GRANULAR ACTIVATED CARBON

Putting It All Together

By Charles "Chubb" Michaud

This is the third and final article in a three-part series on Granular Activated Carbon.

In an academic environment, a student who is correct 90% of the time graduates with awards and honors. To design a water treatment system that works 90% of the time would be to exhibit a total disregard for the well being and safety of the consumer. We, the "water doctors" of our industry, have the responsibility to provide treatment of adequate design and provide a full "disclosure" of the degree of probable success if there is any doubt. This is particularly true of Granular Activated Carbon (GAC) treatment of influent waters where the specific intent of the GAC is to remove or reduce the presence of a health hazard.

In Part II of this series, we discussed the effects of variables such as contaminant type and concentration, pH, temperature, flow rate and type of GAC on the design of the GAC system. In Part III, we will set some guidelines for designing complete systems and provide the reader with some reference point chemical compounds to provide starting points. Equally important, we will discuss some of the aspects of proper system maintenance to insure a continued performance.

Risk Assessment

Earlier, we alluded to an undefinable "fudge" factor in the design of a GAC system. That factor was termed "risk assessment". Two compounds of equal adsorbability-one with a noxious odor, the other a carcinogen; obviously, we do not design the GAC systems for their removal in identical proportions. The chart that follows provides a reference for sizing a GAC contactor with average flow rates based upon average risks, 70°F and pH 7.

To use this chart, first select the proper column (1-6). Next, find the tank size range by identifying the smallest size that exceeds your flow rate needs as a maximum flow and the smallest size that covers the flow rate requirements as a minimum. As Example #1, 150 gpm chlorine removal. The smallest size for "max" is 48″D (190 gpm), the smallest size for "min" is 72″D (170 gpm). We therefore have three choices: 48″, 60″ and 72″. Next we choose the size that gives us the proper hydraulics (column D). This is based on 2 to 10 gpm/sq ft. To flow at 150 gpm would exceed the recommended design parameter for the 48″ tank (125 gpm max) so our choice narrows to the 60″ or 72″.

At a 36″ bed depth we have 59 and 85 ft. (col. C) respective GAC volumes. Assuming 70°F and pH 7 with a 12 x 14 mesh GAC, we have EBCT of 2.95 min for the 60″ and 4.25 min for the 72″. Remember, this is arrived at by multiplying GAC vol x 7.5 and dividing by the flow rate:

$$59 \text{ cu ft} \times \frac{7.5 \text{ gal}}{\text{cu. ft}} \times \frac{1 \text{ min}}{150 \text{ gal}} = 2.95 \text{ min.}$$

If our "risk" assessment dictates caution (pre R/O or hypersensitive tropical fish), we might select the larger system. If 90% removal is acceptable, select the smaller system.

In Part II we stated that elevated pH decreases GAC's ability to remove chlorine and elevated temperature increases it. Let's look at our example with an influent of pH 8.5 and 85°F. From our correction factors we see that we should increase our bed volume by approximately 1.3x for a pH of 8.5 and by .85 for an 85°F influent. (You have to read between the lines). Therefore our volume requirements become:

59 cu ft.	x	1.3	x	.85	=65.2 cu ft.
60″D tank volume		pH correction		temp. correction	

Since our 60″D tank has a surface area of 19.6 sq. ft. (col. B), we need to increase our bed depth to 3.3 ft.:

$$\frac{65.2 \text{ cu ft}}{19.6 \text{ sq ft}} = 3.3 \text{ ft.}$$

This is no problem for a tank with a 60″ side shell but we should allow at least 50% freeboard for bed expansion during backwash.

Don't be afraid of bed depth. Our designs here use minimums of 2.5 ft and maximums of 8 ft. However, bed depths of 10 to 12 ft are common, particularly with coarser mesh GAC's. Structural design sand pressure drop dictate the ultimate design.

