

Surface Water Treatment Part 2: Processes & Treatment Systems

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What we will cover in this class:

- ❑ Who is in class & types of water systems we run
- ❑ Review of key stuff from Part 1 Class
- ❑ Surface water treatment and other water treatment processes
- ❑ Systems & typical equipment set-ups for different kinds of water treatment

POLL: What NM Water Systems License Level do you hold?

- **A. Level 1**
- **B. Level 2**
- **C. Level 3**
- **D. Level 4**
- **E. I don't; I run a wastewater system!**

POLL: Describe the water supply for your system

- **A. Surface water**
- **B. Groundwater with 1-2 wells**
- **C. Groundwater with > 2 wells**
- **D. Groundwater that includes other treatment besides disinfection**
- **E. We purchase all water from a supplier (a consecutive system)**

POLL: What is the class preference for working quiz questions and math problems? (*majority vote will rule!*)

- **A. Individually**
- **B. Operator teams made of folks from same utility**
- **C. Teams made of the 3-5 persons closest to you**

What we are now covering:

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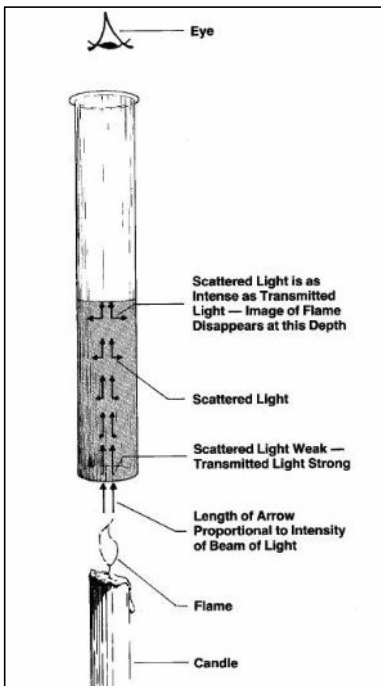
- Systems & typical equipment set-ups for different kinds of water treatment

Review of key stuff from Part 1

- ❑ Types of stuff in the raw water that we don't want & why
- ❑ Important SDWA rules that impact treatment systems
- ❑ Basic chemistry regarding alkalinity and pH and their role in water treatment

Why is removing turbidity important?

- ❑ Customers don't like cloudy or colored water!
- ❑ Turbidity interferes with disinfection!



Rules to remember for Surface Water Trt

- ❑ Revised Total Coliform Rule (RTCR)
 - ❑ It's really about distribution system water quality & the disinfection process
- ❑ Surface Water Treatment Rule or SWTR
- ❑ Long Term Phase 2 Enhanced SWTR or LT2ESWTR
- ❑ Filter Backwash Recycling Rule
- ❑ Disinfection By-Product (DBP) Rule

Filter Backwash Recycling Rule and rule for other process sidestreams

- ❑ Thickener overflow is pretty clean (*except when thickener is overloaded*)
- ❑ Sludge dewatering sidestreams can get “a little chunky”, especially at start-up
- ❑ Think about chemicals you use in these processes; If you are going to recycle the sidestreams; **Are they NSF 60 rated?**



“Fun facts” about pH from chemistry

- Why do we care about this?
 - pH of water impacts predominant species of alkalinity present
 - Alkalinity impacts performance of coagulants we add to remove turbidity
- $\text{pH} = -\log_{10}[\text{H}^+]$; Also $\text{pOH} = -\log_{10}[\text{OH}^-]$
- $\text{pH} + \text{pOH} = 14$ for any concentration of $[\text{H}^+]$
- At neutral pH ($\text{pH} = 7$), concentration of $[\text{H}^+] = \text{concentration of } [\text{OH}^-]$

