DRINKING WATER TREATMENT: PAST, PRESENT, AND FUTURE

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New York City Water Summit
Columbia University
9 April 2010
### Time

<table>
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<tr>
<th>Year</th>
<th>Water Quality</th>
<th>Treatment</th>
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<tr>
<td>0 AD</td>
<td>Clarity Foul</td>
<td>Egypt</td>
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<tr>
<td>Late 1800s</td>
<td>Turbidity (Particles) Waterborne Disease</td>
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<td>Early 1900s</td>
<td>Viruses, Legionella <em>Giardia,</em> Giardia, Pesticides</td>
<td>Science &amp; Engineering Sedimentation Filtration Disinfection</td>
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<td>1950s</td>
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<td>High Rate Sedimentation Flotation (DAF) GAC Ozone</td>
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<td>into 1980s</td>
<td>Cryptosporidium TOC, DBPs Anthropogenic Organic Pollutants Nanoparticles</td>
<td>Coagulation Rediscovered DAF in the USA UV Disinfection Advanced Oxidation Membranes</td>
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<td>to 2000</td>
<td>Future ?</td>
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SEDIMENTATION

• Egypt:
  ~ 1500 BC
  – Alum Coagulation
  – Sedimentation

Alexandria, 47 BC

Invading Romans reported use of Cisterns for Storage and Clarification of water from the Nile

Greece: 500 BC

Bag Filtration
(Microfiltration)

Roman Empire

– Reservoirs for Settling
– See Sextus Julius Frontinus, Commissioner of Water Supply, Rome (from DeAquis Urbis Romae Libri II, 97 AD)

From The Quest for Pure Water, Baker, 1981

FIG. 1. EGYPTIANS SIPHONING OFF WATER OR WINE CLARIFIED BY SEDIMENTATION
Pictured on wall of tomb of Amenophis II at Thebes, 1450 B.C.
Time

0 AD

Late 1800s

Early 1900s

1950s into 1980s

Late 1980s to 2000

Future?

Water Quality

Clarity
Foul

Turbidity (Particles)
Waterborne Disease

Viruses, Legionella
Giardia,
Pesticides
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Cryptosporidium
TOC, DBPs
Anthropogenic
Organic Pollutants
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Treatment

Alum Coagulation
Sedimentation

Egypt
Roman Empire
Greece

Bag Filtration

Sedimentation
Filtration
Disinfection

Science & Engineering

High Rate Sedimentation
Flotation (DAF)
GAC
Ozone

Coagulation Rediscovered
DAF in the USA
UV Disinfection
Advanced Oxidation
Membranes

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George A. Soper: Doctorate at Columbia in late 1890s on the subject of ozone for disinfection of drinking water. He concluded that “drinking water can be sterilized, and that unpleasant colors and odors arising from organic impurities can be removed by ozone.”
SEDIMENATION: 
ENGINEERING PRINCIPLES

• Allen Hazen

   On Sedimentation (Transactions ASCE, 1904)

   - Settling Tank Performance depends on the Overflow Rate (or hydraulic loading rate).
   - This is how we size tanks to this day.

Other contributions to the water field

• Filtration
• Hydraulics (Pipe hydraulics and design)
In 1919 Abel Wolman and Linn Enslow, published a paper in which they developed a test for chlorine absorption, which established a controlled method for chlorination of municipal water supplies. The method, assuring safe drinking water, was adopted worldwide, perhaps the most important contribution to public health in the 20th century. (“Chlorine absorption and chlorination of water”, J. Ind. Eng. Chem. 11:206-13).

Wolman was among the second generation of engineers in the “sanitary revolution” that began in the nineteenth century, succeeding major figures in the United States such George Fuller (Water Filtration) and Allen Hazen (Hydraulics, Sedimentation, Filtration)
SAFE DRINKING WATER IN DEVELOPED COUNTRIES

- Control of Waterborne Disease
  - Essential human need provided by water engineers

- 20th Century
  Control of Waterborne Diseases (Typhoid, Cholera, etc) through Engineering
  - Through Treatment Technologies
  - Role of the Engineer in Public Health
    - Water Supply and Distribution

- Last Part of 20th and Start of 21st Centuries
  - New Pathogen Problems for Developed Countries – Legionella, Giardia, Cryptosporidium

Typhoid Cases 1890-1935 Philadelphia

From McGhee, 6th Ed., 1991

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DISCOVERY OF CHLORINATION BY-PRODUCTS

- **Rook (Rotterdam Waterworks, formerly brewery Chemist)**

- **Bellar, Lichetenberg, and Kroner (USEPA, Cinc., Ohio)**

### Conclusions

Bellar et al.

