

# Design Assumptions and Calculations

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## C.1 Introduction

This appendix presents the design assumptions and calculations used to identify and size key equipment and to estimate the rate of power and chemical usage for the following technologies considered at the North Hollywood Operable Unit (NHOU) treatment system:

- Air stripping
- Ex situ chromium treatment using anion ion exchange
- Ex situ chromium treatment using ferrous iron reduction
- Advanced oxidation treatment of 1-4-dioxane
- Liquid-phase granular activated carbon (LPGAC) treatment of oxidation byproducts and volatile organic compounds (VOC)

## C.2 Design Calculations Method and Assumptions

The following attachments describe the detailed methods for estimating the size of the process equipment; the rate of energy utilization, chemicals, and replacement carbon; and, where appropriate, additional details and computer modeling results:

- Attachment C1 – Air Stripper and Vapor-phase Granular Activated Carbon Treatment Calculation Details
- Attachment C2 – Ex Situ Chromium Treatment Calculation Details (for 600 gallons per minute concept)
- Attachment C3 – 1,4-Dioxane Treatment Details
- Attachment C4 – LPGAC Treatment Details
- Attachment C5 – Hand Calculations and Computer Modeling Results

For each technology, the following three considerations are summarized:

- Assumptions and clarifications
- Modeling equations
- Design standards

**Attachment C1**  
**Air Stripper and Vapor-phase Granular**  
**Activated Carbon Treatment Calculation Details**

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# Air Stripper and Vapor-Phase Granular Activated Carbon Treatment Calculation Details

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## C1.1 Assumptions and Clarifications for Air Stripper Modeling

Air stripper modeling and sizing has been performed using the STRIPR computer model created by CH2M HILL. Modeling results for Alternatives 1 through 5 (“a” and “b” options) are provided in Attachment C4. Using compound and stream-specific data, the model predicts one of three parameters, given the other two parameters. The three variable parameters include: (1) tower packed-bed depth, (2) contaminant removal efficiencies, and (3) air-to-water ratio.

The assumptions and clarifications for the air stripper calculations are included in the following sections.

### C1.1.1 Pretreatment

Based on the assumed low turbidity level of the influent, only a coarse strainer should be necessary as pretreatment for the stripper process. The addition of a sequestration agent and a disinfectant (bleach) has been assumed to control inorganic scales and biological fouling, respectively. Periodic maintenance by high-rate washing with surfactant or acid should be adequate for removing sediments and scales of iron hydroxide and calcium carbonate, if present. Air stripper tower washing system maintenance, waste neutralization, and disposal of the washing solution are considered outside the scope of the *North Hollywood Operable Unit (NHOU) Focused Feasibility Study (FFS)*.

### C1.1.2 Air/Water Equilibrium

These calculations assume that the stripping air quickly equilibrates with the water stream to a temperature of 62 degrees Fahrenheit (°F) and has a negligible effect on the water temperature.

### C1.1.3 Offgas Humidity

The offgas analysis assumes that the exiting air is saturated with water vapor at 62°F. However, the process includes an offgas heater to increase the offgas temperature by approximately 20°F, which reduces the relative humidity to 50 percent.

### C1.1.4 Onda Correlations

The stripper calculations assume all applicable simplifications and correlations pertinent to the Onda Correlations for stripping tower configurations.

### C1.1.5 Chemical Properties

All Henry's constants and diffusion coefficients are in accordance with the database values provided as part of the STRIPR software. Computer model printouts provided in Attachment C5 indicate the values assumed.

## C1.2 Modeling Equations for Air Stripper Calculations

If the packed-bed depth is not known, the depth is calculated from the required percent removal of the key contaminant using Equation 1, which is the basic equation for sizing an air stripper.

$$Z = NTU \times HTU \times F_s \quad (1)$$

Where:

$Z$  = required packed-bed depth in feet

$NTU$  = number of overall liquid-phase transfer units (actual  $N_{\text{IOL}}$ )

$HTU$  = height of an overall liquid-phase transfer unit (actual  $H_{\text{IOL}}$ )

$F_s$  = factor of safety for the column (1.0 means no safety factor, 1.25 means 25 percent safety factor)

## C1.3 Design Standards for Air Stripper Systems

The following guidelines are considered to be standard industry practices for air stripper hydraulics. Configurations developed in this attachment incorporate the following guidelines where applicable:

- Liquid loading of 20 to 35 gallons per minute per square foot
- Minimum<sup>1</sup> volumetric air-to-water ratio of 12:1
- Packed-bed heights of 10 to 25 feet per section
- Maximum tower diameter of 12 feet (for shop-fabricated systems)
- Packed-bed safety factor of 25 percent

For the FFS, the packed-bed stripper depth was assumed to be the same as the current stripper (19.5 feet). The air-to-water ratio was minimized to reduce capital and operation and management costs associated with offgas treatment.

<sup>1</sup>Minimum air-to-water ratio of 12:1 applies only to compounds with Henry's constants greater than 100 atm/mole fraction. A higher minimum air-to-water ratio applies to compounds with Henry's constants less than 100 atm/mole fraction.

## **C1.4 Assumptions and Clarifications for Vapor-phase Carbon Treatment Modeling**

The following sections discuss the assumptions and clarifications for vapor-phase carbon treatment modeling.

### **C1.4.1 Vapor-phase Granular Activated Carbon Multicomponent Adsorption**

Theoretical models for predicting carbon life in the presence of multiple components are useful but not widely accepted by industry. Simple and complex multicomponent models exist. Predicting the loading of volatile organic carbons (VOC) on carbon is not critical in this instance because the low VOC loading results in a relatively minimal operation and maintenance cost. The rate of carbon loading only affects the vapor-phase granular activated carbon (VGAC) adsorber bed replacement frequency and has no impact on capital costs. Therefore, a simple model is assumed. The simple model adds the loading from each contaminant; this assumes that there is no co-adsorption and that all contaminants segregate into discrete bands.

### **C1.4.2 Vapor-phase Granular Activated Carbon Performance**

Similar to the previous discussion on carbon life (C1.4.1), the performance capabilities of VGAC to remove VOCs are not well established. Performance standards used by some in industry are as follows:

- Steam regenerable carbon – 90 to 95 percent removal of VOCs
- Virgin or reactivated carbon – 99 percent removal of VOCs

These removal rates are generally accepted for 1 to 2 inches of bed depth, known as the mass transfer zone. The mass transfer zone depths are typical for superficial velocities of 0.8 to 1.5 feet per second.

For the purposes of estimating air emissions from the VGAC adsorbers, it is recommended to assume 90 percent capture of VOCs per bed.

