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 filteration used in second half of 1800's
1880 – Koch shoed 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 – 8590 of public supplies chlorinated.
Mid 1970s – Formation of THMS demonstrated
1980 – Gardia identified as important pathogens Cryptosporium 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 ,

$$\ln \frac{(N)}{(N_o)} = -kt$$

N_o = starting number of organisms

N/ N_o = survival ratio

Chick –Watson Model – Herbert Watson, 1908

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

C = concentration of disinfectant

n = empirical constant called ‘coefficient of dilution’

K = constant (function of microorganisms)

If n>1 , disinfectant effieciency 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 logC vs logt, by convention, 9970 inactivation is plotted.

If n=1, then Chick Watson model is

$$\ln \frac{(N)}{(N_0)} = - \Lambda_{CW} Ct$$

Λ_{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 Gardia and crypto, so regulation focuses on technology (expressed as C_t) rather than monitering.

Note : Chlorine is relatively ineffective against Cryptosporidium (C. Parrum) UV is particularly effective against Giadia 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.

Chlorine gas $Cl_2 + H_2O \rightarrow HOCl + HCl$

(Hypochlorous acid)

$HOCl \rightleftharpoons H^+ + OCl^-$ (hypochlorite ion favoured above pH 7.5)

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

$NaOCl \rightarrow Na^+ + OCl^-$ (equilibrates with HOCl)

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

HOCl reacts with ammonia

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O \quad \text{favored at pH = 5}$$
$$NH_2Cl + 2HOCl \rightarrow NHCl_2 + 2H_2O \quad \text{favored at pH = 6}$$
$$NHCl_2 + 3HOCl \rightarrow NCl_3 + 3H_2O$$

(Trichloroamine)

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 tri halomethanes (THMs).

$CHCl_3$ Chloroform
$CHCl_2Br$ bromodichloromethane
$CHClBr_2$ dibromodichloromethane
$CHBr_3$ 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 objectable 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

$$SO_2(g) + H_2O \rightleftharpoons H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$$

$$HSO_3^- \rightleftharpoons 2H^+ + SO_3^{2-}$$

$$SO_3^{2-} + HOCl \rightarrow SO_4^{2-} + Cl^- + H^+$$

$$SO_3^{2-} + NH_2Cl + H_2O \rightarrow SO_4^{2-} + Cl^- + NH_4^+$$

Chlorination
Cl_2 added with propriety chlorinators
Desired Ct is be flow achieved in plug flow (or nearly plug flow) reactors.
Trpical 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_2
does not create disinfecting residual
may produce harmful by products
ozone gas is potentially explosive

Ozone treatment design based on C_t, with consideration of ozone decay over time.

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

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

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

Decay of $C_{residual}$ 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 serves 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.

$$O_2 \longrightarrow 2O\cdot$$

$$O. + O_2 \rightarrow O_3$$ (some effect as lightening strom)

Chlorine dioxide ClO_2

Stronger oxidant than 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 Cl_2

UV radiation

Disinfects by :
Damaging nucliec 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.