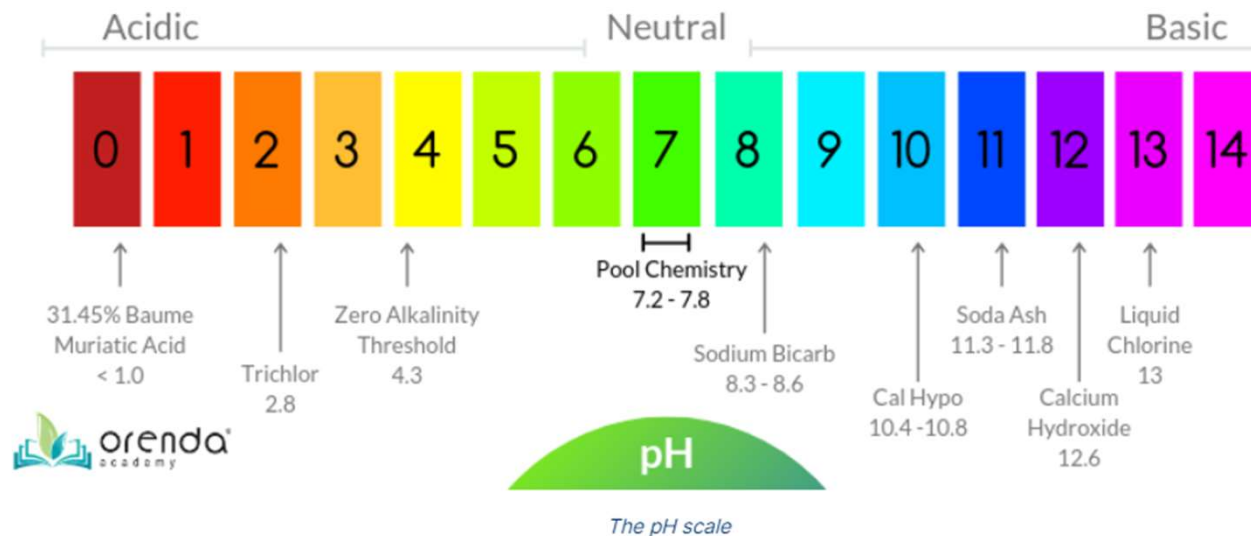
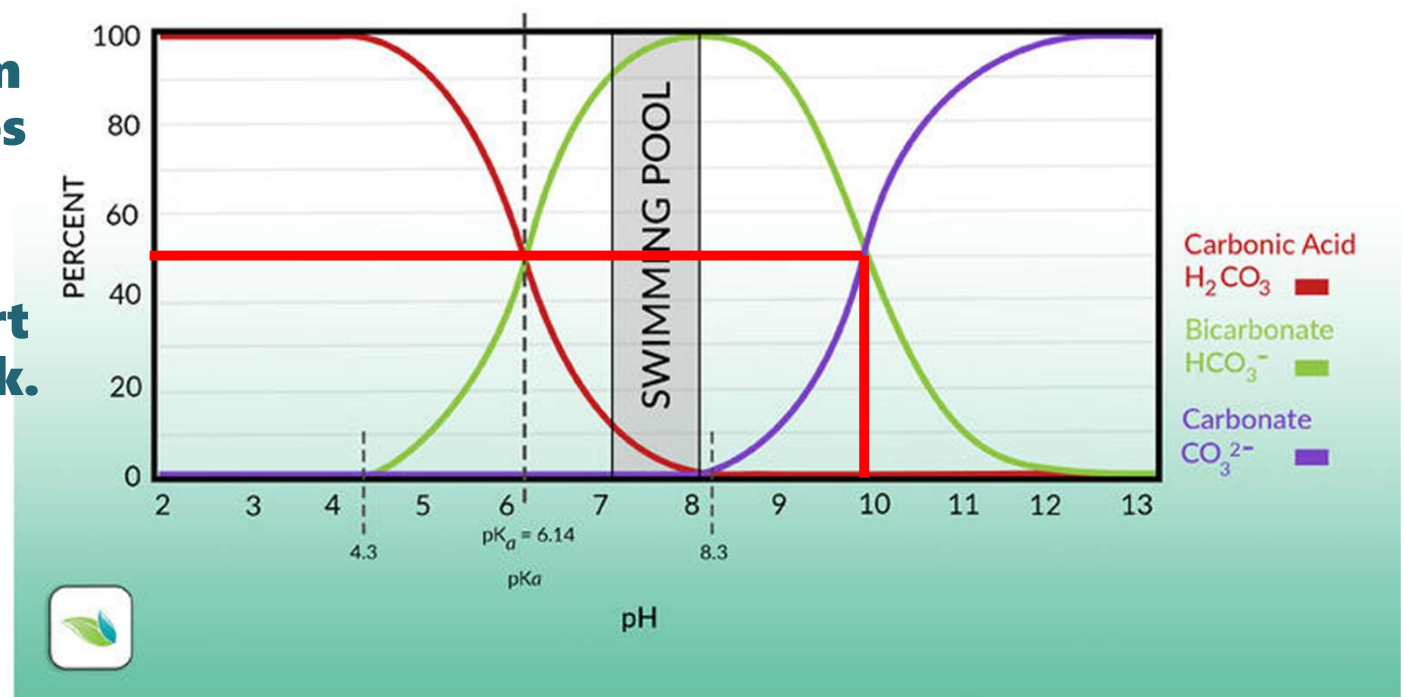


Figure courtesy of Orenda Technologies

The carbonate alkalinity system

Carbonate Alkalinity Equilibria

- Useful chart for alkalinity equilibrium or which ionic species predominates in which pH range...
- For pH \approx 10; the chart says 50% of Total Alk. in solution will be HCO_3^{-1} and 50% will be CO_3^{-2}



TOTAL ALK. = $(\text{HCO}_3^{-1}) + (\text{CO}_3^{-2}) + (\text{OH}^{-1}) - (\text{H}^{+1})$ in mg/L as CaCO₃

Graph courtesy of Orenda Technologies

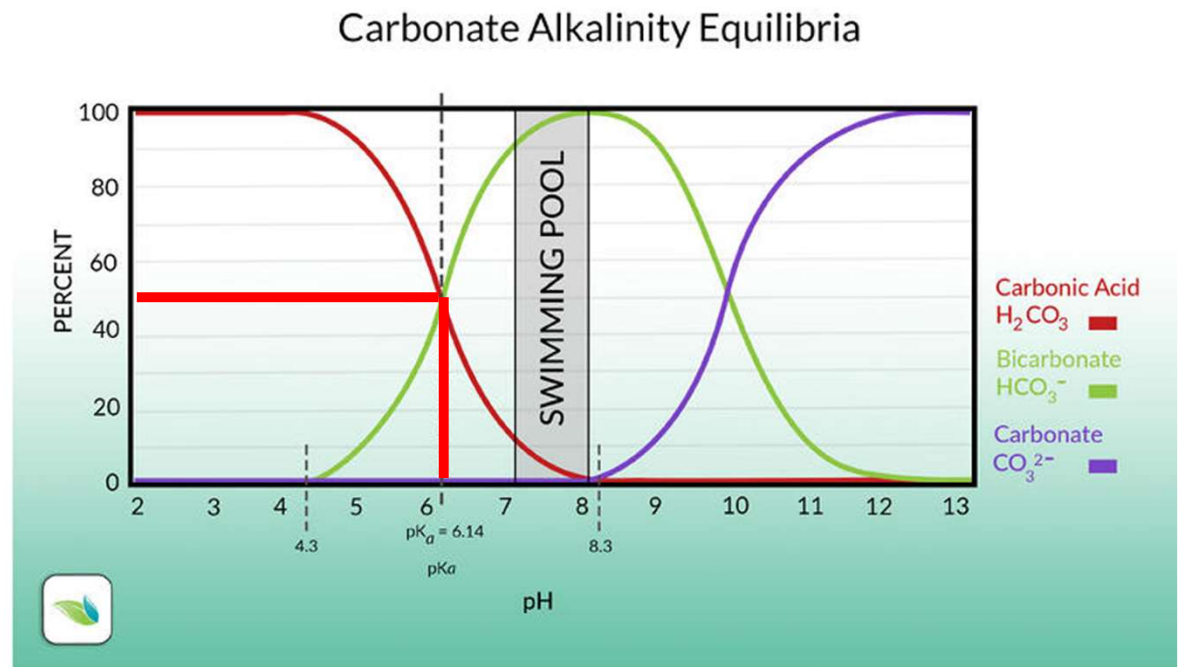
The carbonate alkalinity system

□ Useful table of facts for alkalinity and **hardness** ions:

Ion name	Formula	Weight; mg/mole	Weight; milli- equivalent/mole	Conversion factor for CaCO ₃ equivalent
Bicarbonate ion	HCO ₃ ⁻¹	61	61	1.64
Carbonate ion	CO ₃ ⁻²	60	30	1.66
Carbonic acid	H ₂ CO ₃	62	--	1.61
Hydroxide ion	OH ⁻¹	17	17	5.88
Hydrogen ion	H ⁺¹	1	1	100
Calcium ion	Ca⁺²	40	20	2.5
Magnesium ion	Mg⁺²	24	12	4.12
Calcium carbonate	CaCO₃	100	--	1
Calcium hydroxide	Ca(OH)₂	74	--	1.35

QUIZ: The Clearwater Trt Plant coagulates w/alum to lower the pH to 6.4. What will be the predominant alkalinity ion present at this pH? (Hint: refer to the alkalinity equilibrium chart)

- A. Equal amounts of HCO_3^{-1} and H_2CO_3
- B. HCO_3^{-1}
- C. CO_3^{-2}
- D. H_2CO_3



Graph courtesy of Orenda Technologies

QUIZ: Which elements found in well water are removed by water softening and together form Total Hardness?

- A. Calcium
- B. Magnesium
- C. Calcium & Manganese
- D. Sodium
- E. Magnesium & Calcium

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Types of Water Treatment Processes

- ❑ *Why do we care about this?* Pick the right tool to remove those things we don't want in our water!

- ❑ Pre-sedimentation: A cheap way to remove surface water sands and silt

- ❑ Degasifying / aeration
 - ❑ Often seen in groundwater treatment with waters having odor issues or are slightly acidic
 - ❑ A cheap way to strip out dissolved gases like H_2S and H_2CO_3^*

- ❑ Rapid mixing, coagulation, & flocculation
 - ❑ Series of sequential steps to de-stabilize colloidal suspensions & form precipitates that settle

- ❑ Sedimentation; settle out the flocs that you formed
You can't beat gravity (*most of the time*)

Types of Water Treatment Processes

- ❑ Filtration; get rid of any leftover particles to achieve SDWA turbidity standards; Ways to filter include:
 - ❑ Granular media filtration after sedimentation; pretty standard
 - ❑ Direct filtration for clean raw waters; average turbidity < 10 NTU and “few upsets”
 - ❑ Coagulation goal for direct filtration: create a pin floc
 - ❑ Membrane filtration (ultrafiltration) for really clean raw waters
 - ❑ *Why try to make lots of floc if the water is already pretty clear?*
- ❑ Other variations / applications of filtration
 - ❑ Manganese greensand media for iron and manganese removal
 - ❑ After a lime softening process that removes hardness as CaCO_3 precipitates
- ❑ Disinfection to kill any leftover pathogens

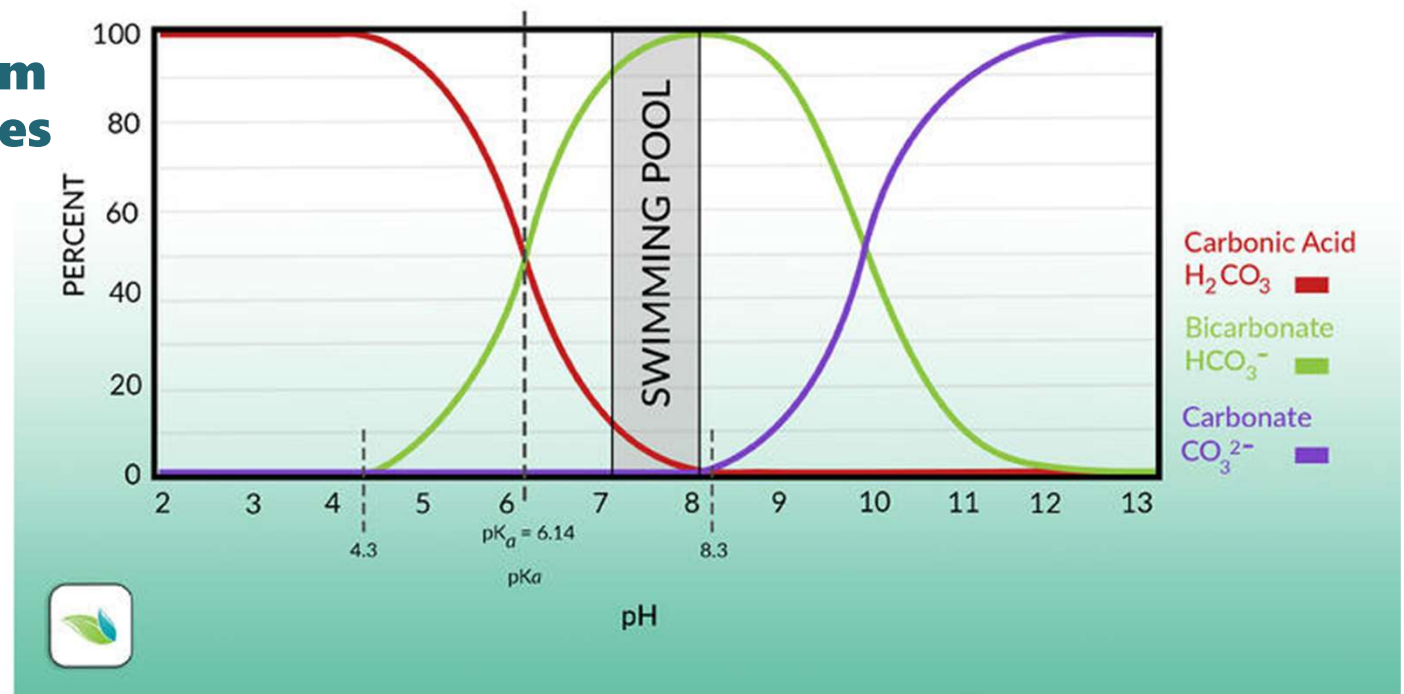
Softening in Water Treatment

- ❑ Softening by lime precipitation to remove hardness ions; Ca + Mg
 - ❑ **Why do this?** Calcium and magnesium can precipitate out and plug equipment e.g., boilers, hot water heaters, & heat exchangers
 - ❑ Add hydroxide ion (OH⁻) to raise pH, convert all alkalinity to CO₃⁻², and precipitate CaCO₃
 - ❑ Will precipitate Mg as Mg(OH)₂ **if pH is raised ≥ 11**
 - ❑ Concentrations of Ca, Mg, alkalinity, and sulfate all impact process
 - ❑ As more Mg is present as hardness, the precipitates become “fluffier”
- ❑ If significant part of Ca hardness is non-carbonate i.e., SO₄⁻² hardness, need to add soda ash (Na₂CO₃) to precipitate CaCO₃ in addition to lime
- ❑ Conventional lime softening usually generates massive quantities of sludge to manage 😞

The carbonate alkalinity system

- Useful chart for alkalinity equilibrium or which ionic species predominates in which pH range...

