DISINFECTION

CE421/521
Environmental Biotechnology
Tim Ellis
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History of Disinfection

- Disinfection = process designed for the deliberate reduction of pathogenic organisms.
- Disinfection of water supplies by chlorination began in Chicago and New Jersey in 1908, within 2 years chlorination of water supplies was practiced in N.Y., Montreal, Milwaukee, Cleveland, Nashville, Baltimore, and Cincinnati.
- By 1918, over 1000 cities treating more than 3 bgd were chlorinating their water supplies.
- While, other processes (e.g., coagulation, sedimentation, filtration) may achieve pathogen reduction, that is not their primary goal.
- Concept of disinfection preceded knowledge of bacteria as the causative agent of many diseases. In 1832, Averill proposed the chlorine disinfection of human wastes to prevent epidemics.
- Chlorine addition to water treatment only became accepted after litigation regarding its efficacy.

History of Disinfection

- Most water utilities currently rely on chlorine________ or hypochlorite________ disinfection.
- Other choices are ammonia________ + chlorine (chloramination), chlorine dioxide________, ozone________, and UV.
- Current challenges in water treatment continues to be protozoan________ pathogens (*Cryptosporidium* and *Giardia*) and viral________ contaminants (Norwalk virus), as well as reducing disinfection byproducts________ (DBPs).
- New challenges are the removal of endocrine________ disruptors, pharmaceuticals, arsenic________, radon________.

Water Utility Disinfection Practices (AWWA, 1989)

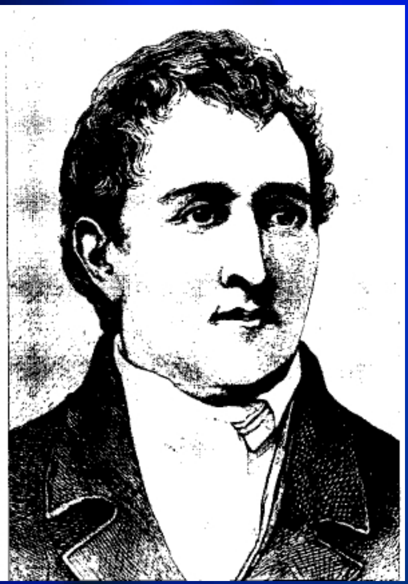
Process	No ammonia	Ammonia
Chlorine alone		
Gas	67%	19..8%
Hypochlorite	6%	0.8%
Chlorine and ClO_2	3.4%	1.5%
Ozone	0.4%	
Other	0.8%	

www.bcwwa.org/magazine/2003-2004
/fall2003/images/

www.mwdslc.org/VirtualTour/wwwroot/
educational/images/cl2_cylinders.jpg

http://www.ci.la-porte.in.us/wwtp/disinfection-1.jpg

Chlorine



Swedish pharmacist Carl Wilhelm Scheele.

- Chlorine gas________ first prepared by Scheele in 1774, but not recognized as a chemical element until 1808. Scheele called it dephlogisticated marine acid.
- Early (1825) uses of chlorine gas include Javelle____________ water (chlorine gas dissolved in alkaline potassium solution) in France for waste treatment and as a prophylactic against the cholera_________ epidemic (major epidemic in 1831).

Chlorine Dioxide

- First produced by Davy in 1811 from the reaction of potassium chlorate and hypochloric acid.
- Not used widely until the industrial production of sodium chlorite from which chlorine dioxide can be readily made.
- Used widely as a bleaching agent in the pulp and paper industry, slow to be adopted by water treatment industry.
- Chlorine dioxide is used in fewer than 100 plants in U.S. Used in approximately 500 plants in Europe.

Ozone

- Discovered in 1783 by Van Marum
- Named by Schlonbein in 1840.
- First electric discharge ozone generator constructed by Siemens in 1857.
- First commercial application occurred in 1893 at Oudshoorn, Netherlands.
- Nice, France is the oldest (1906) continuous user of ozone for water treatment.
- First use in the U.S. in New York City (Jerome Park Reservoir) for taste and odor removal in 1906.
- By 1987, approximately 5 plants in U.S. use ozone as a disinfectant and/or for taste and odor removal. More recent interest since the 1993 outbreak of *Cryptosporidium* in Milwaukee.

