

Laboratory Evaluation of Granular Activated Carbon for Liquid Phase Applications



Introduction

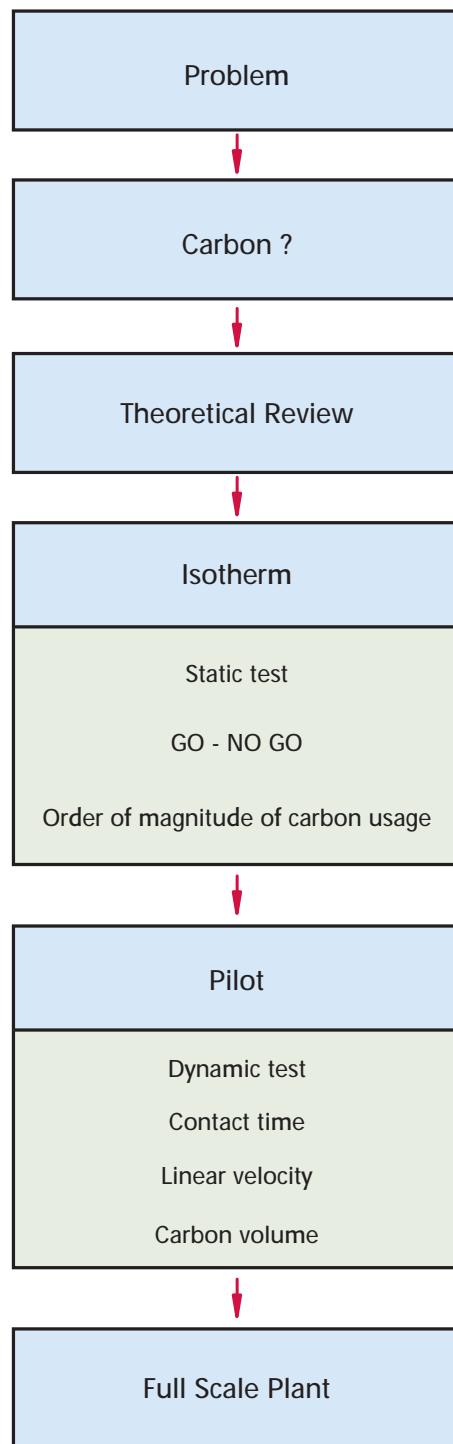
Activated carbon has been used to remove vapor phase contaminants from gas streams for many years. Vapor phase adsorption data can be found in the literature and methods exist for the design of vapor phase adsorbers, sometimes without doing any tests. For liquid phase applications, however, accurate predictions of carbon usage and effectiveness usually cannot be made due to the presence of non-descript species in solution, without some experimental data. Therefore, experimental evaluations must be conducted for each new liquid phase application. Whether granular activated carbon is being considered for a new application or for the replacement of powder carbon systems, a laboratory investigation is essential to determine:

- Efficiency
- Relative advantages in the specific application

A complete laboratory investigation would consist of at least two parts:

- An isotherm, which is a screening test, to evaluate the ability of activated carbon to adsorb the contaminant of concern and to calculate the theoretical, minimum carbon dosage to achieve satisfactory removal
- Column tests, or pilot tests, to obtain system design data such as:
 - Minimum contact time necessary to achieve the treatment objective
 - Capacity of the activated carbon under normal operating conditions
 - Need for pretreatment

Either the isotherm test or the column test may be unnecessary depending on previous experience and background information available.



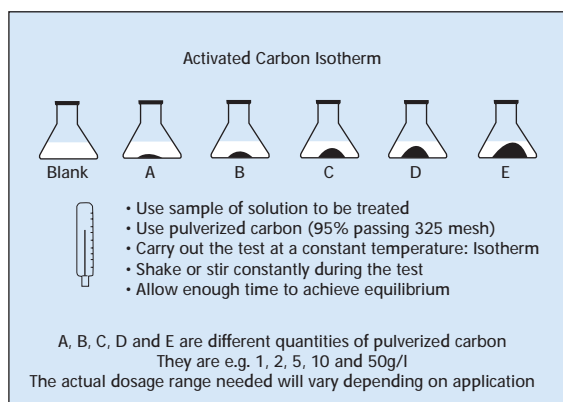
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Isotherms

The adsorbability of a contaminant is determined by its physical and chemical properties. The adsorption capacity of an adsorbate on carbon is related to the adsorbate's concentration in solution and to other competing solutes. The objective of the isotherm test is to determine the relationship between the concentration of the adsorbate and the capacity of the carbon.