Carbonate Alkalinity Equilibria



Graph courtesy of Orenda Technologies

Types of Water Treatment Processes

- ❑ Softening by ion exchange; “Hey Culligan man...”
 - ❑ Simply swapping calcium ions for sodium ions on a resin bed
 - ❑ Sodium ions added to the product water; Calcium sticks to the resin
 - ❑ Adding sodium to the water is not always a good thing!
 - ❑ Periodically regenerate the resin bed with saturated brine solution
 - ❑ Suggestion: Use softened water to prepare the saturated brine!
- ❑ Not usually done for entire public water supply but may be critical for make-up water used in the treatment process e.g., on-site generated hypochlorite (NaOCl) used for disinfection
- ❑ Disposal of the brine regenerant may be an issue for sewer system

Other Water Treatment Processes

- ❑ Desalination using high pressure membranes; salt and ion removal using nanofiltration and/or reverse osmosis
- ❑ Desalination using electrodialysis; motive force for ion separation is electrical charge applied to membranes
- ❑ Absorption processes
 - ❑ Arsenic absorption using a proprietary iron media e.g., Bayoxide₃₃
 - ❑ Media is used one time & then disposed (If it passes the TCLP test!)
 - ❑ Specialty ion exchange medias for exotic stuff: long-chain PFAS
 - ❑ Activated carbon for removing organics
 - ❑ Anyone want to handle your used, PFAS-laced activated carbon?

Final Types of Treatment Processes

- ❑ pH adjustment to stabilize water; a MUST after:
 - ❑ Lime softening; CaCO_3 will gum up the filter bed!
 - ❑ Enhanced coagulation; *pH of water is too acidic to put in system!*
 - ❑ Desalination; Need to replace carbonate ions else permeate will “attack” carbonate films that form on distribution system waterlines
- ❑ Fluoridation to promote dental health in population served
 - ❑ Don't promise more than the technology can deliver
 - ❑ Recommended 0.7 mg/L dose will be met +/- 0.1 mg/L, at best!
- ❑ Specialty chemical additives e.g. polyphosphate / orthophosphate blends to balance corrosion / precipitation reactions in distribution system

QUIZ: Adding lime slurry to filtered & disinfected finished water will...

- **A. Only increase water pH**
- **B. Only increase hardness**
- **C. Increase both water pH and hardness**
- **D. Could cause cloudiness in the water**
- **E. Both C and D**

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Conventional trt. scheme for “turbid” water

- ❑ Treatment goals: get rid of settleable & suspended sediments and pathogens in raw water
- ❑ How?
 1. Start with a **BIG** pond to store diverted water & remove settleables
 2. Add chemicals to destabilize suspended colloidal solids so they stick together & settle: Use rapid mixing, coagulation, and flocculation to get something that will gravity settle
 3. **Gravity settle the flocs; Target clarity is 2-4 NTU for settled water**
 4. Filter out remaining solids to achieve ≤ 0.3 NTU for filtered water turbidity in 95% of all filter cell turbidity readings
 5. **Disinfect the water to kill remaining pathogens**

Step 1: Gravity Settling in a **BIG** pond

- Our goal: get rid of settleable stuff by simple gravity settling
 - Why?
 - 1. Keep the heavy stuff from plugging downstream equipment
 - 2. Provide a buffer for when raw water turbidity spikes
 - How big? As big as available land area will allow the pond to be
 - Have a plan for eventually removing the stuff that settles in the pond (Ask ABCWUA about theirs)
-



QUIZ: Suspended colloidal sediments...

- **A. Are electrically charged particles and repel each other**
- **B. Are stable in solution & will not settle out by gravity**
- **C. May be destabilized if particle surface charges are neutralized**
- **D. All of the above**

Step 2: Destabilize Suspended Colloidal Stuff

- Includes both organic and inorganic colloidal material
- How? Add a chemical(s) to neutralize surface charges on particles and under right conditions, it will glue them together and gravity settle
- Chemical reaction for a ferric salt coagulant; Remember: *It's a 1-way street!*



- **First:** Add lots of mixing energy to quickly disperse the chemicals throughout the bulk solution; How much energy?
 - Evaluate with “G”, the mean velocity gradient \approx energy input to mix chamber
 - For mechanical mixers used in rapid mixing, typical “G” is 500-600 seconds⁻¹

Step 2: Destabilize Suspended Colloidal Stuff

- Includes both organic and inorganic colloidal material
- How? Add a chemical(s) to neutralize surface charges on particles and under right conditions, will glue them together and gravity settle
- Chemical reaction for a ferric chloride coagulant: Remember: *It's a 1-way street!*



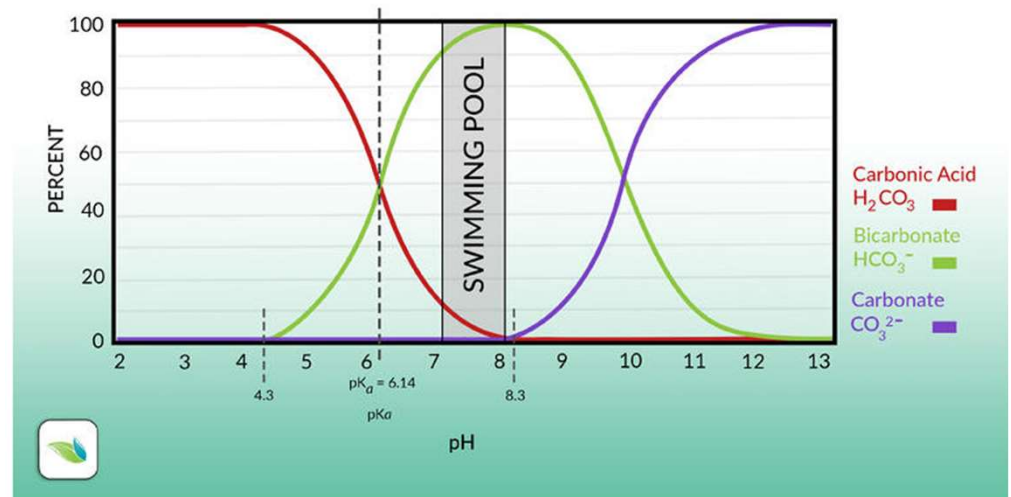
- **Second:** Use gentle mixing to “coagulate the destabilized particles” (glue them together) and grow flocs that will settle later
 - “G” values for gentle mechanical mixing: 25 – 75 seconds⁻¹
 - Typically, 2 or 3 mixing chambers in series w/slow turning mixers; Speed adjustment on mixers is a good thing, **especially if your raw water has seasonal temperature changes!**

QUIZ: In the sample equation for ferric chloride addition, what are the expected outcomes?

