National Association of Nephrology Technicians/Technologists

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How Do Carbon and Chlorine Actually Work?

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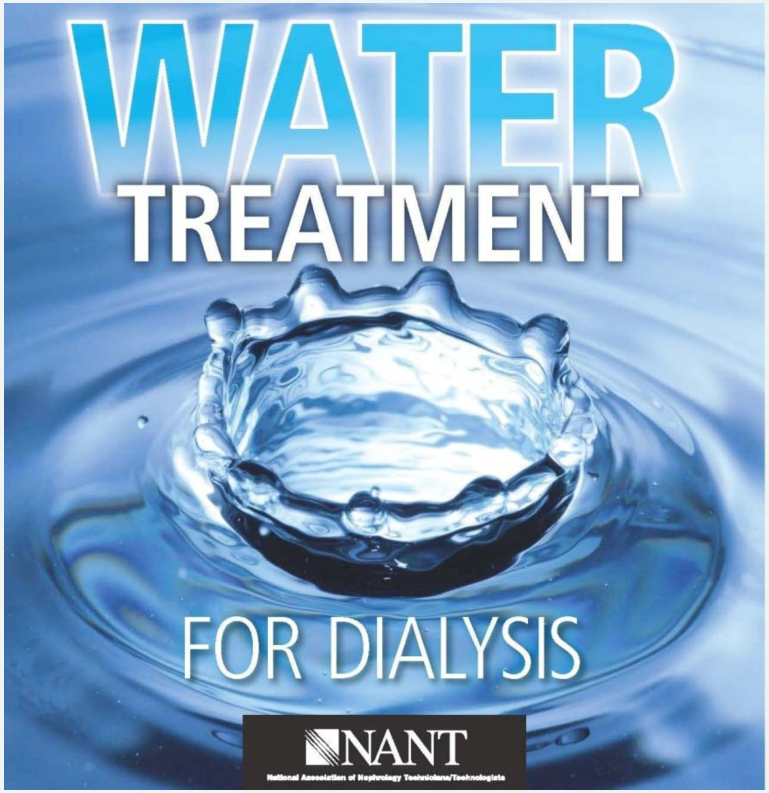
How Do Carbon and Chlorine Actually Work

This Presentation Covers

- ❑ Chlorine
- ❑ Carbon (Granulated Activated Carbon (GAC)
- ❑ Monitoring of Chlorine (Measurement & Instrumentation)
- ❑ Chlorine Problems
- ❑ Carbon Problems

There is an addendum at the end of the presentation (When Municipalities Switch to 100% Free Chlorine) which is included for further reference. Time does not permit inclusion in the presentation

Compliments NANT's Water Treatment Handbook (not a substitute)



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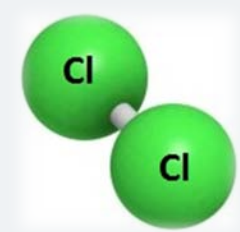
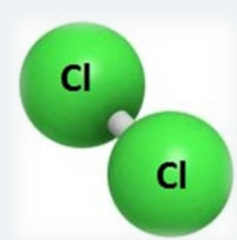


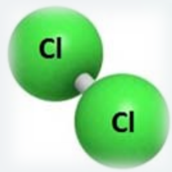
Chlorine is introduced into hemodialysis water treatment systems at two locations :

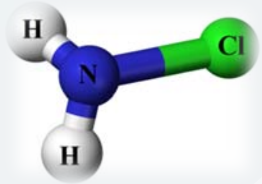
- ❑ Through the municipal supply feed water stream
- ❑ Through the disinfection process of water treatment components and systems



Municipal Water supplies typically have chlorine in three different forms:

- ❑ Dissolved free chlorine
- ❑ Dissolved combined chlorine (mono-chloramines, multi-chloramines, etc.)
- ❑ Chlorine in chlorinated suspended solids such as organics

