ACTIVATED CARBON ADSORPTION FOR TREATMENT OF VOC EMISSIONS

Presented at the 13th Annual EnviroExpo, Boston Massachusetts—May 2001

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A review of the characteristics of activated carbon and its applicability to emission control of VOC's. Design and costs of carbon systems are also discussed.

INTRODUCTION

The principal use of vapor phase activated carbon in the environmental field is for the removal of volatile organic compounds such as hydrocarbons, solvents, toxic gases and organic based odors. In addition, chemically impregnated activated carbons can be used to control certain inorganic pollutants such as hydrogen sulfide, mercury, or radon.

When properly applied, the adsorption process will remove pollutants for which it is designed, to virtually non-detectable levels. In fact one of the first large- scale uses of activated carbon was in military gas masks where complete contaminant removal is essential. Carbon adsorption is equally effective on single component emissions as well as complex mixtures of pollutants.

In the industrial area, the most common applications of activated carbon are for process off-gases, tank vent emissions, work area air purification, and odor control, either within the plant or related to plant exhausts. Additionally, activated carbon is used in the hazardous waste remediation area to treat off-gases from air strippers and from soil vapor extraction remediation projects.

EVALUATION OF ALTERNATIVE TREATMENT PROCESSES	LOW VOC LEVELS	HIGH VOC LEVELS	CONTINUOS LOADS	INTERMITTENT LOADS	HALOGENATED ORGANICS	TEMP>150F	TEMP<150F	HIGH FLOWS	LOW FLOWS	HIGH HUMIDITY	INORGANIC PARTICLES
ACTIVATED CARBON	•		•	•	•		•	•	•		
THERMALOXIDATION		•	•			•			•	•	
SCRUBBERS	•	•	•			•	•	•	•		
PARTICULATE FILTERS			•	•			•			•	•
CATALYTIC OXIDATION		•	•			•			•	•	

TABLE I

APPLICATION CONSIDERATIONS

One of the major issues that must first be addressed when evaluating a specific environmental VOC problem is what treatment technology to consider. For a given situation there are likely a number of treatment alternatives that appear to have some utility.

The first step in this evaluation is to effectively characterize the application. You will need to know at least the following information:

Flow Rate - Continuos vs intermittent
Contaminants Present – individual contaminants, concentration and variability
Temperature - Average and maximum
Falamibility - Upper and lower explosive limits

Once you have characterized your problem, each technology can be considered for its ability to deal with the conditions identified. As an example, *Table I* lists some of the more common technologies used to control industrial vapor phase pollutants, and the conditions under which they might be most favorably applied. I can't stress enough the importance of this review, as this is where most technical solutions fail. If you solve the wrong problem or pick a technical solution that does not respond to all the variables of your application, poor performance will likely result.

HOW IT WORKS

In the adsorption process, molecules of a contaminated gas are attracted to and accumulate on the surface of the activated carbon. Carbon is a commonly used adsorbent due to its very large surface area. It can be made from a variety of base materials including coal, wood and coconut shells, and is manufactured or activated in a high temperature controlled oxidation process. A pound of highly activated carbon has a surface area approaching 140 acres.

CROSS SECTION OF CARBON

This *Figure I* presents an artist's rendition of the cross section of an activated carbon particle. Note that almost all of the surface area available for adsorption is associated with its internal pore structure. Also note the relative change in pore diameters, going from very large at the granule surface boundary, to much smaller within the particle interior. Balancing of the large and small pore volumes during the activation process is what makes individual activated carbons perform differently. Molecules of a contaminant tend to adsorb most strongly in areas where the pore diameter of the adsorbent is close to the molecular diameter of the compound.

While most organic compounds will adsorb on activated carbon to some degree, the adsorption process is most effective on higher molecular weight and high boiling point compounds.