- A. HCO_3^{-1} ion in solution is converted to dissolved carbonic acid (H_2CO_3) and the pH will drop
- B. HCO_3^{-1} ion in solution is being converted to CO_3^{-2} ion and the pH will rise
- C. Ferric hydroxide $\text{Fe}(\text{OH})_3$ will precipitate & settle (quickly)
- D. A and C



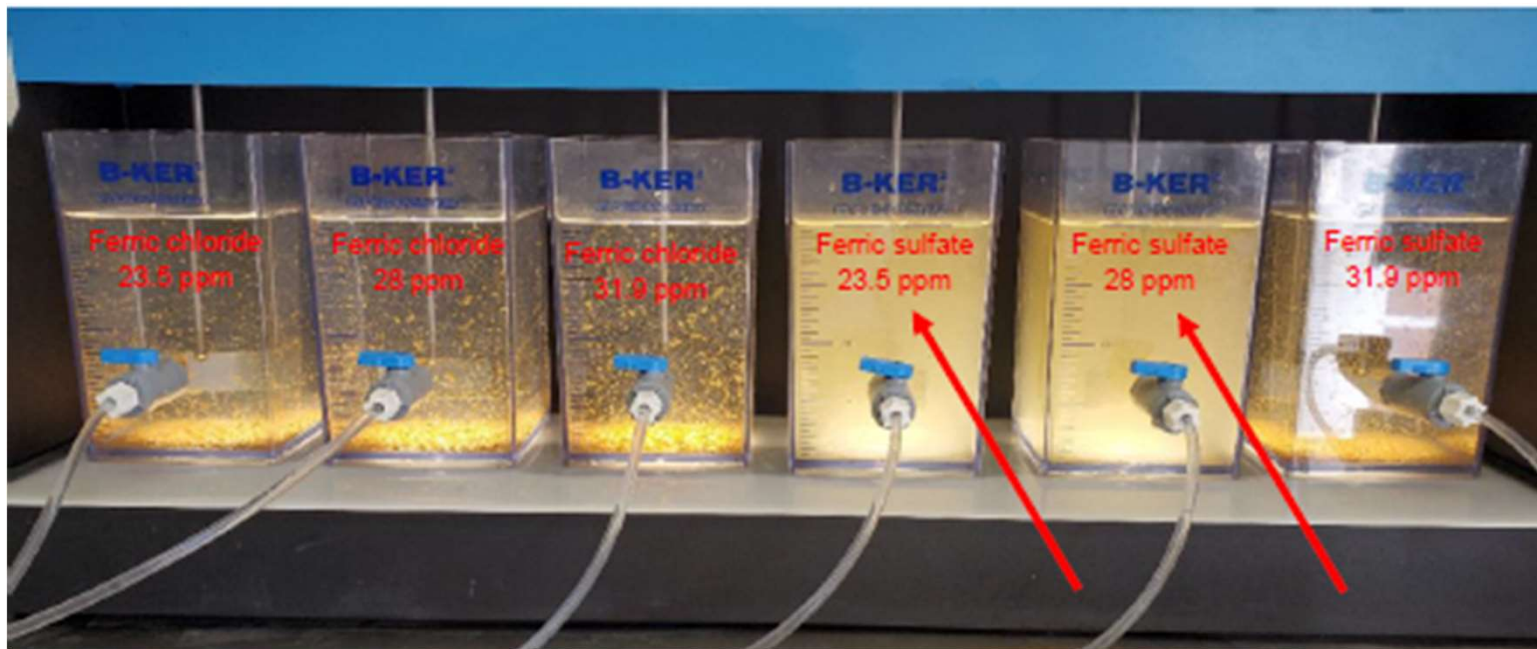
Carbonate Alkalinity Equilibria



Graph courtesy of Orenda Technologies

Step 2: Destabilize Suspended Colloidal Stuff

- A well settling floc looks like the stuff in the 3 jars at left:



- Use jar tests to experiment & fine tune coagulant types and doses

Step 3: Put gravity to work & settle the flocs

- ❑ A big empty tank for gravity settling
- ❑ Turbidity target for settled, “floc free” water: 1-3 NTU
- ❑ Settling is proportional to “rise rate” in the clarifier
- ❑ For a fixed tank volume; more surface area reduces rise rate & gives better settling
- ❑ Typical rise rates for conventional clarifiers: 300 – 900 gpd / foot²
- ❑ Nominal hydraulic detention time ≈ 2 hours
- ❑ Other components of a conventional clarifier
 - ❑ Inclined plates or tube modules that increase net surface area
 - ❑ Scraper system to push sludge to a hopper & drain point
 - ❑ Effluent launders / weirs to control flow of clarified effluent



Step 4: Filter out remaining solids

- ❑ Turbidity target for filtrate: ≤ 0.3 NTU in 95% of all CFE readings
 - ❑ Readings taken every 15 minutes in filtrate from each filter cell
- ❑ Main components of a typical granular media filter:
 - ❑ The media bed
 - ❑ Underdrain to support the media, collect filtrate, & distribute wash water (& maybe scouring air) used to clean the filter media
 - ❑ Troughs to collect dirty filter wash water
 - ❑ Valves & piping to regulate flow of water into / from the filter
 - ❑ Instruments to monitor filtrate turbidity, filtrate flow, and headloss (pressure drop) thru filter
- ❑ Treatment plants typically have 4 or more equal size filter cells

