Microbiology of Distribution Systems

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Outline

Significance of distribution system microbiology

the "Players" (Microbiology 101)

the Problems (possible controls?)

the Future

I) Microbes in the Pipes: Significance

Payment, 1991-1997:

"distribution system could be playing an important role in the contamination of populations"

1) Are a reservoir for human / animal disease

- even though *in compliance* with current regulations

2) Microorganisms in water also can cause biofouling and decay.

the positive side

Microorganisms are natural and essential constituents of water

All *naturally* occurring water contain microbes; majority non-pathogenic, non-corrosive

Microbes: use water as medium for growth and survival

vehicle for distribution

Water: "uses" microbes contribute to chemical quality (Fe, S, Hg, As)

enable C, N, H cycling (CO_2, CH_4, denitrification)

control / eliminate pollutants (hydrocarbons, pesticides)

Humans: microbes in water contribute to / replenish normal flora

- help maintain disease resistance

II) the “Players”

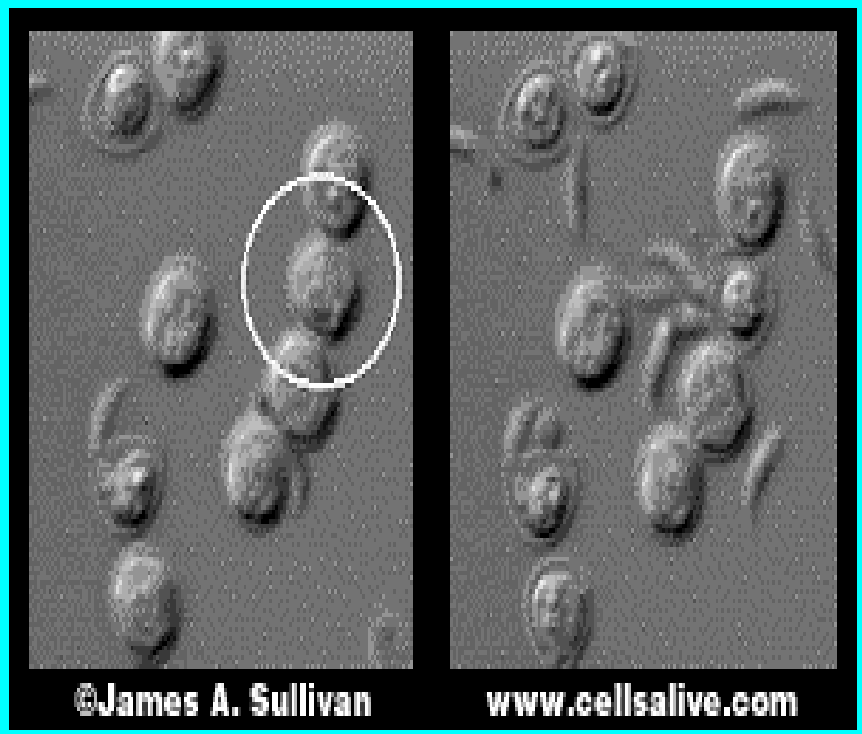
- Representative protozoa, bacteria, viruses
- In order of decreasing size (filterability) and increasing chlorine sensitivity

Water-borne parasitic protozoa

Giardia lamblia

- size: 10 –12 um
- removed by filtration
- thick-walled cysts in water
- resistant to chlorine
- infections: motile trophozoite
- treatable diarrhea
- do not multiply in water
- reservoir settling decreased counts, viability

