Breakpoint Chlorination…

Do you Really Have a Free Chlorine Residual?

Chloramination

Nitrification

Disinfection Byproducts

Bob Spon, chemist
Spon Water Consulting

Water Quality Problems in Distribution Systems

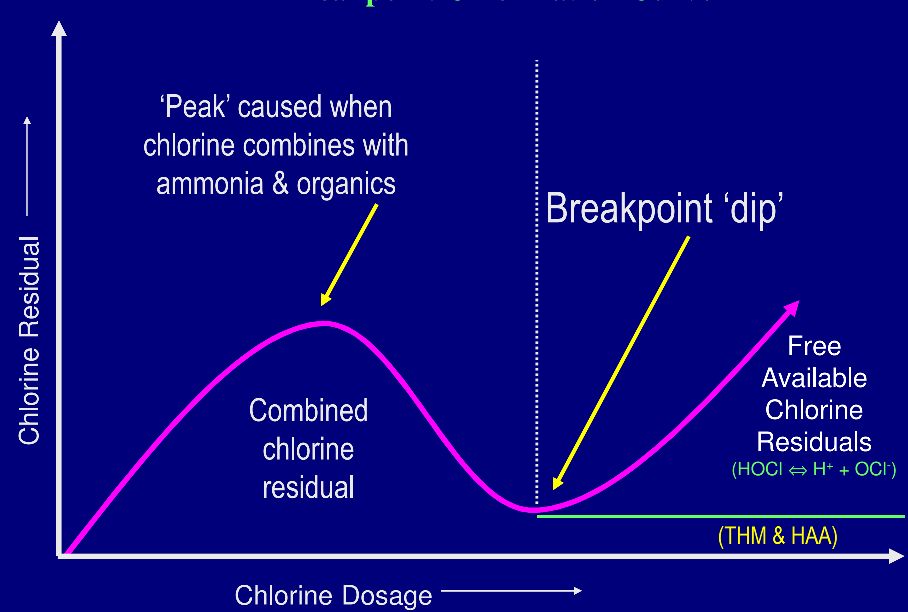
- 160 responses to AWWA survey indicates % of annual reported problems:
- 44% Taste & Odor
- 43% Color & Turbidity
- 5% High Heterotrophic Plate Count
- 5% DBP's, coliforms, corrosion, misc.
- 3% Loss of disinfection residual

Do you have a free Cl_2 residual?

What is a free residual?

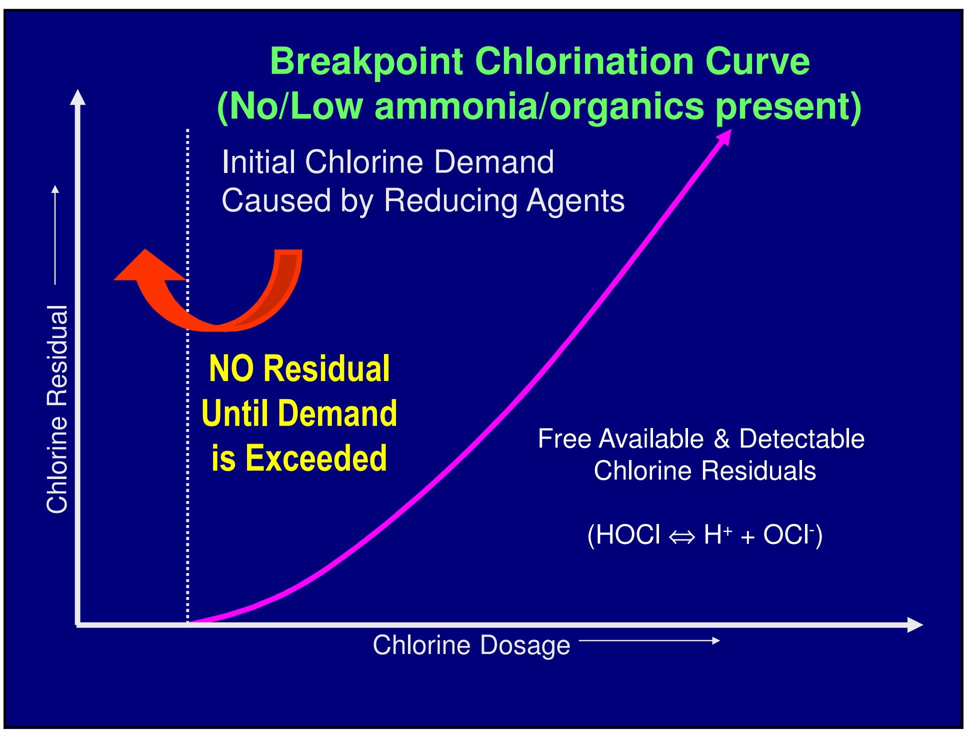
- Chlorine in ‘pure’ H_2O = HOCl + OCl^-
- HOCl = Hypochlorous Acid
- OCl^- = Hypochlorite Ion
- Free chlorine residual = HOCl / OCl^-
- Free ‘available’ chlorine is very reactive
- Total Chlorine – Free = Combined
- Minimum system chlorine residuals:
- IL EPA: 0.2 free / 0.5 mg/L total
- IA DNR: 0.3 mg/L free / 1.5 mg/L total
- FL DEP: 0.2 mg/L free / 0.6 mg/L total

Breakpoint Chlorination Curve



What is Chlorine Breakpoint?