Filter media types:

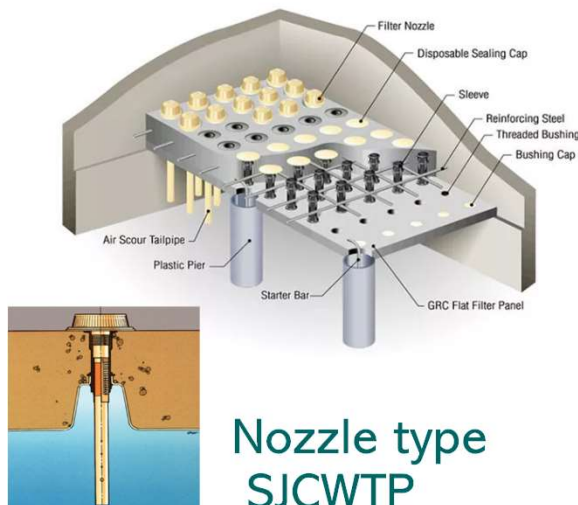
Type	Component	Depth	Media size, mm	Specific gravity	Comments
Dual media	Anthracite coal	24"	1.0-1.2	1.6	Little mixing between sand & anthracite layers after backwash
	Silica sand	12"	0.45-.55	2.6	
Mixed media	Anthracite coal	24"	1.0-1.2	1.6	3 media layers intermix (anthracite w/sand & sand w/garnet) following backwash
	Silica sand	9"	0.45-.55	2.6	
	Garnet	3"	0.20	4.0	
Dual media w/activated carbon	Activated carbon	60"	1.0-1.2	1.4	Activated carbon promotes biological activity in the media which helps absorb organics that cause taste & odors
	Silica sand	12"	0.45-.55	2.6	

Deep bed dual media filters sometimes use anthracite instead of activated carbon e.g., Denver Water's new Northern WTP

- ❑ Nominal filter loading rates: 3-5 gpm/square foot of filter bed area
- ❑ Clean the media w/combination of scouring air and water backwash

Filter components for Step 4:

Popular types of filter underdrains in use today:



- ❑ Purpose: support the media w/out needing any gravel & collect clean filtrate
 - ❑ Eliminating support gravel layer allows for deeper media beds
- ❑ Also: Uniformly distribute scouring air & backwash water during cleanings

Step 4A: Cleaning a dirty filter cell; Parts 1-4

- ❑ Clean a cell when 1) it gets plugged (high headloss), 2) after ≈ 96 hrs of time in service, or 3) turbidity breakthrough ☹️
- ❑ Cell cleaning involves the following general 9-part sequence :
 1. Drain down the cell till 2-3 feet of water left above media
 2. Turn on air compressor for scouring air that gives a high energy scrub to remove particles trapped in the media ≈ 5 minutes
 3. Turn on filter backwash water supply at rate of 5 gpm/ft² while scouring air flow stays on; Start flushing out the loosened debris
 4. Turn off scour air after 5 minutes & slowly begin to increase wash water flow rate to 20 gpm/ft² ; Pick a rate of flow increase and Q that gives “optimal results” (this will change with water temperature)

Step 4A: Clean a dirty filter cell; Parts 5-9

5. Maintain wash rate at 20 gpm/ft²(?) until wash water turbidity < 30 NTU
 6. Slowly ramp down wash water flow to zero
 7. Filter is ready to receive clarifier effluent again
 8. Allow filter to “ripen”; Send initial filtrate flow to waste until its NTU < 0.3
 9. Once the filter media has “ripened”, return the filter cell to service
- ❑ Most WTPs today have control systems that automatically open and close valves on the filters to achieve this 9-part sequence 😊
 - ❑ Operators like you find the best combination of wash flow rates & step durations to achieve “effective filter cleaning”; *More on this in Part 3 Class*

QUIZ: The Clearwater WTP treats 12 MGD using 6 filter cells that give a total of 1800 SF of surface area. With all cells in service, this plant runs its filters at:

- **A. 2.31 gpm/SF**
- **B. 4.62 gpm/SF**
- **C. 6.63 gpm/SF**

Solution Hints:

1. gpm/SF = gallons per minute per square foot of filter area
2. A 12 MGD flow = ??? Gallons per minute
3. Filter loading rate in gpm/SF = Q/A

QUIZ: In the last example, the filter rate increases to what rate when one of the 6 cells is removed from service for cleaning?

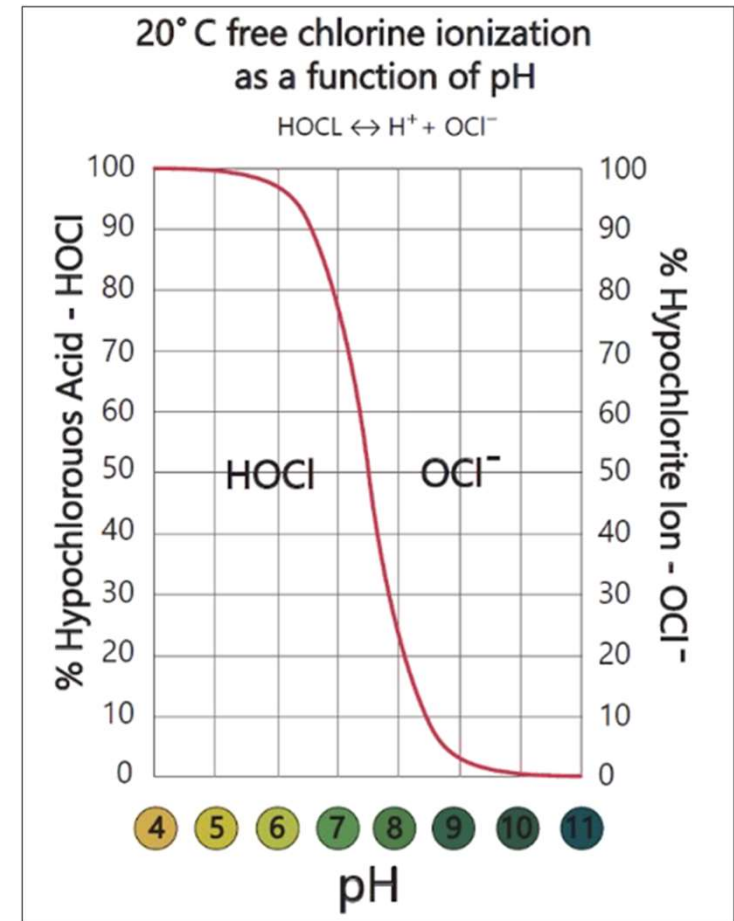
- **A. 5.56 gpm/SF**
- **B. 5.84 gpm/SF**
- **C. 6.17 gpm/SF**

Solution Hints:

1. The old filter loading rate in gpm/SF = ???
2. The flow rate through the plant stays the same
3. Filter area per each of 6 filter cells = ???
4. With 5 cells in service, the total filter area remaining in service = ??
5. The new filter loading rate is ??