Ultraviolet (UV) Radiation

- UV (short wavelength) radiation (primarily associated with sunlight) long known to have biocidal effects
- By 1940 design guidelines for UV disinfection were proposed.
- Accepted use for disinfection on passenger ships.
- – Little enthusiasm in water treatment industry, but that may be changing

Theory of Disinfection

- Chick's Law: $$\frac{dN}{dt} = -kN$$ first order
- rate, k, is a function of c oncentration and t time (i.e., CT) and type of organism
- CT concept: $CT=0.9847C^{0.1758}pH^{2.7519}temp^{-0.1467}$

  where C = chlorine residual concentration (C ≤ 4.23 mg/L)

  T= contact time between microbe and disinfectant to inactivate 99.99% 4 log removal

  temp = temperature in the range of 0.5-5.0 °C

  pH in the range of 6-8

empirical expression for defining the nature of biological inactivation where:

$$CT = 0.9847C^{0.1758}pH^{2.7519}temp^{-0.1467} \quad (3\text{-}114)$$

where C = disinfectant concentration
T = contact time between the microorganism and the disinfectant
pH = $-\log[H^+]$
temp = temperature, °C

Effects of Turbidity

- shields pathogens
- turbidity itself has a chlorine demand
- interferes with detection of coliforms
- clumping and aggregation interferes with disinfection

CT Concept

TABLE 3-21
CT values for 99.99 percent *Giardia* cyst inactivation

	Temperature					
	0.5°C	5°C	10°C	15°C	20°C	25°C
Chlorine dioxide	81	54	40	27	21	14
Ozone	4.5	3	2.5	2	1.5	1
Chloramines	3800	2200	1850	1500	1100	750

Source: Guidance Manual for Compliance with Filtration and Disinfection Requirements for Public Drinking Water Systems Using Surface Water Sources, October 1989.

CT Table

CT = conc. × time

$\frac{mg}{L} \cdot min$ $T = \frac{201 \frac{mg}{L} \cdot min}{2\ mg/L} = 100\ min$

TABLE 3-20

CT values (in mg/L · min) for inactivation of *Giardia* cysts by free chlorine at 10°C

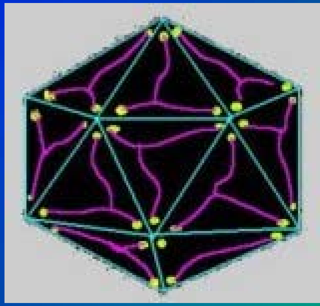
Chlorine concentration mg/L	pH = 6.0						pH = 7.0						pH = 8.0						pH = 9.0					
	Log inactivations						Log inactivations						Log inactivations						Log inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	11	23	34	46	57	69	18	33	33	70	82	105	25	51	76	101	126	152	35	70	105	140	175	210
0.6	12	25	37	49	62	74	19	38	56	75	94	113	27	54	81	109	136	163	38	75	113	150	188	225
0.8	13	26	39	52	65	78	20	40	59	79	99	119	29	57	86	114	143	171	40	79	119	153	198	237
1.0	13	27	40	54	67	81	21	41	62	82	103	123	30	59	89	119	149	178	41	82	123	164	205	247
1.2	14	28	42	56	69	83	21	42	64	85	106	127	31	61	93	126	161	194	42	85	127	170	212	255
1.4	14	29	43	57	71	86	22	44	65	87	109	131	32	63	95	126	158	189	44	87	131	174	218	262
1.6	15	29	44	58	73	88	22	45	67	89	112	134	32	65	97	129	161	194	45	89	134	179	223	268
1.8	15	30	45	60	75	90	23	46	68	91	114	137	33	66	99	132	165	198	46	91	137	182	228	273
2.0	15	30	46	61	76	91	23	46	70	93	116	139	34	67	101	134	168	201	46	93	139	186	232	278
2.2	15	31	46	62	77	93	24	47	71	95	118	142	34	68	102	137	171	205	47	94	142	189	236	283
2.4	16	31	47	63	79	94	24	48	72	96	120	144	35	69	104	139	173	208	47	94	142	189	236	283
2.6	16	32	48	64	80	96	24	49	73	97	122	146	35	70	105	141	176	211	49	97	146	194	243	292
2.8	16	32	48	65	81	97	25	49	74	99	123	148	36	71	107	142	178	214	49	98	148	197	246	295
3.0	16	33	49	65	82	98	25	50	75	100	125	150	36	72	108	144	180	216	50	100	150	199	249	299

Source: U.S. Environmental Protection Agency, *Guidance Manual for Compliance with Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources,* Criteria and Standards Division, Office of Drinking Water (U.S.E.P.A. NTIS Publication No. PB 90-148016), Washington, DC: U.S. Government Printing Office, October, 1979.

