

ExxonMobil DESIGN PRACTICES	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	Section	Page
		XIX-A8	1 of 29
		December, 2001	

Changes shown by ↗

CONTENTS

Section	Page
1.0 SCOPE	3
2.0 REFERENCES	3
3.0 DEFINITIONS	3
4.0 PROCESS DESCRIPTION	5
4.1 ACTIVATED CARBON ADSORPTION THEORY.....	5
4.2 ACTIVATED CARBON CHARACTERISTICS	5
4.3 TYPICAL APPLICATIONS OF ACTIVATED CARBON TREATMENT	6
5.0 DESIGN CONSIDERATIONS FOR GAC	7
5.1 FACTORS WHICH INFLUENCE ADSORPTION	7
5.1.1 Nature of the Contaminants.....	7
5.1.2 Adsorption Isotherms.....	7
5.1.3 Nature of the Carbon	8
5.1.4 pH.....	8
5.1.5 Temperature	8
5.2 WASTEWATER QUALITY AND PRETREATMENT REQUIREMENTS	9
5.3 TYPE AND NUMBER OF CARBON ADSORPTION UNITS.....	9
5.3.1 Downflow Columns.....	9
5.3.2 Upflow Columns	10
5.3.3 Packaged Units	10
5.3.4 Number of Units.....	10
5.4 CONTACT TIME.....	11
5.5 SPENT CARBON REGENERATION AND REPLACEMENT	11
5.6 BIOLOGICAL GROWTH	12
5.7 AIR ENTRAINMENT.....	12
6.0 DESIGN AND FACILITY BASIS SIZING PROCEDURE FOR GAC	12
7.0 DESIGN EXAMPLE PROBLEM	15
8.0 POWDERED ACTIVATED CARBON ADDITION TO BIOX	18
8.1 GENERAL DISCUSSION AND BENEFITS	18
8.2 PATENT ISSUES	18
8.3 PAC DOSAGE RATE AND MIXED LIQUOR CONCENTRATION.....	18
8.4 CONSIDERATIONS	19
8.4.1 Clarifier Solids Loading.....	19
8.4.2 Differentiating Between Biomass and PAC.....	19
8.4.3 Precautions When Adding the PAC to the BIOX.....	19
8.4.4 Aesthetics of PAC.....	19
9.0 NOMENCLATURE	20

**Documents**

Document Sharing Hub

Section XIX-A8	Page 2 of 29	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	ExxonMobil DESIGN PRACTICES
December, 2001			

CONTENTS (Cont)

Section	Page
----------------	-------------

TABLES

Table 1	Properties of Commercially Available Carbons	21
Table 2	Influence of Molecular Structure and Other Factors on Adsorbability	22
Table 3	Classes of Materials Readily Adsorbed and Poorly Adsorbed onto GAC.....	23
Table 4	Typical Freundlich Isotherm Constants for Petroleum Compounds	23
Table 5	Design Parameters for Various ExxonMobil GAC Installations	24
Table 6	Process Operating and Design Parameters For Sites Using PAC Additions to the BIOX.	25

FIGURES

Figure 1	Downflow Fixed-Bed GAC Adsorber	26
Figure 2	Typical Concentration Profiles and Breakthrough Curves for GAC Columns	27
Figure 3	Two Downflow Carbon Beds in Series	28
Figure 4	Straight Line Isotherm Plot (Freundlich) - Sample Problem	29

Revision Memo

12/01	This update includes new guidance on clean water backwashing and air scour flow rates. Also included is a section that assists in quickly defining facility bases for Class V Cost Estimation, which is frequently used as a basis for Gate 2 Project Reviews.
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ExxonMobil DESIGN PRACTICES	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT		Section XIX-A8	Page 3 of 29
			December, 2001	

1.0 SCOPE

This practice presents design considerations and recommended process design procedures for facilities to treat water and wastewater using activated carbon. The practice focuses predominantly on the use of granular activated carbon filters which can be used to treat wastewater from refineries, chemical plants, and marketing terminals. The principles provided can be applied to grass roots designs to handle large flows, as well as the selection of vendor-provided packaged units for treating small or remote streams including recovered contaminated groundwater. The practice also includes a discussion on applying powdered activated carbon in activated sludge (BIOX) systems. The practice does not address the use of activated carbon for treating vapors or gases.