- The initial point where free ‘available’ chlorine residual is present / detected
- Breakpoint residual occurs after the chlorine dosage rate exceeds the demand created by reducing agents, ammonia, and organics
- B.P. curve-shape is determined by contact time, temp, chlorine and ammonia concentration, pH, and water quality



Initial Chlorine Demand- Reducing Agents

- Cl_2 dosage - Demand = Residual
- 1 mg/ - 0.8 mg/L = 0.2 mg/L
- Initial demand = Reducing Agent mg/L (Fe^{+2}, Mn^{+2}, H_2S, NO_2^-)
  - (Fe^{+2}, H_2S, NO_2^-) may reappear in plant/system
- If Dosage </= Demand then '0' residual
- If Dosage > Demand then free residual exists
- Reducing Agents donate / lose electrons (consume oxidizing agents such as chlorine)

Reducing Agent Reactions with Chlorine

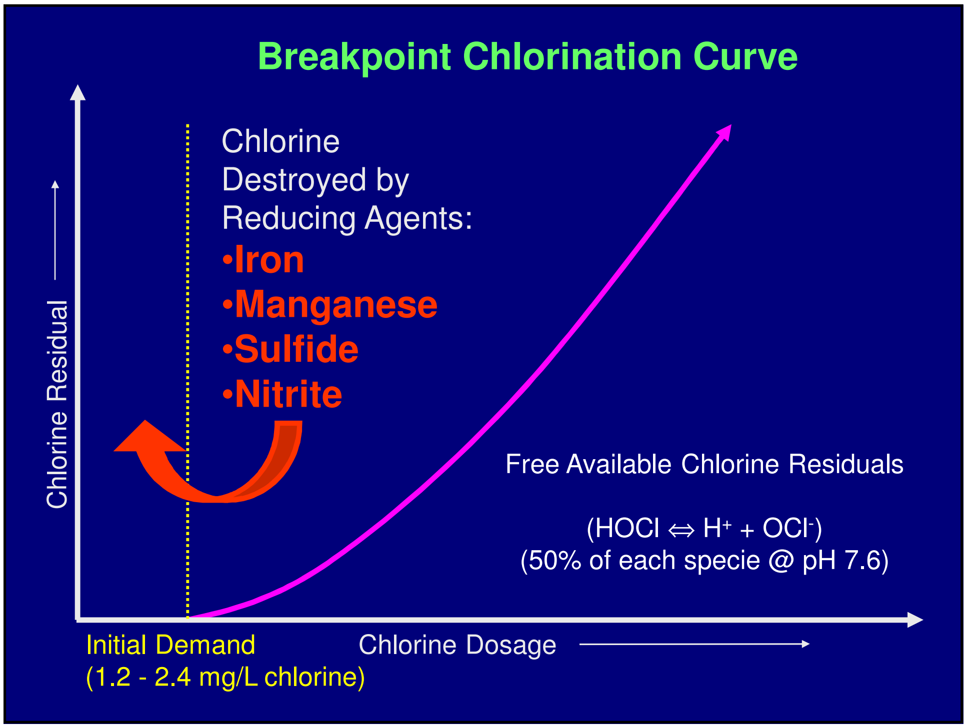
(Demand & Destroy Chlorine Residual)

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 \Rightarrow 2Fe(OH)_3\downarrow + CaCl_2 + 6CO_2$$

$$Cl_2 + MnSO_4 + 4NaOH \Rightarrow MnO_2\downarrow + 2NaCl + Na_2SO_4 + 2H_2O$$

$$H_2S + Cl_2 \Rightarrow 2HCl + S\downarrow^0$$

$$NO_2^- + HOCl \Rightarrow NO_3^- + H^+ + Cl^-$$


Breakpoint Chlorination Curve
Chlorine Residual
Chlorine Destroyed by Reducing Agents:
•Iron
•Manganese
•Sulfide
•Nitrite
Free Available Chlorine Residuals
($HOCl \Leftrightarrow H^+ + OCl^-$)
(50% of each specie @ pH 7.6)
Initial Demand
(1.2 - 2.4 mg/L chlorine)
Chlorine Dosage

Calculate Initial Demand (Reducing Agent Demand)

Water Quality (Example mg/L)	Free Chlorine Demand Factor	Cl_2 Demand
Iron 0.3 mg/L	X 0.64 =	0.192 mg/L
Manganese 0.05 mg/L	X 1.3 =	0.065 mg/L
Sulfide 0.2 mg/L (optional factor) 0.2	X 2.08 to S = X 8.32 to SO_4 =	0.416 mg/L (1.664 mg/L)
Nitrite-N 0.1 mg/L	X 5.0 =	0.5 mg/L
	Total Reducing Agent Demand =	1.173 mg/L Demand (2.421 mg/L)

Free Chlorine vs Lack of Cl_2

Oxidation potential: ORP
Disinfection Protection
Taste & Odor Control
Fe/Mn Oxidation
H_2S Destruction
Bleaching of Color
Algae/ Microbe Control
Byproducts-THM/HAA

- Reduction potential:
- Disease potential
- Taste & Odor events
- Staining & Deposits
- Sulfur bacteria +
- Color - Organics
- Biofilm / Corrosion
- No/low DBPs

What does chlorine do to cells?

- HOCl enters cell wall efficiently- permeates & pokes holes in cell wall of exposed bacteria
- Enzyme systems of microbes are affected, deactivating organisms & ability to reproduce
- In most bacteria, HOCl causes adverse reactions of respiratory, transport, nucleic acid-DNA systems, protein coating of virus deactivated?
- Microbes hiding in biofilm less vulnerable
- HOCl unable to penetrate pipe scale, NH_2Cl longer lasting & reacting against microbes
- Chlorine is similar to…

Free Chlorine Solutions

<u>Concentration (% available)</u>

Chlorine Gas / Liquid 100%

Calcium Hypochlorite 65%

Sodium Hypochlorite 12.5%

a.k.a. Clorox bleach 5.25%$^{+}$

Chlorine + Water = ?

