Aalto University
School of Engineering

Physical & chemical treatment processes of water and waste WAT - E2120

Disinfection

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Content

1. Disinfection theory – 45 min
2. Chlorination, Ozonation, UV, SODIS, AOPs – 45min
3. Methods (Lab) – 45 min
4. Case studies – 30 min

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Introduction

Disinfection

Sterilization

Introduction

<u>Disinfection</u> refers to partial destruction of disease-causing organisms. During disinfection not all organisms are destroyed. The fact that all of the organisms are not destroyed differentiate disinfection from sterilization.

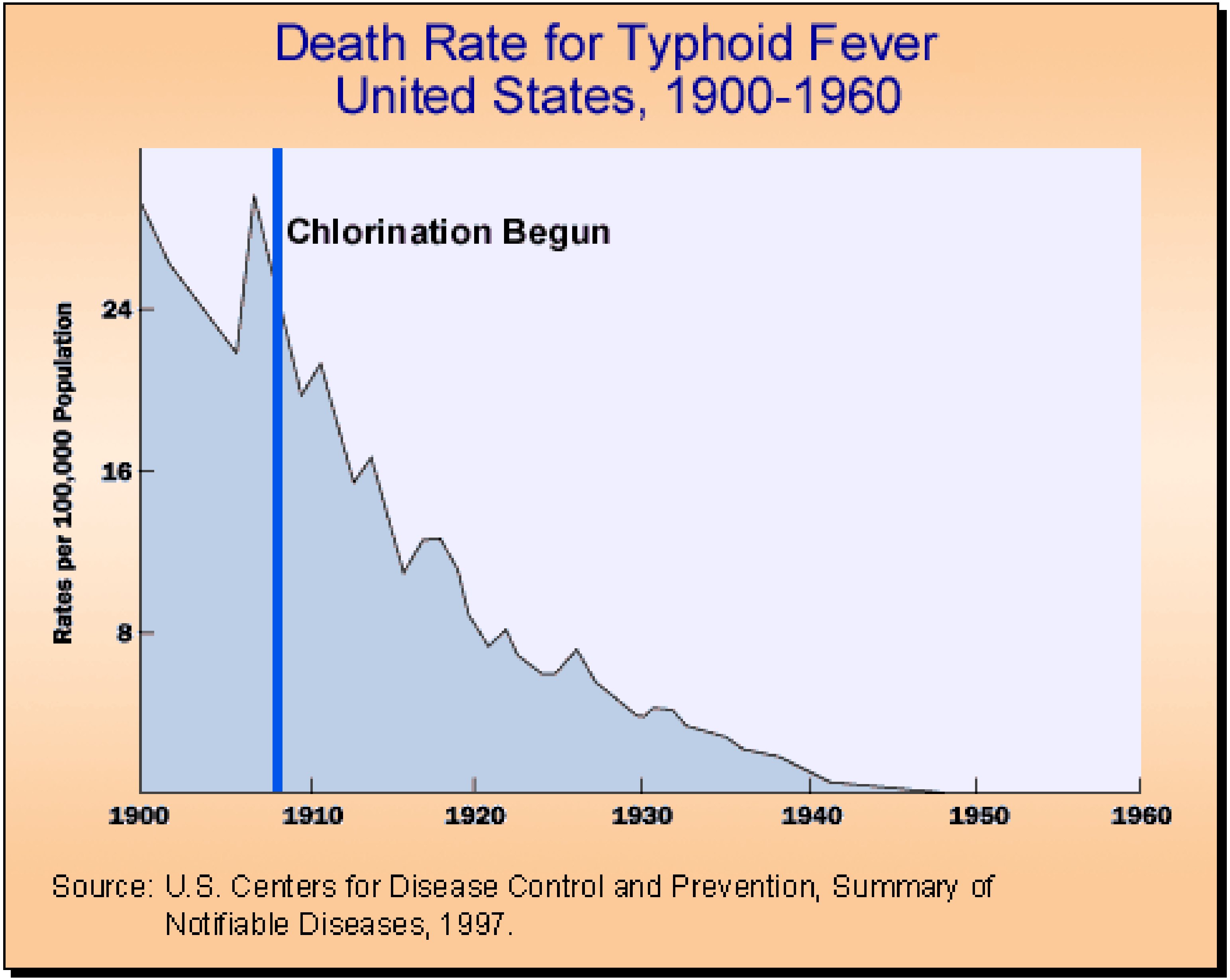
<u>Sterilization</u> is the complete destruction of all organisms. Sterilization removes or destroys all viable forms of microbial life, including bacterial spores

Introduction

Historical records indicate that the **boiling of water** had been recommended at least as early **as 500 B.C**.

The first use of disinfection as a continuous process in water treatment took place in a small town (Middelkerke) in Belgium in the early 1900s, where chlorine was used as the disinfecting reagent.