2.0 REFERENCES

2.1 DESIGN PRACTICE

[Section XIX-A](#) Guidelines for Selecting Wastewater Treatment Systems

2.2 EMRE WATER AND WASTEWATER DESIGN GUIDE (TMEE 080)

DG 11-1-2 Activated Carbon Filters

2.3 OTHER REFERENCES

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3.0 DEFINITIONS

Abrasion Number - A measure of the ability of a carbon to withstand abrasion, which may be useful in comparing carbons for durability. This number is related to the crushing strength of the carbon which is important for downflow pressure operation.

Active Biomass - The portion of the solids in a biological system composed of microorganisms that are actively degrading the contaminants.

Activated Carbon - A highly porous char made from organic material such as coal, wood, and nutshells which has been activated by exposure to an oxidizing gas at a high temperature.

Adsorbate - The material or contaminant that is accumulating onto the surface of the carbon and being removed from wastewater or water.

Adsorbent - The solid onto which contaminants accumulate. For the purposes of this design practice, activated carbon is the adsorbent for wastewater contamination.

Section XIX-A8	Page 4 of 29	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	ExxonMobil DESIGN PRACTICES
December, 2001			

3.0 DEFINITIONS (Cont)

Adsorption - The process of collecting or removing soluble contaminants (adsorbates) from water on the adsorbent, activated carbon. The contaminants are collected on the solid/liquid interface.

Adsorption Capacity - A measure of the amount of a specific contaminant, or contaminant mixture, that can be removed per unit weight of activated carbon. Ultimate adsorption capacity of an adsorbent is estimated using the adsorption isotherm technique, and is reported in terms of mass of contaminant removed per mass of activated carbon.

Adsorption Isotherm - A measure of the adsorptive capacity of a carbon. The adsorption isotherm is the relationship, at a given temperature, between the amount of a substance adsorbed per unit of activated carbon and its equilibrium concentration in the surrounding solution.

Apparent Density - A comparison of oven dried spent carbon to oven dried reactivated carbon which gives an estimate of adsorbate loading on the spent carbon. Also a measure of the degree of reactivation accomplished.

BIOX - Abbreviation for **B**iological **O**Xidation and commonly used to describe an activated sludge system but can be used in reference to other aerobic biological oxidation processes used to treat wastewater.

Breakthrough - The point at which the contaminant being removed appears, or breaks through, in the effluent. Determination of an acceptable level of breakthrough depends on the treatment objective (effluent concentration target or permit limit).

Bulk Density - Weight per unit volume of the dry carbon as packed in the bed (supplied by vendor).

Bulking - An upset condition in the activated sludge system during which the biomass does not settle effectively, leading to suspended solids carryover in the effluent. Bulking is usually associated with large quantities of filamentous bacteria in the mixed liquor, or oil to the biotreatment system. The result of this bulking is excessive solids remaining in the water to downstream units or effluent, in this case it may overload the activated carbon column.

Chemical Oxygen Demand (COD) - A measure of the amount of organic or reduced inorganic compounds in a sample that can be oxidized by a strong oxidizer, usually potassium dichromate and sometimes potassium permanganate.

Contact - The carbon column or vessel in which the wastewater comes into "contact" with the activated carbon. Also referred to as a carbon adsorber.

Contact Time - The time required for the wastewater to pass through a carbon bed based on the superficial velocity, i.e., the volume of empty bed divided by the hydraulic flow rate.

Conventional Downflow Contactor - A fixed bed contactor which is operated in the downflow mode in service, and is backwashed in an upflow direction.

Desorption - The process where previously adsorbed contaminants are displaced or released back into solution.