Test Procedure

The most convenient way to complete an isotherm test is to apply different weights of dried, pulverized granular activated carbon to constant volumes of the test solution, as illustrated below. The mixtures are agitated for the duration of the test. A test is considered complete when there is no further change in residual adsorbate concentration in the mixtures. If the activated carbon is pulverized so that 95 percent will pass through a 325 mesh screen, 24-hour equilibration will usually achieve >90 percent of equilibrium. After equilibration, the sample is filtered to remove the carbon. The residual contaminant concentration in the filtrate is then determined.



Theory

Liquid phase isotherms are generally interpreted using the empirical Freundlich equation, which relates amount of impurity in the solution phase to that in the adsorbed phase by the equation:

$$x/m = kc^{1/n}$$

Where:

x = amount of impurity adsorbed

m = weight of carbon

x/m = concentration of the adsorbed state (i.e. the amount of impurity adsorbed per unit weight of carbon)

c = contaminant concentration in the solution after adsorption equilibrium achieved

k, n = constants

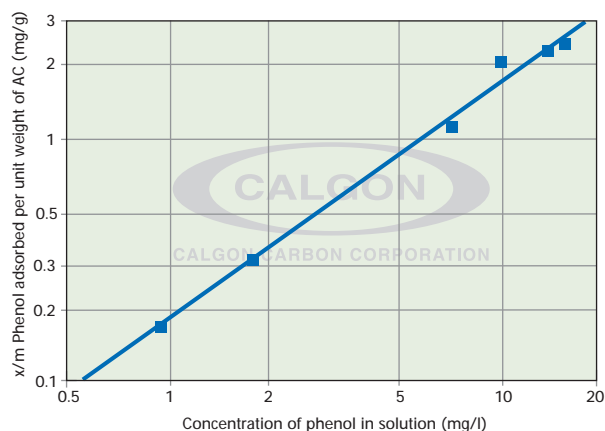
Taking the logarithm of both sides yields:

$$\log x/m = \log k + 1/n \log c$$

A plot of $\log x/m$ versus $\log c$ yields a straight line with slope $1/n$ and intercept k (or x/m versus c can be plotted on log-log paper for convenience). This is true over a wide concentration range, and in particular, for low concentration (dilute solutions) of adsorbates.

Example

The example below is for phenol adsorption on activated carbon. The parameters are: m is mass of activated carbon per volume of test solution, c is the residual phenol concentration once equilibrium is achieved, and x is the phenol adsorbed from solution (it is determined by subtracting the residual concentration from the non-carbon dose, or control).



To estimate the carbon use rate at the initial phenol concentration, 18.15 mg/l, the best straight line is fitted to the data and extrapolated to 18.15 mg/l. The equilibrium loading at this point is 3 mg/g. Dividing 18.15 mg/l by 3 mg/g capacity, a carbon use rate of 6.05 gAC/liter treated is projected for this application.

m (gAC/l)	c (mg Ph./l)	x (mg Ph./l)	x/m (mg Ph./g)
0	18.15	-	-
1	15.90	2.25	2.25
2	14.10	4.05	2.02
5	10.25	7.90	1.58
10	7.15	11.00	1.10
50	1.80	16.35	0.32
100	0.95	17.20	0.17