Introduction



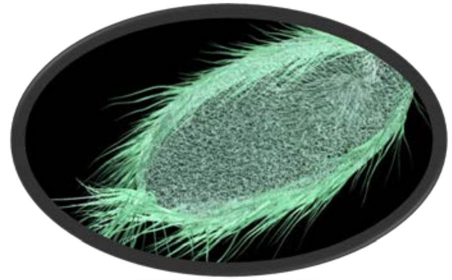
Introduction

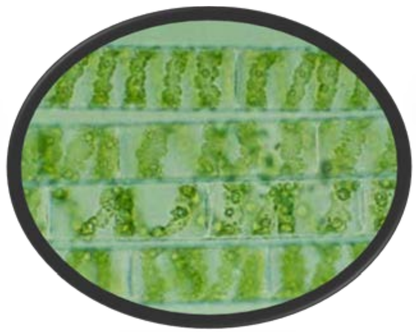
In **1850s** the epidemiological relationship between water and disease had been suggested

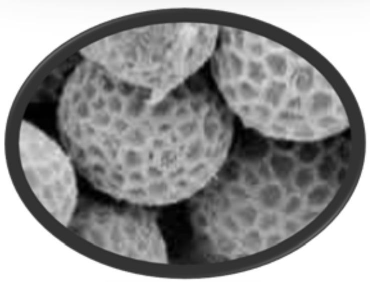
In **mid-1880s** with development of **Germ theory of disease (many diseases are caused by microorganisms)** it was understood that water is a carrier of disease-producing organisms.

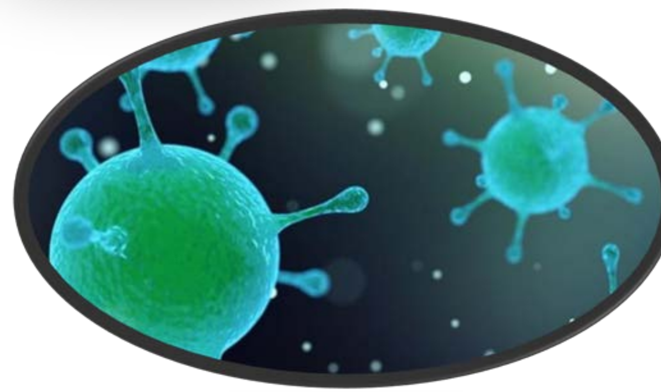
Microorganisms found in Surafce Waters and Wastewater


