THM Formation And Control

By
Ken Roberts

Safe Drinking Water Seminar

Gander, Newfoundland

March 26/27 2001

THM Formation And Control

- DISINFECTION
- DISINFECTION BYPRODUCTS – DBPs
- HEALTH RISKS
- DBP REDUCTION/REMOVAL
- FUTURE

- REGULATIONS; PATHOGENS; DBPs

Disinfection

- A process designed specifically to destroy pathogenic organisms
- Prevents waterborne disease
- Other WT processes such as filtration, or coagulation-flocculation-sedimentation nay achieve reductions; not generally the primary goal

Disinfection

- Waterborne disease is the most significant health risk
- A variety of chemical and physical agents may be used
- The disinfecting agents most commonly used today are chlorine and its compunds
- Chlorine Dioxide, Ozone, UV, membrane

Common Disinfecting Agents

- Chlorine:

  - early 1900s

  - affected by contact time, pH, temperature,turbidity, ammonia

- Chloramines

  - reaction of aqueous chlorine and ammonia

  - less “power’ than free Cl_2, O_3 or ClO_2

Common Disinfecting Agents

- assist in T & O control

- good penetration of biofilms

- Chlorine Dioxide

- potency not affected by pH or ammonia

- controls phenolic T & O

- does not form THMs but chlorite and chlorate

- must be produced on-site

Common Disinfecting Agents

- Ozone

  - in some respects superior to chlorine

  - unaffected by pH, ammonia

  - unstable and no long-time residual

  - must be produced on-site

  - no chlorinated byproducts

  - has its own DBPs: aldehydes, ketones, caboxylic acid and bromate

Common Disinfecting Agents

- Ultra-Violet Iraradiation

  - can kill bacteria, cysts and viruses

  - raw water quality affects

  - turbidity and colour can block UV

  - a viable alternative for Giardia and Cryptosporidium inactivation

  - no residual

Disinfectant Use - 1998 AWWA GW

Type of Disinfectant	**Systems Using - %**
Chlorine gas	61
Sodium Hypochlorite	34
-Bulk	31
- Generated on-site	3.3
Calcium Hypochlorite	4.5
-Powder	1.7
-Tablet	2.8
Other	3.9

Surface Water– 1998 AWWA

Treatment Process	Systems - %
Filtration	97
Clearwell (BW)	94
Coagulation	85
Flocculation	76
Sedimentation	72
Fluoridation	56
Corrosion Control	52
Disinfection Contact Basin	50
Other – PreOx; Softg, Raw storage	10 - 25

DBPs of Current Interest

- Halogenated organic compopunds

  - THMs and HAAs
- Inorganic Byproducts

  -Bromate; Chlorite; Chlorate
- Disinfection Residuals

  - Chlorine; Chloramines; Chlorine Dioxide

Disinfectants as Oxidants

- Nuisance – Zebra Mussels
- Control Iron and Manganese
- Residual to prevent regrowth in DS
- Tastes and Odours
- Improve coagulation efficiency
- Prevent algal growth in sed basins and filters
- Indicators of DS integrity

Health Effects

- THMs formed by chlorination
- Chlorine has virtually eliminated waterborne microbial disease
- Classified as: “probably carcinogenic to humans”
- IMAC of 0.1 mg/l based on chloroform risk
- Extrapolation model - Lifetime risk: 3.64×10^{-8}

Health Effects

- DW standards set on basis of:

  - health impacts

  - occurrence (conc. and frequency)

  - exposure

  - cost benefit

  - analytical

  - treatment availability

Health Effects

Based on similar health effects data, including animal studies, jurisdictions can have different "standards". For example:

- US EPA have a THM standard of 80 μg/L
- Ongoing discussion re chloroform NOEL
- Australia consider a NOEL and have a standard of 250 μg/L

Canadian THM Guideline

- IMAC is 0.1 mg/l based on a running quarterly average
- Based on the chloroform risk
- Interim until all other DBP risks are determined
- Not expected that all supplies will meet immediately
- Efforts to meet as expansion/upgrade
- Precursor removal is preferred
- Any DBP reduction **MUST NOT** compromise disinfection

DBP Production

- Trihalomethanes are produced by chlorination of raw water precursors e.g.:

  - humic and fulvic (peaty) materials.
- Most common THMs.

  - Chloroform.

  - Bromodichloromethane.

  - Chlorodibromomethane.

  - Bromoform.