Downflow Columns - Usually two or more columns in series, which accomplish adsorption of organics and filtration of low concentrations of suspended solids in a single step. The influent enters from the top and flows through the bed where it is discharged. Downflow columns usually require routine backwashing. See conventional downflow contactor definition above.

Expanded Bed Column - A column where the influent is introduced at the bottom with sufficient velocity to allow the carbon bed to expand, much as a filter bed expands during backwash.

Fixed Bed - Contactors where the carbon bed remains fixed. Usually fixed beds employ downward flow to reduce the chance of accumulating particulate material in the bottom of the bed that would be difficult to remove by backwashing for solids removal.

Freundlich Isotherm - An empirically derived relationship commonly used to describe the adsorption characteristics of activated carbon for very dilute contaminants.

Granular Activated Carbon (GAC) - Generally refers to carbon which has a particle size greater than 100 microns. Two general size ranges of commercial GAC are readily available - 8 x 30 mesh and 12 x 30 mesh - but larger (4 x 6 mesh) or smaller (20 x 50 mesh) sizes are also available.

Hydraulic Retention Time (HRT) - The length of time the influent wastewater is retained in the aeration basin, but not including the effect of sludge recycle; i.e., aeration volume divided by influent volumetric flow rate.

Iodine Number - This test provides an indication of the adsorptive capacity of a carbon. It is the milligrams of iodine adsorbed from a 0.02 N iodine solution at equilibrium under specified conditions.

Mesh/Sieve Size - Activated carbon is classified by its ability to be retained by a series of screens or sieves of decreasing mesh size. As the sieve number increases (e.g., 4, 8, 12, 20, 40, 100, 200, 400, etc.), the size of the openings in the mesh decreases. This sieving technique is used to separate and characterize carbon by particle size.

Mixed Liquor - The contents of the aeration basin, consisting of the wastewater, cell biomass, inert materials and perhaps powdered activated carbon.

Nitrification - A biological process where ammonia is converted to nitrate.

Pore Volume - A measure of the total macropore and micropore volume of the carbon which can be of value in screening activated carbons for a specific waste constituent relative to molecular weight.



ExxonMobil DESIGN PRACTICES	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT		Section XIX-A8	Page 5 of 29
	December, 2001			

3.0 DEFINITIONS (Cont)

Powdered Activated Carbon (PAC) - Generally refers to carbon with a particle size of less than 200 mesh (74 microns). Due to its small particle size, PAC is not generally used in columns or filters but instead can be added directly to the activated sludge aeration basin.

Powdered Activated Carbon (PAC) Treatment - The PAC Treatment process is a modification of the traditional activated sludge process which involves the addition of powdered activated carbon to the aeration basin.

Pulsed Bed Column - A column where the wastewater flows upwards through a descending fixed bed of carbon. When the adsorptive capacity of the carbon at the bottom of the bed is exhausted, this bottom portion of carbon is removed and an equivalent amount of fresh carbon is added to the top.

Solids / Sludge Residence Time (SRT) - The average length of time the solids are held in the biox system expressed in days. SRT is calculated as the total weight of solids in the biox system (aeration basin + clarifier) divided by the total weight of solids wasted each day from the system. Also known as sludge age or MCRT (mean cell residence time).

Specific Surface Area - That portion of the total surface area that is available for adsorption. Due to its highly porous microstructure, activated carbon has a very high specific surface area, typically in the range of 500-1500 m²/g.

4.0 PROCESS DESCRIPTION

4.1 ACTIVATED CARBON ADSORPTION THEORY

Activated carbon removes various organic and metal contaminants from water by a process known as adsorption. Adsorption involves the accumulation or concentration of contaminants both at the outer surface of the carbon particle, and within the particle's pore structure. The contaminants accumulate at the carbon-water interface, but do not actually penetrate the carbon. The material being adsorbed is called the adsorbate, and the activated carbon is termed the adsorbent.