bacteria

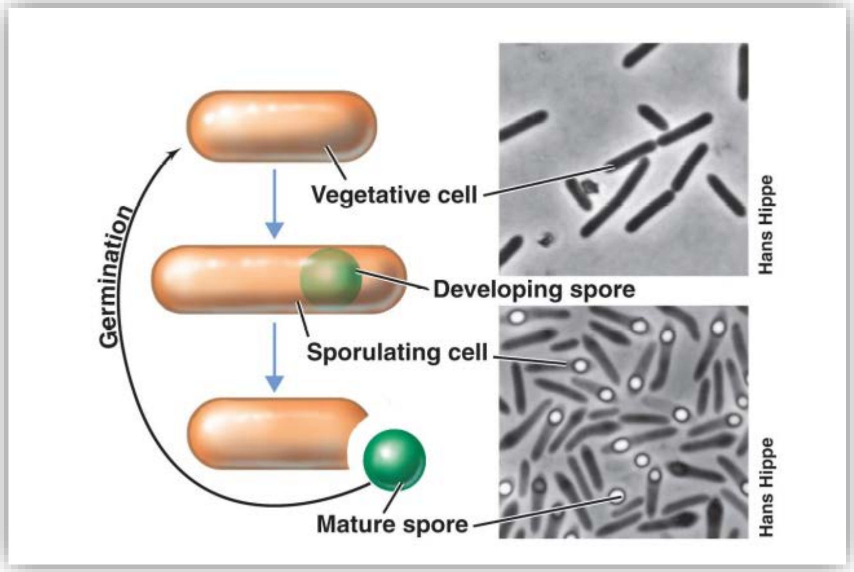

protozoa


algae

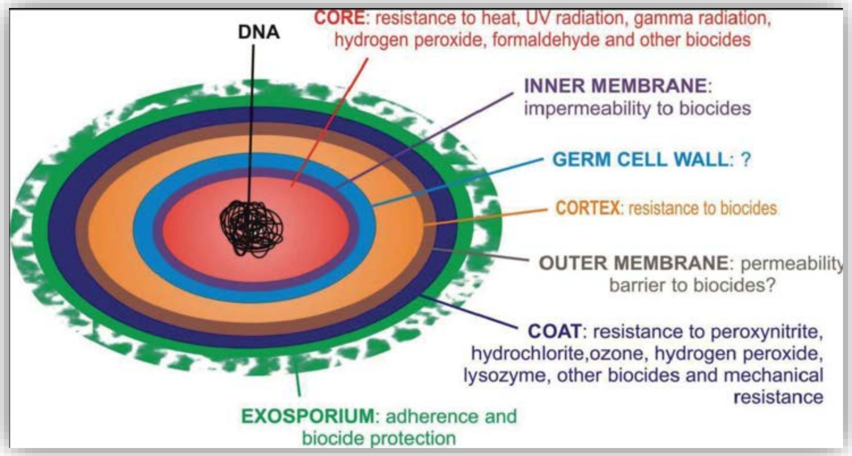

fungi


viruses

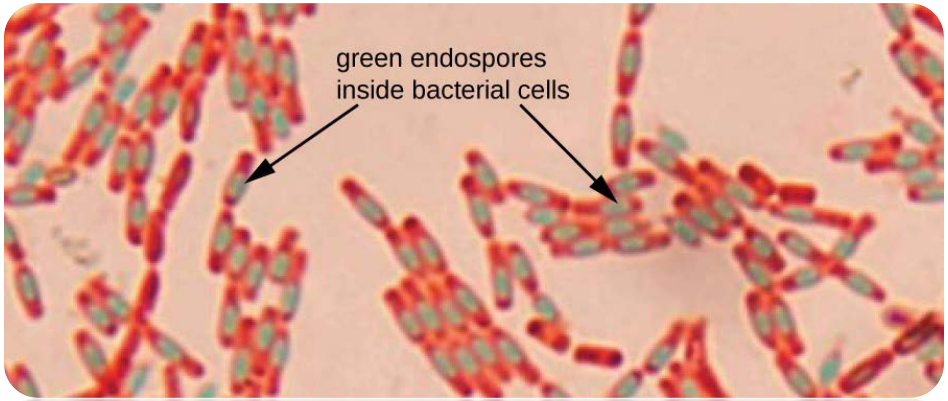
Microorganisms found in Surafce Waters and Wastewater



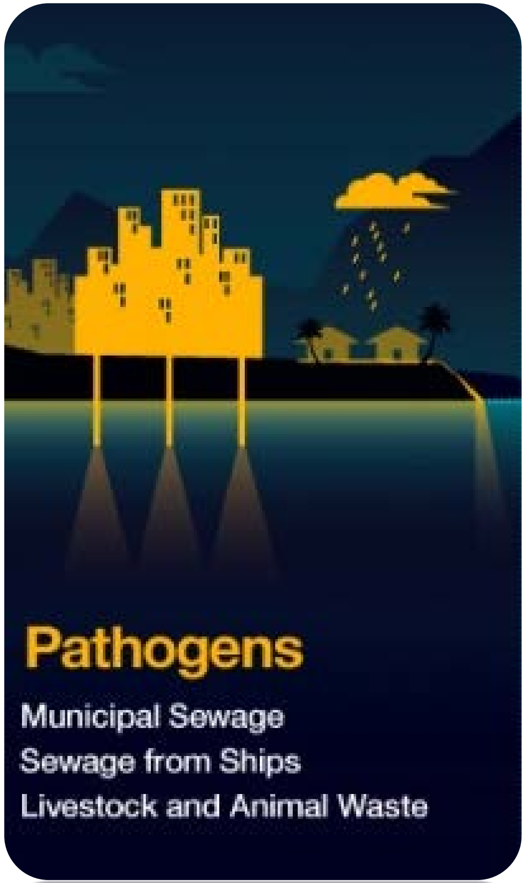
endospores



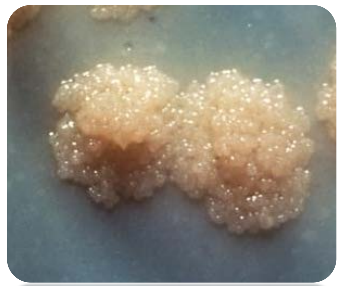
Bacillus



Pathogens in water



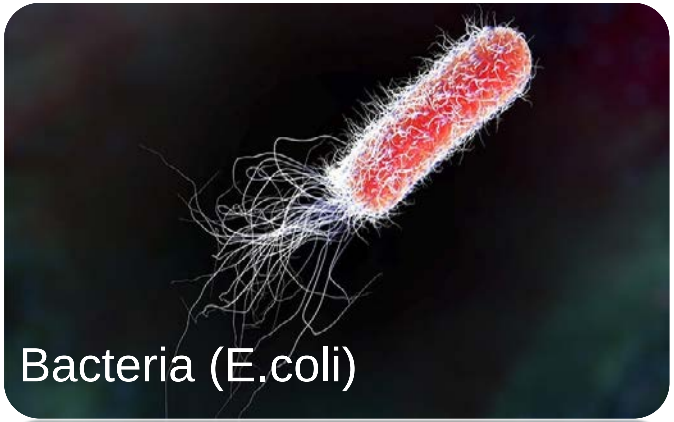
Pathogen – infectious microorganism

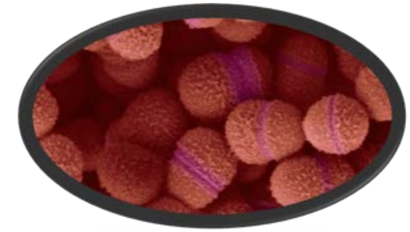


Mycobacterium tuberculosis

→ **Kill about 2 million people a year** (sub-Saharan Africa)

