DECHLORINATION

With Activated Carbon



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ACTIVATED CARBON

DECHLORINATION WITH ACTIVATED CARBON

The most common method of maintaining biologically safe drinking water supplies is by using some form of residual chlorine disinfectant. Many end users require the removal of this disinfectant from water. Granular activated carbon (GAC) is the most effective and reliable technology for dechlorination. Free chlorine is removed by a catalytic reaction which occurs on the particle surface and in the macropores.

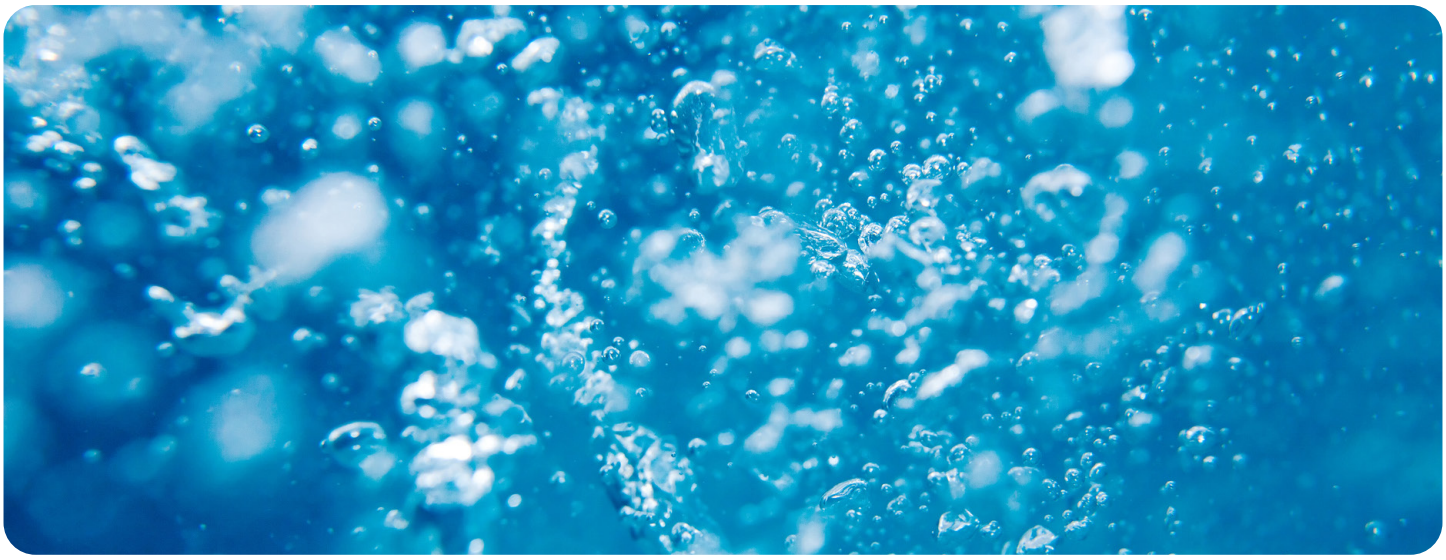
An additional benefit of GAC treatment is the removal of organic compounds, often responsible for unpleasant tastes and odors in the source water. NORIT® produces several carbons ideal for this application, the DARCO® granular series, the NORIT granular series, and the pelletized NORIT ROW 0.8. These carbons have a combination of high external particle surfaces and a large number of macropores for rapid dechlorination. The large transitional pore surface area is especially effective for adsorbing the dissolved organic compounds, which create unpleasant tastes and odors.

CHEMICAL FORM OF DISINFECTANT

Residual chlorine for biological control can be added to water in several forms. The most common method is direct chlorination by injecting chlorine gas. Chlorine may also be added as a solid in the form of sodium hypochlorite. Some municipal systems are using chlorine dioxide.

Some plants are using chloramines to reduce the formation of disinfectant byproducts. In this case, direct chlorination with chlorine gas is followed by injecting ammonia to produce monochloramine.

Activated carbon will catalytically remove these disinfectants using an oxidation/reduction reaction. There are, however, important adsorber design differences depending on the chemical form of the disinfectant.