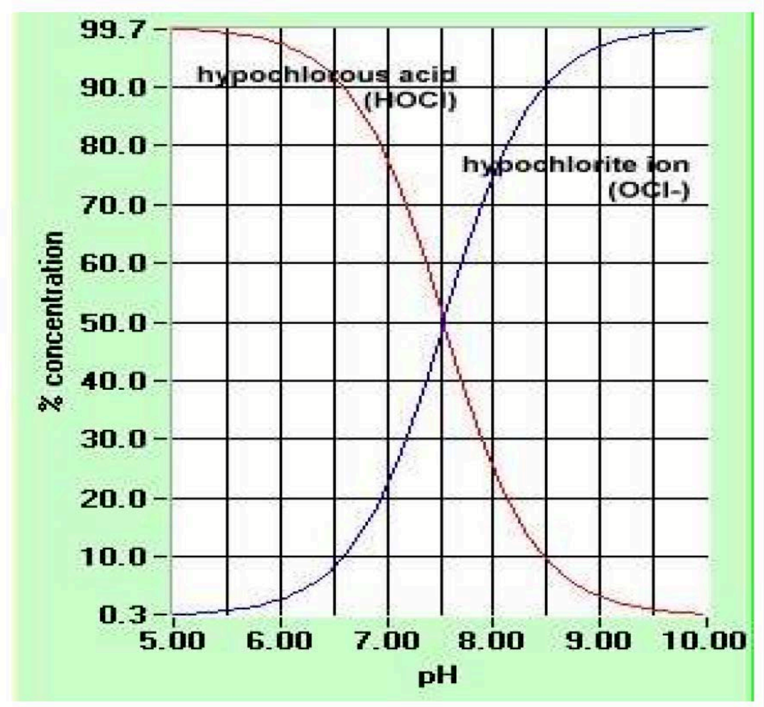




Municipal Water Supplies:

- Use chlorine to disinfect the water
- Originally done by adding chlorine gas to water producing dissolved free chlorine
- Discovered that Trihalomethanes (THMs) a by-product of free chlorine reacting with organics in the municipal water supply were carcinogenic
- Added ammonia into water supply to react with dissolved free chlorine to <u>produce combined chlorine</u> which resolved the THM problem <u>but created another</u>

Free Chlorine/Combined Chlorine Ratio by pH



Dissolved Free Chlorine:

- **Reacts with carbon** on contact (immediately)
- Easy to remove (reaction at top of first carbon bed)
- Not an issue or problem

Dissolved Chemically Combined Chlorine:

- Removed by **adsorption** to granulated **activated** charcoal
- Time and flow dependent – requires sufficient time and low velocity for adsorption
- Empty Bed Contact Time (**EBCT**) is used to indicate the capacity of the carbon bed to remove combined chlorine

Chlorinated Suspended Solids:

- Suspended solids that contain chlorine
- Usually organics exposed to free chlorine
- Can be filtered out of the water (**<u>but not easily</u>** due to small particle size distribution)
- Usually only a problem for municipalities that use surface water