Pathogens of primary concern





Size: 0.1 to 10 µm

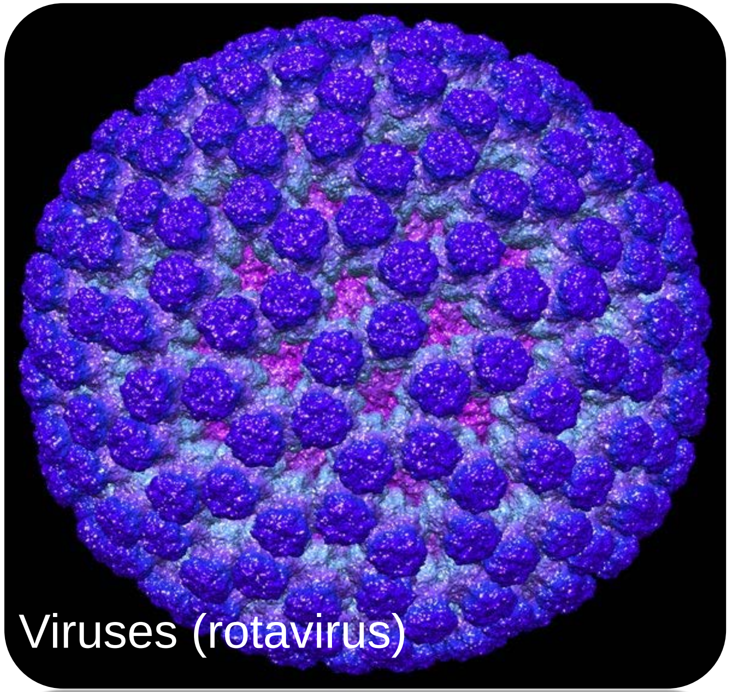
Cocci (spherical bacteria) 1 - 3 µm

Bacilli (rod-shaped) 0.3 - 1.5 µm (width) and 1.0 - 10.0 µm (length)

Vibrios (curved rod-shaped) 0.6 - 1.0 µm (width) and 2 - 6 µm (length)

Spirilla (spiral bacteria) up to 50 µm; filamentous bacteria in excess of 100 µm

Pathogens of primary concern


Viruses (rotavirus)

parasites

0.01 - 0.1 µm in size

very species specific

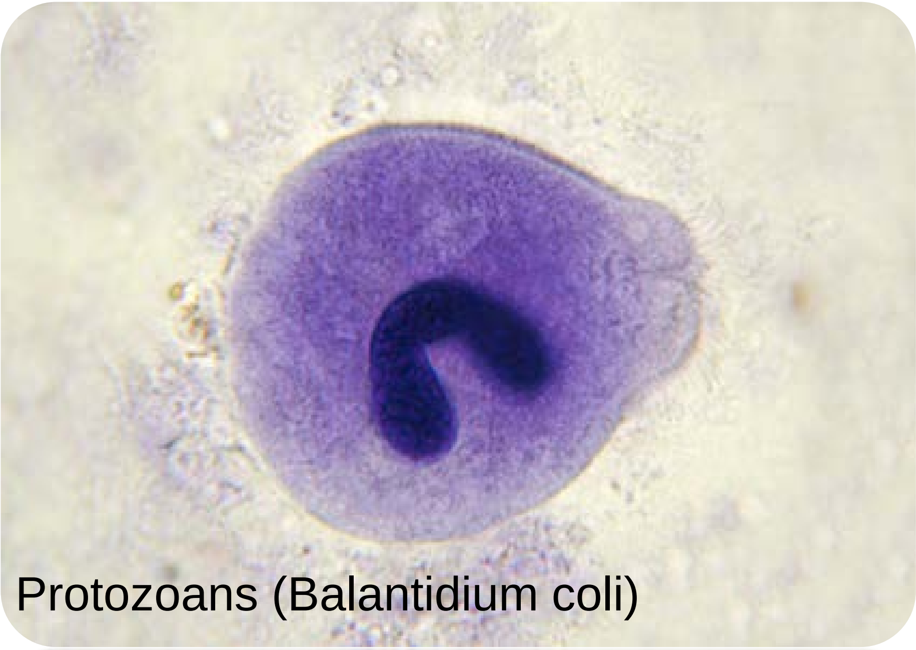
can be transmitted through potable water

Pathogens of primary concern

Protozoa are single-cell eucaryotic microorganisms

Most are free-living in nature

several species are parasitic (algae - human)



Protozoans (Balantidium coli)

Pathogens of primary concern

Waterborne disease from bacteria

Causative agent	Disease
Salmonella typhosa	Typhoid fever
S. paratyphi, S. schottinulleri, *S. hirschfeldi C.*	Paratyphoid fever
Shigella flexneri, Sh. Dysenteriae, Sh. sonnei *Sh. paradysinteriae*	Bacillary dysentery
Vibrio comma, V. Cholerae	Cholera
Pasteurellla tularensis	Tularemia
Brucella melitensis	Brucellosis (undulant fever)
Pseudomonas pseudomallei	Melioidosis