- $Cl_2 + H_2O \Rightarrow HOCl + HCl$ (< pH 6)
- HOCl (**Hypochlorous Acid**) 'Biocidal'

- $HOCl \Leftrightarrow H + OCl^-$ (> pH 9 complete)
- OCl^- (**Hypochlorite Ion**) 'Oxidative'

- ($\%HOCl = \%OCl^-$) @pH 7.6 / 20C

Combined Chlorine Demand-Combining Agents

- Cl_2 Dosage – Demand = Residual
- Combining agents = ammonia, NOM (TOC/DOC), organic nitrogen, decayed plant/animal (proteins, amino acids)
- Combined chlorine residuals are byproducts of ammonia-N and organic contaminants (tannins, lignins, color)
- Chloramines / chlororganic compounds

Calculate Secondary Demand (Combined Demand)

Water Quality (Example mg/L)	Free Chlorine Demand Factor	Cl_2 Demand
Ammonia-N 0.1 mg/L	X 10 to12 =	1.2 mg/L
Organic-N 0.05 mg/L	X 1.0 =	0.05mg/L
Total Organic Carbon 1.0 mg/L	X 0.1 =	0.1mg/L
	Total Combined Demand =	1.35 mg/L Demand

CT Values for Virus Inactivation

Disinfectant	2-log inactivation (99%)	3-log inactivation (99.9%)
Chlorine mg-min/L	3	4
Chloramine mg-min/L	643	1,067
Chlorine Dioxide mg-min/L	4.2	12.8
Ozone mg-min/L	0.5	0.8
UV mW-s/cm^2	21	36

1 CT values based on 10C, pH range 6-9, free chlorine residual 0.2-0.5 mg/L

2 CT values based on 10C, pH 8

3 CT values based on 10C, pH range 6-9

CT Values for Inactivation of Giardia Cysts

Disinfectant	2-log inactivation (99%)	3-log inactivation (99.9%)
Chlorine mg-min/L	69	104
Chloramine mg-min/L	1,230	1,850
Chlorine Dioxide mg-min/L	15	23
Ozone mg-min/L	0.95	1.43

1 CT values based on 10C, pH range 7, free chlorine residual less than or equal to 0.4 mg/L

2 CT values based on 10C, pH range 6-9

3 CT values based on 10C, pH range 6-9

Disinfection Byproducts (DBP) are formed when . . .

- Chlorine and bromide (Br-) reacts with natural organic matter (NOM) in source waters to create DBPs
- HOCl + Br^- + NOM ⇒ Halogenated DBPs
- Bromide comes from mineral deposits and salt water intrusion
- NOM from decaying vegetation and algae

Total Organic Carbon (TOC) analysis primary measurement for natural organic matter (NOM, TOC, DOC, UV254) in source and system drinking water

D/DBP Rule includes TOC as a compliance parameter

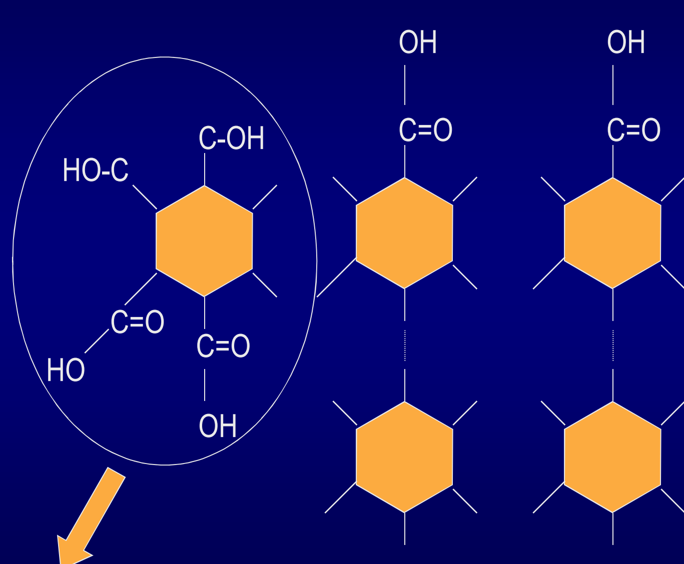
TOC / DOC is an indicator of potential for DBP formation

Free Chlorine + Natural Organics (humic, fulvic, tannin / lignin, color) ⇒ Chlororganics (TOX) DBP, THM, HAA

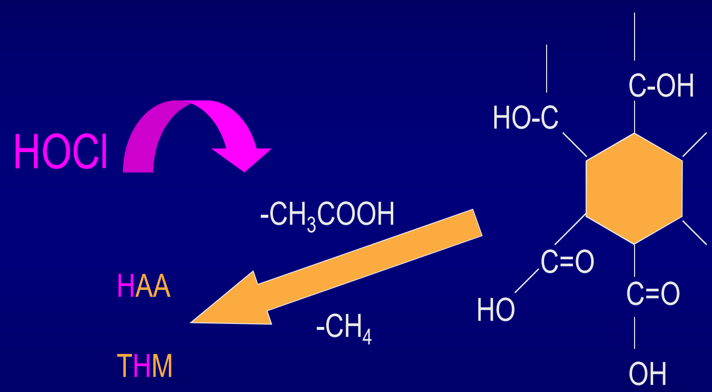
HOCl + Br^- + Natural Organic Matter (NOM) ⇒ Halogenated Disinfection Byproducts (DBPs)