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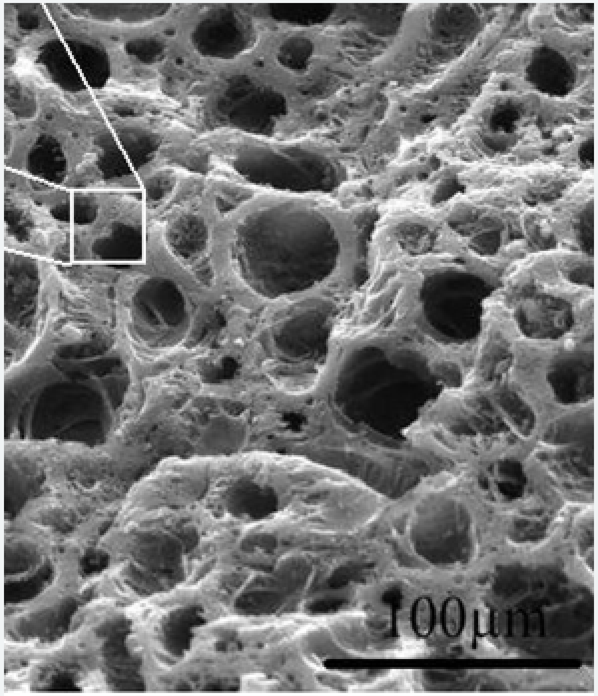
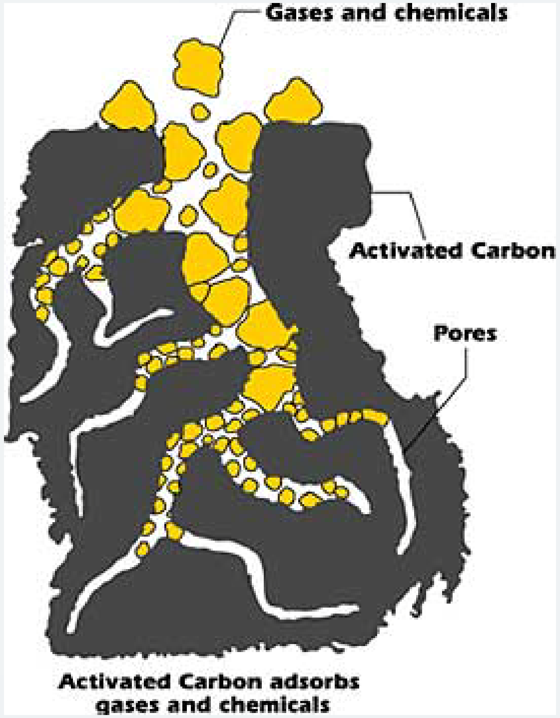
Carbon:

- ❑ Structure is mostly voids
- ❑ Surface area in one table spoon of media = area of a football field
- ❑ Has varying pore size down to sub-micron
- ❑ Pore size distribution is important consideration
- ❑ Media size (12 x 40) minimum

GAC Structure





Carbon Is Typically Made Of:

- Coal
  - Bituminous
  - Lignite
- Coconut Shell

Typical Properties of Granular Activated Carbon

Characteristics	Bituminous	Lignite	Coconut Shell
Iodine Number	1,000-1,100	600	1,000
Molasses Number	235	300	0
Abrasion Number	80-90	60	97
Bulk Density as packed LB/CF	26-28	23	29-30
Volume Activity	26,000	13,800	0

- **Iodine number** is a relative measure of small pores reported in milligrams of elemental iodine adsorbed per gram of GAC. It indicates the ability of the GAC to adsorb low molecular weight organics.
- **Molasses number** measures the degree a media removes color from a stock solution. It indicates the ability of the GAC to adsorb the larger molecular weight organics such as tannins.
- **Abrasion** numbers represent the relative degree of particle size reduction after tumbling with a harder material. No reduction is rated 100, complete pulverization is zero.

Bituminous Coal:

- Almost **universally used** as the media in hemodialysis carbon filters
- High quality (low level of contaminants)
- High abrasion resistance
- Excellent pore-size distribution to meet the demands of municipal supply feed water

Lignite Coal:

- Lower quality (more contaminants, lighter) media (immature coal)
- Inexpensive
- Poor abrasion resistance (dirtier)
- Generally **not first choice** of media for hemodialysis water

Coconut Shell:

- Great, uniform micro-pore pore size distribution
- Most effective carbon for chloramine removal
- Easily fouled by suspended solids in municipal supply feed water
- **Not recommended** for carbon bed filters in hemodialysis water treatment

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Why monitor chlorine in the water treatment system

- Patient safety
  - **<u>Chloramines kill hemodialysis patients</u>**
  - Chloramines can pass through reverse osmosis (RO) membranes
- AAMI/ISO13959:2014 recommends a maximum concentration of 0.1 mg/L for chloramines
- All State Health Departments enforce AAMI recommendations as requirements
- Assurance of complete chloramine removal depends upon vigilant operation of water treatment system

Chlorine Measurement by:

- ❑ DPD(Diethylparaphenylenediamine) technology with reference color wheel or color chart
- ❑ Pocket colorimeter (DPD technology) with digital readout
- ❑ Test strip with reference color chart

DPD (Diethylparaphenylenediamine)

1. Traditional method of testing for chlorine
2. Reacts with **all chlorine** (suspended and dissolved)
3. Not recommended for testing chlorine in pretreatment section of water treatment systems
4. Can be used to identify both free chlorine and dissolved combined chlorine **(if chlorinated suspended solids are not present)**

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5. After a **properly functioning** carbon filter there is **no free chlorine**. The free chlorine reading from DPD is actually **chlorinated organic interference**

6. Chlorine sample port filters (0.1-µm) can be used to filter the post-carbon sample water before testing with DPD. If the chlorine reading is reduced to about 10% or so of the unfiltered water reading, the chlorine is suspended solids. (0.1-µm filter will typically only filter out about 90% of the solids.)

