Today’s discussion will cover

- Contaminants found in water (What)
- Do they have to be removed? (Why)
- How to remove them (How)
Basic Groups of Contaminants

- Suspended Solids or Particles
- Dissolved Salts or Ions
- Organic Materials- low molecular weight organics
- Colloidal Materials- high molecular weight organics
- Bacteria and Other Living Organisms
- Dissolved Gases

Materials that do not dissolve in water
- Can be any shape, but are generally considered hard, spherical particles
- Moving water holds more particles
- Larger particles will settle out by themselves
**Basic Groups of Contaminants**

• Dissolved Salts or Ions
  • Materials that dissolve in water, forming free floating ions
  • Add positive and negative charges to the water
  • Change how much electricity water can transmit

• Organic Materials- low molecular weight organics
  • Materials containing carbon
  • Small in size (MW in the hundreds/thousands)
  • Little change in electrical conductance of water
  • Extremely difficult materials to remove
  • Many substances are manmade: alcohols, fertilizers, pesticides, THM’s
Basic Groups of Contaminants

• Colloidal Materials - high molecular weight organic molecules
  • Contain carbon
  • Large in size (MW in 10,000 to 5,000,000 range)
  • Not really dissolved or particulate
  • Most carry a small negative charge
  • Form a stable suspension in water
  • Abundance measured by silt density index

Basic Groups of Contaminants

• Bacteria and Other Living Organisms
  • Exist in equilibrium with their environment
  • Abundance is based on the amount of food available
  • Capable of rapid multiplication under the right conditions
Basic Groups of Contaminants

• Dissolved Gases
  • Not removed by most purification processes
  • Least understood and least studied water based contaminant group
  • Carbon dioxide is troublesome because it ionizes when it dissolves

Why do we care about contaminants?

• Because organizations say we should?
  • CAP – College of American Pathologists
  • NCCLS – National Committee of Clinical Laboratory Scientists
  • ASTM – American Society for Testing and Materials
  • USP – US Pharmacopoeia
  • FDA – US Food and Drug Administration
  • SEMI – Semiconductor manufacturing standards
  • HIMA – Health Industries Manufacturing Association
  • ISPE – Baseline guides
### LABORATORY GRADE WATER

**USE CAP/NCCLS/ASTM STANDARDS**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CAP/NCCLS</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE 1</td>
<td>TYPE 2</td>
</tr>
<tr>
<td>Conductivity (max)</td>
<td>&lt;0.1</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Resistivity (min)</td>
<td>&gt;10.0</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>pH</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Silica (ppb)</td>
<td>&lt;500</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Sodium (ppb)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chlorides</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total Organic Carbon (ppb)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Bacteria (cfu/ml)</td>
<td>&lt;10</td>
<td>10</td>
</tr>
</tbody>
</table>

### PHARMACEUTICAL GRADE WATER

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>USP PURIFIED</th>
<th>USP WFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Organic Carbon (ppb)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Conductivity</td>
<td>&lt;1.3 @ 25°C</td>
<td>&lt;1.3@25°C</td>
</tr>
<tr>
<td>Bacteria</td>
<td>None given, but recommended to be 100/ml</td>
<td>None given, but recommended to be 10/100 ml</td>
</tr>
<tr>
<td>Endotoxins</td>
<td>----</td>
<td>&lt;0.25 EU/ml</td>
</tr>
</tbody>
</table>
# SEMICONDUCTOR GRADE WATER

## Page 1 of 3

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ATTAINABLE</th>
<th>ACCEPTABLE</th>
<th>ALERT</th>
<th>CRITICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity</td>
<td>18.2</td>
<td>18.2</td>
<td>17.9</td>
<td>17.5</td>
</tr>
<tr>
<td>TOC (online, ppb)</td>
<td>&lt;1</td>
<td>&lt;2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>THM (ppb)</td>
<td>&lt;2</td>
<td>&lt;5</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Particles by laser</td>
<td>&lt;100/1000 ml</td>
<td>&lt;50/1000 ml</td>
<td>&lt;20/1000 ml</td>
<td>&lt;10/1000 ml</td>
</tr>
<tr>
<td>Bacteria (cfu/1000 ml)</td>
<td>&lt;1</td>
<td>&lt;6</td>
<td>25</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Silica (total, ppb)</td>
<td>&lt;0.5</td>
<td>&lt;3</td>
<td>&gt;5</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