O3 + Br^- + (NOM) ⇒ Brominated organics, AOC, BDOC, bromate

Structure of Natural Organic-Humic Substance



Chlorine / Bromine + NOM= Disinfection Byproducts (DBPs- THM/HAA)



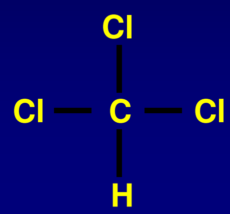
THM = $CHCl_3$ (4 possible combinations)

HAA5 = $CH_2ClCOOH$ (9 combinations)

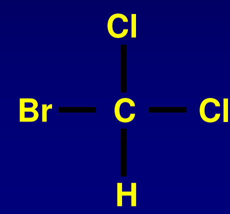
Trihalomethanes (THM) / HAA

- Chloroform $CHCl_3$
- Bromoform $CHBr_3$
- Chlorodibromomethane $CHClBr_2$
- Bromodichloromethane $CHBrCl_2$
- Locational Running Annual Average- LRAA MCL at each sample pt. in distribution system
- (TTHM) MCL = 0.080 mg/L
- (HAA) MCL = 0.060 mg/L
- MRDL 4.0 mg/L Chlorine, chloramines,
- MRDL ClO2 (0.8 mg/L)
- MCL's: Chlorite 1.0 mg/L, bromate 0.01 mg/L

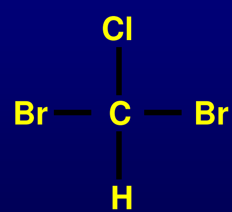
Trihalomethanes (THMs)



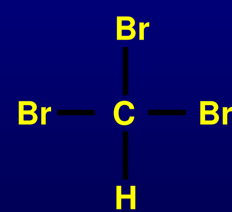
Chloroform



Dichlorbromomethane



Dibromochloromethane



Bromoform

Haloacetic Acids (HAA5)

Monochloroacetic Acid	$CH_2ClCOOH$
Dichloroacetic Acid	$CHCl_2COOH$
Trichloroacetic Acid	CCl_3COOH
Monobromoacetic Acid	$CH_2BrCOOH$
Dibromoacetic Acid	$CHBr_2COOH$

Location on Breakpoint curve

- Analyze ammonia NH_3-N
- Analyze monochloramine NH_2Cl
- Total NH_3 – NH_2Cl = Free NH_3
- When free NH_3 is near zero then NH_2Cl is near optimal peak at top of 'hump'
- Compare to chlorine dosage & residuals
- Does Cl_2 dose change ↑↓ residuals?

Chloramination— (intentional)

Advantages	Disadvantages
Minimal THMs	Added NH_3 in water
Fewer HAAs	Higher chlorine dose to maintain residual
Persistent residual	Worse Byproducts (Nitrosoamines-NDMA, IO-iodoform
Better protection against bacterial regrowth	Nitrifying bacteria-AOB ⇒ nitrites
Higher taste & odor threshold from monochloramine	$NH_3 + O_2 \Rightarrow NO_2^-$

Nitrifying bacteria -AOB

- Recycle organic nitrogenous materials from ammonium (endpoint for decomposition of proteins) to nitrates, in aerobic process
- Nitrifying bact. indicate latter stages of aerobic decay of N-rich organic matter
- NROM from compromised septic tanks, sewage systems, industrial sites, ag, haz.
- Nitrification (ammonium-nitrite-nitrate)
- $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$ (-3, +3, +5 valence)
- Denitrification $NO_3^- \rightarrow NO_2^- \rightarrow N_2$

Chloramination Exposure

- USEPA estimates 30% of surface water use chloramines- secondary disinfection
- 60% projected use- comply with Stage 2 DBPR- applies to all surface waters and groundwater ‘under the direct influence’
- MCL / RAA of 4.0 mg/L chloramines
- Theorized lead release in DC, elevated water & blood lead levels due to chloramination treatment

Which comes 1st (NO_2^- / NO_3^-)

- Nitrite NO_2^- (as N)
- Not in source water
- Intermediate stage in nitrification
- MCL 1 mg/L
- May form nitrosoamines in gut
- Destroyed by free chlorine 5:1

- Nitrate NO_3^- (as N)
- Ag. Runoff into H_2O
- End pt of nitrification
- MCL 10 mg/L
- Methemoglobinemia (Blue Baby Syndrome) diuresis from NO_3 or NO_2

Denitrifying Bacteria- DN

- Reduce nitrate to nitrite, some continue nitrification to gaseous N
- DN indicate high concentrations of nitrate, sample anaerobic, rich in NOM
- DN signal latter stages of decay of N-rich sewage or septic wastewaters
- Limited by availability of fractions
- $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$
- $NO_3^- \rightarrow$ methemoglobinemia (BBS)

N relationship in 'polluted' water under aerobic conditions

- Water containing only nitrates is rather remote in time from any pollution (30-60 days)
- Containing nitrites is highly suspicious (mid pt)
- Shallow waters of mostly organic N and NH3 has been subjected to recent pollution (0-mid)
- Organochloramines are nongermicidal and appear in total chlorine residual, in potable water O-N ranges (0.3-0.6 mg/L) ? 3 mg/L max
- > 0.25 mg/L Organic-N = T&O problems