Chloroform and other trihalogenated methanes have been detected in several municipal water supplies. The highest concentrations (37-150 μg/l) of these compounds were found in finished waters having surface waters as their source. These compounds form as a result of chlorination processes during water treatment. Since a primary limiting factor is the presence of free chlorine in the water, the repeated addition of chlorine at various stages of the treatment process plays an important role in determining the ultimate concentrations of organohalogens that occur.

Although the trihalogenated compounds resulting from chlorination are not an acute hazard to man at the levels detected oral, lethal dose of chloroform to mice is 120 mg/kg, their presence suggests the need to monitor finished waters for these and other organohalogenes and to determine whether there may be chronic effects. There is a need to develop analytical methodology so that the chemistry of the chlorination process can be fully studied and understood.

In addition to chloroform, several other halogenated aliphatic and aromatic compounds were detected in a sewage-treatment-plant’s influent and effluent waters.
DISSOLVED AIR FLOTATION

- Pretreatment for removal of coagulated particles, algae, pathogens, and natural organic matter
  - Conventional Plants
  - Membrane Plants
  - Water Reuse Plants

Greenville, SC
DAF USE IN DRINKING WATER TREATMENT

• First major use of DAF for drinking water: Sweden in the mid-60s
• South Africa and UK: widely used beginning in the 1970s
• Europe, Australia, Asia, South America: since 1980s, increasing use.

• Estimate of some 150+ plants in USA & Canada
  – Fairfield, CT: 50 MGD  DAF over Filtration
  – Greenville, SC: 75 MGD
  – Cambridge, MA: 24-30 MGD
  – West Nyack, NY: 20 MGD  High rate
  – San Joaquin, CA: 40 MGD  High rate
  – Newport News, VA (Lee Hall): 54 MGD
  – Stamford, CT: 33 MGD
  – Haworth (New Jersey): 200 MGD (on-line June 2009)  High Rate
  – Winnipeg: 105 MGD  (on-line late 2009 year)
  – Scottsdale, AZ: 20 MGD now (increase to 30 MGD) (on-line 2010)  High Rate
    (DAF pretreatment for membranes)

• Under Construction
  – New York City: Croton Plant 290 MGD  DAF over Filtration
  – Waco, TX: 90 MGD, On-Line fall 2010
Croton Watershed
New WTP in 2011

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Courtesy of Ian Crossley, Hazen and Sawyer
290 MGD NYC, Croton Plant

Croton Supply → Rapid Mixing → Two Stage Flocculation → DAF → Dual Media Filters

Stacked Vertically

Alum + Cationic Polymer

Cl₂ + pH Adjustment

UV Disinfection

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**Giardia lambia**

- **1970s and 1980s**
  - Waterborne Outbreaks
    - Pittsfield, MA (1986)
  - Protozoa – Cyst Stage
    - Carried by many warm blooded animals
    - Backpacker’s Disease
  - Size: 8-15 µm

- **Surface Water Treatment Rule (SWTR): 1989**
  - EPA Requirement: 3 log Removal/Inactivation (99.9%)
  - For Sedimentation Plants EPA credits removals:
    - Settling: ½ log (68% Eff)
    - Filtration: 2 log
    - Need at least ½ log by disinfection
  - Research done Edzwald *et al.* showed 2-3 log removal by DAF compared to ½ to 1 log removal by Sedimentation

*Jour AWWA, Vol. 92, Dec 2000*
1993, Milwaukee, cryptosporidiosis, 54 deaths (403,000 illnesses)

\[ \sim 3-6 \, \mu m \]
REMOVALS OF CRYPTOSPORIDIIUM BY DAF

- **DAF**
  - DAF ~ 2 Log Removal

- **DAF + Dual Media Filtration**
  - Total of 4-5 Log Removals

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**Graph:**

- **Y-axis:** Log Cryptosporidium Removal
- **X-axis:**
  - DAF
  - Plate Sed.
  - DAF
  - Plate Sed.