## Page 2 of 3

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ATTAINABLE</th>
<th>ACCEPTABLE</th>
<th>ALERT</th>
<th>CRITICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&gt;0.01</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Silicate (ppb)</td>
<td>&lt;0.05</td>
<td>0.1</td>
<td>&lt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Sodium (ppb)</td>
<td>&lt;0.01</td>
<td>0.05</td>
<td>&gt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Potassium (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&gt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Ammonium (ppb)</td>
<td>&lt;0.06</td>
<td>0.1</td>
<td>&lt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Calcium (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&gt;0.01</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Magnesium (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&lt;0.01</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Fluoride (ppb)</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&gt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Chloride (ppb)</td>
<td>&lt;0.02</td>
<td>0.1</td>
<td>&lt;0.02</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Bromide (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&gt;0.01</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Nitrate (ppb)</td>
<td>&lt;0.02</td>
<td>&lt;0.1</td>
<td>&lt;0.01</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>
**SEMICONDUCTOR GRADE WATER**

**Page 3 of 3**

**METAL ION CONTAMINANTS, ALL ARE MEASURED IN PARTS PER TRILLION**

<table>
<thead>
<tr>
<th>Metal Ion</th>
<th>Concentration Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (ppt)*</td>
<td>7 50 &gt;0.0 200</td>
</tr>
<tr>
<td>Barium (ppt)*</td>
<td>2 10 &gt;50 100</td>
</tr>
<tr>
<td>Boron (ppt)*</td>
<td>300 &lt;2000</td>
</tr>
<tr>
<td>Chromium (ppt)*</td>
<td>8 30 &gt;30 50</td>
</tr>
<tr>
<td>Copper (ppt)*</td>
<td>5 50 &gt;50 &gt;200</td>
</tr>
<tr>
<td>Iron (ppt)*</td>
<td>10 100 200 &gt;200</td>
</tr>
<tr>
<td>Lithium (ppt)*</td>
<td>4 30 100 &gt;100</td>
</tr>
<tr>
<td>Magnesium (ppt)*</td>
<td>2 20 100 &gt;200</td>
</tr>
<tr>
<td>Manganese (ppt)*</td>
<td>4 30 &gt;30 100</td>
</tr>
<tr>
<td>Nickel (ppt)*</td>
<td>5 50 &gt;50 100</td>
</tr>
<tr>
<td>Sodium (ppt)*</td>
<td>10 60 &gt;200 &gt;500</td>
</tr>
<tr>
<td>Strontium (ppt)*</td>
<td>2 10 &gt;10 &gt;10</td>
</tr>
<tr>
<td>Zinc (ppt)*</td>
<td>8 60 &gt;50 &gt;100</td>
</tr>
</tbody>
</table>

Why do we care about contaminants?

- We care when contaminants interfere with what we’re trying to do
- Water is the most abundant single ingredient coming into contact with our product
- Pure water variability decreases repeatability
  - Bacteria and cell fragments interfere with cell and tissue culture work
  - Bacteria and cell fragments interfere PCR processes
  - Ions interfere with buffer prep, atomic analysis, etc.
How do we remove these contaminants?

- Particle removal equipment
- Ion removal equipment
- Bacteria removal equipment
- Organics removal equipment

Particle Removal Technologies

- Nominally rated particle filters
- Absolute membrane filters
- Ultrafilters
- Reverse Osmosis
Particle Filters

- Particles are classified by “micron or micrometer size”
- For reference, 1 mil = 25 microns
- 25 microns is smallest particle visible to naked eye
- Remove particles from 1 to 200 microns
- Particle filters are rated using a ‘nominal’ or 80 - 99% removal efficiency
- Filters can be permanent or disposable

Absolute Membrane Filters

- An order of magnitude finer than particle filters
- Removes particles from 1 micron down to 0.05 microns in size
- Removes bacteria, spores, yeasts, etc.
- Pharmaceutical industry uses these filters to produce “sterile” filter products
- Filters can be integrity tested
Ultrafilters

• An order of magnitude finer than absolute membrane filters
• Pore size is defined by Molecular Weight Cut Off (MWCO)
• Retention varies from 5,000 to 5,000,000 MWCO based upon membrane composition and the containment being removed

Ultrafilters

• Removes particles, bacteria, some/all large colloidal organics, and cell fragments
• Most are not Integrity testable, so they can have defects and let bacteria through
• Cross flow device- some water goes to waste
• May need added driving force to operate
Reverse Osmosis

• An order of magnitude finer than ultrafilters
• Approximately 200-500 MWCO
• Removes particles, bacteria, colloidals, many organics, AND most ions
• Performance measured by salt rejection
• Pumps needed to add driving force

Reverse Osmosis

• Cross flow device- send more water to drain than ultrafilters
• Not Integrity testable- defects can let bacteria through
• Many types cannot tolerate free chlorine
• Lots of buzz about RO, both positive and negative
• Lots of regulations surrounding its generation of “reject water”
Inquiring minds want to know

Why does Reverse Osmosis remove ions smaller than its pore size?