Pathogens of primary concern

Waterborne disease from viruses

Causative agent	Disease
Enterovirus Polio	Muscular paralysis, aseptic meningitis
Hepatitis	Infectious hepatitis, Serum hepatitis. Down’s syndrome
Enterovirus Echo	Aseptic meningitis, Muscular paralysis, Guillain-Barre’s syndrome, Respiratory disease, Diarrhea, Epidemic myalgia, Pericardits and myocarditis, Hepatitis
Adenovirus	Respiratory disease, Acute conjunctivitis, Acute appendicitis, Subacute thyroiditis

Pathogens of primary concern

Waterborne disease from protozoa

Causative agent	Disease
Ascario lumricoidis (round worm)	Ascariasis
Cryptosporidium muris, Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis
Giardia lamblia	Giardiasis
Naegleria gruberi	Amoebid menigoecephalitis
Schistosoma mansoni	Schistosomiasis

Disinfection theory

Characteristics of an ideal disinfectant

Characteristics	Properties/Response
Availability	Should be available in large quantities and reasonably priced
Deodorizing ability	Should deodorize while disinfecting
Homogeneity	Solution must be uniform in composition
Interaction with extraneous materials	Should not be absorbed by organic matter other than bacterial cells
Noncorrosive and nonstaining	Should not disfigure metals and stain clothing
Nontoxic to higher forms of life	Should be toxic to microorganisms and nontoxic to humans and other animals

Disinfection theory

Characteristics of an ideal disinfectant

Characteristics	Properties/Response
Penetration	Should have capacity to penetrate through surfaces
Safety	Should be safe to transport, store, handle, and use
Solubility	Must be soluble in water or cell tissue
Stability	Should have low loss of germicidal action with time on standing
Toxicity to microorganisms	Should be effective at high dilutions
Toxicity at ambient temperatures	Should be effective in ambient temperature range

Disinfection theory

Disinfection methods and means

- **Chemical agents**
- **Physical agents**
- **Mechanical means**
- **Radiation**

Disinfection theory

Chemical agents

- Chlorine and its compounds
- Bromine
- Iodine
- Ozone
- Phenol and phenolic compounds
- Alcohols
- Soaps and synthetic detergents
- Quaternany ammonium compounds
- Hydrogen peroxide
- Peracetic acid
- Various alkalies
- Various acids

Disinfection theory

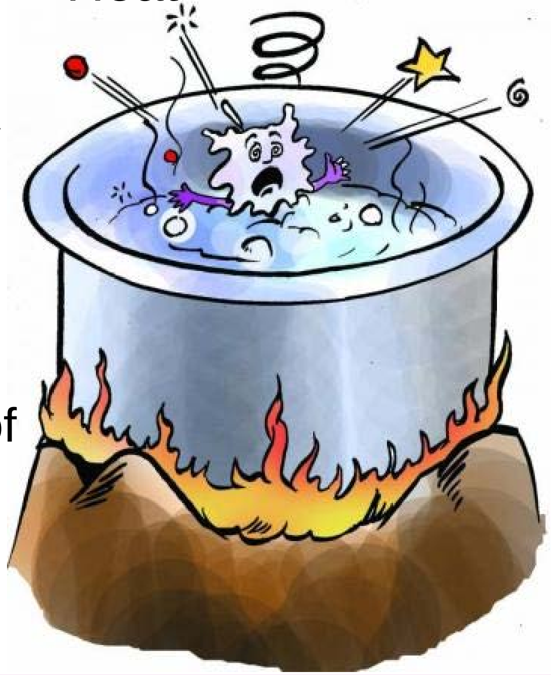
Physical agents

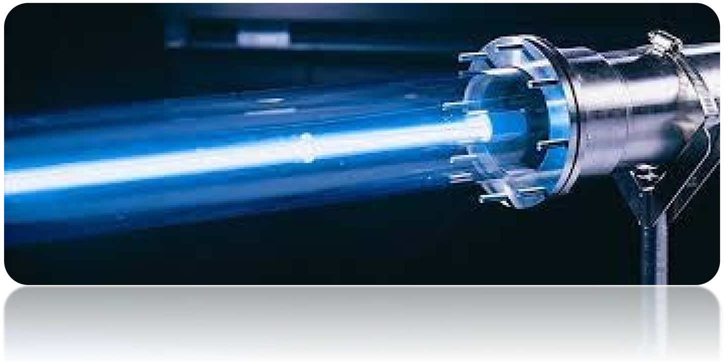
Destroy major disease-causing bacteria;

Common in dairy industry;