**Summertime** vs. **Winter:**

- **SUMMER**
- **WINTER**

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*Jour Water Supply: Research and Technology – Aqua, Vol. 52, June 2003*

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Alum Coagulation
Sedimentation
Low Energy

Bag Filtration

Sedimentation
Filtration
Disinfection
Low Energy

High Rate Sedimentation
Flotation (DAF)
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Ozone
Medium Energy

Coagulation Rediscovered
DAF in the USA
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Advanced Oxidation
Membranes
High Energy

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20th CENTURY AND TO THE FUTURE

20th Century

- Turbidity
- TOC and DBP Precursor Control
- Multiple Barriers for Pathogen Control
  - Source Water Protection
  - Clarification with Coagulation-Flocculation Pretreatment
  - Media Filtration
  - Disinfection

21st Century

- Turbidity
- TOC and DBP Precursor Control
- Multiple Barriers for Pathogen Control
- Multiple Barriers for Control of Anthropogenic Chemicals
# Early 21<sup>st</sup> Century Challenges and Treatment

## Water Quality

- **Particles**
  - Colloidal Particles
  - Nanoparticles

- **Pathogens**
  - Protozoan Cysts
  - Emerging Pathogens
    - *E. coli* O157:H7
    - Hepatitis E
    - Mycobacterium

- **NOM and DBPs**
  - Chlorine and other oxidant by-products

- **Taste and Odor Compounds**

- **Anthropogenic Compounds**
  - Pesticides
  - EDCs
  - Other

## Treatment

- **Coagulation, Clarification, Media Filtration**
  - Essential pretreatment
  - Remove particles, NOM
  - Reduce Fouling

- **Oxidation Processes**
  - Advanced Oxidation
    - Ozone/peroxide
    - UV/Peroxide

- **Adsorption Processes**
  - GAC

- **Membrane Processes**
  - Low to Medium Pressure Membranes (Particle Removal)
  - High Pressure; Nanofiltration and Reverse Osmosis (Solute Removal)
    - Desalination

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WTP FOR THE 21ST CENTURY

- Lake Water Supply
  - NOM (low to moderate)
  - Algae, Tastes and Odors
  - Turbidity (low to moderate)
  - Pathogens
  - Low levels of anthropogenic compounds
    - Pesticides
    - EDCs
  - Other: produce biologically stable water for the distribution system

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Winnipeg, 105 MGD, on-line late 2009 (courtesy, Dave Pernitsky, CH2M Hill)

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Zurich-Lengg


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SEAWATER PRETREATMENT FOR REVERSE OSMOSIS

WATER QUALITY PROBLEMS

- Turbidity
- Fe/Mn
- Oils
- TOC
- Algae
- Biofouling of membranes
- Fe/Mn
- Precipitation of solids on membranes

PRETREATMENT

- Deal with specific problems
- Reduce fouling
- Increase efficiency of membranes
- Reduce energy

Extent of treatment depends on the water quality (type and concentration)

Often clarification and media filtration

- DAF Pretreatment for Cases
  - Turbidity and Oils
  - Turbidity, Algae
  - Turbidity, TOC

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HARMFUL ALGAL BLOOMS
Dinoflagellates

- **Noctiluca scintillans**
  - Red Tide (sometimes Green Tide)
  - 200-2000 µm
  - Found: Coast of Oman

- **Cochlodinium polykrikoides**
  - Red Tide
  - 30-40 µm (2-8 cells in chains)
  - Forms cyst (persistent)
  - Found
    - Coast of Oman
    - Western and Eastern Pacific
      - Asia (Korea, Japan)
      - Vancouver
    - Atlantic
      - York River

- **Karenia brevis** (formerly Gymnodinium breve)
  - Red Tide
  - Size: ~ 25 µm
  - Found: Florida, Gulf of Mexico

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HARMFUL ALGAL BLOOMS

- *Auerococcus anophagefferens*
  - Chrysophyte
  - Brown Tide
  - Size: ~ 2-3 µm
  - Found: New Jersey, New York

Long Island

Sandy Hook Bay (northern NJ/Southern end of NY Bay)

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TYPICAL DAF SEAWATER PRETREATMENT FOR REVERSE OSMOSIS

Coagulant

Supply → Rapid Mixing → Flocculation → DAF → Media Filters → Cartridge Filters → To Membranes