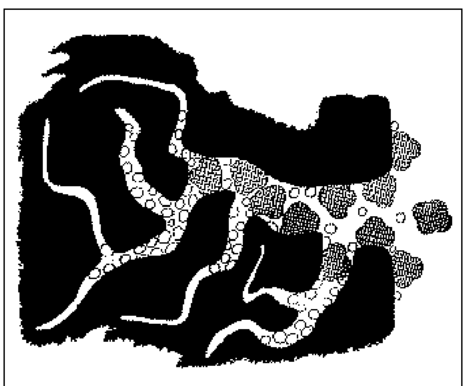


FIGURE I

LIST OF ORGANIC COMPOUNDS

RELATIVE ADSORBTION RATE

		MOLECULAR WEIGHT	BOILING POINT	CARBON CAPACITY %
STRONGER	NITROBENZENE	123	211 C	51
	TETRACHLOROETHANE	166	147 C	40
	TETRACHLOROETHYLENE	165	121 C	35
	STYRENE	104	145 C	25
	XYLENE	106	138 C	21
	NAPATHYLENE	128	217 C	20
	TOLUNE	92	111 C	20
	BENZENE	78	80 C	12
	MTBE	88	55 C	12
	HEXANE	86	68 C	7
	ETHLY ACRILATE	100	57 C	5
	DIDHLOROETHANE	99	99 C	7
	METHYL ETHYLKETONE	72	80 C	4
	METHYLENE CHLORIDE	84	40 C	2
	ACRILONITRILE	53	74 C	2
	ACETONE	58	56 C	0.8
	VINYLCHLORIDE	62	neg 14 C	0.7
	CHLOROETHANE	64	12 C	0.5
	BROMOTRI FLOROMETHANE	149	neg 58 C	0.13
WEAKER	METHANE	16	neg 161 C	0.0003

TABLEII

Compounds having a molecular weight over 50 and a boiling point greater than 50 degrees centigrade are good candidates for adsorption. *TABLE II* presents a representative list of organic compounds and their relative adsorption strength. Organic contaminants are often classified as weakly, moderately, or strongly adsorbed. You will note that a compound such as nitrobenzene having a molecular weight of 123 and a boiling point of 211 C is characterized as a very strong adsorber. On the other hand a compound such as methane which has a molecular weight of 16 and a boiling point of –161 C is a very weakly adsorbed compound. In fact, at this capacity, for all practical purposes, methane removal with activated carbon would not be cost effective.

ABSORPTION CAPACITY

Physical adsorption is dependant on the characteristics of the contaminant to be adsorbed, the temperature of the gas stream to be processed, and the concentration of the contaminant in the gas stream. The adsorption capacity for a particular contaminant represents the amount of the contaminant that can be adsorbed on a unit weight of activated carbon consumed at the conditions present in the application. Typical adsorption capacities for moderately adsorbed compounds range from 5 to 30 percent of the weight of the carbon.

TRICHLOROETHYLENE ISOTHERM

The adsorption isotherm plot shows the influence of concentration on adsorption capacity. *Figure II* presents an adsorption isotherm used to predict adsorption capacity for trichloroethylene. Note how the adsorption capacity varies from 20 to 65 percent over the concentration range of 10 to 10000 ppm in the gas stream.

A series of isotherms at differing temperatures shows the influence of temperature on adsorption capacity. In Figure III you can see the effect of temperature on the same trichloroethylene compound. At 100ppm the capacity of activated carbon for trichloroethylene varies from 17 to 40 percent as the temperature changes from 140 to 32 degrees F.

Fortunately, most carbon suppliers have developed isotherms for a range of environmental contaminants. At Carbtrol we have built a computerized database of adsorption isotherms so that we can easily model most environmental applications. By supplying to us the gas flow rate, the contaminant concentration and the temperature of the gas stream, a carbon usage prediction can be made.