Step 5: Disinfect to kill remaining pathogens

- ❑ Hypochlorous acid (HOCl) is the workhorse!
 - ❑ Much stronger disinfectant than hypochlorite ion (OCl^{-1})
- ❑ It's effective in waters w/pH range of 6-8.5
- ❑ Higher dose is required in more alkaline waters as hypochlorite ion (OCl^{-1}) becomes the more prevalent compound in solution:



Step 5: Disinfect to kill remaining pathogens

- ❑ Free chlorine residual measures the combined concentration of HOCl, OCl⁻, and any undissolved gaseous chlorine (very little is present at typical doses for disinfection)
- ❑ Total chlorine residual also includes chloramines (if present; these are monochloramine, dichloramine, & trichloramine)
- ❑ Testing for chlorine residual
 - ❑ DPD test & the color wheel (test for Total & Free Chlorine)
DPD = Diethyl-p-Phenylene-Diimine
 - ❑ Amperometric titration; *A good method for collecting real-time data*
 - ❑ Colorimeters replace the color wheel



Stuff to remember about disinfection w/Cl:

- ❑ Warmer water temperature will increase the reactivity of all chlorine-based disinfectants BUT also helps drive them out of solution faster
 - ❑ Opposite happens w/colder water temps
- ❑ Organic substances in the water will consume some of the chlorine and form organo-chlorine compounds e.g. THMs & other DPBs
- ❑ Often seen when disinfecting waters w/TOC content > 1 mg/L

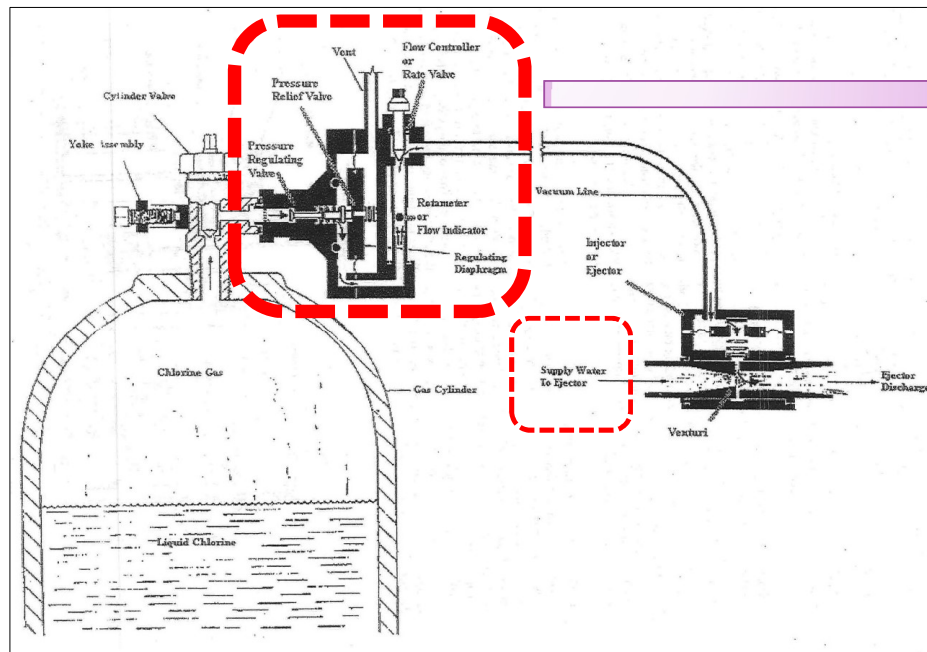
Disinfection w/chloramines; interesting stuff:

- ❑ Weakest & slowest reaction time of all chlorine-based disinfectants; required CT for chloramine disinfection much higher than w/free chlorine
- ❑ Also the disinfectant that's least likely to form DBPs
- ❑ Key concern in controlling chloramination reactions for disinfection systems: adding too much ammonia
 - ❑ Free ammonia becomes food for bacterial films growing in your distribution system pipes
- ❑ If you have an inter-connect agreement with another system for emergency water supply and you chloraminate the water in your system but they use free chlorine for disinfection...

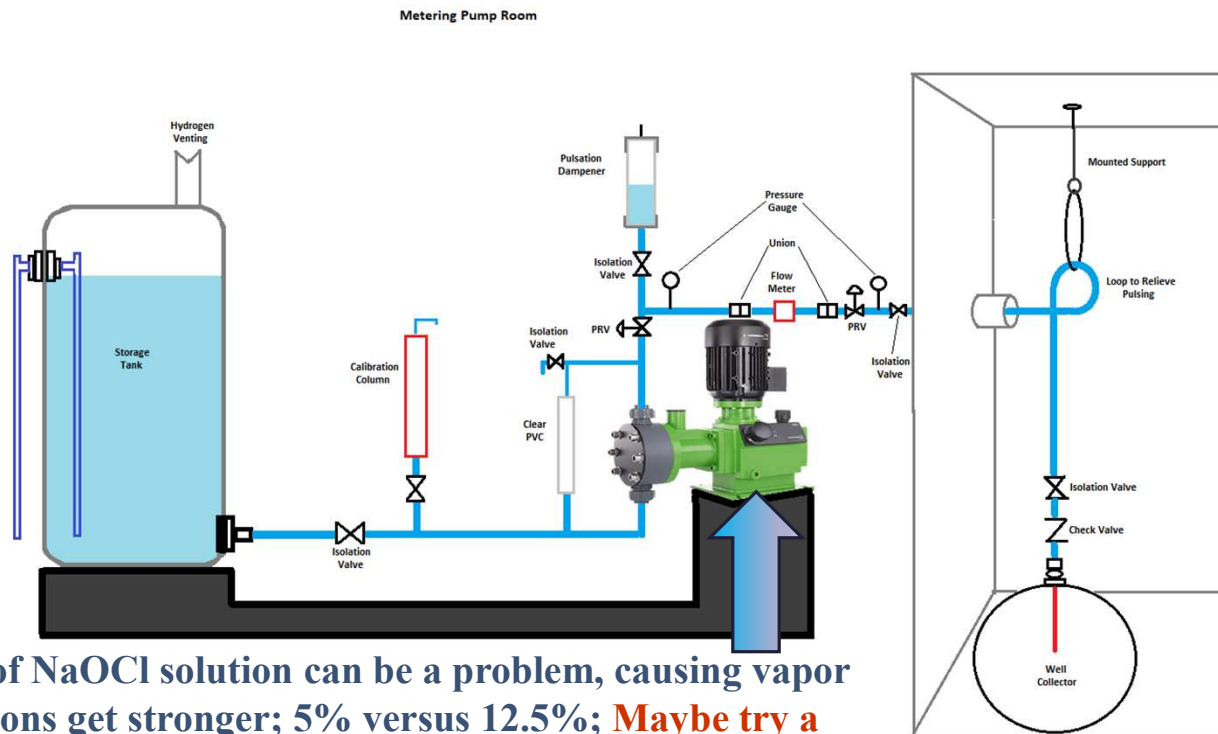
POLL: What chemical does your system use for disinfection?