Not feasible for disinfection of large quantities of water

Heat





Sound waves

Disinfection theory

Mechanical means

- Coarse screen
- Fine screens
- Grit chambers
- Plain sedimentation

Disinfection theory

Radiation

- Electromagnetic
- Acoustic
- Particle

Well studied

No commercial devices available

Disinfection theory

Comparison of disinfectants

Process	Percent removal of bacteria
Coarse screen	0 - 5
Fine screens	10 - 20
Grit chambers	10 - 25
Plain sedimentation	25 - 75
Chemical precipitation	40 - 80
Trickling filters	90 - 98
Activated sludge	90 – 98
Chlorination of treated water	98 – 99.9

Disinfection theory

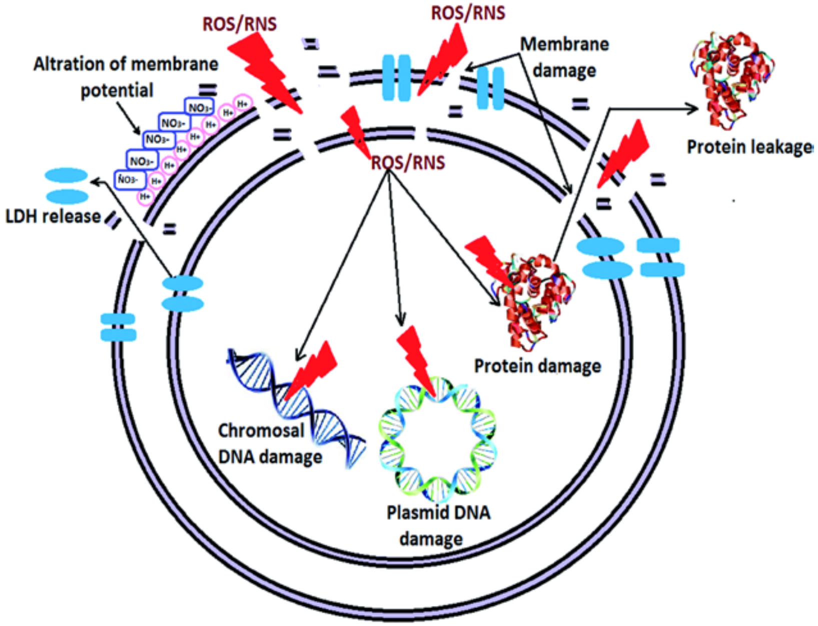
Comparison of disinfectants

Characteristic	Chlorine	Ozone	UV
Availability/cost	Low cost	Moderately high	Moderately high
Deodorizing	high	high	-
Homogeneity	homogeneous	homogeneous	-
Interaction with extraneous material	Oxidizes organic matter	Oxidizes organic matter	Absorbance of UV
Noncorrosive	Highly corrosive	Highly corrosive	-
Nontoxic to higher forms of life	Highly toxic	toxic	toxic

Disinfection theory

Mechanism of disinfection

1. Damage of the cell wall
2. Alteration of cell permeability
3. Alteration of the colloidal nature of the protoplasm
4. Alteration of the organism DNA or RNA
5. Inhibition of enzyme activity



To large extent, performance differences for various disinfectants can be explained on the basis of the operative removal mechanism

Disinfection theory

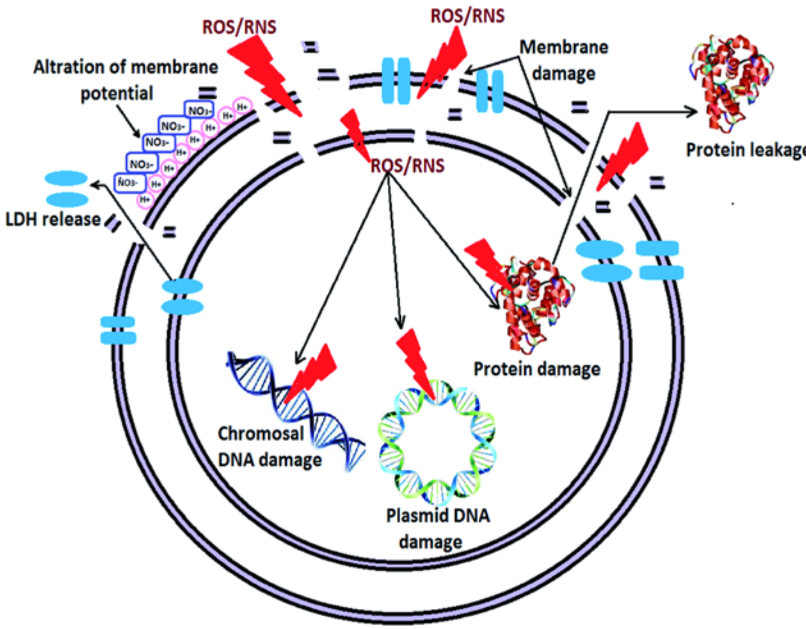
Mechanism of disinfection

Penicilin inhibit synthesis of bacteria cell wall;

Phenolic compounds alter permeability of membrane;

Heat and radiation alter colloidal nature of protoplasm;