In some of our examples, correction factors may increase or decrease our

Granular Activated Carbon Flow Rate and Systems Design Chart

(A)	(B)	(C)	(D)		(1)		(2)		(3)		(4)		(5)		(6)	
Size of Vessel inches	Area sq ft	Volume cu ft 36" bd	Flow Rates		CHLORINE		CHLORAMINE		TASTE & ODOR		GEN ORGANICS		TOXIC ORGANIC		RADON	
			Min gpm	Max gpm	Min 2.0	Max 5.0	Min 1.0	Max 3.0	Min 0.75	Max 1.5	Min 0.6	Max 1.5	Min 0.375	Max 1.0	Min 0.375	Max 1.0
8	0.35	1.0	0.7	3.5	2.1	5.2	1.0	3.1	0.8	1.6	0.6	1.6	0.4	1.0	0.4	1.0
10	0.55	1.6	1.1	5.5	3.3	8.2	1.6	4.9	1.2	2.5	1.0	2.5	0.6	1.6	0.6	1.6
12	0.79	2.4	1.6	7.9	4.7	11.8	2.4	7.1	1.8	3.5	1.4	3.5	0.9	2.4	0.9	2.4
14	1.07	3.2	2.1	10.7	6.4	16.0	3.2	9.6	2.4	4.8	1.9	4.8	1.2	3.2	1.2	3.2
16	1.40	4.2	2.8	14.0	8.4	20.9	4.2	12.6	3.1	6.3	2.5	6.3	1.6	4.2	1.6	4.2
18	1.77	5.3	3.5	17.7	10.6	26.5	5.3	15.9	4.0	7.9	3.2	7.9	2.0	5.3	2.0	5.3
20	2.18	6.5	4.4	21.8	13.1	32.7	6.5	19.6	4.9	9.8	3.9	9.8	2.5	6.5	2.5	6.5
24	3.14	9.4	6.3	31.4	18.8	47.1	9.4	28.3	7.1	14.1	5.7	14.1	3.5	9.4	3.5	9.4
30	4.91	14.7	9.8	49.1	29.4	73.6	14.7	44.2	11.0	22.1	8.8	22.1	5.5	14.7	5.5	14.7
36	7.07	21.2	14.1	70.7	42.4	106.0	21.2	63.6	15.9	31.8	12.7	31.8	7.9	21.2	7.9	21.2
42	9.62	28.8	19.2	96.2	57.7	144.2	28.8	86.5	21.6	43.3	17.3	43.3	10.8	28.8	10.8	28.8
48	12.56	37.7	25.1	125.6	75.4	188.4	37.7	113.0	28.3	56.5	22.6	56.5	14.1	37.7	14.1	37.7
60	19.63	58.9	39.3	196.3	117.8	294.4	58.9	176.6	44.2	88.3	35.3	88.3	22.1	58.9	22.1	58.9
72	28.26	84.8	56.5	282.6	169.6	423.9	84.8	254.3	63.6	127.2	50.9	127.2	31.8	84.8	31.8	84.8
84	38.47	115.4	76.9	384.7	230.8	577.0	115.4	346.2	86.5	173.1	69.2	173.1	43.3	115.4	43.3	115.4
96	50.24	150.7	100.5	502.4	301.4	753.6	150.7	452.2	113.0	226.1	90.4	226.1	56.5	150.7	56.5	150.7
108	63.59	190.8	127.2	635.9	381.5	953.8	190.8	572.3	143.1	286.1	114.5	286.1	71.5	190.8	71.5	190.8
120	78.50	235.5	157.0	785.0	471.0	1177.5	235.5	706.5	176.6	353.3	141.3	353.3	88.3	235.5	88.3	235.5

Above data based on hydraulic loadings of 2 to 10 gpm/sq ft. for 12 × 40 mesh GAC, 5 to 15 for 8 × 30 and .5 to 5 for 20 × 50. Minimum bed depth is 2.5 ft. Maximum bed depth is 8.0 ft.

	(a)		(b)		(c)		(d)	
CORRECTION FACTORS	pH	factor	Temp F	factor	% Eff.	factor	Mesh	factor
Mutiply the vol of GAC	5	0.8	50 F	1.4	90.0%	1.0	8 × 30	2.0
by the factors a,b,c,d	6	0.9	60 F	1.2	95.0%	1.3	12 × 40	1.0
to adjust bed size for	7	1.0	70 F	1.0	98.0%	1.7	20 × 50	0.5
pH, Temp, % Efficiency	8	1.2	80 F	0.9	99.9%	2.8		
and Mesh size of GAC.	9	1.45	90 F	0.8				
Adjust tank size, depth.	10	1.75	100 F	0.7				

EXAMPLE: 150 gpm chlorine removal for pre R/O (90%), pH 8.5, 85 F, 12 × 40 mesh.