Theory of Disinfection

- Biocides — interact with a target on cell, possible targets include:
  - cytoplasmic membrane
  - peptidoglycan layer
  - outer membrane
  - structural proteins
  - thiol groups of enzymes
  - nucleic acids

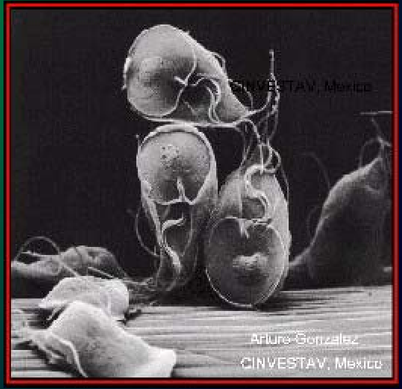
Susceptibility depends on microorganism



least resistant   most resistant

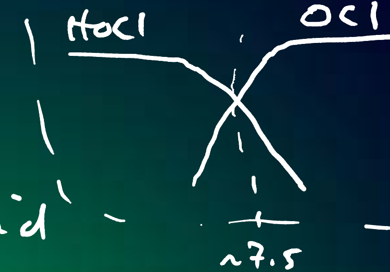
vegetative bacteria < enteric viruses < spore forming bacteria < protozoan cysts

helminths



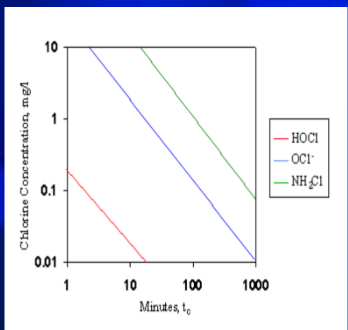
Typical disinfectants

HOCl >> OCl
10x more powerful



- **Chlorine:**
  - $Cl_2 + H_2O \rightarrow HOCl + Cl^-$

    ↑ hypochlorous acid



- **Chloramines**
  - Chloramination began in Denver, CO and Ottowa Canada in 1917. Both employed pre-reaction of the chemicals prior to their addition to the treated water. Sometime later, preammoniation (adding ammonia prior to chlorine) was practiced. Shortages of ammonia in World War II, caused the practice to diminish, but concern over DBPs has caused an increased interest.

Chlorination

- $NH_3 + HOCl \rightarrow NH_2Cl + H_20$
- $NH_2Cl + HOCl \rightarrow NHCl_2 + H_20$
- $NHCl_2 + HOCl \rightarrow NCl_3 + H20$

mono & di chloramine will be main products

↑ carcinogenic

Ozonation

- strong oxidant, but no residual
- no THM formation, but other (non-chlorinated) DBPs possible
- often used as a primary disinfectant & taste & odor removal

Chlorine Dioxide

- strong oxidant, but not a powerful as O_3
- dose limited to 1.0 mg/L due to health concerns of chlorite and chlorate
- residual is not long lasting

UltraViolet Light

- uses thin layer of water and mercury vapor arc lamp emitting UV in the range of 0.2 to 0.29 micron
- depth of light penetration limited to 50 to 80 mm
- powerful, but no residual

Disinfectant Strength

in general:

ozone > chlorine dioxide > chlorine > chloramines

Ozonation

- strong o__________, but no residual
- no THM f_____________, but other (non-chlorinated) DBPs possible
- often used as a p______________ disinfectant

Chlorine Dioxide

- strong oxidant, but not a powerful as O___
- dose limited to 1.0 mg/L due to health concerns of chlorite and c____________
- residual is not long l___________

UltraViolet Light

- uses thin layer of water and mercury vapor arc l_________ emitting UV in the range of 0.2 to 0.29 micron
- depth of light p_____________ limited to 50 t 80 mm

Breakpoint chlorination