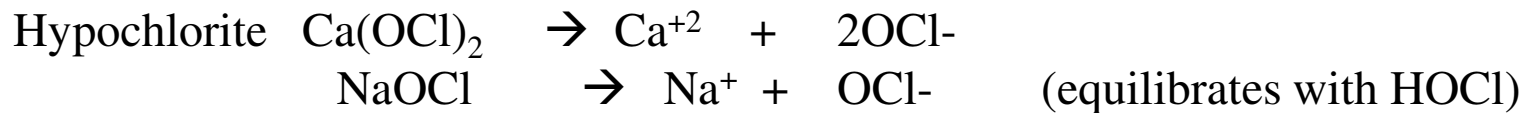
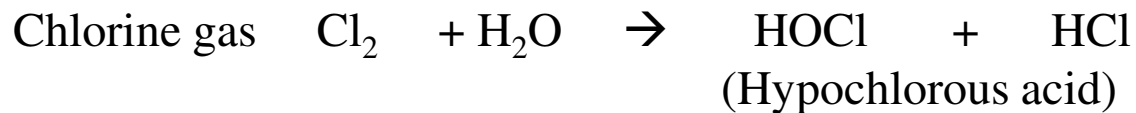
# Chlorine disinfection

Most widely used – effective at low conc. , inexpensive , forms residual

## Drawback : forms THMs

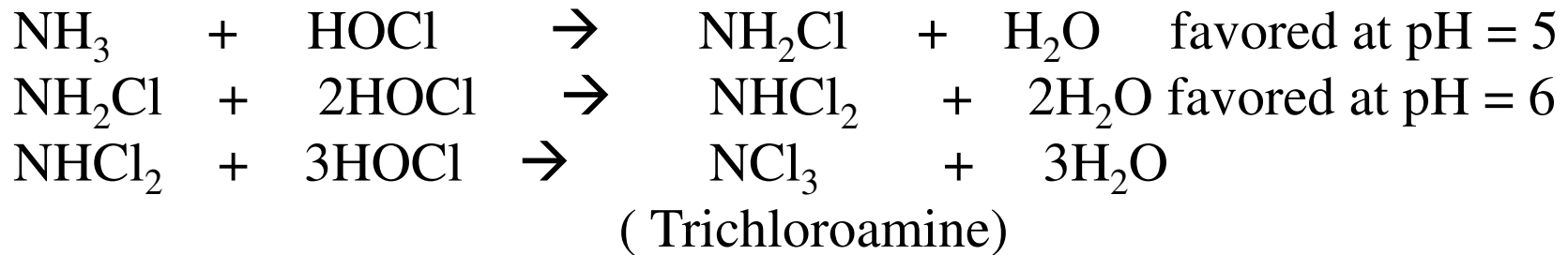
Applied as chlorine gas or hypochlorite

Acts by oxidizing enzymes of cells, preventing essential metabolic processes.



HOCl is more effective disinfectant than OCl- but both are excellent.

HOCl reacts with ammonia



Chloroamines are effective against bacteria(e.g. pipe growth ) much less effective against Viruses.

Chloroamines contributes to chlorine residual free chlorine (HOCl + OCl-) Chlorine also reacts with organics

With phenol to form chlorophenols- strong taste and odor.

With NOM (natural organic matter eg. Humic acids) to form trihalomethanes (THMs).

$\text{CHCl}_3$  Chloroform

$\text{CHCl}_2\text{Br}$  bromodichloromethane

$\text{CHClBr}_2$  dibromodichloromethane

$\text{CHBr}_3$  bromoform

Known as DBP – disinfection by products problematic because THMs are suspected human carcinogens.

Chlorine dosage is determined so as to ensure adequate residual known as breakpoint Chlorination.

Determined by lab experiments in which chlorine is added and residual is measured.

### Chlorine demands

1. At first, inorganic reducing chemicals.
2. After satisfaction of initial demand, chloramines formed, creating combined residual.
3. With increasing Cl dosage, formation favors over monochloramine , then trichloroamine over dichloroamine. Trichloroamine is unstable, breaks down to nitrogen and reduces chlorine residual.
4. Low point of chlorine residual is breakpoint.
5. Further increase in Cl adds free residual.



Desired dosage for water treatment is beyond the breakpoint.

Actual breakpoint concentration varies with the water quality of the raw water typically 4-10mg/L.