Chlorine inactivate enzymes



Disinfection theory

Factors affecting the action of disinfectants

- Contact time
- Concentration of disinfectant
- Intensity and nature of physical agent or means
- Temperature
- Types of organisms
- Nature of suspending liquid

Disinfection theory

Contact time

In early 1900s Harriet Chick observed that for given concentration of disinfectant, the longer contact time, the greater the kill. This observation was first reported in 1908. The Chick's law:

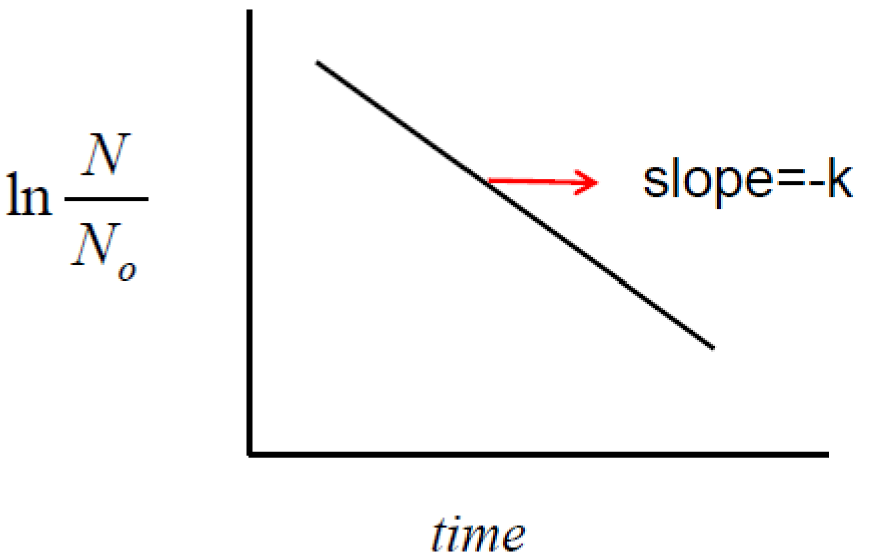
6.1.1875 –9.7.1977

$$\frac{dN_t}{dt} = -kN_t$$

$\frac{dN_t}{dt}$ is rate of change in the concentration of organisms with time;
k is inactivation rate constant $[1/s]$;
N_t is number of organisms at time t $[-/m^3]$;
t is time $[s]$

Disinfection theory

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



Disinfection theory

time	CFU/100 mL
0	80000
0,5	42000
1	19000
2	1950
3	430
4	30
5	2
6	1

k - ?

Disinfection theory

Concentration of disinfectant

In early 1900s Herbert Watson reported that the inactivation rate constant was related to the concentration as follows:

$$k = k' C^n$$

k is inactivation rate constant;
k' is die-off constant;
C is the concentration of disinfectant;
n is coefficient of dilution

Combination of expressions proposed by Chick and Watson in differential form leads to **Chick-Watson model** (include both disinfectant and pathogen concentrations)

$$\frac{dN_t}{dt} = -kN_t C^n \quad \Longrightarrow \quad ln(N/N_{0)}) = -k' C^n t$$