Nitrification- by AOB

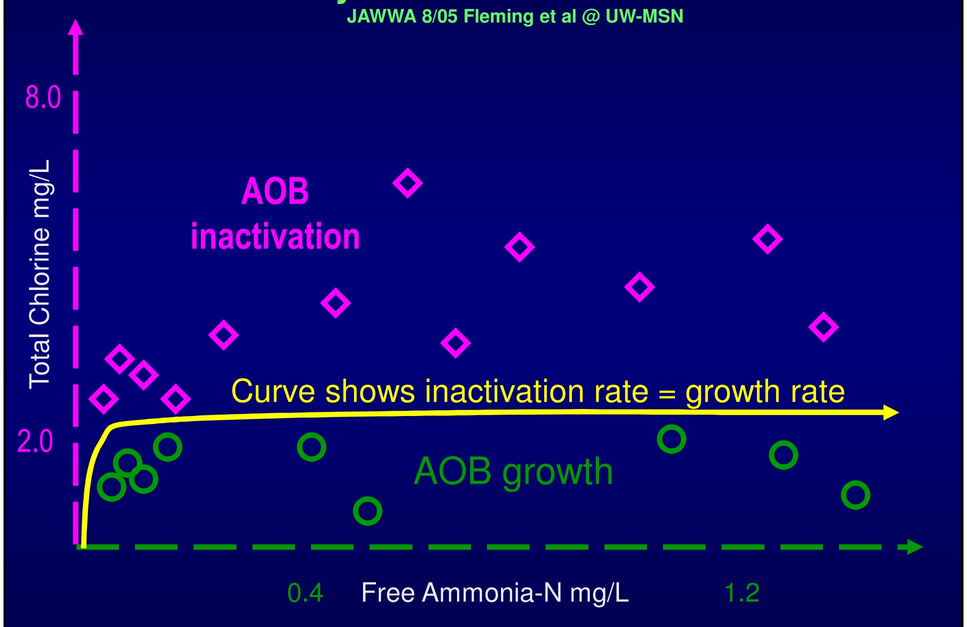
- NH_3 (Nitrosomonas) $\Rightarrow$ Nitrite $(NO_2)^-$
- Resistant to chlorine/chloramines
  - Nitrite oxidized by free chlorine
- Nitrite (Nitrobacters) $\Rightarrow$ Nitrate $(NO_3)^-$
- Less resistant, so $(NO_2)^-$ accumulates
- NH3 and Cl2 stress nitrobacters
- Thrive in reservoirs during summer
- Byproducts can support coliforms
- Free ammonia generates more nitrites

Nitrification

- $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$
  - Nitrosomas genus involved in conversion under aerobic conditions, occurs within biological slime on filter media (8 hr)
- $NO_2^- + 0.5O_2$ <u>Nitrobacter</u>$\rightarrow NO_3^-$
  - 1 mg/L NH_3-N oxidation requires 4.6 mg/L O_2 excluding nitrifier synthesis (24 hr)
- $HOCl + NO_2^- \rightarrow NO_3^- + HCl$
  - 1 mg/L nitrite demands 5 mg/L free Cl_2
  - Chloramines do not oxidize nitrites
  - Nitrites interfere / biological growths occur

Biostability / Nitrification Potential Curve

JAWWA 8/05 Fleming et al @ UW-MSN



Steps to control nitrification

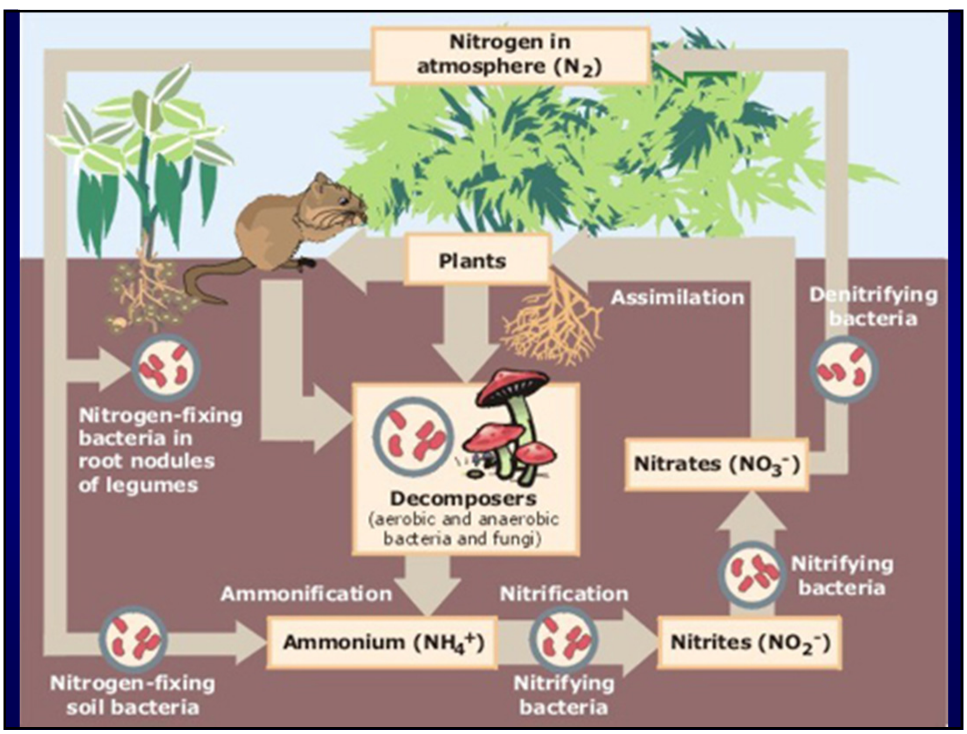
- Maintain Total NH_2Cl residual > 2 mg/L
- Free chlorinate (periodic), if TOC is low
- Remove more TOC in raw H_2O
- More turnover of reservoirs / tanks
- Flushing / cleaning of system & tanks
- Boost Cl_2 re-chlorinate free residual in system
- Free residuals annually, few days, flushing
- Increase chloramine dosage initially
- Optimize ratio of Cl : NH_3 for chloramines
- Adjust water to pH > 8.0 (8.3 optimal)
- Monitor with BART test kits (N & DN)