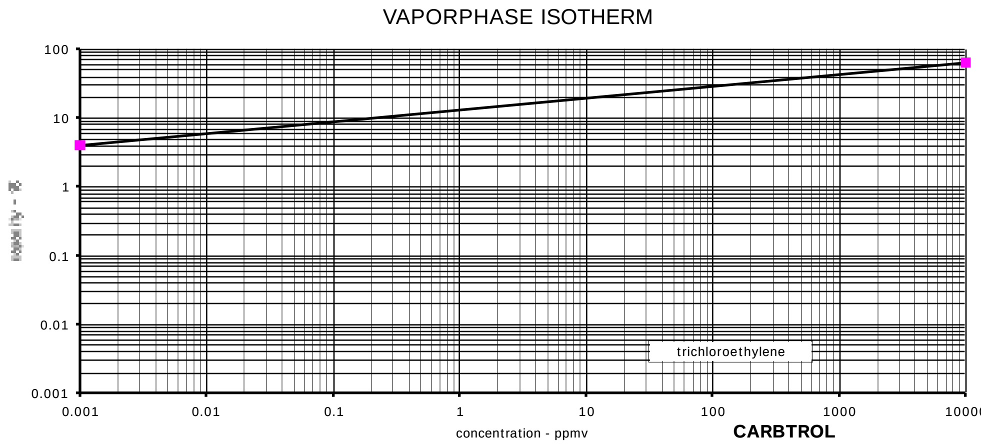


FIGURE II

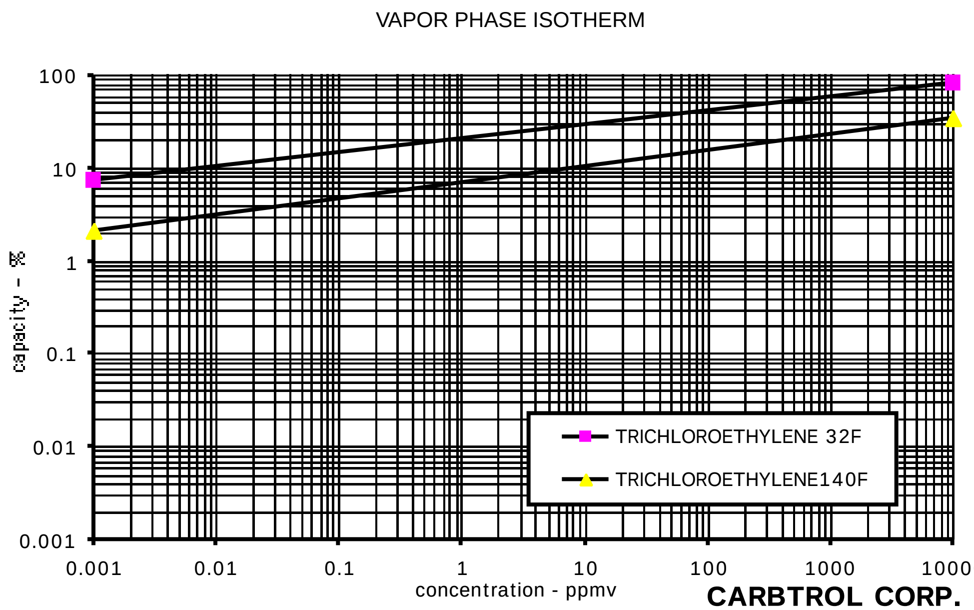
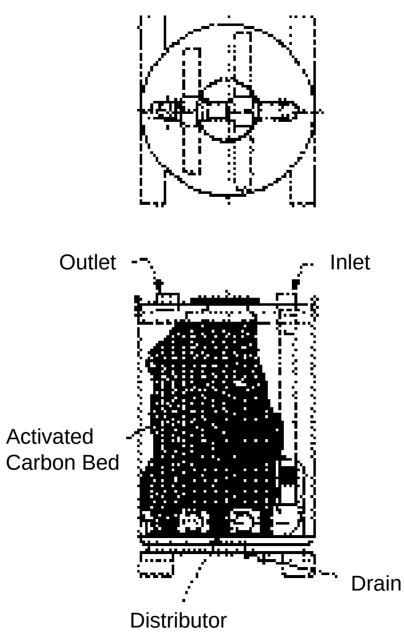


FIGURE III

DESIGN CONSIDERATIONS



CARBTROL G-4 ADSORBER

FIGURE IV

Activated carbons used in the air pollution control field are normally supplied in a granular form with a particle size ranging from 1 to 5 millimeters. In the granular form activated carbon can easily be packed into a containment device through which a contaminated gas stream can be processed for purification.

Figure IV shows the cross section of a typical fixed bed vapor phase adsorber. An adsorption system in its simplest form is made of a containment device (drum or vessel), distribution and collection devices to effect proper circulation of the gas stream through the activated carbon bed, and a means for moving the gas stream through the bed (such as a fan, a blower, or pressurized gas displacement). Packed activated carbon beds can be conveniently configured into small transportable drums or tanks, or into large fixed contacting devices depending on the application.