Modeling DBP Formation

Mechanistic models have been developed to predict DBP formation

- These models have included:

  - Colour
  - TOC
  - UV absorbance
  - chlorine decay kinetics

Some general trends have been noted but definitive concentrations difficult

Best results are obtained from on-site testing

DBP Reduction/Removal

Three basic treatment approaches for THM reduction:

- Removal after formation
- Removal of precursors before Chlorine addition
- Use of alternative disinfectant

DBP Reduction/Removal

Removal of THMs - + and -:

- No need for change of disinfectant +
- Lack of precursor removal and so free chlorine continues to react –
- THMs are transferred to another medium e.g. air or activated carbon, and disiposal issue -

DBP Reduction/Removal

THM removal:

- By Air Stripping – potential air pollution; energy intensive; winter operation difficult
- By GAC – an advantage is that the process is reversible and GAC can be regenerated (energy and air issues); problems are short bed lives and possible desorption

Overall not optimum solution

DBP Reduction/Removal

Disinfection process changes:

- Moving point of disinfectant addition
- Changing type of disinfectant (e.g. chlorine to ozone, UV)
- Process change e.g. contact chamber layout, pH
- Raw water source change

THM Reduction

Changing location of disinfectant addition:

Issues

- Zebra mussel control
- Adequate disinfection contact time

Precursor removal can achieve 50% reductions through conventional coagulation and settling

US EPA TOC % Removals

TOC mg/L	Alk'y; mg/L 0 – 60	Alk'y; mg/L 60 - 120	Alk'y; mg/L > 120
	%	%	%
2.0 – 4.0	35	25	15
4.0 – 8.0	45	35	25
>8.0	50	40	30

THM Reduction

Membrane Filtration (ultrafiltration, nanofiltration and reverse osmosis)

- Effective removal of:

  - particles
  - TOC, DOC and THM precursors
  - other organic compounds
  - microorganisms eg. *Giardia* and *Cryptosporidium*
  - ionic dissolved salts

THM Reduction

Biological treatment

- Slow sand filtration

  - simple operation

  - up to 15 – 20% THM reductions through precursor removal

  - disadvantage is the large filter area required

- High Rate e.g. bilogical GAC (possibly 40% but relatively costly and complex)

THM Reduction

Developing a strategy for THM reduction should consider:

- Ability to meet guidelines (can colour be relaxed?)
- THM reduction potential
- Cost – capital and O&M
- Reliability and ease of water quality change adjustment
- Complexity of operation
- Flexibility
- Climate sensitivity

Alternative Disinfectants

- Ozone

  - Effective disinfectant

  - good for colour removal, T & O, iron and manganese

  - must be produced on-site

  - not persistent and therefore requires a second DS disinfectant

Alternative Disinfectants

Free Chlorine plus ammonia

- chloramines do not produce THMs
- must have adequate disinfection prior to ammonia addition
- persistent in DS
- chloramine toxicity being evaluated

Alternative Disinfectants

Chlorine Dioxide

- strong disinfectant
- does not form THMs
- residual will persist in DS
- chlorite and chlorate toxicity

Iodine

- historical use in emergency situation
- relatively high cost
- iodinated THMs & pot’l physiological effects

Disinfection/Disinfection ByProducts (DBPs)

- Optimal disinfection is important – <u>too much</u> of a good thing e.g. in chlorine application **-** <u>it is not</u>
- DBP production occurs with disinfectant addition
- Chlorine produces trihalomethanes, haloacetic acids
- Ozone can produce ketones, aldehydes, bromates
- Chlorine dioxide – chlorate and chlorite
- Chlorine and Chloramines

What’s in the Future ?

Disinfection Needs

Health Canada has established a Chlorinated Disinfection ByProducts (CDBP) Task Group to comprehensively assess the risks from THMs in Canadian drinking water supplies and develop risk management recommendations.

- work is ongoing

Disinfection Needs

Groundwater (unless exclusion is granted)

- Disinfection minimum level of treatment
- Chlorine, or other equivalent, for disinfection and DS residual
- GW under direct surface water influence likely to require contact time and disinfectant concentration (CT) as per developed tables

Disinfection Needs

Surface water

- a minimum 3 Log removal/inactivation (99.9%) of *Giardia* cysts and 4 Log viruses

- CT tables will define

- higher requirements for poor source bacterial qualities

Disinfection Needs

US EPA considering additional treatment based on raw water *Cryptosporidium* concentrations

- Additional treatment may need to use:

  - ozone
  - chlorine dioxide
  - UV
  - membranes
  - bag/cartridge filtration, or
  - in-bank filtration

Down the Road DBPs

DBPs TO HAVE GUIDELINES

- Disinfection residuals
  - chlorine
  - chloramines
  - chlorine dioxide
- Inorganic ByProducts
  - Bromate ion
  - chlorite ion

Down the Road DBPs

- Halogenated Organic Byproducts

  - THMs (chloroform, Bromodichloromethane, Dibromochloromethane, Bromoform)

  - Haloacetic Acids (Monochloroacetic, Dichloroacetic, Trichloacetic, Monobromoacetic, and Dibromoacetic)