These are conservative estimates, and actual operation of the VGAC units is expected to result in higher capture rates. However, a 90 percent capture rate is typical of performance guarantees available from suppliers. The performance standards previously discussed indicate that the actual performance should be better than the vendor guarantee; however, only 90 percent capture should be assumed when estimating system emissions.

### **C1.4.3 Isotherms**

The isotherm constants used and presented here were determined using isotherm graphs provided by Calgon Carbon Corporation and American Norit Company, Inc. However, these isotherms are only representative of virgin VGAC.

### **C1.4.4 Volatile Organic Compound Loading**

The VOC loading into the VGAC adsorbers was estimated using the output from STRIPR. For VOCs that were predicted to have 95 percent or higher removal by air stripping, loading to the VGAC adsorber system was assumed to be 100 percent.

### C1.4.5 Relative Humidity

Relative humidity affects the adsorbing capacity of VGAC; a relative humidity of 50 percent is recommended as an economical breakpoint between heating costs and carbon savings. For this study, postheating (increase of 20°F) of the stripper offgas to 50 percent relative humidity is assumed.

### C1.4.6 Bench or Demonstration Scale Testing

Similar to most applications using activated carbon, bench- or demonstration-scale testing might be required to predict carbon performance and usage rates for multicomponent systems. However, because the usage rate of carbon is relatively small, the cost of carbon replacement is not a key driver in alternative selection, and pilot testing is not justifiable.

## C1.5 Modeling Equations for Vapor-phase Granular Activated Carbon

For VGAC, equations are generally used to predict carbon bed life. The effects of changing hydraulic parameters on the effluent quality or concentration profile are not as predictable as they are for stripping systems. This section focuses on methods used to predict carbon bed life to establish operating costs. Equipment sizing and capital costs will be established by the bounds set, using the hydraulic parameters for VGAC. The system performance is assumed as stated in Section C1.4.

The single component carbon saturation rates were established using the Freundlich Equation (Equation 2).

$$\frac{X}{M} = K * C_f^{(1/n)} \quad (2)$$

Where:

$X/M$  = carbon adsorption capacity ( $\mu\text{mol}(\text{solute})/\text{gC}$ ) for the solute at the influent concentration  $C_f$

$K$  = Freundlich isotherm constant with units  $[(\mu\text{mol}(\text{solute})/\text{gC})/((\mu\text{mol}(\text{solute})/\text{l}(\text{air}))^{(1/n)})]$

$1/n$  = Freundlich isotherm exponent (unitless)

The single solute isotherm capacity ( $X/M$ ) for each compound is calculated using the Freundlich isotherm (see Equation 2). The isotherm capacity is converted to carbon usage rate or carbon bed life using the molecular weight, influent flows, and concentration. All isotherm capacities are based on virgin coconut-based VGAC data. The single component carbon usage rates for all components are summed. This assumes no coadsorption of contaminants.

## C1.6 Design Standards for Vapor-phase Granular Activated Carbon Systems

The following guidelines are considered to be industry-accepted practice for VGAC systems:

- Vapor superficial velocity 0.5 to 1.5 feet per second
- Carbon bed depths 2 to 6 feet
- Maximum adsorber diameter of 12 feet

The systems developed for the FFS incorporate these guidelines where applicable.

Following are some of the considerations in developing the VGAC usage rate values:

- All VGAC usage estimates are based on average influent conditions.
- All VGAC adsorbers are double-pass operation, and multiple adsorbers are also arranged in parallel.

The VGAC adsorber calculations, which are based on the standards presented, are summarized in Attachment C4.

## C1.7 Other Considerations

The following sections discuss other considerations for VGAC modeling.

### C1.7.1 Radon and Other Naturally Occurring Radionuclides

The San Fernando Valley groundwater database indicates that naturally occurring radionuclides are present in groundwater at NHOU. Radon, and to a lesser extent radium and uranium, can influence the design and operation of air strippers and VGAC adsorber systems. Radon adsorbs onto VGAC and decays to a long-lived isotope (lead-210). The radon decay releases alpha, beta, and gamma radiation. If the concentration of radon is great enough, handling the spent VGAC can become a safety concern.

A similar remedial feasibility study (prepared by CH2M HILL) at Baldwin Park Operable Unit in April 1992 found that treatment plant operators were required to limit their exposure (i.e., proximity) to the VGAC carbon adsorber units to a maximum 3 to 4 hours per day, based on the cumulative annual maximum allowed by U.S. Environmental Protection Agency (EPA) guidelines (EPA, 1990) available at that time. The actual daily maximum exposure time was determined by the final system configuration and influent radon levels. To maintain radiation exposure below EPA guidelines, no additional measures were needed. The maximum operator time near the carbon adsorbers was found to be 3.9 hours per day, which was considered to be adequate for system operation and maintenance. Therefore, no additional cost allowance was added to provide system automation, remote instrumentation, or vessel shielding.

For the same study, preliminary calculations showed that spent carbon was not considered to be a low-level radioactive waste (according to the EPA guidelines). However, an allowance was included to temporarily store the spent carbon onsite to allow radioactive

decay of the adsorbed radon to lower levels that are believed to be acceptable for offsite disposal or regeneration.

If the radon levels in the NHOU treatment system influent are high, consideration of these complications might bias the technology selection to those that do not accumulate radon, such as air stripping with catalytic offgas treatment.

### **C1.7.2 Inorganic Scaling Threats**

All of the extracted groundwater contains dissolved inorganic substances and VOCs. Some inorganic substances, such as iron, manganese, and calcium, can form precipitates when subjected to pumping or aeration. All alternatives assume the continued addition of hexametaphosphate as a sequestration agent to control scaling.

## **C1.8 Work Cited**

U.S. Environmental Protection Agency (EPA). 1990. *Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides*. EPA/570/F-90/018.

**Attachment C2**  
**Ex Situ Chromium Treatment**  
**Calculation Details**

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# Ex Situ Chromium Treatment Calculation Details

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This attachment presents the design assumptions and calculations used to identify and size key equipment and to estimate power and chemical usage.

## C2.1 Anion Exchange Assumptions and Clarifications

This section discusses anion ion exchange assumptions and clarifications applicable to concept systems that incorporate anion ion exchange treatment.

### C2.1.1 Hexavalent Chromium Loading

Theoretical models for predicting the resin bed service period exist but are not widely accepted by industry. The capacity of anion ion exchange resin to hold hexavalent chromium only affects the ion exchange bed replacement frequency and has little impact on capital costs. This evaluation relies on anion ion exchange capacity estimates developed in recent work by the City of Glendale and in vendor cost information.