Two types of adsorption mechanisms have been demonstrated. The predominant adsorption mechanism for petroleum wastewater contamination is physical adsorption. This occurs when the contaminant molecules are held loosely to the carbon surface by van der Waals forces. Theory suggests that the molecules are mobile and migrate on the carbon surface. This type of adsorption occurs largely in the micropores of the carbon particle. The second mechanism is chemical adsorption. This occurs because molecular functional groups of the contaminant and the carbon interact at the particle surface to form a stable carbon bond. Due to the nature of the carbon surface, physical adsorption rather than chemical adsorption is the predominant force of importance in wastewater treatment systems.

Simply stated, adsorption occurs in three basic steps: outer film diffusion, pore diffusion, and adhesion of the molecules to the carbon surfaces. Film diffusion is the penetration of the adsorbate through the carbon particle's surface film; pore diffusion involves the migration of the molecules through the macropores and micropores to an adsorption site (the rate limiting step); adhesion then occurs when the adsorbate molecules adhere or adsorb onto the carbon particle's surface.

Adsorption is a dynamic rather than a static process. This implies that adsorption and desorption occur continuously as different adsorbates approach adsorption sites. A loosely bonded organic structure can be displaced at an adsorption site by a molecule that has a greater affinity for that site. Thus the displaced molecule "desorbs," or is released by the carbon, during the adsorption of the preferred species.

4.2 ACTIVATED CARBON CHARACTERISTICS

Activated carbons can be made from a variety of carbonaceous materials such as wood, lignin, bituminous coal, lignite, peat, nut shells, and petroleum residues. The material used to manufacture the carbon and the manufacturing process used affects the characteristics of the activated carbon. Most activated carbon used in wastewater treating applications comes from bituminous coal and lignite which are relatively inexpensive and readily available.

Activated carbon is manufactured by a process consisting of dehydration and carbonization followed by activation. The raw material is dehydrated and carbonized through slow heating in the absence of air. Frequently chemicals are used to create a porous structure of carbon. Final temperatures can be approximately 600°C. The process of carbonization converts the organic material to primary carbon, which is a mixture of ash, tars, amorphous carbon, and crystalline carbon.

The carbonized material is then treated with an activating agent, often steam, at temperatures of 750-950°C. This burns off of the tars and other products of decomposition, which opens up, enlarges, and increases the number of pores. In this fashion, the particle becomes highly porous and the active area now available for adsorption is greatly increased. Typical surface areas are 800-1000 m²/g.

Activated carbons are broadly classified according to their size, specifically granular and powdered. Granular activated carbons (GAC) are those which are larger than approximately U.S. Sieve Series No. 50 (~ 300 microns, or 0.3 mm), while powdered activated carbons (PAC) are those with a size lower than No. 100 Sieve, 150 microns. Generally, carbon used in commercial practices for water treatment is about 1.5-1.7 mm, or No. 12 Sieve.

Section XIX-A8	Page 6 of 29	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	ExxonMobil DESIGN PRACTICES
December, 2001			

4.0 PROCESS DESCRIPTION (Cont)

It is very important to specify the limits on fines (usually 1% maximum) in granular activated carbon purchases. Too many fines will require an extended period of washing the carbon prior to being put in service, and can cause effluent TSS target exceedances when put in service.

Particle size is generally considered to affect adsorption rate, but not adsorptive capacity. Particle size also affects backwash fluidization and governs the maximum backwash flowrate which can be used in a carbon bed. This is because again the outer surface area of the carbon particle represents only a small percent of the total active adsorptive area. Since adsorption capacity is related to total adsorptive area, a given weight of carbon gains little adsorptive capacity when crushed to a smaller size. The rate of adsorption will be increased, however, due to the influence on the pore diffusion process.

The properties of several commercially available carbons are given in **Table 1**. Properties for specific carbons should be obtained from vendors.

4.3 TYPICAL APPLICATIONS OF ACTIVATED CARBON TREATMENT

The use of activated carbon in wastewater treatment has many applications. The most common applications are discussed briefly below.