Adsorber sizing for a particular application is governed primarily by bed surface loading rate. With a standard 4-foot carbon bed depth, a maximum gas-loading rate of 100 cfm per square foot of bed surface should be maintained. This insures adequate gas contact and sufficient time to reach adsorption equilibrium. Higher gas flows are handled by increasing the carbon bed surface (larger adsorbers) or adding multiple beds in parallel.

One of the chief advantages of granular activated carbon adsorption is its simplicity of application, Pre-engineered fixed bed adsorbers can be purchased and installed on most existing exhaust systems with a minimum of capital expenditure. Transportable adsorbers from 100 to 5000 pounds are readily available as standard supply from several manufactures. Air flows for these stock units go up to as much as 5000 CFM. Larger systems up to 20,000 CFM or higher are available on a custom basis. Once installed these systems operate for the most part unattended until the carbon becomes spent and requires replacement. The frequency of replacement will vary for each application but may range from weekly to annually.

Another significant advantage of an adsorption process is that it provides on line reserve capacity on a passive basis. The system is, in effect, available on a continuos basis to handle varying loads but only consumes carbon when contaminants are present in the exhaust stream. Other processes may have significant fuel or chemical operating costs even when no contaminants are being treated.

REACTIVATION

Once the activated carbon has become spent it must be removed from service and replaced with fresh carbon in order to maintain the effectiveness of treatment. The spent carbon can be disposed of and replaced with virgin carbon, or the spent carbon can be returned to the supplier for reactivation and reuse. Reactivation restores most of the original carbon adsorption capacity and avoids expensive disposal costs. Most carbon adsorption applications rely on offsite reactivation to support their activated carbon supply.

The spent carbon can be vacuumed from fixed adsorption vessels and shipped to the reactivation center in bulk, or returned to the reactivation facility in a transportable adsorber that serves both as an adsorption vessel and a UN shipping container.

CAPITAL AND OPERATING COSTS

Adsorption system capital and operating costs can vary widely but depend primarily on the gas volume to be treated and the amount of carbon consumed.

A simple100 cubic foot per minute adsorption system consisting of two 200 pound canisters and a blower would require about 20 sq ft of area and cost about 2-$3,000. When spent these smaller adsorption units can often be exchanged for new units with the original supplier.

Larger custom carbon adsorption systems can cost from several thousand, up to several hundred thousand dollars, and are usually supported with off site reactivation services.

A 5000 cfm system with two adsorbers and an exhaust blower would have a capital cost in the 30-$40,000 range and if skid mounted would take up an area of about 100sq ft.

The Custom reactivation service to support this system usually costs about $2.00 per pound of carbon processed including transportation.

ACTIVATED CARBON QUALITY

You should be aware that there is a significant difference in adsorption capacity among the various commercial activated carbon products available. When procuring activated carbons it is important to recognize that the value of the activated carbon product that you are purchasing is related to its adsorption capacity, and not its weight or volume.

The carbon manufacturing industry, in conjunction with ASTM, has developed several standard tests that enable comparison of the relative adsorption capacities of various activated carbons. These tests can be used to assess the quality of a virgin or reactivated carbon product and to predict its cost effectiveness.

The industry standard quality tests for VAPOR PHASE activated carbons is the CARBON TETRACHLORIDE ADSORPTION CAPACITY, or ASTM D3467. Typical vapor phase virgin activated carbons have CARBON TETRACHLORIDE ADSORPTION CAPACITIES ranging from 45 to 70 percent by weight.

When procuring either virgin or reactivated carbon products, make sure the appropriate adsorption number is specified. Then compare the alternative product specifications to insure you are getting the best activated carbon value.

SUMMARY

In summary, activated carbon has been shown to be applicable for treatment of a wide variety of environmental contaminants. It is a proven technology that is simple to install and easy to operate and maintain. Capital costs are among the least expensive for most alternative treatment technologies. Operating costs are primarily related to the amount of activated carbon consumed in the adsorption process.