The work to date at Glendale indicates that a weak base anion ion exchange resin by Rohm and Haas (Duolite® A7) performs best for the conditions at Glendale. It is assumed that the conditions at the North Hollywood Operable Unit (NHOU) will be similar. Duolite® A7 is a cross-linked, phenol-formaldehyde weak base anion ion exchange resin. The work at Glendale indicates that Duolite® A7 can treat up to 40,000 bed volumes with an influent hexavalent chromium concentration of 35 micrograms per liter ( $\mu\text{g}/\text{L}$ ). The resin supplier expects the resin to treat about 80,000 bed volumes. Other testing indicated a chromium holding capacity up to 3.2 percent by weight (about 750,000 bed volumes), but significant concerns exist regarding the validity of that capacity value. For the purposes of this study, annual operation and maintenance cost estimates will assume a resin treatment capacity of 80,000 bed volumes at 35  $\mu\text{g}/\text{L}$  hexavalent chromium loading, adjusted for the higher chromium loading predicted for NHOU. The bed volume treatment capacity is derated linearly based on the higher hexavalent chromium loading for NHOU (i.e., derated by a factor of 2,000/35) and increased by a factor of 2.0 to account for typically higher resin treating capacity due to higher inlet hexavalent chromium concentrations (i.e., 2,000 versus 35  $\mu\text{g}/\text{L}$ ).

### C2.1.2 Anion Ion Exchange Performance

Similar to the previous discussion on vapor-phase granular activated carbon usage rate, estimating the performance capabilities of ion exchange resin to remove hexavalent chromium is not well established. Performance standards used by some in industry assume that an ion exchange column will remove 90 percent in a few inches of bed depth (mass transfer zone). These mass transfer zone depths are typical for superficial flux rates of 5 to 8 gallons per minute per square foot.

For the purposes of estimating anion ion exchange column adsorbers, it is assumed that two anion ion exchange columns will operate in series to achieve the specified effluent requirements. Higher flow systems may also use additional parallel columns for higher flow capacity. This is a conservative assumption and may be re-evaluated pending further demonstration-scale testing results.

Finally, there is significant concern regarding the potential ability for the weak base resin to release partially oxidized organic material due to an oxidation reduction reaction with the hexavalent chromium. Strong base resin does not appear to experience the same degradation reaction. However, because the resin holding capacity is much less, it is rationalized that if weak base resin is not cost-effective compared with ferrous iron treatment, strong base resin treatment will be even less cost-effective.

### **C2.1.3 pH Adjustment**

Work at the City of Glendale indicates that the loading capacity of Duolite® A7 anion ion exchange resin is pH-dependent. At the native pH of 6.8, the resin had a capacity to treat about 2,500 bed volumes (based on 35 µg/L influent). However, at a pH of 6.0, the capacity of Duolite® A7 increased to 25,000 bed volumes. Thus, the system design assumes a pH reduction system (acid addition) to reduce the inlet pH value to approximately 6.0 and a pH increase system (caustic addition) after ion exchange and air stripping treatment to restore the pH to normal groundwater values or as desired for potable use.

### **C2.1.4 Bench- or Demonstration-scale Testing**

Similar to most applications using activated carbon, bench- or demonstration-scale testing of the selected ion exchange resin may be required to predict resin performance and capacity.

Disposal as a wet sludge is assumed.

## **C2.2 Design Standards for Ion Exchange Adsorber Systems**

The following guidelines are considered to be industry-accepted practice for ion exchange adsorber systems:

- Superficial flux of 4 to 8 gallons per minute per square foot
- Resin bed depths 3 to 8 feet (minimum of 40 percent of vessel diameter)
- Maximum adsorber diameter of 12 feet

The systems developed for the NHOU focused feasibility study incorporate these guidelines where applicable.

## **C2.3 Ferrous Iron Reduction Design Assumptions and Clarifications**

The detailed methods for estimating the size of the chromium reduction reactors (using ferrous iron) and ferrous iron oxidation reactors are described in the following sections. The assumptions and clarifications made for the ferrous iron reduction process calculations are also discussed.

### C2.3.1 Pretreatment

No pretreatment is assumed. In instances where chromium and volatile organic carbon treatment systems are at the same facility, it is assumed that chromium treatment is conducted first.

### C2.3.2 Volatile Organic Carbon Air Emissions

All air emissions from the chromium treatment system will be routed to the vapor-phase granular activated carbon adsorbers with the air stripping system emissions.

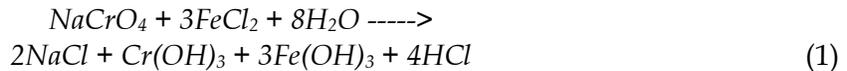
### C2.3.3 No Chelating Agents

The chromium removal concept using ferrous iron reduction assumes that there are no chelating or sequestration agents in the water. Lactate and biological byproducts of lactate are known to chelate chromium and iron.

## C2.4 Modeling Equation for Ferrous Iron Reduction

The estimated equipment sizes assume the chromium reduction rate according to Fendorf and Li (1996), ferrous iron oxidation according to Sung and Morgan (1980), and all applicable simplifications and pertinent correlations.

Hexavalent chromium is reduced by ferrous ions as shown in Equation 1:



The rate of hexavalent chromium reduction using ferrous ions can be predicted using Equation 2 (Fendorf and Li, 1996):

$$d[\text{Cr(VI)}] / dt = -k\text{Cr}[\text{Fe}^{2+}]0.6[\text{Cr(VI)}]1.0 \quad (2)$$

Where:

- t = time (minutes)
- k = 56.3 millimole, 0.6 minute - 1 liter 0.6
- [Fe<sup>2+</sup>] = iron concentration, millimole per liter (constant)
- [Cr(VI)] = chromium (VI), millimole per liter

Dissolved oxygen competes with the hexavalent chromium for oxidizing ferrous iron to ferric iron. The ferrous iron is oxidized by dissolved oxygen as shown in Equation 3:



The rate of ferrous iron oxidation by dissolved oxygen can be predicted using Equation 4 (Sung and Morgan, 1980):

$$d[\text{Fe}^{2+}]/dt = -k[\text{OH}^-]2p\text{O}_2[\text{Fe(II)}] \quad (4)$$

Where:

- k =  $8 \times 10^{13} \text{L}^2 / (\text{atm} \cdot \text{min} \cdot \text{mole}^2)$   
[Fe<sup>2+</sup>] = iron concentration, millimole/L (constant)  
[Cr(VI)] = chromium (VI), millimole/L  
[OH<sup>-</sup>] =  $[10^{(\text{pH}-14)}]$   
pO<sub>2</sub> = 0.21 atm at 8.3 milligrams per liter O<sub>2</sub> (fresh water)

## C2.5 Design Standards

Based on a recent CH2M HILL design for a similar treatment facility in Southern California that used these design equations, ferrous iron dosage and reaction tank sizes are estimated by comparisons of similar mass and hydraulic loading.