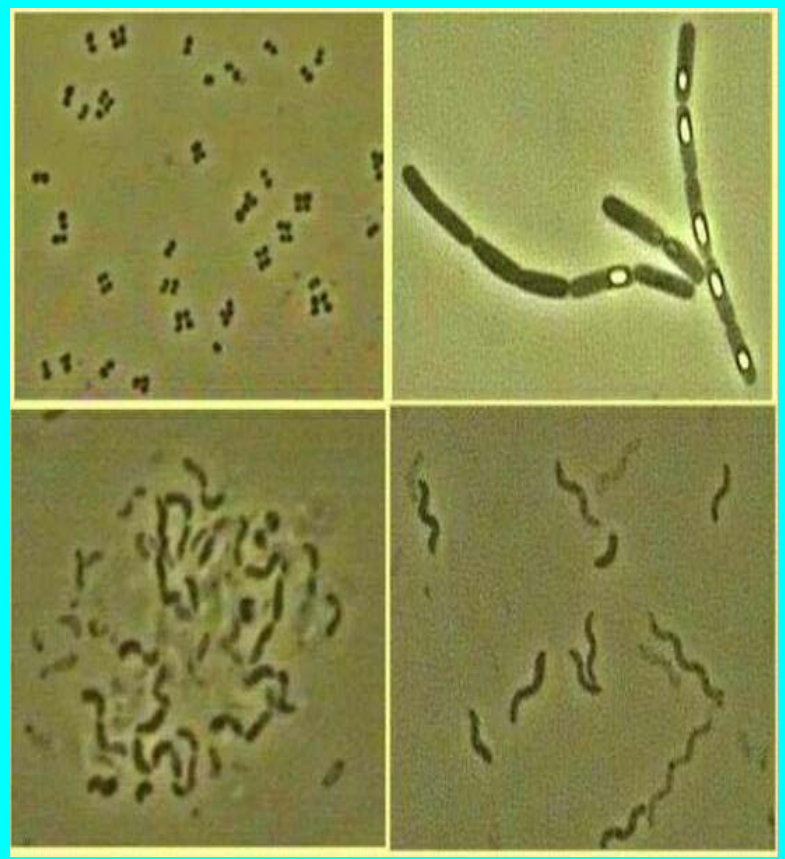
Water-borne parasitic protozoa



Cryptosporidium parvum

- size: 4 – 6 um
  (filtration inconsistent)
- thick-walled oocysts
- UV, ozone sensitive
- infections: non-motile
  sporozoites (invasive)
- ID_{50}: 10-1000 oocysts
- diarrhea lasts1-2 weeks
- not antibiotic treatable
- do not multiply in water
- OB source: human waste

Water-borne Bacteria (heterotrophic)