CHLORINE REMOVAL

Chlorine may be added as chlorine gas or as sodium or calcium hypochlorite. Normally, levels of 1-5 ppm chlorine are added at the water purification plant with the goal of having a residual 0.1 ppm reaching the consumer. Some bottling plants may super chlorinate the water to over 10 ppm. In water, free chlorine reacts to form hypochlorous acid.

$$Cl_2 + H_2O \rightarrow HCl + HOCl$$

Chlorine + Water → hydrochloric acid + hypochlorous acid

The hypochlorous acid dissociatesin water to form the hypochlorite ion (OCl^-). This is the active disinfectant form of free chlorine.

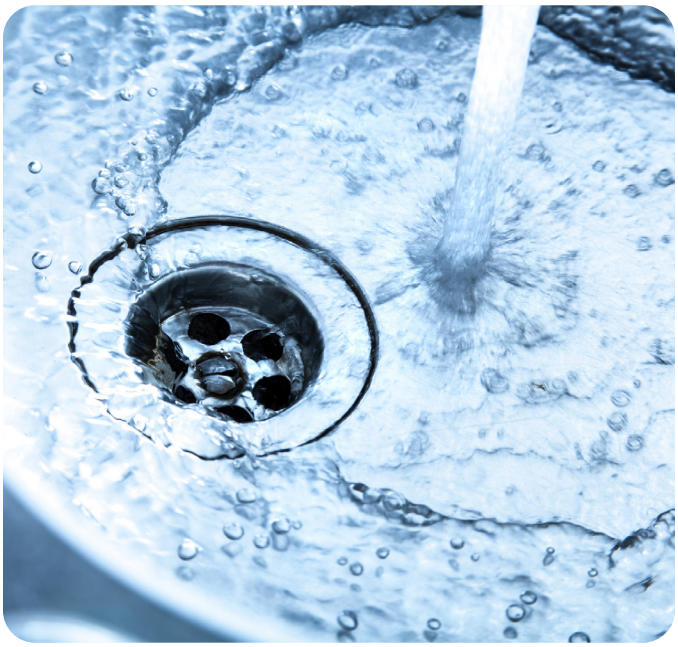
Activated carbon is often used as an adsorbent to retain dissolved organic compounds, which impart tastes and odors to the water. In the case of dechlorination it is not adsorption, but a chemical reaction, which removes the hypochlorous acid. The C* represents the surface of the activated carbon in this simplified expression of the dechlorination reaction.

$$HOCl + C^* \rightarrow HCl + C^*O$$

This reaction is relatively rapid. With optimal conditions, the chlorine concentration can be cut in half every few seconds with 99% removal in minutes.

CHLORAMINE REMOVAL

Hypochlorous acid has been the primary disinfectant for many years. It is a very strong oxidant that reacts with naturally occurring dissolved organic material to produce trihalomethanes (THM). Studies have shown that THMs are carcinogenic.



The EPA has placed maximum limits on this type of compound. To meet these regulations, many municipal water purification plants have switched from direct chlorination to the less chemically aggressive chloramines. Chloramines still provide residual biocide protection while generating much lower levels of THMs. There have been recent health concerns about chloramines and their byproducts.

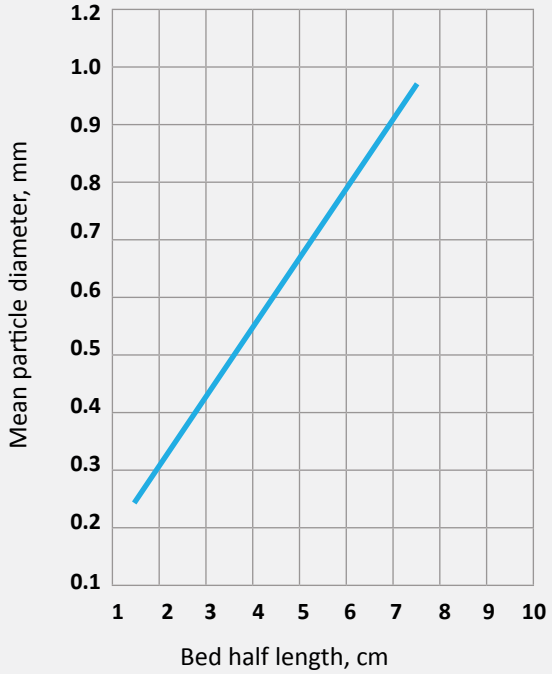
The switch to chloramines has created problems for industrial and commercial operations, which dechlorinate their water. While activated carbon catalytically removes both chloramines and hypochlorous acid, chloramines require much more reaction time. Most GAC adsorbers in dechlorination service were initially designed to remove hypochlorous acid. When local municipalities change to chloramines, these adsorbers are usually undersized.