## C2.6 Works Cited

- Fendorf, G., and G. Li. 1996. "Kinetics of Chromate Reduction by Ferrous Iron." *Environmental Science Technology*. Volume 30. January.
- Sung, Windsor, and James J. Morgan. 1980. "Kinetics and Product of Ferrous Iron Oxygenation in Aqueous systems." *Environmental Science and Technology*. May.

**Attachment C3**  
**1,4-Dioxane Treatment Details**

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# 1,4-Dioxane Treatment Details

1,4-Dioxane is considered persistent in groundwater but is readily degraded in the atmosphere by photolysis. In groundwater, it is considered to have the characteristics of a tracer (low affinity for soil sorption, high solubility, and low vapor pressure). 1,4-dioxane is highly mobile in groundwater and is difficult to treat by conventional methods.

## C3.1 Treatment Options

Table C3-1 presents an assessment of the feasibility of potential options for ex situ treatment of 1,4-dioxane.

**TABLE C3-1**

Assessment of Ex Situ Treatability of 1,4-Dioxane

*Focused Feasibility Study, North Hollywood Operable Unit, San Fernando Valley Area 1 Superfund Site – Design Assumptions and Calculations*

Treatment Methods Likely to Be Feasible	Treatment Methods Not Likely to Be Feasible
UV/Peroxide (if turbidity of groundwater is low)	Ambient air stripping
Ozone/Peroxide	Granular activated carbon (unless used as a biofilm system)
Biofilm Aerobic Cometabolism (with THF and butane)	Fenton's reagent

Notes:

UV = ultraviolet

THF = tetrahydrofuran

Advanced oxidation processes (AOP), such as ozone/peroxide and ultraviolet (UV) light/peroxide (UV/Ox) treatment processes, are commercially viable. Biological methods have also been evaluated at bench-scale, but results have been inconsistent, and full-scale commercially viable biological treatment processes have not been identified.

### C3.1.1 Selection of Treatment Process for 1,4-Dioxane

The only reported commercially viable process available for 1,4-dioxane is an AOP. AOP-based treatment systems oxidize organics by generating hydroxide radicals, which have a high oxidation potential. Hydroxide radicals can be generated by four types of AOP: (1) ozone with hydrogen peroxide, (2) UV light with hydrogen peroxide, (3) ozone with UV light, and (4) ozone with UV light and hydrogen peroxide. Of these combinations, the first two (ozone with hydrogen peroxide and UV light with hydrogen peroxide) are the most common. Of these AOP-based treatment systems, the UV-light and hydrogen peroxide process (UV/Ox process) currently provides the most flexibility and is recommended as the basis for the cost evaluation. This type of AOP also removes several other VOCs, including trichloroethene and tetrachloroethene.

### **C3.1.2 UV/Oxidation Reactor Design**

Before entering the UV/hydrogen peroxide system (reactor), the influent groundwater should be prefiltered using bag filters (25-micrometer rating maximum) or other media filters. The hydrogen peroxide is injected into the contaminated water, which then passes through a tank containing UV lamps. The UV light causes the hydrogen peroxide to split and form hydroxyl radicals that react with certain VOCs and 1,4-dioxane. The UV light also reacts directly with 1,4-dioxane. In all cases, the oxidized chemicals are either fully mineralized or produce partially oxygenated byproducts, such as acetone and ketoacids.

To treat the discharge from extraction well NHE-2 under Alternatives, 2a through 5b (300 gallons per minute maximum flow rate), two UV/Ox reactors will be required, including the unit planned by Honeywell with 190 gpm capacity, and a new unit with 110 gpm capacity (300 gpm total combined capacity). The total power draw is estimated at 15kW. The hydrogen peroxide will be metered through the feed pipeline to the UV tank. A static mixer will be located after the hydrogen peroxide injector and before the UV tank.

After the treated water exits the UV/Ox tank, a reducing agent will be added to remove the remaining hydrogen peroxide. The UV/Ox reactor will have inlet and outlet sampling ports, temperature sensors, and oxidation/reduction potential probes.

**Attachment C4**  
**1,4-Dioxane Treatment Details**

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# Liquid-Phase Granular Activated Carbon Treatment Details

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This attachment presents the design assumptions and calculations used to identify and size adsorber vessels and key equipment and to estimate power and liquid-phase granular activated carbon (LPGAC) usage.

## C4.1 LPGAC Adsorption Assumptions and Clarifications

This section discusses LPGAC adsorption assumptions and clarifications.

### Assumptions and Clarifications for LPGAC Modeling

#### LPGAC Multicomponent Adsorption

Similar to the discussion regarding vapor phase granular activated carbon (VPGAC) theoretical models for prediction of carbon life in the presence of multiple components are useful, but not well accepted by industry. A simple multi-component model often is used to develop an estimate of carbon volatile organic compound (VOC) holding capacity. However, in this instance, the LPGAC adsorbers are functioning as polishers after air stripping. The inlet water already meets MCLs. Therefore, a bed service life is assumed primarily to limit excess biogrowth that can accumulate on LPGAC.

#### VOC Loading

The influent VOC concentrations into the LPGAC adsorbers are estimated based on the virtually complete removal of TCE and PCE by the upstream air strippers. CH2M HILL assumes that the air stripper will be designed to reduce concentrations of both TCE and PCE to less than 60 percent of their MCLs. The LPGAC adsorbers will function strictly as a polisher to guard against unexpected stripper failure. Therefore, for estimating purposes, the LPGAC adsorbers are assumed to have a bed service life of 1 year.

#### Natural Background Organic Matter

The presence of natural background organic matter can have a negative effect on the adsorption capacity of the LPGAC. The analyses available indicate that the presence of humic and fulvic materials is minimal. However, background organics are present, and should be compensated for.

For the purpose of this study, the impact of natural background organic matter and other VOCs on carbon usage rates shall be compensated for using a correlation.

#### Type of LPGAC Vessel

For the purpose of the FFS, only pressure vessel LPGAC adsorbers are considered.

## Hydraulic Standards for LPGAC Systems

The following guidelines are considered industry-accepted practices for gravity flow activated carbon adsorbers. The LPGAC systems developed for this FFS incorporated these guidelines where applicable.