1. GAC adsorption columns are often used as a tertiary polishing process following conventional biological secondary treatment. Processes upstream of the GAC are usually designed to remove the free oil, the oily and biological treatment solids, and essentially all of the soluble biodegradable organics. This leaves relatively small quantities of refractory organics and heavy metals which are the target of the carbon. Polishing with GAC can also be effective in reducing effluent toxicity. The wastewater treatment facilities at Valero's Benicia Refinery (formerly Exxon) and at EMRE's Corporate Research facility in Clinton, New Jersey are typical of tertiary polishing following biological treatment.
2. GAC adsorption can be used to remove soluble organics following physical-chemical primary treatment. In this case, the wastewater is first treated by oil/water separation, followed by either chemical coagulation and sedimentation, dissolved air flotation, or dual media filtration. This primary treated wastewater is then passed through GAC columns where the soluble organic compounds are removed. The physical-chemical system with activated carbon can be designed to produce the same effluent quality as that achieved with tertiary treatment. For large flows, these systems are rarely cost effective when compared to biological secondary treatment. The wastewater treatment facilities at the Sakai and Tonen Refineries in Japan are indicative of this application.
3. GAC adsorption is finding increasing application to treat low flow, dilute wastewaters from remote locations such as marketing terminals and ground water pump-and-treatment situations. Additionally, carbon systems find application in emergency situations, such as a major wastewater treatment plant upset or when temporary additional treatment capacity is required. In these cases, relatively simple packaged units can be used to produce a very high quality effluent.
4. Adding powdered activated carbon (PAC) to a plant's activated sludge or biox system combines activated carbon adsorption with biological secondary treatment. In this process, PAC is added, generally on a continuous basis, to the activated sludge mixed liquor. This approach is often applied to activated sludge systems which are subjected to shock loadings of toxic or destabilizing organic contaminants. The PAC acts to initially adsorb these surges, then releases the contaminants over time at a rate at which they can be metabolized by the biomass. PAC Treatment is also used at sites with stringent effluent toxicity limits. Since PAC increases the specific gravity of the activated sludge floc, PAC can improve the sludge settling characteristics. This is discussed in more detail in **Section 8.0**. Valero's Benicia Refinery (formerly Exxon) and EMRE's Corporate Research facility in Clinton use PAC to improve Biox Treatment.

In summary, GAC adsorption should be considered for the following applications:

- When the inlet wastewater biochemical oxygen demand (BOD₅) is less than 100 mg/L (too low to support suspended growth activated sludge).
- Downstream of biological treatment when necessary to meet an acute or chronic toxicity limit.
- Downstream of biological treatment when further polishing is required to remove non-biodegradable organics and selected heavy metals.
- Treatment of small streams for discharge such as terminals, remote tank fields, and ground water cleanup.
- Emergency situations when temporary additional treatment capacity is required.
- Upstream/in-plant treatment of low contaminant level streams for onsite reuse, or to assist in sewer segregation modifications.

More detailed information on wastewater technology selection can be found in [Design Practices Section XIX-A](#), *Guidelines for Selecting Wastewater Treatment Systems*.

ExxonMobil DESIGN PRACTICES	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	Section XIX-A8	Page 7 of 29
		December, 2001	

5.0 DESIGN CONSIDERATIONS FOR GAC

5.1 FACTORS WHICH INFLUENCE ADSORPTION

5.1.1 Nature of the Contaminants

The adsorptive capacity of an activated carbon is dependent to a large extent on the properties of the specific contaminant to be adsorbed. Generally speaking, low molecular weight (< 50), highly water-soluble, highly-polar compounds such as alcohols, aldehydes, glycols, organic acids, and simple amines are poorly adsorbed. Conversely, compounds with lower solubility in water such as aromatic solvents (e.g., benzene, toluene) and higher molecular weight compounds such as polynuclear aromatic, are effectively adsorbed. Generally, carbon adsorbs based on the carbon number of molecules; the higher the carbon number, the greater the adsorption capacity. The influence of solubility and molecular structure on adsorption effectiveness is shown in **Table 2**. The relative adsorbabilities of various wastewater contaminants are listed in **Table 3**. Other references are provided for more detailed information on individual compounds.