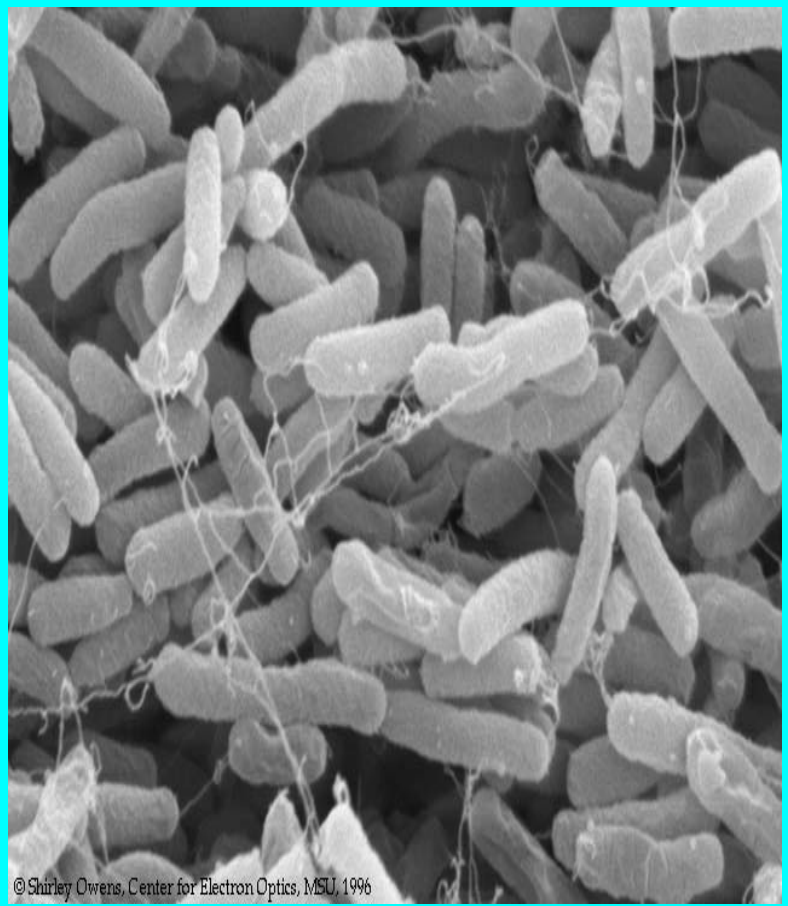


- diverse shapes (sphere, rod, comma, spiral)
- size: 0.2 – 4 um

- most chlorine sensitive

Examples: *Enterococcus*
Klebsiella, Serratia
Vibrio cholera
Sprillium

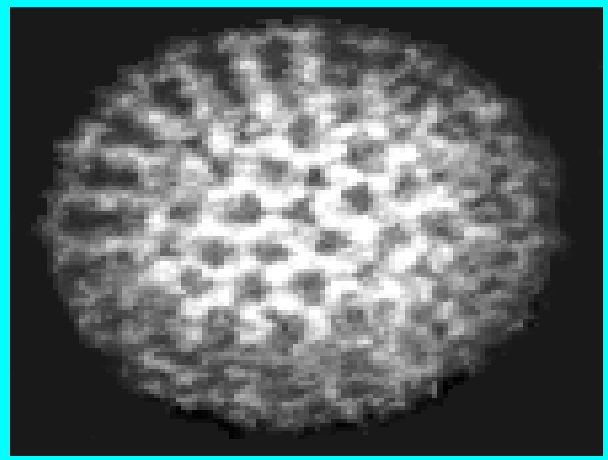
Water-borne bacterium: *Escherichia coli* (coliforms)



- both pathogenic and non-pathogenic forms in water

Pathogenic type:0157:H7
- attaches to wall of intestine
- forms potent toxin
  → bloody diarrhea, kidney damage, death
- half-life: approx. 8 days (ground water)
- acid resistant

Water-borne viruses



Small round viruses (SRV)

- 0.02 - 0.07um diameter
- chlorine resistant
- untreatable gastroenteritis

← Rotavirus

- diarrhea in children

← Enterovirus

- diarrhea children/adults

- est half-life: 2 – 8 hours

III) the Problems

High quality water leaving treatment plant subsequently may be subject to several processes that degrade this quality:

a) disinfection proficiency

b) regrowth

c) nitrification

d) biolfilms

e) intrusion events

Problems cont'd

a) Variation in treatment proficiency, transient failures

- breakthrough inoculation → reseeding, increase nutrients, color
- microbes: original complement (esp viruses, protozoans)

Control: effluent monitoring, secondary disinfection

Problems cont'd

b) Regrowth: post treatment increase in counts within system

- disinfectant resistance, nitirification, biofilm sloughing
  → loss of bacterial quality, new biofilm formation, increased corrosion, taste, odor, grazing macroinvertebrates
- microbes: coliforms, Gm+, heterotrophs, film formers

Control: limit biodegradable organic material (BOM) entering system with coagulation, filtration (carbon, biologic, membrane)
action level: effluent AOC > 150 ug/liter, BDOC > 0.5 mg/l

NB. chlorination, ozone >> BOM in water

Problems cont'd

3) Nitrification: increase in nitrite/nitrate content via microbial activity

- secondary disinfection with ammonium chloride (**chloramination**)
- less reactive than Cl (fewer DBPs), penetrates biofilms, but promotes growth of ammonium / nitrite oxidizing bacteria [AOB,NOB] (*Nitrosomonas, Nitrospira*) that deplete chloramine, foster growth of heterotrophic bacteria → loss of water quality. Occurs with residuals of 0.2 -1.1 mg Cl_2/l, 0.3 – 0.6 mg N/l

Control: monitor effluent pH, NH_4 conc, AOB densities
routine flushing, breakpoint chlorination
action level: effluent: 50 ug nitrite / nitrate/l

Problems cont'd

3) Biofilms: organized community bacteria adhering to physical surface

- enables microbe to resist flush, survive nutrient deprivation

- cause physical damage (corrosion), reduces proper function (flow rates)*, source of pathogens (regrowth), color/odor/taste

- microbes: coliforms, aerobes (oxidizers), anaerobes (reducers) resistant to disinfectants (1-2 mg Cl_2/l,) antibiotics*

Pipe Encrustation

Figure 18.2 Distribution system pipeline heavily encrusted with iron and manganese oxide deposits. From Herro (1991).