- Liquid superficial flux 3 to 10 gpm/square foot
- Carbon bed depths 4-foot minimum
- Maximum adsorber diameter of 12 feet (for shop fabricated systems)
- Empty bed contact time (EBCT) of 5 to 40 minutes (total all vessels in series)
- Maximum LPGAC Bed life of 2 years

## C4.1 LPGAC Biologically Active Reactor Assumptions and Clarifications

LPGAC can also be used to treat for partially oxidized byproducts from UV/Ox processes. UV/Ox treated water will contain residual partially oxidized byproducts. These byproducts are typically acetone, ketones, and ketoacids. A common method to eliminate the partially oxidized byproducts is to pass the effluent through LPGAC adsorber columns. LPGAC adsorber columns develop an aerobic biological population which destroys the partially oxidized byproducts.

This section describes the assumptions used to estimate the LPGAC Biologically Active Reactor (BAR) system size:

- Liquid superficial flux 3 to 8 gpm/square foot
- Carbon bed depths 7-foot minimum
- Maximum adsorber diameter of 12 feet (for shop fabricated systems)
- Empty bed contact time (EBCT) of 5 minutes minimum to achieve 80 to 97 percent removal
- Water is fully aerobic prior to entering the LPGAC BAR
- The oxygen demand of organic loading to the LPGAC BAR is well below the inlet dissolved oxygen concentration

## Works Cited

Bouwer, E.J., Goel, S., Hozalski, R.M. Removal of Natural Organic Matter in Biofilters, AWWA Research Foundation, Denver CO, 1995

Carlson, K.H., Amy, G.L., Blais, G., MacMillan, S., 1996. The Formation of Filter Removable BOM During Ozonation, Proceedings of the 1996 Fourth International BOM Conference, Waterloo, ON

Price, M.L., Ozone and Biological Treatment for DBP Control and Biological Stability, AWWA Research Foundation, Denver CO, 1994

**Attachment C5**  
**Hand Calculations and Computer Modeling**  
**Results**

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# Hand Calculations and Computer Modeling Results

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## Anion Ion Exchange Resin Use Estimate

Q = 2000 gpm

Usage = 80,000 B.V.

$$\text{Resin Use} \cong \frac{\left(2000 \frac{\text{gal}}{\text{min}}\right) \left(1440 \frac{\text{min}}{\text{day}}\right) \left(365 \frac{\text{day}}{\text{yr}}\right) \left(\frac{\text{cf}}{7.48 \text{ gal}}\right)}{\left(80,000 \frac{\text{cfH}_2\text{O}}{\text{cf Resin}}\right) \left(\frac{35 \text{ ppb}}{200 \text{ ppb}}\right) (150 \% \text{ capac adjust for higher inflow rate})}$$

$$= 6,700 \text{ cf Resin/ yr}$$

Q = 600 gpm

Usage = 80,000 B.V.

$$\text{Resin Use} \cong \frac{\left(\frac{600 \text{ gpm}}{2000 \text{ gpm}}\right) \left(6,700 \frac{\text{cf Resin}}{\text{yr}}\right)}{}$$

$$= 2,010 \text{ cf Resin/yr}$$

## Ferrous Iron Reduction Reactors Estimate

- (1) To estimate the reaction rate for reducing Cr(VI) to trivalent chromium (Cr[III]), CH2M HILL recommends "Kinetics of Chromate Reduction by Ferrous Iron," by Scott Fendorf, *Environmental Science & Technology* **1996** 30, 1614-1617 (attached). The chemical reaction between Cr(VI) and Fe(II) is:



The kinetic equation obtained by Fendorf is:

$$\frac{d[\text{Cr(VI)}]}{dt} = -k_{\text{Cr}}[\text{Fe}^{2+}]^{0.6}[\text{Cr(VI)}]^{1.0}$$

where,

$$k_{\text{Cr}} = 56.3 \text{ millimole}^{-0.6} \text{ minute}^{-1} \text{ L}^{0.6}$$

$$[\text{Cr(VI)}] = \text{Cr(VI), millimole/L}$$

$$[\text{Fe}^{2+}] = \text{initial Fe}^{2+}, \text{ millimole/L}$$

$$[\text{Cr}]_t = [\text{Cr}]_o * \exp(-k_{\text{Cr}} * [\text{Fe}]_o * t)$$

$$\text{Let } [\text{Fe}]_o = 10 \text{ mg/L} = 0.18 \text{ mmol/L}$$

Therefore,

At time = 2 minutes,

$$[\text{Cr}]_t = 200 \text{ } \mu\text{g/L} * \exp(-56.3 \text{ millimole}^{-0.6} \text{ minute}^{-1} \text{ L}^{0.6} * 0.18 \text{ millimol/L})^{0.6} * 2 \text{ minutes})$$

$$[\text{Cr}]_t < 1 \text{ } \mu\text{g/L} \text{ at time} = 2 \text{ minutes}$$

### Inline Reactor Estimate

Operating Southern California System

$$\text{Residence Time} = \Theta_{R1} = 2 \text{ minutes}$$

Use 5 minutes (cheap to add excess)

$$\begin{aligned} \therefore V_{\text{Reactor Tank}} &= \frac{(5 \text{ min})(600 \text{ gpm})}{1} \\ &= 3,000 \text{ gal} \end{aligned}$$

### Tank Reduction Reactors Estimate

Operating Southern California System

$$\text{Residence Time} = \Theta_{R2} = 15 \text{ minutes}$$

Use 20 minutes

$$\begin{aligned} \therefore V_{\text{Reduct Tank}} &= \frac{(20 \text{ min})(600 \text{ gpm})}{1} \\ &= 12,000 \text{ gal} \end{aligned}$$

## Tank Oxidation Reactors Estimate

To estimate the reaction rate for oxidizing residual ferrous iron (Fe[II]) to ferric iron (Fe[III]), CH2M HILL recommends "Kinetics and Product of Ferrous Iron Oxygenation in Aqueous Systems," by Windsor Sung and James Morgan, *Environmental Science & Technology* **1980** 5, 61-568 (attached). The kinetic equation CH2M HILL recommends for the reaction rate between Fe<sup>2+</sup> and dissolved oxygen in a backmix reactor is given by the following equation:

$$\frac{d[\text{Fe}^{2+}]}{dt} = -k[\text{Fe}^{2+}][\text{OH}^-]^2 p\text{O}_2$$

where,  $k = \sim 1.348 \times 10^{13} \text{ L}^2 / (\text{atm} \cdot \text{min} \cdot \text{mole})$  for 3,800 mg/L TDS groundwater  
 $k = \sim 1.445 \times 10^{12} \text{ L}^2 / (\text{atm} \cdot \text{min} \cdot \text{mole})$  for 44,125 mg/L TDS groundwater  
 $[\text{Fe}^{2+}]$  = ferrous iron concentration, mole/L  
 $[\text{OH}^-] = [10^{(\text{pH}-14)}]$  mole/L  
 $p\text{O}_2$  = effective oxygen partial pressure (temperature and salinity) typ. 0.12 to 0.18 atm