Chloramines may be present as mono-, di-, and tri-chloramine. At normal pH levels, the monochloramine is the predominant chemical form. There are two reactions taking place to remove monochloramine.

1. $NH_2Cl + H_2O + C^* \rightarrow NH_3 + HCl + C^*O$
2. $2NH_2Cl + C^*O \rightarrow N_2 + C^* + 2HCl + H_2O$

Initially, only the first reaction takes place. When surface oxides have built up, the second reaction occurs, converting the ammonia to elemental nitrogen. Early in the life of a GAC bed, a 5-10 minute retention time will remove over 95% of the chloramines. However, at equilibrium, empty bed contact times (EBCT) of 25-30 minutes may be required.

Figure 1

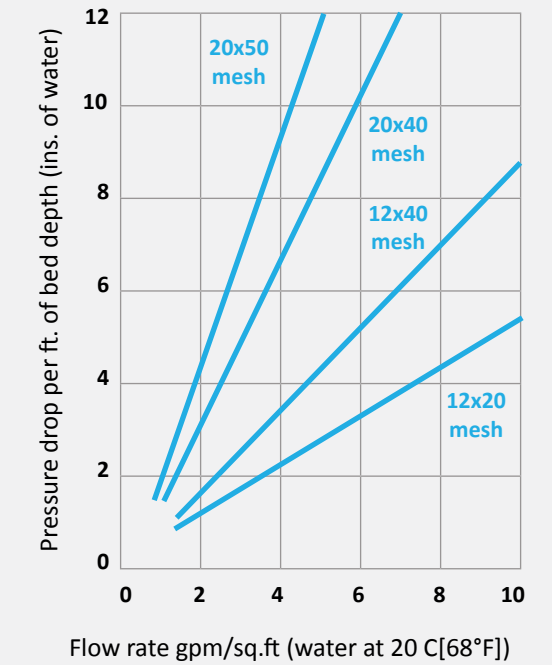


PARTICLE SIZE EFFECTS

The smaller the GAC particles are, the faster the dechlorination rate. A disadvantage of smaller particles is a higher pressure drop. Generally, a 12x40 mesh GAC is more than twice as effective as an 8x30 mesh GAC. Likewise, a 20x40 mesh GAC is up to 50% more effective than a 12x40 mesh GAC; see Figure 1. However, the smaller 20x40 mesh GAC has about double the pressure drop of the 12x40 mesh GAC and four times the pressure drop of the 8x30 mesh GAC.

The effects of particle size on a GAC bed pressure drop are demonstrated in Figure 2 for DARCO granular grades typically used for dechlorination. Pressure drop characteristics for DARCO GACs are described by the following equation, which should be used at high flow rates or where high/low water temperatures significantly affect viscosity.

Figure 2



$$\triangle P = 129 \frac{uVL}{D_p^2 D_c^2}$$

Where:

- △P = pressure drop in inches of water
- u = viscosity in centipoise
- V = flow rate in gallons per minute
- L = GAC bed height in feet
- D_p = geometric mean particle diameter (GMD) in millimeters
- D_c = column diameter in inches
- DARCO granular 12x20 GMD = 1.20 mm
- DARCO granular 12x40 GMD = 0.92 mm
- DARCO granular 20x40 GMD = 0.63 mm
- DARCO granular 20x50 GMD = 0.55 mm

pH EFFECT

The pH of the water being treated has an important effect on dechlorination halving value. GAC is very effective for removing HOCl, which is the primary form of chlorine in water below pH 7. At a pH of 8.5 and higher, however, the chlorine exists primarily as the hypochlorite ion (OCl^-).

GAC efficiency drops off sharply at high pHs. While it may take less than 20 seconds of contact time for 99% chlorine removal at a pH of 7, it could require over 3 minutes for the same chlorine reduction at a pH greater than 9. This can be an important consideration for the designer. If source water pH fluctuates, there may occasionally be chlorine breakthrough, which indicates the need for a larger adsorber. The adsorber should be designed to accommodate the highest expected pH during normal operation.