- **A. Chlorine gas**
- **B. Liquid sodium hypochlorite (NaOCl or bleach)**
- **C. On-site generated hypochlorite (HOCl)**
- **D. High Test Hypochlorite (HTH) tablets disinfection**
- **E. Chloramines**

Typical set-up for chlorine gas feed

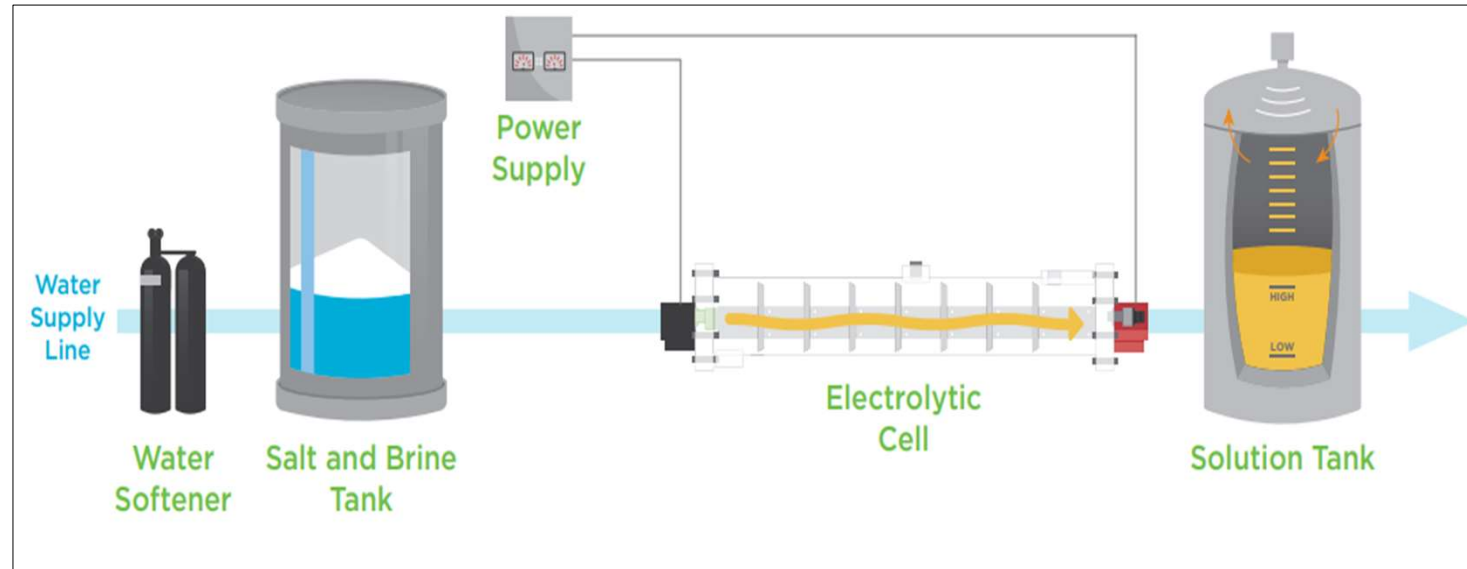
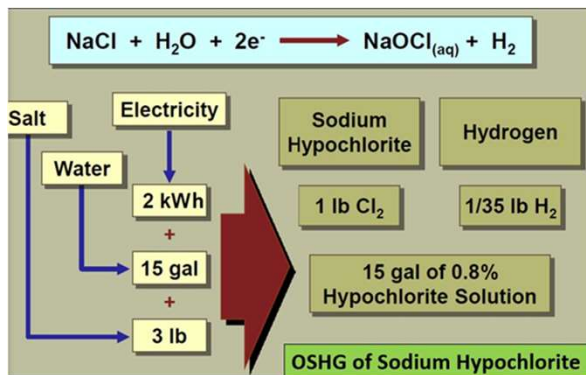


Typical set-up for liquid NaOCl feed



Off-gassing of NaOCl solution can be a problem, causing vapor lock as solutions get stronger; 5% versus 12.5%; **Maybe try a peristaltic pump instead of a diaphragm pump?**

Typical System for On-site Generated HOCl Solution



OSHG systems generate 0.8% strength HOCl

QUIZ: Comparing typical pump set-ups for feeding 10% bleach vs on-site generated 0.8% HOCl, to feed the same chlorine dose, the metering pump...

- **A. Gets smaller if feeding 12.5% bleach**
- **B. Gets bigger if feeding 12.5% bleach**
- **C. Stays the same; there would be no change in pump size**

Need Continuous Measurement of Cl Residual?



- Example of a flow-through device w/no waste discharge
- Detects HOCl strength using amperometric titration
- Compensates for pH
- Calibrated w/DPD method

THANK YOU AND WISHING YOU SUCCESS IN YOUR UTILITY OPERATIONS CAREER!

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