Nitrification (partial) Critical Threshold Concept (Article JAWWA 7/05)

- Increased use of monochloramination
  - Huron, SD THM 154 ug/L down to 37 ug/L
- Excess NH_3 released during monochloramine use and decay (free)
- Promotes growth of AOB → nitrification
- NH_3 → AOB → NO_2^- → NO_3^-
- Monitor NO_2^- to detect nitrification
- 0.05 mg/L NO_2^--N as critical threshold

Warning signs and option

- Nitrification occurs when NH2Cl decomposes
- 0.05 mg/L NO_2^- too high to predict nitrification
- If NO_2^- detected, too late to prevent nitrification (2-3 months after loss of Cl_2)
- Loss of total Cl_2 or monochloramine residuals gives early warning of nitrification
- Sodium chlorite (0.1 mg/L) inhibits nitrificaton
- Chlorite MCL 1 mg/L, byproduct of Cl02 use
- IA- 0.3 mg/L chlorite, PO3 0.9 mg/L = stable residuals, <0.01 NO_2^-, 0.6 mg/L NH3 stable & no signs of nitrification in consecutive systems



Nitrogen fertilizer- NH_3 / NO_3^-

- Des Moines river in Ottumwa, IA yields springtime NH_3 & summer NO_3^-
- Anhydrous NH_3 converts to NO_3^- runs off or into aquifer if ground (frozen), cool soil hold tends to hold N, too hot evaporates (IA State) 55F soil temp
- NH_3 /NH_4^+ bonds to soil, NO_3^- repels charge
- Soil microbes convert N to NO_3^- (water soluble used by plants)
- Fall fertilizer application up to 70% N loss
- IA DNR has opinions on fall NH_3 applications

Chloramination Controls

- Maintain 3-4 mg/L chloramine at plant
- Keep chlorine / ammonia 4-5:1
- Minimize free ammonia < 0.1 mg/L
- Keep filter media clean, shock Cl_2 + PP
  - Unless media is bioactive $NH_3 \rightarrow NO_3$
- Monitor chlorine / chloramine, ammonia, nitrite, biofilm, water quality
- Keep residuals or boost up in system

Demand versus Decay

- Demand = loss of residual after chloramine reaction with reducing agents (iron, manganese, sulfide, nitrite) and NOM in distribution system
- Decay = loss of chloramine residual due to automatic decomposition as follows:
- $3NH_2Cl \Rightarrow N_2 + NH_3 + 3HCl$
- ($NH_3\uparrow$ as pH $\downarrow$ (8.3 optimal), T $\uparrow$, $CO_3\uparrow$, DO$\downarrow$

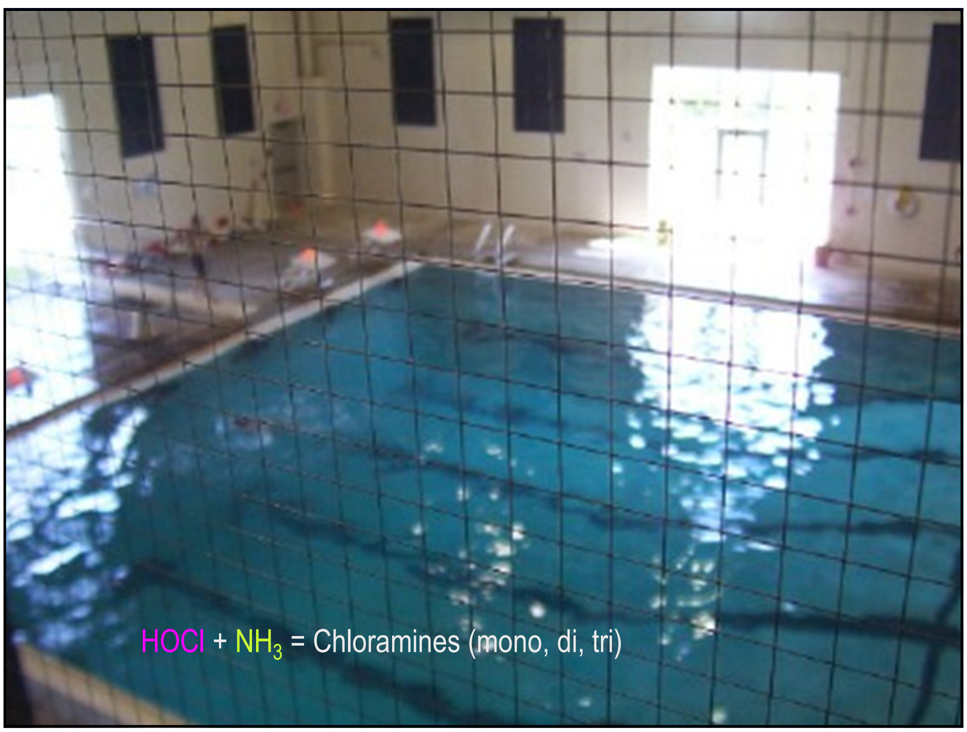
Polyphosphate treatment

- Sequesters iron Fe^{+2} (rusty water control)
  - Reduces apparent color/turbidity of Fe^{+3} particles
- Suspends manganese Mn^{+2} (black/brown water)
- May sequester/chelate metal from pipes
  - Overdose disrupts pipe surface & byproducts
- Prevents scale formation
  - 'Thresholding' calcium Ca^{+2} carbonate formation
  - Removes existing scale and corrosion deposits reducing chlorine demand & regrowth potential
- Reduced THM's (HOCl demand & pH operation)
  - Less chlorine available for THM formation and less byproducts NOM in distribution system

