Should we use a residual in our drinking water distribution systems?

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How did the practice of maintaining a residual come about?

In a word, by serendipity (by accident)

- *Chemistry:* **After chlorine is added to water to accomplish primary disinfection, what chlorine is not consumed, remains as a persistent residual**
- *Old history:* **So, when chlorine was first used to make unsafe water supplies safe, the presence of a residual of chlorine was taken, by both professionals and by consumers, as a sign that sufficient chlorine had been added and the water was, indeed, safe**
- *Modern History:* **Today, most consumers take the bacteriological quality of municipal drinking water for granted and now they see the presence of a noticeable chlorine residual as a sign of incompetence, sloppy management on the part of the professionals managing the water system**

Primary disinfection vs. Residual maintenance

- It is important to differentiate between primary disinfection and residual maintenance because it helps us to come to terms with their purpose
- The purpose of primary disinfection is to ensure that the water entering the distribution system is free of pathogens
- So the purpose of residual maintenance must be to ensure that the water in the distribution system *continues* to be free of pathogens until it reaches the consumer
- On the other hand, more or less worldwide, the practice of residual maintenance is more consistently applied in treated *surface water* than it is in *groundwater*

Primary disinfection vs. Residual maintenance

- For example, many utilities using deep groundwater supplies do not use disinfection at all
- So the question arises, "is it necessary to have residual maintenance in order to ensure that the water in the distribution system *continues* to be free of pathogens until it reaches the consumer?"
- It is clear that the reason we disinfect surface water is that our traditional methods of water treatment are not adequate to produce a safe, pathogen-free water from a heavily contaminated surface water without disinfection
- Once disinfection is applied, if chlorine is used, then we have a residual
- In the case of many deep groundwaters there has never been a reason to doubt their safety and so disinfection has never been applied

Primary disinfection vs. Residual maintenance

- During the past three decades two developments have worked to destabilize this pattern of practice:
  - The discovery of disinfection byproducts
  - The development of methods that produce pathogen-free water but do not leave a disinfectant residual behind (e.g. ozonation, UV, membrane filtration, etc.)
- This talk is about whether we actually need that residual and, if so why do we need it?
- Let's take a moment and explore some of the reasons that are often cited as to why a residual should be maintained in the distribution system

Reasons cited for maintaining a residual

- To overcome any contamination that might enter the system
- To inhibit biofilm formation. We don't want excessive biofilms because:
  - » The presence of other bacteria can interfere with the analysis of indicator bacteria
  - » Biofilms can promote microbiologically-induced corrosion
  - » Biofilms can harbor opportunistic pathogens

Reasons cited for maintaining a residual

- To overcome any contamination that might enter the system
- To inhibit biofilm formation.
- To stabilize water quality in the system
- So that the absence of residual can be used as sign of contamination
- To prevent opportunistic pathogens (directly)

Residual Maintenance is an area where U.S. & Continental European practice are diverging

- *In the States practice is moving toward more thorough residual maintenance*
  - Regular to heavy use of disinfectant residuals is common
  - SWTR requires a residual in 95% of samples from distribution system
  - Trend is higher residuals
  - More use of NH_2Cl
- *On the Continent practice is moving toward the use of a low residual or no residual*
  - Trend is to low residual or no residual
  - Reduce assimilable organic carbon (AOC) before the distribution system
  - NH_2Cl are much less common

Let’s take a moment to step back and look more closely at the alternatives

Three approaches to residual maintenance might be taken

- Approach 1: Keep a strong residual
- Approach 2: Avoid the residual altogether
- Approach 3: Keep a residual while trying to minimize adverse effects

Three approaches

- Approach 1: Keep a strong residual
  - The old way
    - » Before DBPs were discovered
    - » When risk of infection was considered higher
    - » More was better (the smell is good for you)
  - Difficult to address aesthetic and DBP concerns
  - Not feasible for the long term
  - Will not discuss further

Three approaches

- Approach 1: Keep a strong residual
- Approach 2: Avoid the residual altogether
  - Let's examine this idea further
  - Our approach:
    - » Look at why residual is required
    - » See if the issues can be addressed in other ways
    - » See where that leads us

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Reasons cited for maintaining a residual

- To overcome any contamination that might enter the system

Setting residual maintenance aside for the moment, what are some alternative strategies for overcoming system contamination?