Pocket Colorimeter

1. Basically a more accurate **DPD test** with ability to quantify low values that were not detected before
2. Has all of the DPD issues

Test Strips

1. React only with **dissolved chlorine** (free and combined)
2. Eliminates chlorinated organic interference problem
3. Preferred method of chlorine monitoring in pretreatment

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Chlorine Problems usually occur due to:

1. Mechanical Equipment failures
    a. Carbon filter head seal and/or piston failure
    b. Riser tube failure
    c. Head casting failure
    d. Backwash flow restrictor failure
    e. Riser tube and screw-on distributor separate during the re-bedding of a carbon filter
    f. By-pass valve leaking

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2. Increase in organics due to local floods or other phenomenon can result in naturally occurring multi-chloramines. If persistent, sodium bisulfite may be the only practical solution to the problem.

3. **Municipal water** department **switching to 100% free chlorine** to clean out the distribution system of bacteria that thrive on the monochloramines that the city puts into the water. Special preparation and separate protocols need to be in place (being proactive vs. reactive)

4. Monitoring issues – **false positive readings**

Identifying Real vs. False Positive Chlorine Readings ("Acid Test")

1. 40% to 60% of dissolved chlorine will pass through an RO membrane. Test for chlorine pre-RO, RO product water (permeate), and RO drain water (concentrate).
2. If **chlorine** is **detected** **in the RO product water** and drain water, it is true chlorine **breakthrough**
3. If **chlorine** is **detected only in** the RO **drain water** (concentrate), it is a **false positive** reading.

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4. My experience for chlorine breakthroughs:
    a. 95% are false positives from chlorinated suspended solids (organics)
    b. 5% are real positives caused by multi-chloramines and other dissolved combined chlorine forms
    c. (not scientifically derived – only personal experience)
    d. Real chlorine breakthroughs require:
        i. A carbon filter media re-bed
        ii. An investigation as to why the chlorine breakthrough occurred

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Almost All Carbon Problems Are Caused By Backwashing The Carbon Beds

Carbon beds have historically been backwashed:

1. To remove the silt that has entered the bed and been filtered out at the top of the bed. Carbon is an excellent sediment filter. (If sediment is removed prior, less significant)
2. To “freshen” the bed. It was thought that if the bed was not backwashed that the capacity of the bed would be diminished by the water channeling through the same path in media. (Not proven)

However, Backwashing Of The Media Creates The Following Problems:

1. Contaminants in the feed water are introduced to the bottom of the bed during backwash.
2. The carbon bed is expanded 50% to ensure that these contaminants are distributed throughout the bed.
3. The carbon bed is compressed by fast forward rinse to ensure that the contaminants are trapped in the bed.
4. The contaminants then are sloughed off during the service cycle to contaminate the downstream components.
5. Backwashing carbon beds generates carbon fines which are the principal food of microorganisms living on the RO membranes causing membrane fouling.