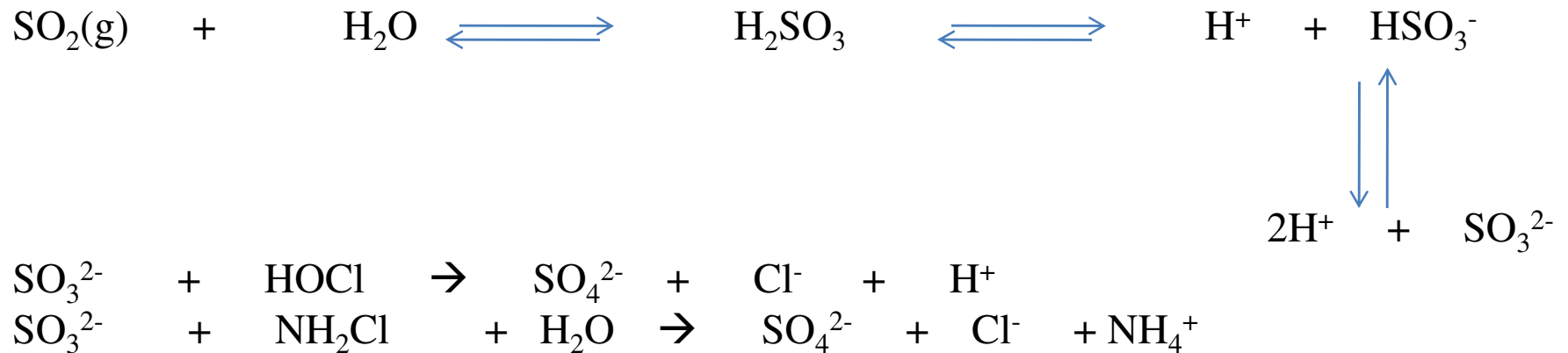
Desired residual = 0.2 mg/L at furthest point in distribution system.

(note 0.5mg/L is generally objectionable to consumers)

## Dechlorination

Chlorination is also used as a final step in wastewater treatment but here residual chlorine has adverse effects on aquatic life and is not desired.

Sulphur dioxide used to remove residual Cl



## Chlorination

Cl<sub>2</sub> added with propriety chlorinators

Desired Ct is be flow achieved in plug flow ( or nearly plug flow ) reactors.

Typical chlorine contact chamber is serpentine chambers with baffles

## Ozonation

Ozone is more powerful oxidant than HOCl

Ozone inactivates microorganisms by

1. Direct oxidation
2. Decomposition into hydroxyl radicals HO which are also strong reactants.

Widely used in Europe, increasingly used in US.

Advantages – excellent disinfectant (including for Gardia and Cryptosporidium)

does not form THMs ,chlorophenols effective against taste and odor requires

Short contact time.

Disadvantages – short contact time reactors prone to short circuiting

more costly than Cl<sub>2</sub>

does not create disinfecting residual

may produce harmful by products

ozone gas is potentially explosive

Ozone treatment design based on C<sub>t</sub>, with consideration of ozone decay over time.

Ozone is sparingly soluble- usually introduced as gas by fine-bubble porous diffusers in deep basins

Ozone consumption by specific water to be treated measured in lab ( analogous to determining chlorine demand)

$$C_{\text{residual}} = C_{\text{dose}} - C_{\text{demand}}$$

Decay of C<sub>residual</sub> over time measured in lab reactors pulsed with ozone

Ozone contactors usually introduce  $O_3$  and get water contact in same tank.

Ozone bubbled into chamber creates fully mixed conditions

But desire plug flow to ensure Ct is achieved.

Solution is to create tanks in series to approximate PFR.

Some designs seek counter current flow to achieve better ozone transfer (bubble rise is slowed by counter flow of water)

Ozone is generated on-site in a corona discharge- electric arc generated by high voltage between two plates separated by air gap.



Chlorine dioxide    $\text{ClO}_2$

Stronger oxidant than  $\text{Cl}_2$

Creates long – lasting residual

Effective against taste and odor.

Produces few by products, however chlorate and chlorite.

Ions are produced but limited by regulations to non toxic concentrations.

Widely used in U.S.

More expensive than  $\text{Cl}_2$

## UV radiation

Disinfects by :

Damaging nucleic acids – DNA, RNA

Forms hydroxyl radicals – strong oxidant

200-300nm wavelength is absorbed by DNA – disinfecting range for UV (also range likely to cause skin cancer)

Very effective against cryptosporidium.

Radiation produced by lamps.

Low pressure UV lamp- 254 nm only

Medium –pressure UV lamp – 210-300nm range

Medium pressure disinfects more but takes more power.

Interferences due to

Absorption by dissolved substances in water.

Shading of organisms of particulates.

UV contactors have very short residence times seconds to minutes.

Treatment equipment consists of array of electricity – powered lamps suspended in water flow or pipe with long lamp down the middle

SODIS – solar disinfection – is low –tech solution that uses sunlight to disinfect water.