Chart shows 48", 60" or 72" Dia tank. Choose 60" (mid range).
Vol GAC = 59 c.f.
Vol pH Temp Eff. Mesh
59 cf × 1.3 × .85 × 1.0 × 1.0 = 65.2 cf
62.2 cf – 19.63 sq ft = 3.3 ft bed depth
Hydraulics for 60" tank = 40 to 196 gpm.

GAC Flow Rate Chart

bed volumes such that a change in tank diameter is necessary. Always check the hydraulic design and stay within 2.5 to 8 ft. bed depths, 2 to 10 gpm per sq ft. of surface area and the recommended flow rates per cu ft found at the top of the columns. Follow along with these additional examples:

Example #2 Same as #1 but influent water is 65°F

1. same tank size selection procedure, (60")
2. 59 cu ft. of GAC
3. 59 x 1.3 x 1.1 x 1.0 x 1.0 = 84.4 cu ft.
4. 84.4 cu ft. ÷ 19.63 sq ft. = 4.3 ft. bed depth
5. requires side shell of 84"

Example #3 Same as #l but with 8 x 30 mesh GAC

1. same tank size selection procedure (60")
2. 59 cu ft. of GAC
3. 59 x 1.3 x .85 x 1.0 x 2.0 = 130.4 cu ft.
4. 130.4 cu ft. ÷ 19.63 sq ft. = 6.65 ft. bed depth
5. requires side shell of 120"

Example #4 Taste and Odor Reduction, 100 gpm, 80°F, pH 6

1. tank size is 72, 84 or 96"
2. acceptable hydraulics: 48 to 96" OK for 100 gpm
3. select 84" (mid range) = 115 cu ft.
4. 115 x .9 x .9 x 1.0 x 1.0 = 93.2 cu ft.
5. 93.2 cu ft. ÷ 38.47 sq ft. = 2.4 ft. bed depth
6. below min bed depth, use 2.5 ft bd = 96 cu ft.
7. assumes that 90% reduction of taste and odor is OK

Example #5 Gasoline reduced from 2 ppm to 50 ppb (98% removal) 50 gpm, 75°F, pH 8.3

1. treat as general organic
2. tank size is 48 to 72". Hydraulics show 48 or 60"
3. select 60" (59 cu ft.)
4. 59 x 1.3 x .95 x 1.7 x 1.0 = 123.8 cu ft.
5. 123.8 cu ft. ÷ 19.63 = 6.3 ft. bed depth
6. use 120" side shell

Example #6 same as #5 but with 99.9% removal

1. 59 x 1.3 x .95 x 2.8 x 1.0 = 204 cu ft.
2. 204 cu ft.—19.63 = 10.4 ft. bed depth
3. exceeds bed depth limit for our premise. Use 72" tank
4. 204 cu ft. ÷ 28.26 = 7.2 ft. bed depth
5. use 132" side shell
6. consider a 20 x 50 mesh GAC
7. 59 x 1.3 x .95 x 2.8 x .5 = 102 cu ft
8. 102 cu ft. ÷ 19.63 = 5.2 ft. bed depth

While it would be impossible to cover all the bases, the above chart and examples should permit the user to come up with a workable design for most applications. Generally speaking, when given a choice, be conservative.

Mesh size selection will greatly affect particulate removal and frequency of backwash as well as pressure drop. Prefiltration may be necessary in waters of high turbidity.

Installation of GAC

When loading new GAC systems it will be necessary to precondition the GAC to prepare it for use. On larger systems where top loading is possible it is advantageous to fill the vessel half full of water and drop the GAC into the water-minimizing dust.