Asked a little differently, how can a 200 MWCO reverse osmosis membrane remove over 90% of ions that are much smaller than 200 MW?

Reverse Osmosis

We need to understand the water molecule a little bit better to answer the question

Negative End

Positive end
Reverse Osmosis

Lets consider a typical salt molecule \( \text{NaCl} \)

\[
\text{Na}^+ \quad \text{Cl}^-
\]

Water separates and surrounds ions

\[
\text{Na}^+ \quad \text{Cl}^-
\]

Making them larger and easier to remove.
• Used to remove dissolved ions from water
• Can shed particles
• Can generate bacteria
• Resins are attacked by chlorine

• There are hundreds of types, so let's keep it simple
  • Cation exchange resin (+)
  • Anion exchange resin (-)
Ion Exchange
How Ion Exchange Works

Na⁺  Cl⁻

H⁺  OH⁻

Cation Resin  Anion Resin

H₂O
Ion Exchange

Salts are attracted to resins based on size and charge.

- Greater size
- Greater attraction to resin

- Greater charge
- resin

Carbon Filters

• Removes small organics
• Complements reverse osmosis
• Removes disinfectants present in water
  • chlorine / chloramine
  • downstream design must account for this
• Place where bacteria can grow
• Many different types of carbons
**UV Sanitizers**

- Irradiate water, denature DNA, prevent multiplication
- Adds nothing to water
- Produces 254 nm radiation
- Particles interfere with operation

**TOC Reducing Sanitizers**

- Use shorter wavelength than UV unit, 185 nm
- Oxidize organics into acids, making for easier removal
- Particles interfere with operation
**Electro Deionization**

- Uses electricity to keep resins clean
- Generates a waste stream during operation
- Can produce 2-16 meqohm water
- Requires softened RO water feed

**Distillation**

- Only process that removes water from its contaminants
- Heat kills all bacteria
- The gold standard in the pharmaceutical industry
- Can carry through materials with similar or lower boiling points
Ozone

- Powerful oxidizing agent
- Kills bacteria
- Reduces Total Organic Carbon levels
- Dangerous gas that must be properly vented

Table 1 - Removal Capabilities of Various Water Purification Processes

<table>
<thead>
<tr>
<th></th>
<th>Coarse Particle Filters</th>
<th>Absolute Membrane Filters</th>
<th>Ultrafilters</th>
<th>Reverse Osmosis</th>
<th>Carbon Filtration</th>
<th>Ultraviolet Disinfection</th>
<th>Deionization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>F</td>
<td>G-E</td>
<td>E</td>
<td>E</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Dissolved Ions</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>G-E</td>
<td>N</td>
<td>N</td>
<td>E</td>
</tr>
<tr>
<td>Small Organics</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>F-G</td>
<td>G-E</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Colloids</td>
<td>N</td>
<td>F-P</td>
<td>G-E</td>
<td>E</td>
<td>P-F</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Bacteria</td>
<td>P</td>
<td>E</td>
<td>E</td>
<td>A</td>
<td>G</td>
<td>A-P</td>
<td></td>
</tr>
</tbody>
</table>

N = None  P = Poor  F = Fair  G = Good  E = Excellent  A = Adds contaminants to systems
In Summary

• We discussed
  • “What” contaminants are present in water
  • “Why” they need to be removed
  • “How” to remove them
  • However, this is an introductory level discussion, so......

In Summary

• We did not discuss
  • Best equipment sequences for effective removal
  • Unit process limitations
  • Conveying water to points of use
  • Many other important details and considerations
For additional information

Brian Hagopian  
VP of Research and Development  
Mar Cor Purification / Fluid Solutions  
160 Stedman Street  
Lowell, MA  
(978) 453-9600  
e: BHagopian@mcpur.com  
www.mcpur.com  
www.fluid-solutions.com