Alternatives for overcoming contamination to the system

- To rigorously enforce a minimum, continuous system pressure
- To more rigorously enforce cross-connection standards
- Replace old conduits
- Upgrade system monitoring
- Upgrade system maintenance
- Upgrade system to reduce surge

What does a Residual do to overcome contamination to the system?

- If the contamination is very slight, the residual will disinfect it
- If the contamination is significant, the residual will likely be consumed
- Taken in total, the alternative measures listed on the previous slide would seem to provide greater protection than does the residual itself

Reasons cited for maintaining a residual

- overcome system contamination
- inhibits biofilm formation

are there some alternatives?

Alternative measures for controlling biofilm formation

- Remove assimilable organic carbon (heterotrophs)
- Use only inert materials
  - For the distribution system & consumer plumbing
  - Don't use metals that can serve as a source of electrons for autotrophs
- Clean, reline or replace old pipes
- Upgrade treatment (no seed)
- Improve system monitoring techniques
- Eliminate dead-ends
- Improve storage tank design & operation

What does a residual do for controlling biofilm formation?

- The presence of a disinfectant residual does result in a dramatic reduction biofilms on almost any surface
- On some surfaces (e.g. glass, plastic, copper, concrete) free chlorine is remarkably effective at reducing biofilm density
- On other surfaces (particulary iron) chloramines have been shown to be a little more effective
- Disinfectant residuals have been shown to slow or arrest microbiologically-induced corrosion

What does a residual do for controlling biofilm formation?

- Nevertheless the microbial consortia that make up biofilms are remarkably robust - ask anyone who has ever had black algae in their swimming pool
- Experience has shown, time and again, that, if biofilms are to be controlled, residual maintenance must be supported by other measures as well
- At the same time, eliminating biodegradable matter is not enough
  - even the pure water systems used by the electronics industry are plagued by biofilms
  - Some autotrophs do not need AOC

Complete biofilm control probably requires every arrow in our quiver

Reasons cited for maintaining a residual

- overcome system contamination
- inhibits biofilm formation
  - » interference with coliform analysis
  - » risk of microbiologically-induced corrosion
- stabilizes water quality in the system

Are there alternatives to achieve this objective?

Alternatives for stabilizing water quality in the system

- There are questions of both Biostability and chemical stability
- The same measures we discussed for biofilm formation would be helpful where biostability is concerned

Alternatives for stabilizing water quality in the system

- There are questions of both Biostability and chemical stability
- Where chemical stability is concerned, there are three aspects:
  - Interaction of the water with the conduit itself (corrosion)
  - The stability of the disinfectant residual itself
  - The formation of precipitative scales ($CaCO_3$, Aluminosilicates, etc.)

Alternatives for stabilizing water quality in the system

- There are questions of both Biostability and chemical stability
- Where corrosion is concerned
  - Selection of materials is critical, so new standards, replacement and relining of old pipe can all help
  - A modest residual is sometimes helpful
- Where residual stability is concerned:
  - Corrosion control is key - the chlorine goes early

So what is the bottom line on stability?

- Seems like there are two keys to stability:
  - The quality of the water as it enters the system
  - The quality of the materials that the water comes in contact with
- If these issues are addressed, it's not clear that a residual is of much advantage
- On the other hand if we need to make things work with an old legacy system made of unlined cast iron, a residual may be part of the formula for success
- Even then it seems like proper water treatment, corrosion control and materials are the key here - *the residual being 2ndry*

Reasons cited for maintaining a residual

- overcome system contamination
- inhibits biofilm formation
  - » interference with coliform analysis
  - » risk of microbiologically-induced corrosion
- stabilizes water quality in the system
- absence of residual as sign of contamination

Addressing the value of absence of residual as sign of contamination

- **The Principle**
  - When pollution enters the system, the disinfectant residual reacts with it, and disappears in the process
  - So the absence of residual in an area where residuals are usually observed is a sign of contamination
- How widely is this practiced?
  - Not very widely - at least not in a timely manner
  - It would require a new level of vigilance in monitoring to make it effective
    - » automated stations for residual throughout system
- Is there a substitute?
- Substitute other, comprehensive monitoring
  - Use more aggressive manual monitoring
  - Automated monitoring for pressure, flow, temperature, surge
  - Automated stations for HPC and/or Coliform

Some of these are as practical than using the residual as a sentinal for contamination