If a gravel subfill is used, make sure it is level. Soak gravel or anthracite subfill for two hours, then backwash to remove dirt and fines. After the GAC is loaded, button up the tank and fill the vessel with water. Upflow is preferred to dispel air and gases escaping from the GAC pores. Soak overnight, then backwash until clear. Start the backwash at 5-7 gpm/ft and gradually increase it to maximum bed expansion for at least one hour.

Depending upon the intended use of the GAC it may be desirable to complete the above procedure with a clean water source to avoid loading the bottom of the bed with dirt or organics. For portable exchange, these steps can be carried out at the plant. For large, fixed in place systems, the situation may dictate the use of two columns, utilizing one to backwash the other in alternate service cycles.

Postfiltration

In use, tiny specs of GAC material will eventually work their way through the bed. This is particularly true for GAC in use for heavily chlorinated waters and systems specifically designed for upflow operation. If carbon "flecklettes" pose a problem for you, install a 25 micron (or less) cartridge filter down stream.

Acid Washing

New GAC will contain some water soluble ash and a slightly greater quantity will be acid soluble. This ash will leach with use and give a background TDS of a few ppm for days or even weeks. Even low ash GAC's have a soluble fraction.

The nature of the leachables is usually as metal oxides which become alkalinity (CaO, MgO, Na$_2$O, K$_2$O) in water-raising the pH of the effluent by as much as 2 pH points. This can lead to hardness precipitation if hard water is the feed source. This can play havoc with GAC for pre R/O service.

Acid washing will reduce both water and acid soluble ash components and result in a cleaner effluent of lower pH. Acid washing can be accomplished in situ during the preconditioning soak cycle by introducing about 16 oz (1 pint) of 35% HCl/ft of GAC to the bed, letting it soak overnight, then backwashing. For high ash GAC's or super critical applications, use 2 to 3 times the acid level.

Acid washing must be done in a

Acetaldehyde	4	Emulsions	2	Lead	3	Precipitated Sulphur	2
Acetic Acid	3	Ethyl Acetate	5	Lime	0	Propioic Acid	4
Acetone	4	Ethyl Acrylate	5	Mercaptans	4	Propionaldehyde	3
Alcohols	4	Ethyl Alcohol	4	Metal Salts	1	Propyl Acetate	4
Alkalinity	1	Ethyl Amine	4	Methyl Acetate	4	Propyl Alcohol	4
Amines	3	Ethyl Chloride	4	Methyl Alcohol	4	Propyl Chloride	4
Ammonia	1	Ethyl Ether	4	Methyl Bromide	5	Radon	4
Amyl Acetate	5	Fertilizers	1	Methyl Chloride	4	Rubber Hose Taste	5
Amyl Alcohol	5	Fluorides	2	Methyl Ethyl Ketone	5	Sea Water	1
Antifreeze	4	Formaldehyde	2	Naphtha	5	Sediment	2
Arsenic	1	Gasoline	5	Nitrates	0	Soap	3
Benzene	5	Glycols	5	Nitric Acid	3	Sodium Hypochlorite	5
Bleach	5	Hardness	0	Nitrobenzene	5	Soluble Iron	2
Boron	1	Heavy Metals	3	Nitrotoluene	5	Solvents	4
Butyl Alcohol	5	Herbicides	5	Odors (General)	5	Sulfuric Acid	1
Butyl Acetate	5	Hydrogen Bromide	2	Oil–Dissolved	5	Sulphonated Oils	4
Calcium Hypochlorite	5	Hydrogen Chloride	1	Oil–Suspended	2	Suspended Matter	2
Carbon Dioxide	0	Hydrogen Fluoride	1	Organic Acids	4	Tannins	4
Chloral	5	Hydrogen Iodide	2	Organic Esters	5	Tar Emulsion	4
Chloramine	4	Hydrogen Peroxide	5	Organic Salts	4	Tartaric Acid	4
Chloroform	5	Hydrogen Selenide	3	Oxalic Acid	5	Taste (DI Water)	4
Chlorine	5	Hydrogen Sulfide	3	Oxygen	5	Taste (From Organics)	4
Chlorobenzene	5	Hypochlorous Acid	5	Ozone	4	THM's	5
Chlorophenol	5	Inorganic Acids	1	PCB's	5	Toluene	5
Chlorophyll	4	Inorganic Chemicals	1	Pesticides	5	Toluidine	5
Citric Acid	4	Insecticides	5	Phenol	5	Trichlorethylene	5
Cresol	5	Iodine	5	Phosphates	0	Turpentine	5
Defoliants	5	Isopropyl Acetate	5	Plastic Taste	5	Urine	2
Detergents	3	Isopropyl Alcohol	5	Plating Wastes	3	Vinegar	3
Diesel Fuel	5	Ketones	5	Potassium Permanganate	4	Xanthophyll	4
Dyes	5	Lactic Acid	4	Precipitated Iron	2	Xylene	5