In backmix reactors, the reaction rate equation takes the form of,

$$C_1 = C_0 / (1 + k_1 V / Q)$$

where,

$C_1$  = Concentration of Fe<sup>2+</sup> discharged from the backmix reactor

$C_0$  = Concentration of Fe<sup>2+</sup> influent to the backmix reactor

$k_1 = k[\text{OH}^-]^2 p\text{O}_2$

$V$  = reactor volume, gallons

$Q$  = flow rate through the reactor, gallons/minute

At pH = 7.5,  $p\text{O}_2 = 0.21$

$$\begin{aligned} k_1 &= k[\text{OH}^-]^2 p\text{O}_2 \\ &= 1.68 \text{ min}^{-1} \end{aligned}$$

$$[\text{Fe}]_{\text{outlet}} = [\text{Fe}]_{\text{inlet}} / (1 + (1.68 \text{ min}^{-1} * \text{Vol}) / Q)$$

Let  $[\text{Fe}]_{\text{outlet}} = 0.3 \text{ mg/L}$  (Secondary MCL)

$Q = 600 \text{ gpm}$

Solve for Vol = 12,000 gal (theoretical minimum)

Let  $[\text{Fe}]_{\text{outlet}} = 0.1 \text{ mg/L}$  (Secondary MCL)

$Q = 600 \text{ gpm}$

Solve for Vol = 36,000 gal (theoretical minimum)

Operating Southern California System

Residence Time =  $\Theta_{R3} = 3 \times 52 = 156 \text{ minutes}$

@ residual of 50 ppm

$$\begin{aligned} \therefore V_{\text{Ox Tank}} &= \frac{\left(\frac{10 \text{ ppm}}{50 \text{ ppm}}\right)(156 \text{ min})(600 \text{ gpm})}{1} \\ &= 18,700 \text{ gal total} \end{aligned}$$

NOTE: Kinetics not actually linear, but assumed for estimating purposes
---

Round up and add 50% excess: 3 @ 12,000 gal each (based on field example)

NOTE: Actual minimum tank volume will depend heavily on pH during oxidation step.

## 1,4-Dioxane Treatment UV/Peroxide Power Estimates

$$Q = 300 \text{ gpm}$$

$$[1,4\text{-dioxane}]_{in} = 10 \text{ } \mu\text{g/L}$$

$$[1,4\text{-dioxane}]_{ef} = 1.8 \text{ } \mu\text{g/L}$$

### Order Reduction

$$x = \log \frac{10}{1.8} = 0.75$$

Figure 4.1 (see Calgon AOT Handbook)

$$EE/O = 6.1$$

$$\begin{aligned} \text{UV Dose} &= EE/O * \log_{10} \left( \frac{C_i}{C_f} \right) \\ &= 6.1 * \log_{10} \left( \frac{10}{1.8} \right) \\ &= 4.5 \text{ kWh/1000 gal} \end{aligned}$$

@ 300 gpm

$$\begin{aligned} P &= \left( \frac{4.5 \text{ kWh}}{1,000 \text{ gal}} \right) \left( 300 \frac{\text{gal}}{\text{min}} \right) \left( 60 \frac{\text{min}}{\text{hr}} \right) \\ &= 81 \text{ kW} \end{aligned}$$

### Adjust Power for Trojan Lamps

Use data from other U.S. Environmental Protection Agency Projects

$$\begin{aligned} \text{Calgon Power Est.} &= 2872 \text{ kW}^a \\ &(\text{Calgon, April 30, 2007}) \end{aligned}$$

$$\begin{aligned} \text{Trojan Power Est.} &= 333 \text{ kW}^a \\ &(\text{Trojan, May 2, 2007}) \end{aligned}$$

<sup>a</sup>Based on equal performance.

Power for North Hollywood Operable Unit Focused Feasibility Study based on Calgon's method → 650 kW

**If Equivalent System by Trojan**

$$P_{\text{TrojanDesign}} = 81 \text{ kW} \left( \frac{333 \text{ kW}}{2872 \text{ kW}} \right)$$
$$= 9.4 \text{ kW}$$

Add 50 percent Safety Factor

$$\rightarrow P = 1.5 (75 \text{ kW})$$

$$= 14 \text{ kW}$$

Use 15 kW
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BBS RELEASE DATE: Aug 1995  
BBS REVISION LEVEL: 2  
BBS PROGRAM NAME: VGAC\_R2.XLS

This spreadsheet will allow the user to estimate the off-gas analysis of an air stripper, estimate the usage of vapor phase carbon (VGAC) and estimate design features of a system. This spreadsheet is set-up for an air stripping application. However, it can be readily converted and used to estimate the VGAC usage and system design parameters for any organic vapor source (i.e., an SVE system).

The estimates of carbon usage in this program are crude estimates. For design projects or where more precise estimates are needed, it is recommended to also estimate the carbon usage using the Equilibrium Column Model (see Kart Vaith/TPA) and to get vendor estimates.

The original version of this program was written by Ken L Martins/LAO in June, 1990.

This program can be misused. This program is not intended to be a "model" but is intended only to be a tool to aid in carbon use calculations. Persons without significant experience in VGAC system design should have all calculations verified by a senior engineer.

If a program bug is found or a conceptual flaw is noted, please do not modify the program. Instead please contact the Technical Service Leader immediately.

Enter Client's Name: EPA, North Hollywood FFS  
Alt 1, Ave Flow and Ave Concs

System Data:

~~~~~  
Enter the total flow for all wells..... 900 gpm

Enter flow for fluctuating concentrations..... 300 gpm

NOTE: The flow for fluctuating concentrations is a value used later in the "Sensitivity Analysis" section. This value should be the flowrate a contributing stream which can fluctuate in contaminant concentration. A good example is a groundwater treatment system with a number of wells. The fluctuating flowrate may be the flowrate of 1 of the wells. If you do not have a segregated stream which can fluctuate then enter the total system flowrate.

Enter the total number of strippers on-line..... 1 --

Individual Stripper Data:

~~~~~  
The water flowrate per Stripper..... 900 gpm

Enter the stripping air flowrate..... 4,000 acfm @ 62 F

Enter the Air Temperature..... 82 F

NOTE: Enter temperature after off-gas heater, if any. Typically 20F higher than stripper off-gas temperature, which is assumed the same as the influent water temperature.