TEMPERATURE EFFECT

At higher temperatures, the dechlorination reaction is faster. For example, the time required for chlorine removal at 35°F is double the value at 88°F, requiring twice the GAC bed volume to achieve the same effluent chlorine level. It is a good practice to design the GAC adsorber for winter water temperatures.

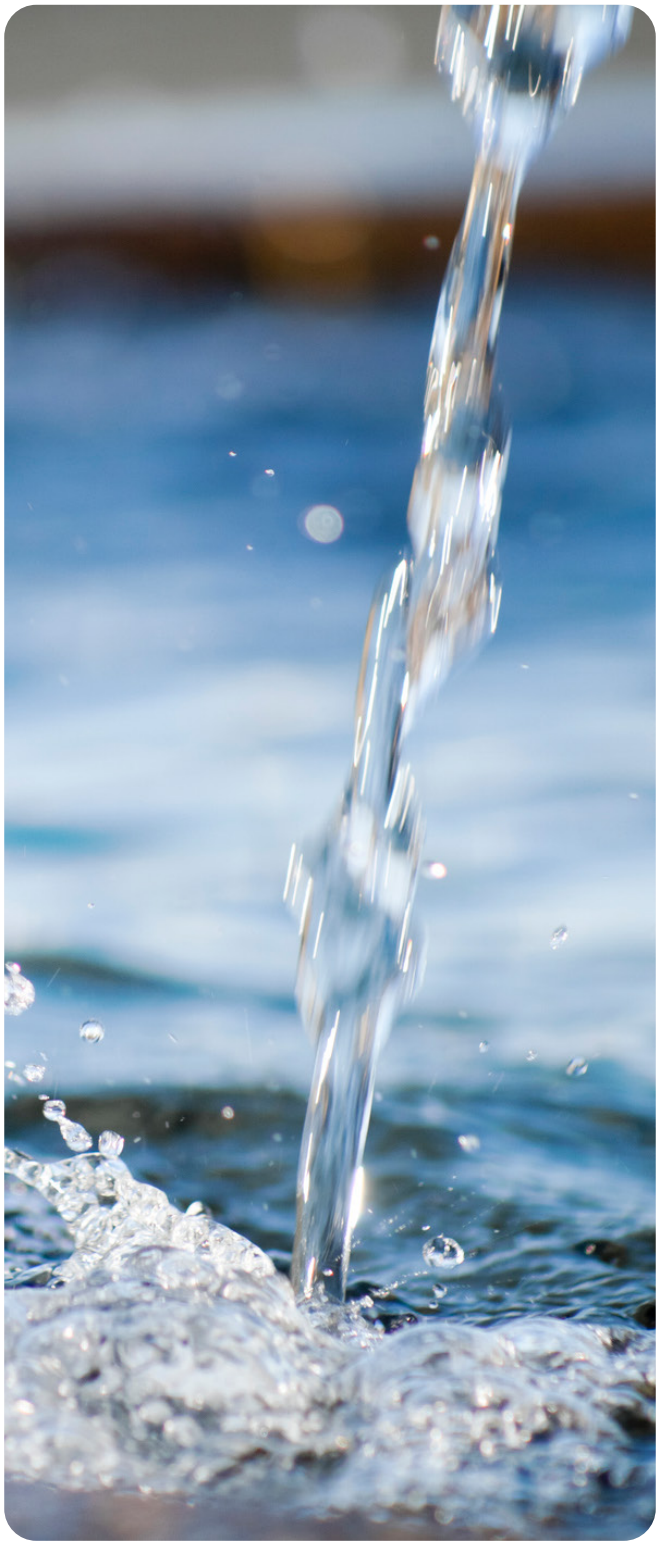
IMPURITIES

Generally, impurities in the source water shorten the life of a GAC bed. Suspended solids and colloidal material will plug up the macropores, creating a higher halving value and increasing pressure drop. Regular backwashing will remove some of this material.

Organic compounds, typically causing taste and odor, are adsorbed onto the carbon. They reduce the dechlorination efficiency of the GAC because they form a thin molecular coating over the carbon surface. Some of the smaller organic molecules are eventually oxidized by incoming chlorine. However, many of the larger compounds are not easily oxidized.