KEY TO ABOVE LIST: 0–Not an application for GAC
1–POOR not a recommended use
2–FAIR limited application
3–GOOD very acceptable results
4–VERY GOOD a proven application
5–EXCELLENT a proven application

vessel that is acid resistant. Short contact times with epoxy lined vessels is OK depending upon the epoxy. PVC, ABS, and FRP exchange tanks are OK. Mild steel, certain stainless steels, copper, galvanized and lead are not. Plan ahead. If necessary, purchase an acid washed grade of GAC.

Disinfection

Acid washing will disinfect new GAC. To treat a bed already in service, chlorine is preferred. Soak the bed 8 hours in 50 ppm of chlorine from hypochlorous acid or sodium hypochlorite. Backwash thoroughly after disinfection since hyper chlorination will cause formation of GAC fines.

Pretreating for Chloramine Removal

It has been found that the removal of monochloramine is facilitated by a buildup of surface oxides on the GAC particles. Until the GAC "acclimates", its performance for chloramine removal may not be satisfactory.

Surface oxides are formed when hypochlorite (OCl^-) ions react with GAC. Therefore, chloramine removal is enhanced by pretreating the GAC with chlorine. For this, common bleach (sodium hypochlorite) is acceptable. Add one pint of bleach per cubic foot of GAC, soak 8 hours or overnight and backwash thoroughly.

This process also disinfects the bed and is a good "rejuvenation" procedure for tired GAC used for taste and odor reduction.

Backwashing

Backwashing does not regenerate or rejuvenate a GAC column. It does, however, remove debris and dirt and small GAC particles that have broken down in service. Backwashing also serves to redistribute the GAC to give better flow distribution and reduce pressure drop. Backwashing will not remove adsorbed materials from the GAC pores. The need for backwashing is usually triggered by pressure drop readings but may be automated to a timed cycle.

Allow sufficient free board in your system design to get at least 50% bed expansion. The following figures can be used to determine the proper backwashing rates for GAC's of 8 x 30 and 12 x 40 mesh.

"Regeneration" of GAC

For certain volatile organic removal systems the GAC media can be reactivated in place by a periodic steaming of the bed. Steam flow is usually introduced opposite to service flow for 10 to 30 minutes. Vessel and piping must be temperature resistant (no PVC). If you plan to include steaming to prolong the useful life of GAC, make sure the tank and its fittings can handle the temperature.

Reactivation of GAC

Spent GAC can be reactivated by the same process used to activate it. This is sometimes referred to as "reburning" or "refiring" the GAC. Most GAC manufacturers will reactivate quantities (usually 100 cubic feet minimum or so) for a fee of about 50 to 60 cents per pound. Expect 20% shrinkage and don't expect any miracles.

Reactivated GAC will never be like new. As discussed in Part II, it may be worse and it may be better depending upon the service requirements and the interplay with the GAC pore structure.

Not all contaminants are removed by reburning. Organics will be vaporized but the inorganic residual from salts and metals will remain. It may be necessary to precondition once again.