Pilot Testing

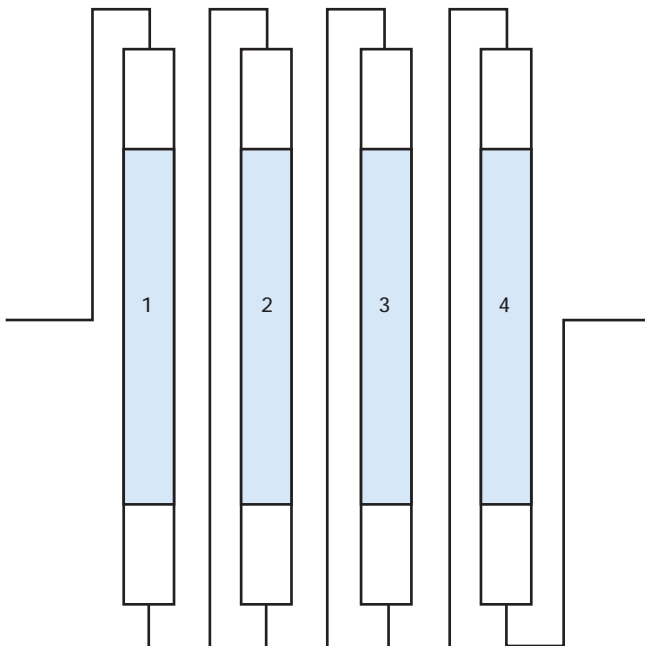
Purpose

Pilot tests are necessary follow-ups to isotherm testing. The isotherm use rate estimates are used to decide whether granular activated carbon is appropriate for the application (i.e. will carbon sufficiently remove the contaminant of concern). The objective of the pilot study is to determine the optimal operating conditions that provide the most efficient usage of the GAC's capacity while meeting the treatment requirement.

The equipment required for a pilot study consists of columns one inch in diameter or larger (the larger the columns, the more representative the results). Several columns are placed in series and various tests are conducted at different linear velocities. The column effluent is monitored for the appearance of the target contaminant (i.e. adsorbate breakthrough). Monitoring breakthrough with time develops the so-called breakthrough curve from which the contaminant mass transfer zone (MTZ) can be determined. The pilot study will also demonstrate whether a pretreatment step, such as filtration, is needed to improve the GAC's performance.

The results of the pilot study will determine:

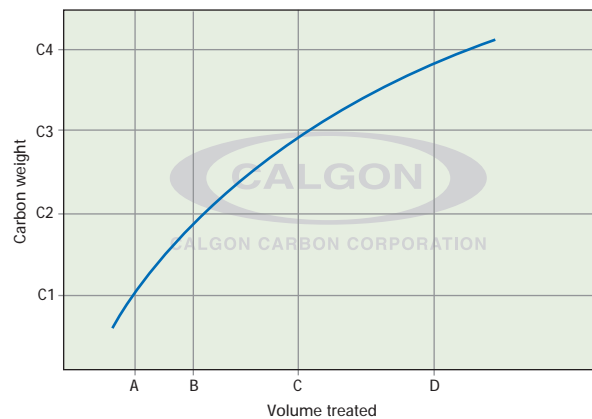
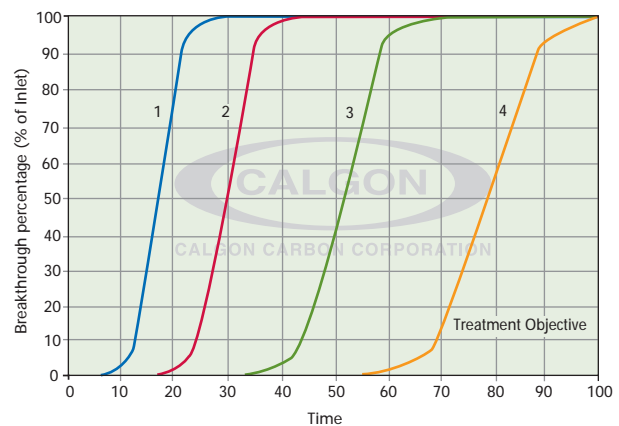
- Optimal linear velocity and contact time necessary to achieve the treatment objective
- Effective capacity of the granular carbon for impurity removal, i.e., the real carbon dosage (lbs. carbon/1,000 gal. treated)
- Bed depth to be taken into account for the mass transfer zone (MTZ)
- Need for pretreatment, for example, prefiltration to remove suspended solids



Breakthrough Curves

In defining the optimal configuration of a GAC system, several aspects of the breakthrough curve must be taken into account. Once the MTZ has been established and contained within a column, the shape of the MTZ will not change in subsequent columns. If the MTZ shape changes, this may indicate that mechanisms other than physical adsorption are occurring. Also, the equilibrium capacity calculated at 100 percent breakthrough should be the same for each column.