Wastewater contains a mixture of contaminants, mostly soluble but some suspended matter (fine oil droplets or silt / clay), at the stage where carbon treatment is considered. The various compounds may mutually enhance adsorption, may act relatively independently, or may interfere with one another. As there are only a finite number of adsorption sites, the compound with the highest affinity for the carbon can be expected to be preferentially adsorbed over those with lesser affinities. In general, this usually results in lower unit loading for any individual compound in a mixture versus as a single contaminant.

5.1.2 Adsorption Isotherms

In addition to knowing which compounds are adsorbable onto activated carbon, it is useful to conduct a series of tests to determine the applicability of adsorption for the specific wastewater. The prediction of GAC treatment performance by laboratory testing is at best a rough estimate of what can be expected in the actual application to most wastewaters. As wastewaters are often complex mixtures which can vary significantly in makeup and concentration over time, long term pilot testing represents the best means of predicting actual carbon performance. That being said, there are relatively quick analytical techniques which are valuable in determining the effects of contact time and particle size, in defining the ultimate removal effectiveness, and in obtaining rough estimates of carbon utilization.

The most common analytical test for GAC is the adsorption isotherm. This isotherm provides the ultimate capacity of carbon. This test determines the adsorptive capacity of a carbon for a particular contaminant, or contaminant mixture, at equilibrium conditions over a range of carbon loadings. For most petroleum constituents at low concentration in water, this relationship can be adequately described by the empirical Freundlich equation:

$$X / M = k \cdot C_e^{1/n} = \text{Amount of contaminant adsorbed per unit weight of carbon at equilibrium, mg/g} \quad \text{Eq. (5-1)}$$

where: X = Amount of contaminant adsorbed, mg
M = Weight of the carbon, g
C_e = Concentration of the contaminant remaining in solution at equilibrium (after adsorption), mg/L
k, 1/n = Freundlich constants

The constants in the Freundlich equation can be determined by plotting X / M versus C_e on log-log paper, and making use of the logarithmic form of the equation:

$$\log (X / M) = \log k + 1/n (\log C_e) \quad \text{Eq. (5-2)}$$

When graphed on log-log paper this equation defines a straight line whose slope is 1/n and whose intercept is k at C_e = 1.

Freundlich constants for more than 100 single contaminants in water are given in *References 4, 9 and 13*. Some Freundlich constants pertinent to petroleum compounds are listed in **Table 4**. Using these constants and setting C_e equal to the initial starting concentration of the contaminant can provide an estimate of the carbon maximum usage.

As stated above, isotherm analysis should be run on actual wastewater samples. The Freundlich graphical technique for single contaminants can also be applied to a complex mixture, typically by using COD or TOC as the measurement parameter. Isotherm analyses are straightforward and can be done in most moderately equipped laboratories in one or two days. A laboratory test would first combine known quantities of wastewater and carbon, mix them at a constant temperature, and then measure the test parameters's final concentration in the wastewater at equilibrium. This should be repeated several times while varying the carbon loading, then graphing the results as described. A standard methodology for performing the carbon isotherm analysis is contained in **ASTM Method D 3860 (Reference 12)**.

Section XIX-A8	Page 8 of 29	<i>WATER POLLUTION CONTROL</i> ACTIVATED CARBON TREATMENT	 DESIGN PRACTICES
December, 2001			

5.0 DESIGN CONSIDERATIONS FOR GAC (Cont)

Carbon vendors can also perform Isotherm analyses. Some vendors can also perform short duration dynamic column studies or laboratory scale pilot tests to better predict carbon usage and performance. Laboratory testing beyond isotherm analyses serves to optimize the facility and investment.

5.1.3 Nature of the Carbon

The physicochemical nature of the activated carbon can have profound effects on both the rate and capacity of adsorption. Manufacturers of activated carbon have become relatively sophisticated in terms of the types and properties of carbons they produce, and can offer a variety of carbons depending on the characteristics of the wastewater to be treated.