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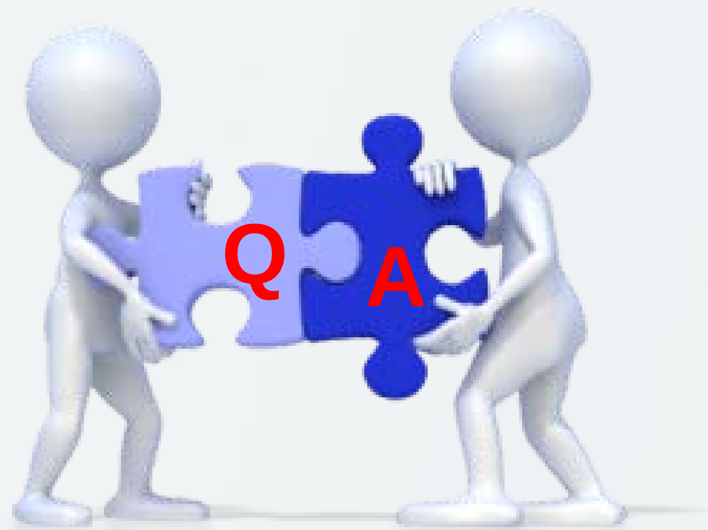
6. Rules for backwashing carbon beds:
    a) Backwash the beds as few times as possible (once a quarter if sediment is controlled before bed)
    b) Always backwash the polisher bed before the worker bed (if backwashed the same day)
    c) Always remember: PROTECT YOUR BOTTOM

Question & Answer:




Addendum

When Municipalities Switch to 100% Free Chlorine:

1. The municipal water department should call the hemodialysis facility to advise of the change at least two weeks in advance. Make sure your facility is on the call list.
2. The city goes to 100% free chlorine to kill the nitrification bacteria that thrive on the ammonia that is added to the free chlorine at the treatment plant to make monochloramines.

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3. Starting on the first day of the 100% free chlorine water, a bloom of dead bacteria will flood the end users water system. This bloom will continue as long as there are nitrification bacteria in the distribution system. The quantity of dead bacteria will follow an exponential decay.
4. By the end of the two weeks (typical) period of 100% free chlorine, the organics will be significantly reduced and the major part of the chlorine will be free chlorine.

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3. The carbon filter is then forward rinsed in order to compact the bed once again. This means that all of the dead bacteria that were easily introduced to the expanded bed are not compacted into the entire bed.

4. During service these bacteria and their body parts will gradually slough off

5. The same process will happen to the secondary carbon filter. The increased flow will punch the bacteria through the primary carbon filter and expose the bottom of the secondary filter to the bacteria.

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If no preparations are taken before the first day of the 100% free chlorine water:

1. The bloom of dead bacteria will be filtered by the primary carbon filter and most likely will not be detected
2. When the carbon filter is backwashed that night, the supply water is then introduced to the bottom of the carbon bed at an increased flow (typically 30 gpm) in order to expand the bed 50%. This causes chlorinated dead bacteria to be spread throughout the bed.

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6. At the beginning of the second day the primary carbon filter will show breakthrough, the second carbon filter will show breakthrough, the biotech gets a 4:00 AM phone call, and panic and pandemonium runs rampant.
7. The water vendor then gets a 5:00 AM call to come and change out carbon. If the breakthrough cycle is just at the beginning, the water treatment company will get another call when they are half way to the facility telling them that it was a false alarm, the biotech checked for chlorine and the nurse must have made a mistake. Then within a day the water treatment company will get another call advising that it really is a breakthrough.

Recommended Temporary Operating Practices When Municipals Switch to 100% Free Chlorine:

1. After receiving the two-week warning, advise the medical director and facility administrator about the upcoming change

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2. If the facility does not have sodium bisulfite injection, contact the water treatment vendor and get portable exchange (PE) carbon tanks installed before the primary carbon filter. It is important that the PE tanks be installed in parallel to ensure the minimum velocity through the tanks. The carbon media will filter out the organics. If the municipal delivery system is exceedingly contaminated by nitrification bacteria, two PE tanks may not last for the whole two weeks.

3. Program the carbon filter heads to not backwash for the duration of the municipal distribution system cleaning (two weeks typically). Document any changes in the water treatment log.

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6. Replace the PE carbon tanks if necessary
7. After the city returns to the normal free and combined chlorine disinfection combination, remove the PE tanks and put the water treatment system back into its original conditions. Document the changes in the water treatment log.

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4. Use test strips to monitor for chlorine (if normally using traditional DPD testing). If chlorine is detected with the DPD method, verify the RO product water to ensure that it is a false positive (in addition to the test strips in pretreatment).
5. If a false positive chlorine reading is detected, have a procedure in place to periodically test the RO permeate water to ensure that a false positive reading does not mask a true positive reading.

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