If the MTZ is small compared to the GAC bed depth in a column, very efficient capacity usage can easily be realized with a single adsorber. If the MTZ is large relative to the GAC bed depth, very efficient capacity usage can easily be realized by series adsorber operation and staging. The pilot test results will provide sufficient data to determine the most economical approach for installing GAC.



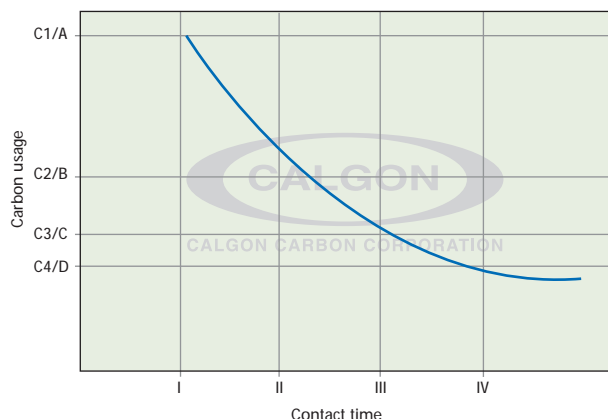
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Operating Line

The operating line gives carbon dosages as a function of the corresponding superficial contact times, for a well determined treatment objective. The operating line allows the selection of the optimum combination of carbon dosage and contact time. Since both capital cost (via contact time = carbon volume) and operating cost (via carbon dosage) are involved, the system has to be chosen so that a minimum total cost is reached.

The operating line approaches both axes. The minimum carbon dosage for a given adsorption duty is that which is achieved when the exhausted carbon in the column is in equilibrium with the influent concentration. This value is obtained experimentally by the isotherm test or from the loading curves.



Safety Message

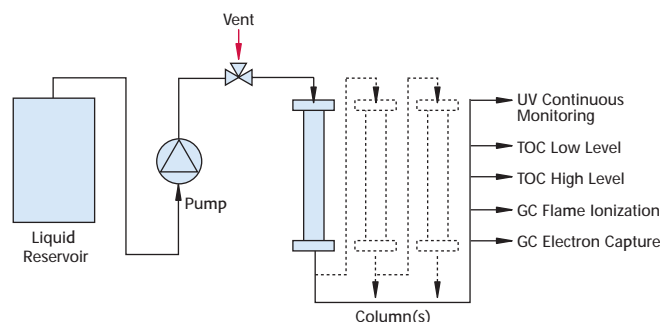
Wet activated carbon preferentially removes oxygen from air. In closed or partially closed containers and vessels, oxygen depletion may reach hazardous levels. If workers are to enter a vessel containing carbon, appropriate sampling and work procedures for potentially low oxygen spaces should be followed, including all applicable federal and state requirements.

ACT (Accelerated Column Test)

Pilot testing as previously described above predicts accurate design and carbon use rate data, but it can be very time consuming and expensive. In order to reduce the time and costs of pilot testing, Calgon Carbon developed the Accelerated Column Test. This test simulates the performance of full-scale GAC systems within a fraction of the time needed for a pilot test.

Acceleration of the carbon adsorption cycle is achieved through a scaling-down of the conventional column testing hardware. Except for their reduced scale, the other components of the test system and the overall system design are essentially identical to larger scale laboratory or field evaluation systems.

The technology behind the ACT is based upon Calgon Carbon's research into the basic kinetics of carbon adsorption. This research enabled Calgon Carbon scientists to develop an accurate model of the column adsorption process, upon which the accelerated test is based. With this model, the breakthrough curves for full-scale adsorption systems can be readily calculated from the data generated by the accelerated column test.



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