Effects of Polyphosphate

- Study examined disinfection ability of free chlorine and monochloramine for controlling biofilm and effect on corrosion control
- Application of corrosion inhibitors improved chlorine disinfection, allowing for penetration of pipe scale and biofilm removal
- Polyphosphate application resulted in 1,000 fold decrease of biofilm counts (∴ reduces DBP precursors and formation potential)
- Chlorine alone reacts with surface of scale

LeChevallier, Mark W.;Lowry, Cheryl D.;Lee, Ramon G., **Disinfecting Biofilms in a Model Distribution System,** JAWWA Vol. 82 - No. 7, 1990



Free Chlorine + Ammonia-N = Combined Residuals

	ODOR LIMIT
$Cl_2 + H_2O = HOCl + HCl$	20 mg/L
$HOCl + NH_3$ = Chloramines (mono, di, tri)	30 mg/L taste
$HOCl + NH_3 \Leftrightarrow NH_2Cl$ (monochloramine) $+ H_2O$	5.0 mg/L
$HOCl + NH_3 \Rightarrow NHCl_2$ (dichloramine)	0.8 mg/L
$HOCl + NH_3 \Rightarrow NCl_3$ (trichloramine)	0.02 mg/L

What is total residual?

- Total Chlorine = Free + Combined
- Chlorine in 'contaminated' H_2O = chloramines & chlororganics (combined)
- Chloramines = mono, di, tri
- Chlororganics = DBP, THM, HAA
- Combined residual is less reactive
- Combined chloramine residual is formed before reaching the breakpoint, a nuisance trace remains after

What are phantom residuals?

- False positive results- NOT VALID
- Observed in DPD free chorine analysis
- Interference from chloramine residuals in the water sample, while free not really present
- "3 mg/L monochloramine will cause increase of < 0.1 mg/L free chlorine reading" (per DPD low range method 0-2 mg/L -Handbook)
- Contradicted by the DPD high range 0-5 mg/L

Why do phantoms exist?

- Natural ammonia in raw water is primary problem, often unrecognized
- Monochloramine residuals 'bleed over' into the DPD free test results
- As the water sample ages, the free chlorine DPD results drifts higher indicating nearly the same result as the total chlorine test

Monochloramine interference during DPD free chlorine test

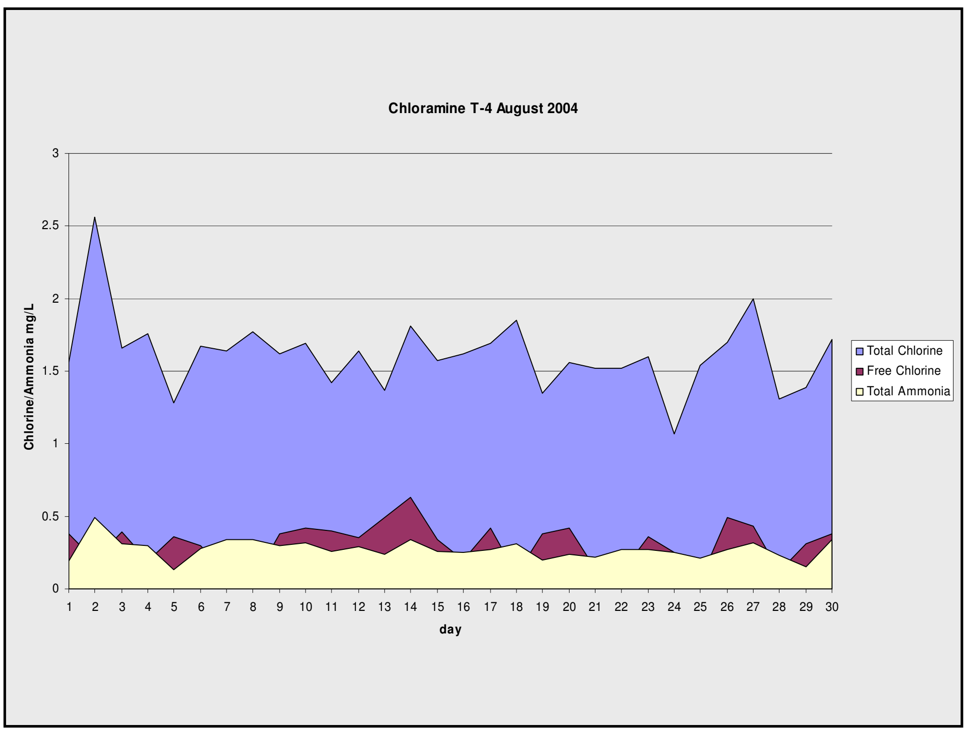
When do phantoms exist?