Biofilm: tubercle anatomy / activity

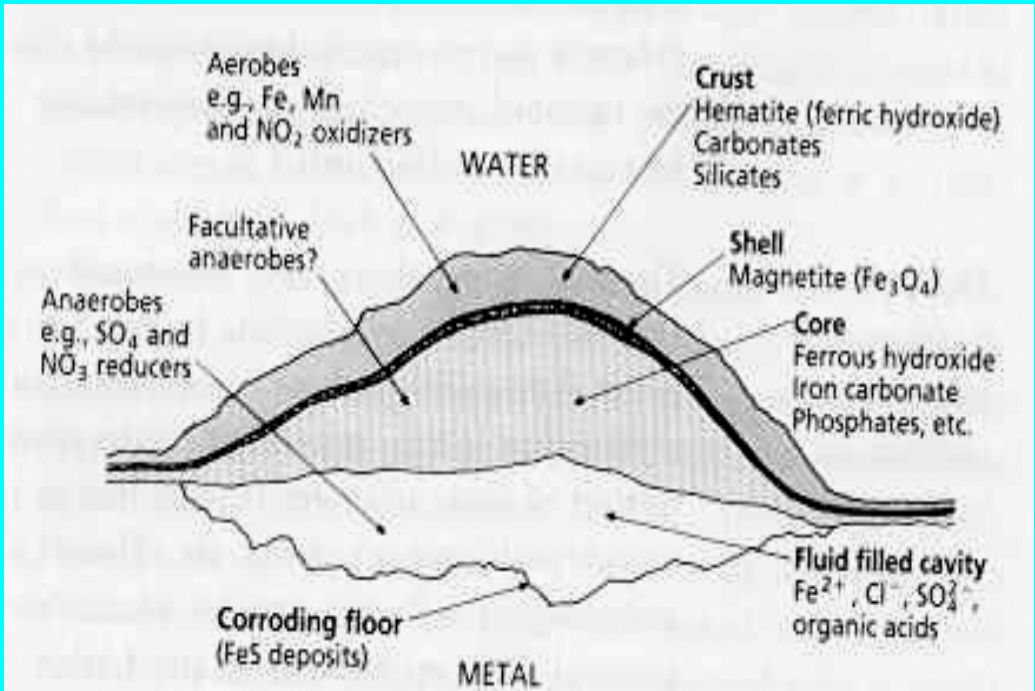
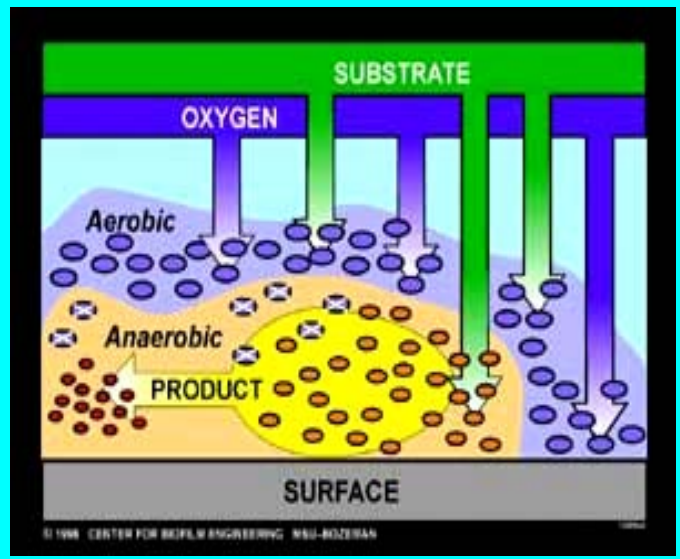


Figure 18.4 Chemical and biological characteristics of a tubercle. Adapted from Herro (1991).



Biofilms cont'd

Control: use antifouling / anti-adhesive surface^ (iron vs cPVC)
chemical biocides (monochloramine)^
physical removal of tubercles
reduce AOC (nutrients)^

^ all influence rate and amount of formation

Recognition: sporadic, unexplained change in counts, color, turbidity
seasonal flushing

Problems cont'd

4) Intrusions: introduction of microbes from outside system

a) accidental: pressure loss, breaks/repairs, cross-connection, seepage, flooding

b) intentional: bioterrorism (deliberate tampering)

- toxigenic bacteria *(eg. E.coli* 0157:H7^, *B. anthracis*)*
- parasitic protozoans (*Cryptosporidium parvum)*^
- enteropathogenic viruses (Norwalk^?)*

Control: good SOPs, communication, controlled access
rapid detection, response plan

Confirmed Bioterrorism Agent

Bacillus anthracis (anthrax)