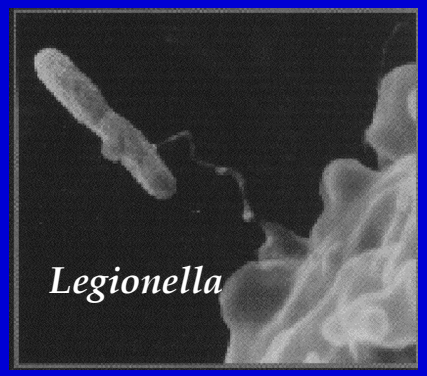
Reasons cited for maintaining a residual

- overcome system contamination
- inhibits biofilm formation
  - » interference with coliform analysis
  - » risk of microbiologically-induced corrosion
- stabilizes water quality in the system
- absence of residual as sign of contamination
- prevention of opportunistic pathogens

Alternatives?

Alternatives for controlling opportunistic pathogens

- Four of the "opportunists" that are often mentioned are:
  - *Legionella pneumophila*
  - *Mycobacterium avium complex*
  - *Aeromonas hydrophila*
  - *Pseudomonas aeruginosa*



- Measures might include
  - Efforts to reduce the seed coming into the system
  - Efforts to reduce nutrients (they are all heterotrophs, so AOC makes sense)
  - The issues are similar to improving stability and controlling biofilms

What does residual maintenance do for opportunistic pathogens?

- It depends on the residual and it depends on the organism
- In the SWTR EPA states that its requirement for a residual is designed to address *Legionella*
- There is evidence the chloramines do a better job of that than does free chlorine
- Aeromonas and Pseudomonas are reasonably sensitive to chlorine

What does residual maintenance do for opportunistic pathogens?

- MAC is known to be rather resistant
- So the results are mixed.
  - Chances are a residual helps
  - But a residual, alone may not be enough
  - And there is the question of which residual

One concern I have: *legionella* often show up in places (like air conditioning equipment) where I would expect plenty of nutrients from the local environment and little likelihood that a residual would remain.

Is this a problem that municipal water systems should be expected to manage?

If it is, then guess I am in a place where I'd feel better if I could include a residual among my alternatives

Summary on using no residual

Issue	Alt. Measures	Residual	Alt. Meas. + Residual
Contamination			
Biofilms			
Stability			
Sign of contamination			
Opportunistic Pathogens			

Summary on using no residual

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Biofilms			
Stability			
Sign of contamination			
Opportunistic Pathogens			

Summary on using no residual

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Stability	Want AOC and corrosion	Can't catch up	Small improvement
Sign of contamination			
Opportunistic Pathogens			

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Opportunistic Pathogens			

Summary on using no residual

Issue	Alt. Measures	Residual	Alt. Meas. + Residual
Contamination	Helpful	Not much use	No improvement
Biofilms	Helpful	Helpful	Need all the arrows
Stability	Want AOC and corrosion	Can't catch up	Small improvement
Sign of contamination	Helpful	Not much use	Small improvement
Opportunistic Pathogens	Might work sometimes	Might work sometimes	Why not both?

Bottom line: Either way is o.k., nice to have a residual if we could manage the issues

Three approaches

- Approach 1: Keep a strong residual
- Approach 2: Produce a stable water and a stable system where no residual is required
- Approach 3: Keep a residual, but work to minimize the residual required and the byproducts produced
- In other words, can we maintain a residual without major sacrifice?

Minimize the residual required and the byproducts produced

- Treat water to improve stability
- Do those system improvements
- Choose Oxidants that provide:
  - Maximum residual stability
  - Maximum biofilm control
  - Minimum toxicity
  - Minimum DBP formation
  - Minimize taste and odor

Comparison of oxidants most often used for residual control

Disinfectant	Residual Stability	Residual Limit mg/L	Biofilm Control	Byproduct formation	Aesthetic Properties
Cl_2					
ClO_2					
NH_2Cl					

Comparison of oxidants most often used for residual control

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Cl_2	Good				
ClO_2	Good				
NH_2Cl	Very Good				

Comparison of oxidants most often used for residual control

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Cl_2	Good	4.0 mg/L			
ClO_2	Good	0.8 mg/L			
NH_2Cl	Very Good	4.0 mg/L			

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NH_2Cl	Very Good	4.0 mg/L	Very Good	Good	

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NH_2Cl	Very Good	4.0 mg/L	Very Good	Good	Good

Comparison of oxidants most often used for residual control

Candidate Disinfectant	Primary Strengths	Primary Weaknesses
Cl_2		
ClO_2		
NH_2Cl		