Short descriptions or applications of the important physical properties are provided as follows:

1. **Surface Area** - Adsorption is a surface phenomenon, therefore total surface area is a useful value for screening the capability of a particular carbon for adsorption.
2. **Apparent Density** - This property is of little value in the initial evaluation and selection of an activated carbon. However, it is very useful as one of the measures of successful reactivation. Apparent density measurement is a simple test, and the density of saturated virgin carbon relative to the density of reactivated carbon indicates the degree of reactivation accomplished.
3. **Bulk Density** - Useful in determining the volume requirements of a carbon column after the contact time requirements have been established.
4. **Effective Size, Mean Particle Diameter, and Uniformity Coefficient** - Measures of the gradation of carbon particle size which are important in evaluating head loss in flow through the bed.
5. **Pore Volume** - A measure of the total macropore and micropore volume of the carbon which can be of value in screening activated carbons for a specific waste constituent. Pore volume is also related to the strength of the carbon particle.
6. **Pore Volume Distribution** - The distribution of pore volume among pores of different size or diameter. Of value in screening activated carbons for removal of a specific waste constituent relative to molecular weight.
7. **Sieve Analysis** - Useful in checking carbon production, in checking conformance of purchased carbon to specifications, and in evaluating the effects of plant carbon handling procedures on carbon attrition.
8. **Abrasion Number** - A measure of the ability of a carbon to withstand abrasion, which may be useful in comparing carbons for durability.
9. **Crushing Strength** - Important for downflow operations and is a measure of carbon strength due to weight of carbon and force exerted by the flowing water.

5.1.4 pH

For a number of reasons, the pH of a solution may influence the extent of adsorption. Because hydrogen and hydroxide ions are adsorbed quite strongly, the adsorption of other ions is influenced by the pH of the solution. Furthermore, to the extent to which the ionization of an acidic or basic compound affects its adsorption, pH affects adsorption in that it governs ionization.

In general, adsorption is increased with decreasing pH. This may result from neutralization of negative charges at the surface of the carbon with increasing hydrogen-ion concentration. This effect can be expected to vary in degree for different carbons, because the charges at the surfaces of the carbon depend on the composition of the raw materials and on the technique of activation.

Carbon will function satisfactorily over a broad pH range, and a decrease in feed pH during a run is not a problem. However, care must be taken to avoid a substantial increase in feed pH which can result in desorption of contaminants. This is especially a concern if the bed is nearing exhaustion. In other words, if a GAC column which has been operating at a pH of 7.0 suddenly sees a pH of 8.5 for several hours, desorption of previously adsorbed materials may occur. This pH behavior may change as carbon becomes exhausted over its run length.

5.1.5 Temperature

Adsorption reactions are normally exothermic; thus the extent of adsorption generally increases with decreasing temperature. Thus adsorption would be expected to be somewhat better in winter with cooler influent water than in summer. Small variations in water temperature will not have any significant effect.

ExxonMobil DESIGN PRACTICES	WATER POLLUTION CONTROL ACTIVATED CARBON TREATMENT	Section XIX-A8	Page 9 of 29
	December, 2001		

5.0 DESIGN CONSIDERATIONS FOR GAC (Cont)

5.2 WASTEWATER QUALITY AND PRETREATMENT REQUIREMENTS

To be fully effective, feedwater to the carbon unit should be of relative uniform quality, without large surges in flow, and low in free oil and suspended solids content. This often implies a need for upstream flow equalization, pretreatment for free oil removal via dissolved air flotation or equivalent, and/or granular media filtration for oil and solids removal.

Surges in flow rates can result in entrainment of the carbon in the effluent and premature breakthrough of contaminants. Excessive quantities of free oil in the feed to the carbon bed can quickly reduce the activity/capacity of the carbon.