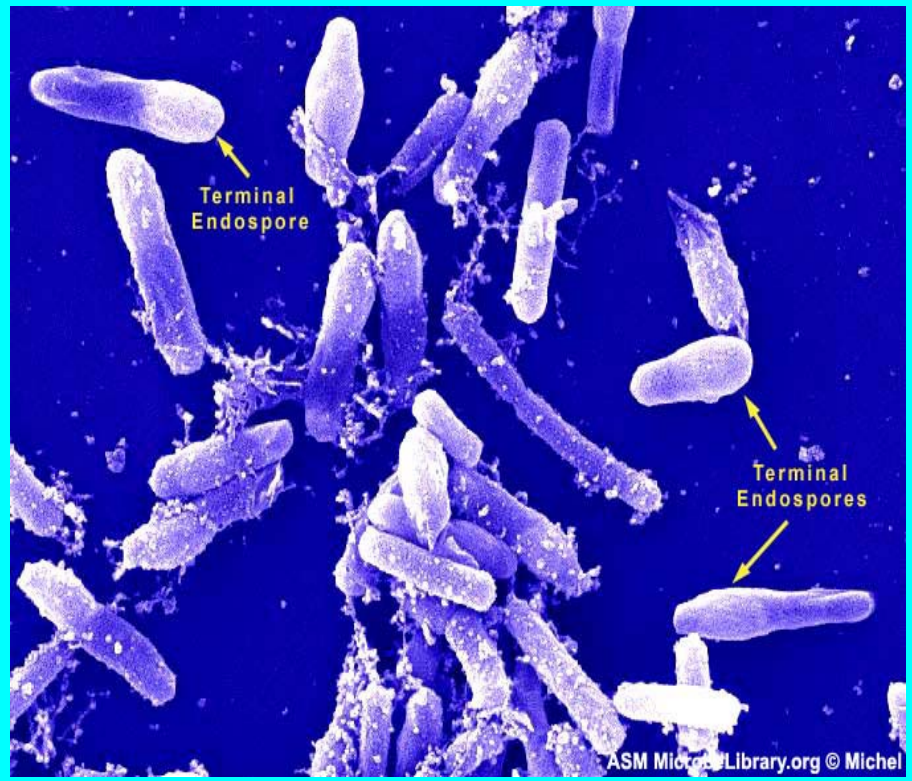
- spores survive soil, water, air

- toxins: skin, GI tract, lungs
  (resp.> 60% mortality, 48h)

- ID_{50}: 2000 spores/person

- vaccine, antibiotics useful

- spores Cl resistant



Potential Bioterrorism Agent

Norwalk virus

- small round, contain RNA
- infections associated with water, aerosols
- incubation period 24-48h
- diarrhea and vomiting
- no vaccines, no antivirals
- chlorine sensitive

IV) the Future

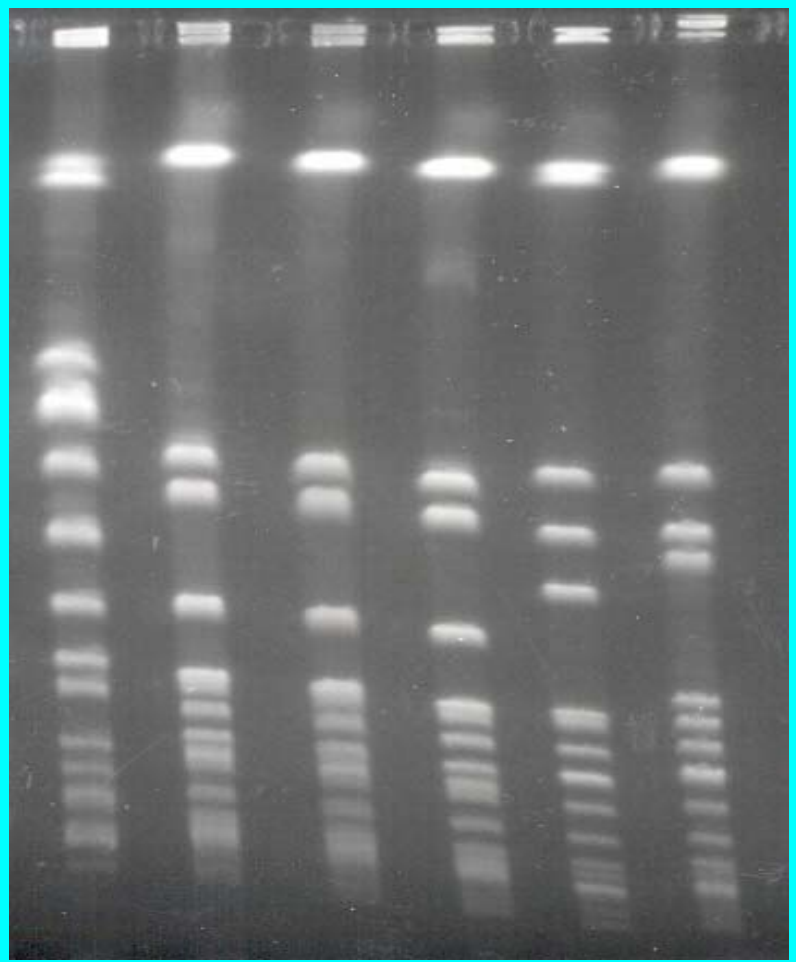
a) Monitoring / detection
- non-culturable microbes: post-concentration particle counts?
  (acoustic energy concentration, microfluidic/capillary sampling)
- screen for specific pathogens? (molecular probes, PCR)

b) Disinfection
- greater use of UV irradation, ozonation?
- soft X-ray sources?