Disposal of Spent GAC

GAC that is used for general purpose dechlorination and removal of taste and odor is usually not considered as a hazardous material for disposal. However, if GAC is used to remove a hazardous product from water, it would most likely be considered as hazardous waste for disposal purposes. It is our best advice that you check with

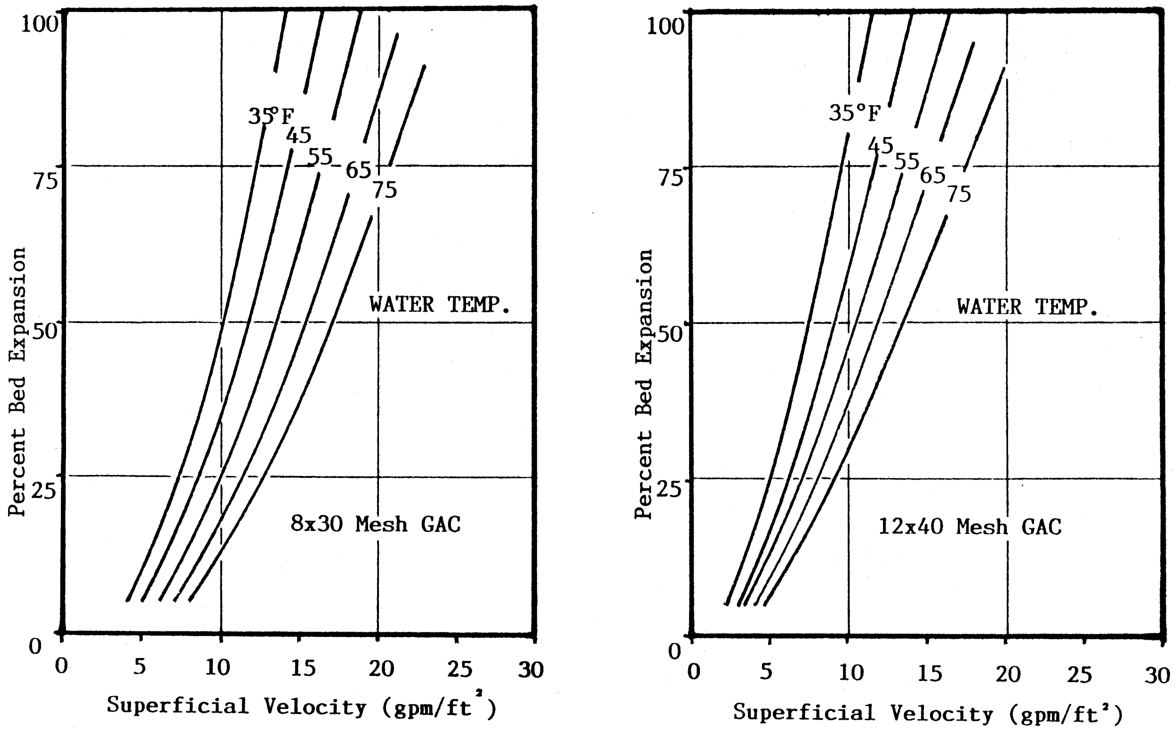

Figure 1. Backwash Expansion Characteristics of GAC

the local authorities for proper disposal. Non-hazardous waste can be sent to a sanitary landfill. Hazardous waste cannot.

If you are considering having spent GAC reburned or reactivated as a possible means of disposal, keep in mind that not all reactivators are properly equipped to handle the burning of a hazardous material such as chlorinated solvent and halogenated organics (pesticides, herbicides, PCB's, THM's, etc.). However, gasoline, benzene, diesel fuels and oils can generally be handled with little or no problem.

In Closing

The information and recommendations contained in this series are based on the personal experience of the writer plus facts and figures gleaned from countless articles written and rewritten so many times that the origin and credits have been lost. This information has not been verified by the publisher and publisher is therefore not responsible for its validity.

The recommendation for systems design are based on information believed to be correct and provided in good faith but without guarantee.

It is suggested that when doubt exists as to the suitability of GAC for a given application that a pilot study be conducted to discover any hidden variables before construction and installation of the system. Continual monitoring is a must.

THE AUTHOR

Chubb Michaud wishes to thank the dozens of nameless conbributors who have helped over the years to compile the information contained in this series. He wishes to acknowledge and thank the CECA Division of Atochem and WESTATES Carbon for their time and material contribution. If you have any specific questions, please direct them to Chubb at Coast Filter Media Supply Co., Inc., 1219 W. Imperial Hwy, Brea, CA 92621. (714) 680-8321. Chubb is president and founder of Systematix Co. and its parent, Coast Filter Media Supply Co. Inc.