Feed suspended solids levels should be kept below 15 - 30 mg/L. Particle size should be kept below 25 microns (depending on type of unit), and free oil and grease levels kept below 10 mg/L. These solids and oils can deposit on the carbon granules and clog the bed, leading to pressure drop, flow channeling and short circuiting, increased carbon losses due to higher localized velocities, and an overall decrease in bed life. The presence of colloidal materials can also be a problem. Colloidal material can reduce the adsorptive capacity of the carbon by restricting pore openings which interferes with the diffusion process and reduces effective adsorption sites. To avoid or minimize such impairment, pretreated wastewater of high clarity is desirable. Dual media filtration upstream of the GAC is recommended and is sufficient to insure acceptable feed quality.

5.3 TYPE AND NUMBER OF CARBON ADSORPTION UNITS

Several types of activated carbon contactor systems are used in plant designs. Generally, adsorption systems are designed around five basic types of adsorbers: (1) downflow pressure, (2) downflow gravity, (3) upflow fixed bed, (4) upflow expanded bed, and (5) upflow pulsed bed. With the exception of the last type of adsorber, most systems are designed with two or more columns in series. The preferred type is conventional downflow pressure contactors, with an upflow backwash and air scour. However, for upflow backwash, velocities should be kept so that carbon does not leave the bed. EMRE's Crude Distillation and Separation (CDS) Section should be consulted for acceptable velocities through carbon beds to prevent excessive fluidization. Questions on special types of carbon treatment applications should be directed to EMRE's Environmental Technology Section or the CDS Section.

5.3.1 Downflow Columns

These are fixed beds usually in series. The most commonly applied GAC design for industrial wastewater treatment is the downflow fixed-bed pressure system. In addition to adsorbing organics, downflow columns will act as filters by removing suspended solids in the feed water. Unless the water has been pretreated for solids removal to a very high quality (< 2 mg/L TSS), these systems will require backwashing to be included in the design to remove the accumulated particulate material. An example of such a unit is shown in **Figure 1**.

The wastewater is introduced above the carbon bed, often without a distributor because the bed will serve to distribute the flow. The water flows down through the bed, and is collected in the bottom of the bed by an underdrain consisting of slotted screen collectors and a header or collection system. Wedge-wire type slotted screens will retain the carbon and allow water to flow out of the adsorber. The underdrain also serves as the inlet for the backwash water. Feed distribution, underdrain, and carbon support designs vary from vendor to vendor. Minimum requirements are given in **DG 11-1-2**.

The adsorbers are normally carbon steel pressure vessels that meet the ASME pressure vessel codes. As carbon in the presence of water will create a corrosion cell due to an oxidation-reduction differential, the interior of the adsorber should have a corrosion resistant lining. This lining needs to be thick enough (nominally 35 mils or greater) to accommodate the abrasive nature of the carbon. The designer is referred to **DG 11-1-2** for specifications related to materials and coatings.

In a downflow column, the carbon is spent relatively evenly across the vertical cross-section of the bed due to the nature of flow through the bed. Completely non-adsorbable compounds immediately pass through a carbon bed, followed by breakthrough of the less adsorbable compounds. Eventually even the highly adsorbable compounds break through as the bed becomes saturated, at which time the carbon is removed from the column for regeneration. Breakthrough is not a step change; rather it occurs slowly at first but depending on the application may quickly advance with the outlet concentration approaching the inlet concentration. A typical breakthrough curve for a single adsorbing component for a downflow GAC column is shown in **Figure 2**.

Downflow systems usually consist of at least two columns in series, typically referred to as a lead bed / polish bed configuration. Operating in this design mode becomes particularly important when a wide range of contaminants or wide fluctuations in contaminant concentration are present. Highly adsorbable compounds will tend to adsorb on the carbon preferentially in the top of the bed. This displaces or prevents the adsorption of lower affinity compounds until they reach lower, cleaner portions of the lead bed or break through to the polish bed. Similarly, a significant reduction in inlet concentration (perhaps caused by rainwater temporarily diluting the flow) will alter equilibrium conditions, desorbing some contaminants from the top of the bed and carrying them through to less loaded areas lower in the bed or into the polish bed.