c) Bacterial source tracking
- eliminate cause rather than deal with outcome (asses similarity) *

d) Regulation
- WHO recommends adoption of HACCP approach

Detection / Confirmation of Contamination Source: DNA Typing



- Comparison of chromosome fragment banding patterns implicates cattle manure as source of *E. coli* polluting well water.

← Left to right: manure

“

well water

“

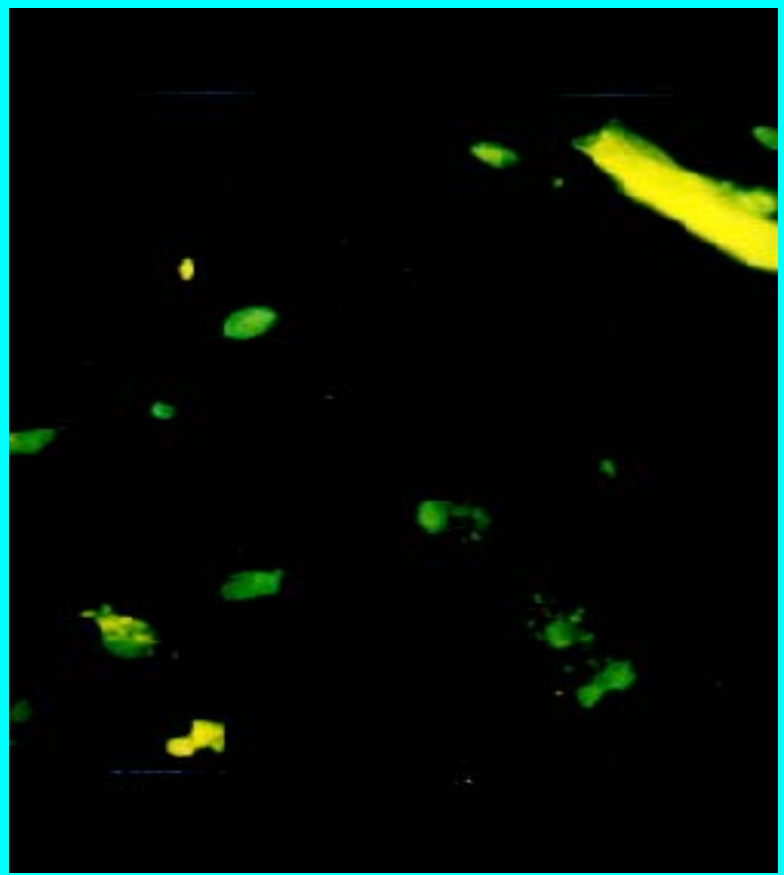
septic tank

“

Detection of Parasitic Protozoa

- Collect contents of >340 litres water in polypropylene wound-string filter
- Recover, concentrate, stain and examine under epifluorescence microscope

Fluorescent Immunoassay for Protozoa



← *Giardia* cyst

← *Cryptosporidium* oocyst

← Cross-reacting algae

WBB: Iron bacteria: *Gallionella*

- Filamentous, fragmented strands occurring at aerobic/anaerobic interface
- Also includes *Thiobacillus* and *Leptothrix*
- Aerobic oxidizers of soluble ferrous iron (FeII) to obtain energy → insoluble ferric (FeIII) oxyhydroxides
- Fe II fr. water → clogs

  " pipes → pitting

Microbiology 101: the "Basics"

Microorganisms: small, singled-celled, self-replicating life forms

Three major groups: Eubacteria (bacteria, Gram stain + or -)
Eukarya (algae, fungi, protozoa)
Archaea (methanogens)

Viruses (obligate parasites)

Exist as interactive communities in natural systems
- the **Prokaryotes** = Eubacteria, Archaea, viruses
- the **Eukaryotes** = protozoa, fungi, algae

Either aerobic (O_2 requiring) or anaerobic (O_2 independent)
Net negative charge at cell surface (adhere to solids)