Disinfection theory

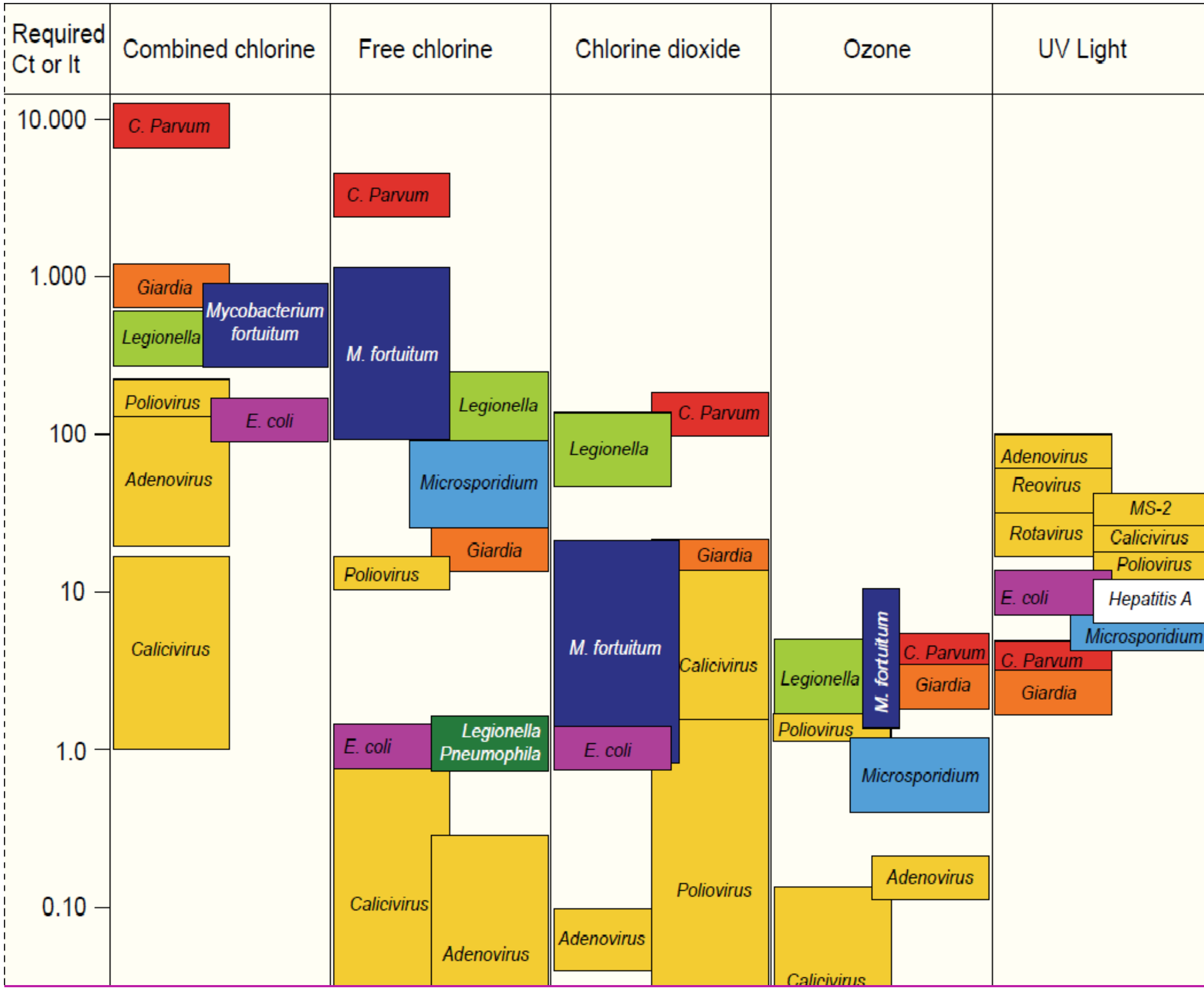
C t - values

In most cases the C t -value is used as the basis for disinfection. For many pathogens and disinfectants, information can be found on C t -values and inactivation.

C t = concentration of disinfectant (mg/l), multiplied by inactivation time (min)

This approach is also used for disinfection with UV radiation, for which the C t -value is modified into UV light intensity (mJ /(s cm^2)) multiplied by the time of exposure (s), giving the dose (mJ/cm2).

Disinfection theory

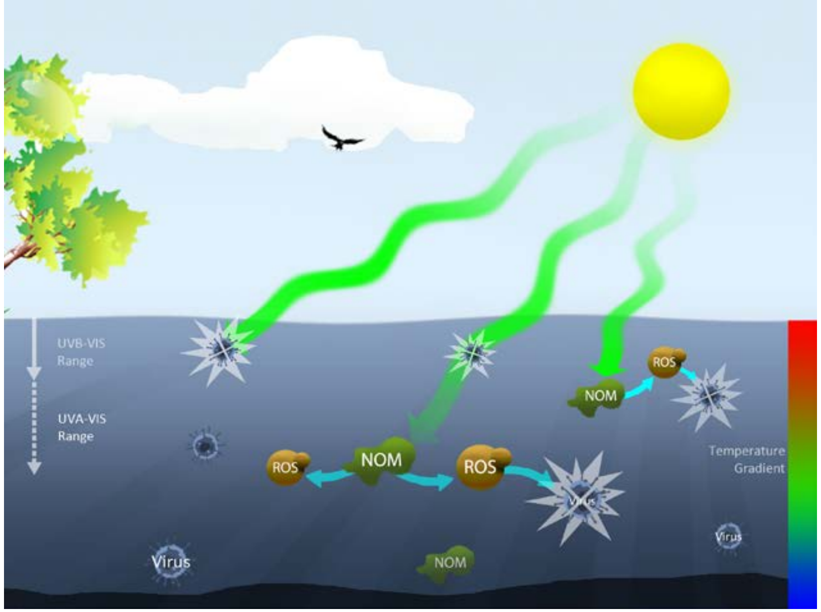


Disinfection requirements for 99% inactivation (min mg/l or mJ/cm^2)

Disinfection theory

Intensity and nature of physical agent or means

Heat and light are physical agents that can be used for water disinfection. It has been found that their effectiveness is a function of intensity.



Disinfection theory

Types of organisms

Type, nature and condition of microorganism affect the effectiveness of disinfectant;

viable, growing bacteria cells are often killed more easily than older cells;

bacteria spores are extremely resistant;

Disinfection theory

Nature of suspended liquid

Often experiments on water disinfection are conducted in distilled or buffer water, under laboratory conditions. In practice, the nature of the suspending liquid must be evaluated carefully. For example, natural organic matter will react with most oxidizing disinfectants and reduce their effectiveness. The presence of suspended matter will reduce the effectiveness of disinfectants by absorption of the disinfectant and by shielding the entrapped bacteria.