- Chloramine interferes with the DPD free chlorine reagents
- Sample may turn faint pink to dark magenta color (0.1-1.0^{+} mg/L) free chlorine.
- Sample turns pink over time indicating a phantom residual (seconds - minutes)
- Free DPD analysis should be rejected if the color drifts higher over time

Interference from monochloramine on 1 minute DPD free chlorine test

(per DPD high range 0-5 mg/L method Hach Analysis Handbook)

NH_2Cl mg/L	5C temp	10C	20C	30C
1.2 mg/L	+0.15	+0.19	+0.30	+0.29
2.5 mg/L	+0.35	+0.38	+0.56	+0.61
3.5 mg/L	+0.38	+0.56	+0.69	+0.73
5.0 mg/L	+0.68	+0.75	+0.93	+1.05



How to determine if I have phantom free residuals

- Perform DPD free chlorine test, measure results 'immediately'
- Allow sample to age and continue analyzing DPD free chlorine residual
- If results drift higher over time, it maybe a phantom – false positive result
- Compare with DPD total chlorine test

What to do next?

- Analyze water for ammonia (ISE) and monochloramine (Hach Monoclor F)
- If ammonia exists (> 0.5 mg/L) then sufficient combined residual may interfere with the Free DPD test
- Calculate Free ammonia = (Total ammonia – monochloramine)
- Determine location on breakpoint curve

3 key parameters

- Analyze Ammonia & monochloramine
- Calculate free ammonia content…
- Total ammonia – monochloramine = free ammonia
- APA 6000 analyzer
- CL 17 uses DPD reagents for free/total
- DR colorimeters test monochloramine & free NH3, New #10200- Indophenol
- Auto Cat 9000 Amperometric titrator

Testing Methods

- Analyze NH_3 by ISE, nessler, salicylate
- Monochlor F monochloramine
- Calculate Free NH_3
- DPD total / free chlorine
- Amperometric titration- PAO solution
- Reference Hach Handbook

PWS, MS (DPD analysis)

- 1.67 mg/L total chlorine residual
- 0.52 mg/L free chlorine residual
- 1.67-0.52 = 1.15 combined (calculated)
- 9 mg/L Cl_2 dosage (75 lb Cl_2 / MG water)
- Where are they on the breakpoint curve? Do they have a free residual?
- Do they have ammonia?
- Fe/Mn/Sulfide negligible

Sampling suggestions

- Perform free chlorine test immediately after adding DPD reagents
- Minimize sample storage time
- Use separate sample cells (free/total)
- Do both tests (free/total) per quality
- Record and plot results to isolate decay rates and location of decomposition

Treatment steps to improve system chlorine residuals

- Remove Fe/Mn, organics, precursors
- Sequester Fe/Mn with polyphosphate
- Corrosion control keeps pipes cleaner and free of biofilm, byproducts, organics
- Pre-oxidize with permanganate / ozone to destroy DBP precursors and demand
- Pre-aerate to release hydrogen sulfide
- Consider Chloramination (Cl_2 + NH_3-N)

Contact Information:

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Ground Water, Filter System

- Natural occurring ammonia in 8 wells (0.1 – 5 mg/L) supplying pressure filters
- Ammonia fluctuates (10-400% weekly)
- Pre/post chlorination (1-12 mg/L)
- Very high TOC (1-8 mg/L), color
- Bacterial fouling, taste/odors, hydrogen sulfide, slime in toilet bowls, complaints

Problems & treatment change

- Unable to maintain free chlorine residuals, Fe breaking through filters, mud balls, media fouling, flow decreased & backwash frequency increased, water quality poor

- Switched from free chlorine to chloramine (3-4 mg/L residual) by reducing chlorine dosage (moved back up the breakpoint curve)

Treatment & Results

- Wells & filters cleaned regularly / Qtr.
- Permanganate / chlorine soak
- Sand/anthracite media cleaned / topped
- Filter flow at designed rate 3 gpm/ft^2
- THMs low at plant 10 ug/L
- TTHM low in system 7 ug/L average
- Water quality improved, residents now calling asking what happened, 'water is great'

Suggestions

- Keep monochloramine high (3-4 mg/L)
- Keep free ammonia low < 0.1 mg/L
- Flush yearly, free chlorinate, monitor
- Clean & flush wells, filters, tanks
    - Check filters for AOB, if so leave alone?
- Inhibit corrosion, sequester Fe/Mn
- Monitor regrowth & deterioraton

Ground Water, Filter System

- Wells, pre-aeration, chlorination, pressure filters Fe-removal, ion exchange softening, post chlorination, O-P corrosion inhibitor, fluoridation
- Not aware if NH_3 present in wells
- Variable Cl_2 residuals in plant/system, pre/post chlorination
- Moderate N-bacteria in filters
- Prior filter cleaning = loss of free Cl_2

Source	Ammonia	Nitrite	Total Cl2	Free Cl2
Well	1.1-1.2	0.001	pre 2.2 dose	
Booster	1.05 well off	0.118	0.89/0.88 monochl	0.03 Not valid
Fe filter discharge	0.7 off 1.3 on	0.227	post 10 dose	
Finished tap	0.0 off 0.05 on	.007	3.8	3.8
Other wells	0.5-1.2		2.9	0.16 phantom

Options & Changes Made

- Switch pre/post chlorination dosages-destroy ammonia with pre, adjust free residual in post
- Utilize natural ammonia for seasonal combined residuals in summer
- Free residuals in fall prior to hydrant flushing and maintain post spring flush
- Blending of system waters compatible
- Top off lost filter media with 9" anthracite
- Evaluate filter/well rehabilitation methods
- Monitor total/free ammonia, Pb/Cu, Fe, corrosion, biofilm, and chlorine residuals

FYI

- Waste influent 8-10 mg/L P, effluent limit 1-2 mg/L P
- NH3 inflow 20-25 mg/L, outflow 1.2-2 mg/L discharge
- Limit on fish kill from NH3
- Anaerobic digesters concentrate NH3 to 600-1000 mg/L


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