Enter the Relative Humidity of Air..... 50 % RH

NOTE: Enter relative humidity of off-gas after heater, if any. Typically a 20F rise in temperature will reduce the relative humidity from 100% to 50%. Typically, the vapor stream to be treated should be no higher than 50 %RH. Air stripper designs with off-gas vapor at 100% RH may be severely limited in VGAC performance.

\*\* Estimate Carbon Usage Rate \*\*

Input Influent and Isotherm Data:

Typically input data for all contaminants in the water phase (for air stripping applications), including those that are low enough not to require removal. The low concentration contaminants can influence the overall performance due to "the chromatographic effect." Then, determine which contaminant is the lead contaminant. If the lead contaminant does not require removal (e.g., it does not exceed the discharge standard for the local air district) then "turn-off" the contaminant in question using the "Include ? (y or n)" column. If the lead contaminant must be removed then procede to the next calculation section. Do not "turn-off" any other contaminants.

NOTE: The lead contaminant is assumed to be the contaminant with the lowest "K" factor - See column "Lead Contaminant I.D."

Organic Name (NOTE)	Conc (ppm)	Strip (%)	Loading #VOC/d	Gas Conc (ug/l)	Load ? y or n	K (umol/g)/(umol/l)^(1/n)	1/n	Mol. Wt (g/gmol)	Cap. (#VOC/#C)	1/Cap. (#C/#VOC)	Usage (#C/day)	Lead Contaminant I.D.	SENSITIVITY ANALYSIS I (NOTE 3)			SENSITIVITY ANALYSIS CHECK I	
													Max Liq. Ph. Conc. Allowed before Controlling Design (ppm)	Ratio: Max Liq. Ph. Conc. Allowed	Ratio: Max Liq. Conc. at one well if others remain Constant	Max Vapo Conc. for Isotherm Data (ug/l)	Calculation: Max Vapor Conc. using Existing A/W Ratio (ug/l)
PCE	0.0115	100	0.12	0.33	y	1511	0.19	166	7.7E-02	1.3E+01	1.6E+00	not lead	0.1001	8.7	24	500	2.8993
TCE	0.07	100	0.76	2.03	y	1589	0.227	132	8.1E-02	1.2E+01	9.3E+00	not lead	0.07	1	1	400	2.0275
CTC	0.001	100	0.01	0.03	y	1429	0.217	154	3.4E-02	2.9E+01	3.2E-01	not lead	0.0752	75.2	224	470	2.1781
111-TCA	0	100	0.00	0.00	n	1601	0.222	133	N/A	N/A	0.0E+00	not lead	0	0	0	400	#DIV/0!
11-DCA	0.0007	100	0.01	0.02	y	940	0.301	99	7.2E-03	1.4E+02	1.0E+00	LEAD	0.0159	22.7	66	300	0.4605
11-DCE	0.0014	100	0.02	0.04	n	658	0.395	97	N/A	N/A	0.0E+00	not lead	0	0	0	200	0
cis-12-DCE	0.0018	100	0.02	0.05	n	851	0.341	97	N/A	N/A	0.0E+00	not lead	0	0	0	40	0
trans-12-DCE	0	100	0.00	0.00	n	851	0.34	97	N/A	N/A	0.0E+00	not lead	0	0	0	300	#DIV/0!
1122-TCA	0	100	0.00	0.00	n	2994	0.112	168	N/A	N/A	0.0E+00	not lead	0	0	0	510	#DIV/0!
Acetone	0	5	0.00	0.00	n	429	0.425	58	N/A	N/A	0.0E+00	not lead	0	0	0	180	#DIV/0!
Benzene	0	100	0.00	0.00	n	1582	0.262	78	N/A	N/A	0.0E+00	not lead	0	0	0	70	#DIV/0!
Eth.benz.	0	100	0.00	0.00	n	2386	0.127	106	N/A	N/A	0.0E+00	not lead	0	0	0	70	#DIV/0!
Meth Chlor	0	100	0.00	0.00	n	325	0.459	85	N/A	N/A	0.0E+00	not lead	0	0	0	260	#DIV/0!
Toluene	0	100	0.00	0.00	n	2178	0.177	92	N/A	N/A	0.0E+00	not lead	0	0	0	50	#DIV/0!
Total Xylene	0	100	0.00	0.00	n	2541	0.097	106	N/A	N/A	0.0E+00	not lead	0	0	0	320	#DIV/0!
V Chlor	0	100	0.00	0.00	n	89	0.522	63	N/A	N/A	0.0E+00	not lead	0	0	0	190	#DIV/0!
MEK	0	5	0.00	0.00	n	1284	0.435	72	N/A	N/A	0.0E+00	not lead	0	0	0	220	#DIV/0!
Bromoform	0	100	0.00	0.00	n	2925	0.176	253	N/A	N/A	0.0E+00	not lead	0	0	0	770	#DIV/0!
DBCM	0	100	0.00	0.00	n	2000	0.25	208	N/A	N/A	0.0E+00	not lead	0	0	0	35	#DIV/0!
Chloroform	0.0021	100	0.02	0.06	y	943	0.33	118	9.1E-03	1.1E+02	2.5E+00	not lead	0.0151	7.2	20	35	0.4374
12-DCA	0	100	0.00	0.00	n	947	0.29	99	N/A	N/A	0.0E+00	not lead	0	0	0	360	#DIV/0!
TCFM	0	100	0.00	0.00	n	444	0.35	137	N/A	N/A	0.0E+00	not lead	0	0	0	N/A	#DIV/0!
1,2 DiChlBenz	0	100	0.00	0.00	n	3054	0.097	147	N/A	N/A	0.0E+00	not lead	0	0	0	450	#DIV/0!
Chlbenz	0	100	0.00	0.00	n	1879	0.257	112	N/A	N/A	0.0E+00	not lead	0	0	0	340	#DIV/0!
Other	0	100	0.00	#DIV/0!	n	?	?	?	N/A	N/A	0.0E+00	not lead	0	0	0	410	#DIV/0!
Other	0	100	0.00	#DIV/0!	n	?	?	?	N/A	N/A	0.0E+00	not lead	0	0	0	40	#DIV/0!
~~~~~																	
0.95656															1.5E+01		

NOTE 1: The data for the isotherms are based primarily on Calgon's BPL and American Norit RB. Graphic isotherms were provided. The equations for each were derived. The resulting carbon use rates for Calgon BPL and Norit RB at concentrations typical of air stripper off-gas were compared. The more conservative value was used.

NOTE 2: All isotherm values are based on a temperature of 84 F and 0% humidity. Adsorption capacity tends to increase as temperature decreases and decreases with increasing relative humidity. The calculations below provide a crude estimate to compensate for your actual temperature and relative humidity.

WARNING: The temperature and humidity correction factors provided herein are crude and subject to error.

NOTE 3: A Sensivity Analysis of the carbon usage calculation is provided. Two sections are provided. The Carbon Usage Sensivity Analysis and the Check of the Maximum Concentration that the existing data is valid for.

**CARBON USAGE SENSITIVITY ANALYSIS**

This section back-calculates the concentration each compound could have been before it would have "controlled the design", as calculated using the "Single Largest Carbon User" method. The column labeled "Max Conc. Allowed before Controlling Design" is this calculated value. For the controlling contaminant, the calculated value should equal the actual influent. The column labeled "Ratio: Max. Conc. Allowed/Actual Influent" is the ratio indicated. This ratio should be equal to 1.0 for the controlling contaminant and greater than 1.0 for all other contaminants. And, finally, the column labeled "Ratio: Max Conc./Actual if others remain Constant" indicates the concentration a single source could increase if the other sources remained constant. At the top of the spreadsheet, values were entered for the "Total Flow" and "Flow for Fluctuating concentrations." If one of many sources vary then this column will calculate how much the individual source can vary without significantly changing the total carbon usage (as calculated using the Single Largest Carbon User method).

**CHECK OF MAXIMUM APPLICABLE CONCENTRATION**

And, finally, the column labeled "Max Conc. for Isotherm Data" indicates the applicable range for the isotherm data used in the default isotherm values used in the calculation section above. The actual off-gas concentrations are also calculated.

**Temperature and Relative Humidity Factors**

Based on a vapor temp. of ..... 82 F, the temp. correction factor is..... 1.058  
 Based on a vapor %RH of ..... 50 %, the humidity correction factor is..... 0.69

**Summary of Alternative Carbon Usage Rate Predictions:**

Method	Estimate (lbs C/day/adsorber)	
	Series Configuration	Single Bed Configuration (See NOTE 1)
Single Largest Carbon User	13	14
Sum of All Contaminants	20	22

NOTE 1: The single bed configuration estimate is 10% higher than the corresponding value for series configuration to account for incomplete exhaustion of bed before carbon change out. Typically, use the Single Bed Configuration value.

NOTE 2: The above calculated values include compensation for the actual relative humidity and temperature.

NOTE 3: The methods for accounting for multicomponent adsorption have not been accounted for in the above calculations. The above calculations identify the single largest carbon user and the sum total of carbon load rates for all contaminants. The actual carbon use rate will be between these two values. For a conservative estimate, use the sum total of carbon load rates for all contaminants. If the difference between the single largest value and the sum total value is small (Less than 25%) then the impact of using the larger value is not particularly significant. This assumption is likely to be within the range of error for the isotherm data.

Based on the above information,  
 enter desired carbon usage rate..... 22 lbs C/day/adsorber

The rate of VGAC carbon usage is..... 22 lbs C/day/stripper  
 Based on 1 Stripper(s) on-line the Total  
 Carbon Usage will be..... 22 /day 8.0E+03 lbs/yr

Mechanical Design:

~~~~~  
COMMENT The following section is used to develop mechanical design features for a carbon adsorber system. Typically, carbon adsorbers are NOT custom designed. In most cases, carbon adsorbers are off-the-shelf units. Most off-the-shelf units are based on the poundage of carbon which they hold. Typical poundages for drum size units are 150 lbs each, medium tank size units holding 300 lbs each, and for vessel size units poundages of 1,500 lbs, 2,000 lbs, 5,000 lbs, 10,000 lbs, and 13,600 lbs are representative of available systems (based on Systems by Carbonair).

Typical Design Parameters

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Design Values:

Minimum Flux Rate      0.8 ft/sec  
Typical Flux Rate        1.0 ft/sec  
Maximum Flux Rate       1.4 ft/sec

Activated Carbon bed depth should be at least equal to 1/3 the diameter of the bed or 2.0 ft (except drums size units), whichever is more.

Typical Off-the-Shelf Designs

~~~~~  
Enter the Qty of Adsorbers/Stripper.....                      1    Unit(s).

The table below will summarize designs for off-the-shelf adsorbers sizes treating                      4000    cfm.

| Type of Unit | Pounds of C (lbs) | Surface Area (sq.ft.) | Surfacial Velocity (ft/sec) | Bed Depth (inches) | Bed Life before Breakthrough (days) |
|--------------|-------------------|-----------------------|-----------------------------|--------------------|-------------------------------------|
| Drum         | 150               | 2.7                   | Unit Too Small              | 22                 | 6.8                                 |
| Tank         | 300               | 4                     | Unit Too Small              | 30                 | 13.6                                |
| Vessel       | 1,500             | 12                    | Unit Too Small              | 50                 | 68.2                                |
| Vessel       | 2,000             | 20                    | Unit Too Small              | 40                 | 90.9                                |
| Vessel       | 5,000             | 48                    | 1.4                         | 42                 | 227.3                               |
| Vessel       | 10,000            | 70                    | 1                           | 57                 | 454.5                               |
| Vessel       | 13,600            | 120                   | Unit Too Large              | 45                 | 618.2                               |

Custom Designs

~~~~~

Enter Design Gas Velocity..... 1 ft/sec  
Note: Typical VGAC Velocities are .8 to 1.4 ft/sec

Rough Vessel Area..... 66.7 sq.ft. (Total Area Required)  
Note: 12' Dia = 113 sq.ft.  
8' Dia = 50 sq.ft.

Enter the Qty of Adsorbers/Stripper..... 1 --

Rough Area per vessel..... 66.7 sq.ft.  
Rough Vessel Dia..... 9.2 ft

Enter the Vessel Dia..... 10 ft

The Total Gas Flow Area will be..... 78.5 sq.ft.  
The Gas Velocity will be..... 0.85 ft/sec

Enter the Act. Carbon Bed Depth..... 4 ft

Total Carbon Volume on-line will be..... 314 cu.ft. (All Vessels Total)

Enter the Act. Carbon Density..... 30 lbs/cf (30 lbs/cf is typical)

The Carbon Bed Service Life will ..... 428.2 days  
.....