Large pore volume activated carbon grades like the DARCO granular series, the NORIT granular series, and NORIT ROW 0.8, are less susceptible to fouling with organic impurities due to their high adsorption capacity.

In systems with very clean source water, GAC beds will effectively dechlorinate for many years. Most waters, however, contain at least small quantities of dissolved organics, which usually deplete the GAC bed in 1-3 years.



GAC ADSORBER STARTUP PROCEDURE

NORIT GAC grades are delivered in bags, super sacks, and bulk trucks. Sufficient GAC should be ordered to fill the adsorber 2/3 to 3/4 full, leaving approximately 50% freeboard above the backwashed and drained bed height. Do not overfill the adsorber: leave sufficient freeboard to allow for bed expansion during the backwash step.

CHARGING THE ADSORBER

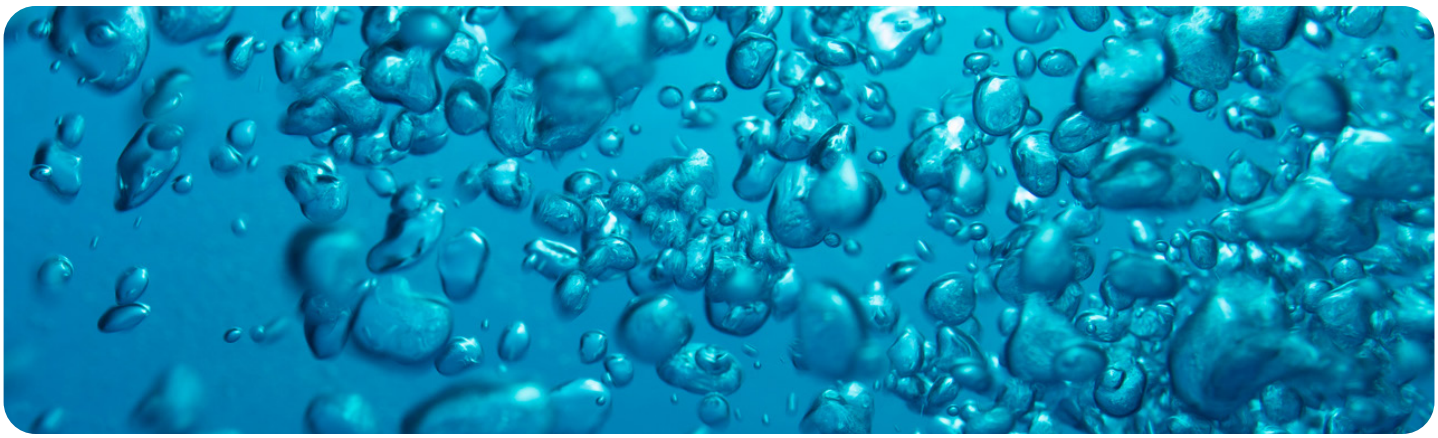
1. Prior to charging the adsorber with GAC, it should be filled with water under hydraulic pressure to check for gasket leaks. After a successful pressure test, drain the adsorber and open the top manway. If the adsorber is equipped with screened distribution nozzles (typical) or a bed support screen over the outlet line or distributor, then skip to step 4.

2. Some adsorbers use GAC bed support media, for example, gravel or anthracite. Some manufacturers design the adsorbers to take layers of graded support media. The larger media goes in first; each layer should be leveled before adding the next smaller size of support media. The particle size of the top layer of media should be 1-3 mm. Support media should cover the top of the outlet distributor to a depth of 4 inches.

3. After loading the support media, it should be backwashed to remove any fine material or impurities. Backwash the support media at the rate indicated by the backwash expansion curve for 30% bed expansion.

4. If gravity loading the new GAC from bags, partially fill the adsorber with water to a level of 2 feet above the support bed or screen. Maintain a water level over the GAC bed while charging, as this will cushion the impact as GAC is poured in. Fill 2/3 to 3/4 of the available volume with GAC, leaving sufficient room for bed expansion during the backwash.