Comparison of oxidants most often used for residual control

Candidate Disinfectant	Primary Strengths	Primary Weaknesses
Cl_2	• Fast Acting • Residual is Perisistent • Removes Many Agal odors	• Too many DBPs • Lousy Flavor of its own
ClO_2		
NH_2Cl		

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Cl_2	• Fast Acting • Residual is Perisistent • Removes Many Agal odors	• Too many DBPs • Lousy Flavor of its own
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NH_2Cl		

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Cl_2	• Fast Acting • Residual is Perisistent • Removes Many Agal odors	• Too many DBPs • Lousy Flavor of its own
ClO_2	• Fast Acting • Residual is Persistent	• Limited to low doses
NH_2Cl	• Extremely Persistent • Low DBPs • Better biofilm	• Slow Acting • Subject to nitrification • Doesn't control HPC as well

So can we make residuals work?

- Answer is yes
- But nothing is perfect and we still have much to learn, particularly about the management of chloramines

So can we make do with out a residual?

- As a practical matter, I'm inclined to think there are situation where it makes sense
  - Where the water is biologically stable before it enters the system
  - Where system does not have metallic conduits
  - Where the water system is not held accountable for opportunistic pathogens (e.g. *Legionella*)
  - Where regulations allow
- On the other hand, there are situations where I think it does not make sense:
  - not surface waters in the U.S. (regulations)
  - not if water systems are to be held accountable for opportunistic pathogens
  - not in systems with significant amounts of unlined iron pipe

So can we make do with out a residual?

- In the U.S. we are likely to continue with a residual maintenance strategy - at least for surface waters
- However that should not be an excuse for avoiding proper water treatment
- I'm hoping we in the U.S. will learn from European experience.
  - Most of the forces at play when there is not a residual are still present when a residual is used
  - And we need to learn how to manage them better