5. Allow the GAC to soak for at least 8 hours to remove most of the air from the pores of the activated carbon.

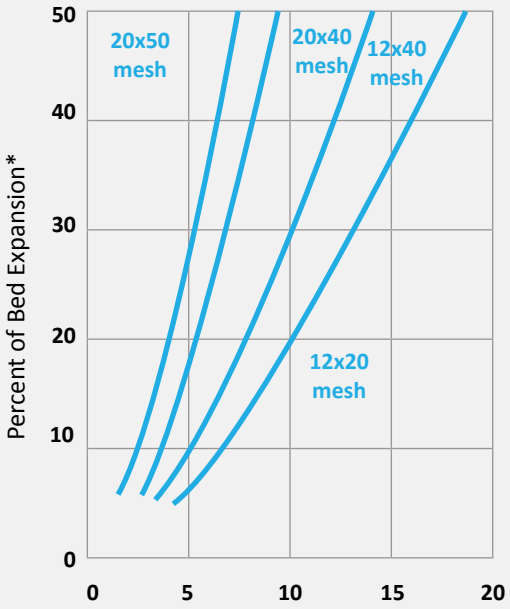


INITIAL BACKWASHING

Prior to putting a new GAC charge into service, it should be backwashed to remove any fines generated during shipping and loading of the GAC. Start backwash slowly (i.e. 2-3 gpm/sq.ft.). This will flush out any air trapped in the bed. Continue increasing the backwash flow rate to achieve approximately 30% bed expansion; use a backwash expansion curve (provided by NORIT) to determine the proper flow rate for your GAC grade (see examples in Figure 3). Continue backwashing for an hour or until the exit water is free of any fines or particulates. After backwashing, adjust valves for normal downflow operation. In ultra-pure water applications, it is suggested that backwashing be followed with a downward rinse cycle to remove any fines trapped in the bottom of the adsorber.

The example backwash curves in Figure 3 show fluidization of DARCO granular grades over a broad range of bed expansions in water at 68°F. When water gets cold, the viscosity increases significantly, increasing bed expansion. If back flush rates are not reduced at low water temperatures, then the GAC may be washed out of the adsorber.

Figure 3



*Expansion is expressed as percent of the backwashed and settled bed depth

Please ask your NORIT regional sales manager for backwash rates. The equation below can help with estimation if another option is needed.

$$F = 10.9 \frac{AD_p}{u}$$

F = gallons per minute
A = cross section flow area in square feet
Dp = geometric mean particle diameter (GMD) in millimeters
u= viscosity in centipoise (Table B)

ROUTINE BACKWASHING

If the water being filtered contains suspended solids, it may be necessary to periodically backwash the adsorber. Normally, a 10-15 minute backwash with approximately 30% bed expansion is sufficient to remove trapped solids from the GAC bed. Backwashing is effective for removing dirt and debris that build up on the top few inches of the GAC bed. Typically, backwashing is triggered by increasing pressure drop, although some units are on automated timers. Backwashing does not regenerate the GAC bed: adsorbed organics will stay on the activated carbon.

STERILIZATION

Activated carbon can become fouled with biological growth after being in service for several months. To avoid this, the bed should be sterilized periodically. Sterilizations can be accomplished by steaming, hot water recirculation (minimum 180°F), or super chlorinating the GAC bed. Steaming is generally the most effective sterilization procedure.

Steam Sterilization Suggestions

Make sure any equipment exposed to steam and hot condensate is compatible with the high temperatures.

1. Carbon needs to be heated completely to at least 85°C (180°F)
2. Steam cycles usually take around 8-10 hours and involve steam over 105°C (220°F)
3. Maximum steam temperature should be limited to less than 110°C (230°F)
4. Face piping should also be sanitized, and all valves exercised
5. Vessel should be backwashed before and after steaming