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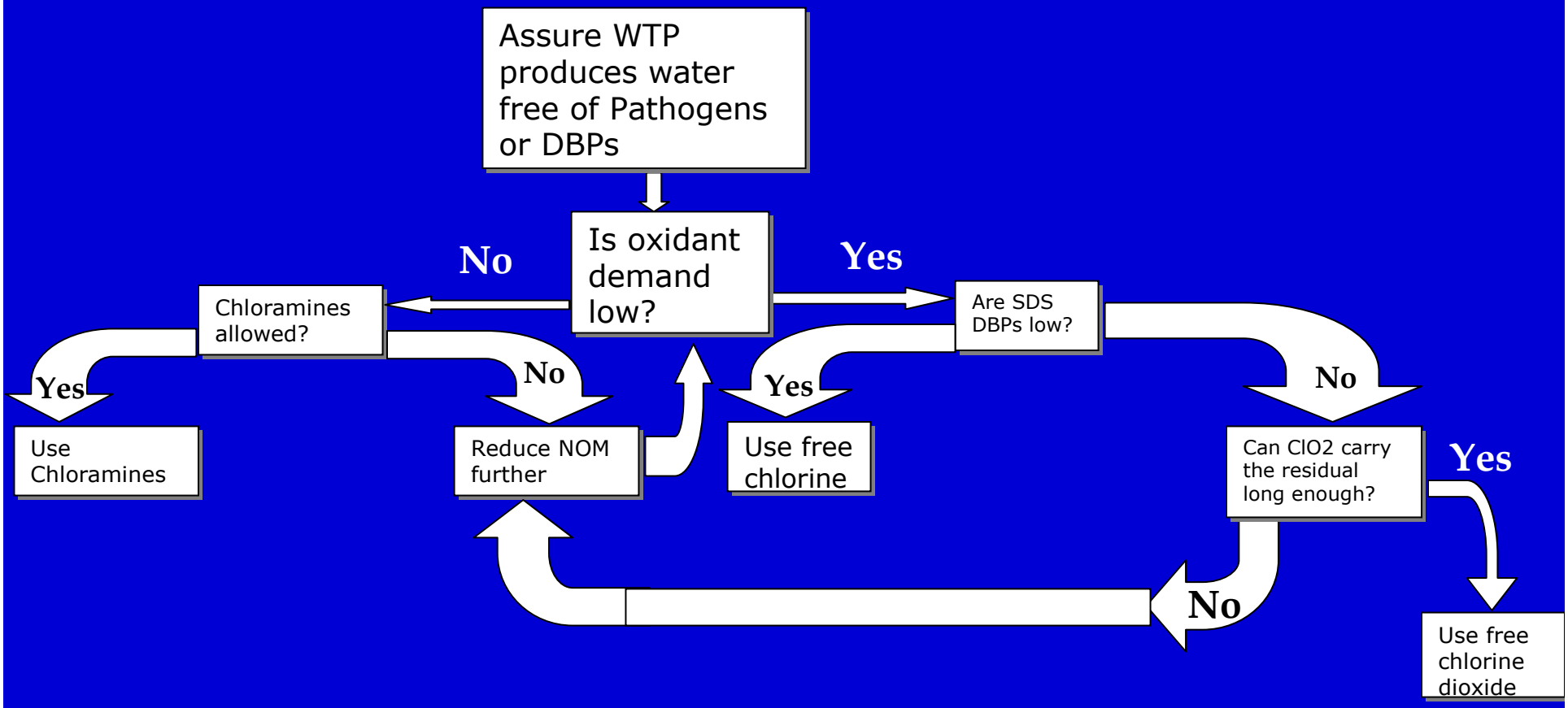
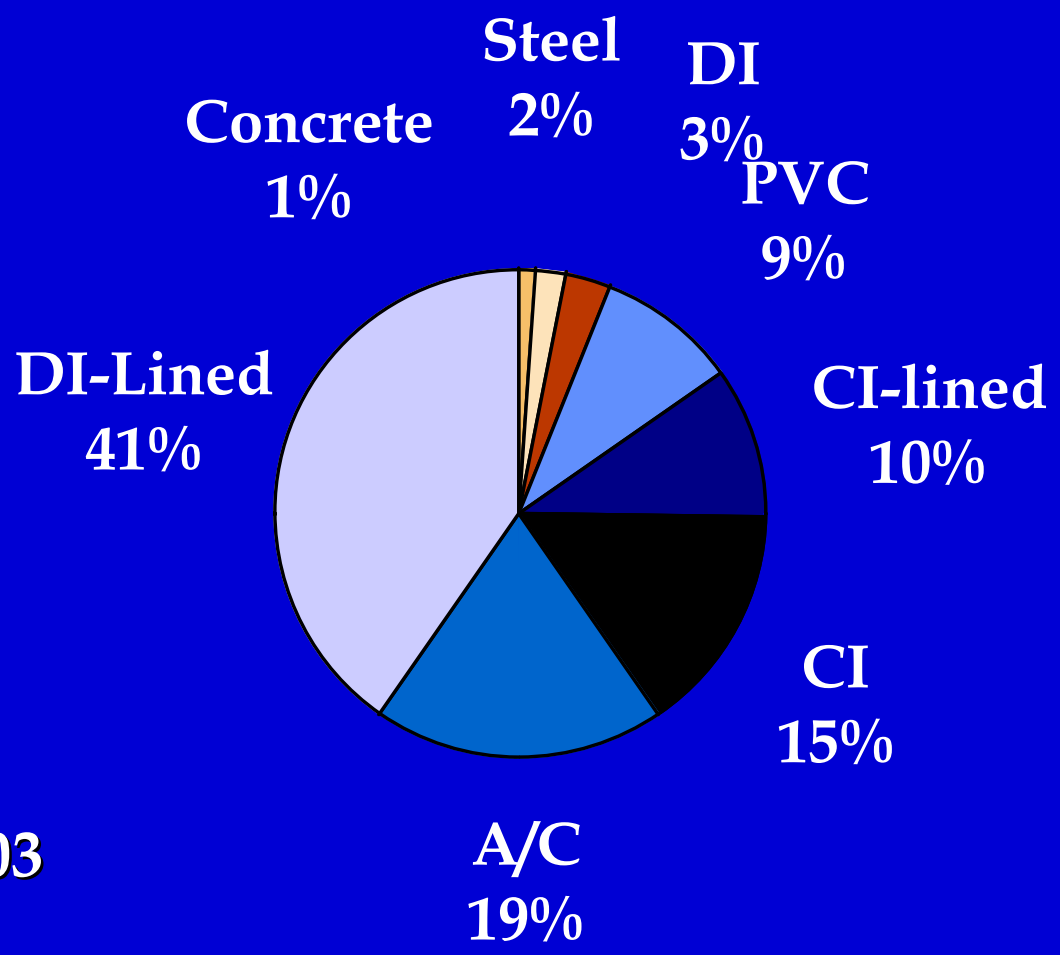
The decision-making process taking place in the US today



Distribution of materials in US distributions systems



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