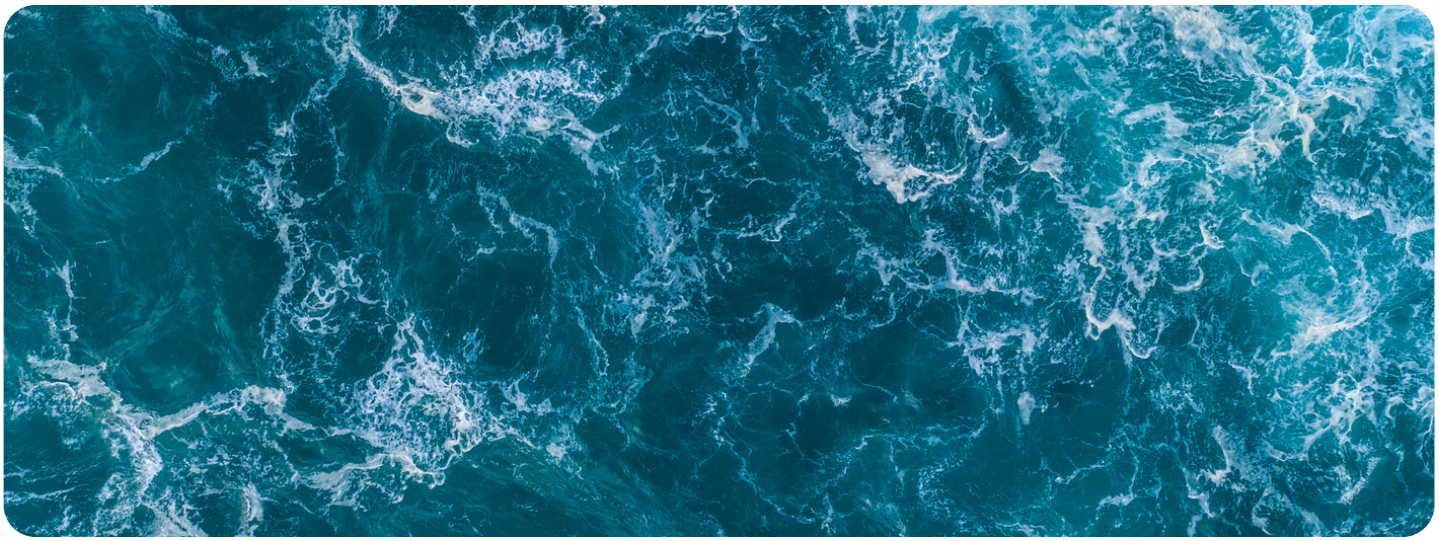


Table B

Viscosity of Water	
Temp. F	*Cp*
0	1.79
40	1.55
50	1.31
60	1.12
70	0.98
80	0.86
90	0.76
100	0.68



SUPER CHLORINATION

When steam is not available, or equipment suggestions are not compatible with higher temperatures, super chlorinating the GAC bed will sterilize it. Verify that the system components are compatible with the hypochlorite solution.

1. Isolate the adsorber, drain it, and close the drain valve.

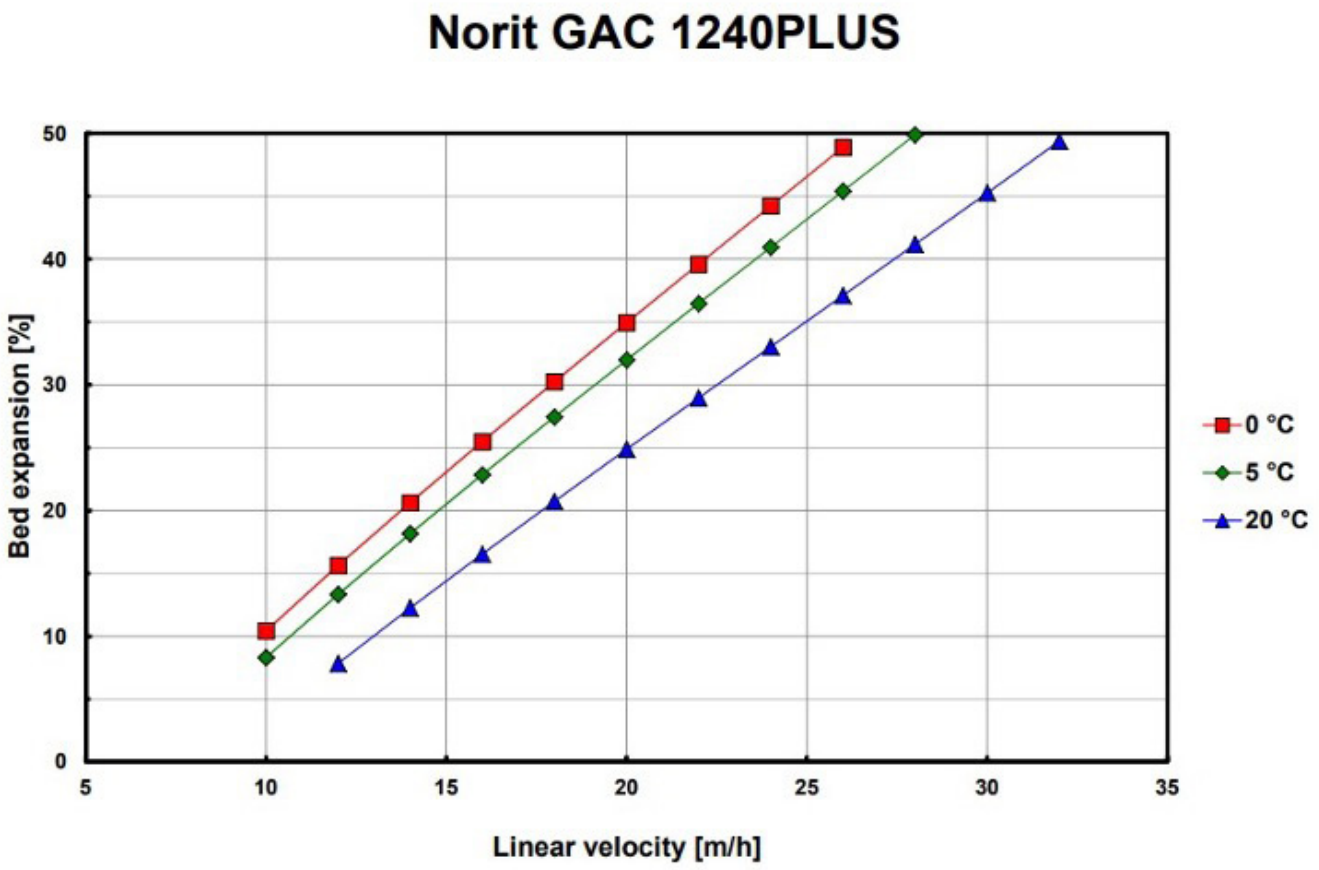
2. Using 2.5% hypochlorite solution (common household bleach), pour one gallon per 25 cubic feet of GAC bed into the top of the adsorber.

3. Partially open the backflush valve and slowly fill the adsorber with water to 1-2 feet over the GAC bed.

4. (Optional) If an air source is available, hook it to the backwash line and let it bubble up through the column. Do not vigorously blow air up through the GAC bed. The goal is to gently stir the hypochlorite solution; do not agitate the GAC bed.

5. Soak the GAC bed in hypochlorite solution for 8 hours, then drain the bed.

6. Backflush the adsorber for at least 30 minutes and the free chlorine level is nondetectable before putting it back into service.



Some source waters are high in dissolved organic material. These compounds often impart unpleasant tastes and odors to the water and are adsorbed onto the carbon. Eventually, the organic loading will interfere with dechlorination. Cold water temperatures will also reduce dechlorination efficiency.

If the adsorber is designed for 60°F operation, there may be a chlorine breakthrough when a cold snap forces source water temperatures down to 40°F. Likewise, an increase in water pH from 8 to 9 will reduce dechlorination efficiency by 20%.

For locations where source water properties can deviate significantly from design conditions, increasing GAC bed volume provides a greater margin of safety. It is generally more economical to increase bed volume with greater bed depth. If the resulting bed depth exceeds 8 feet, then go to the next larger vessel diameter.

This general design information is based on experience with GAC in dechlorination applications and is intended to provide guidelines to help the designer specify the proper size of a GAC adsorber. This design information is conservative for most applications; however, no warranties are expressed or implied. When the source water has high pH excursions, low winter temperatures, or high levels of organic contamination, the designer may choose to improve the margin of safety. Contact your NORIT representative for more information concerning the use of GAC in your specific applications.

ADSORBER VESSEL

Materials of construction are determined by vessel size, service pressure, and sterilization method. Generally, stainless steel or coated carbon steel vessels are preferred for steam or hot water sanitization. If neither steam nor hot water sanitization will be used, carbon steel vessels can be lined with suitable liners, such as epoxy, vinyl ester, or rubber. Ensure that the specified materials of construction for both the adsorber and the piping are compatible with the sterilization method, i.e. steaming or super chlorinating.

Adsorbers in dechlorination service should be designed for down flow operation. If the inlet line comes through the top head of the adsorber, directing flow directly onto the GAC bed, then it should be baffled so the flow does not disturb the bed. An inlet line entering the top side of the adsorber does not need to be baffled. The bottom of the adsorber should be equipped with a distributor to pick up the treated water.



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