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Determining Activated Carbon Performance

EBCT can establish the effectiveness of granular activated carbon in fixed-bed adsorbers.

by William F. Naylor and Dennis O. Rester

Empty bed contact time (EBCT) is a term used to describe the length of time a liquid stream being treated is in contact with a granular activated carbon bed. The EBCT is the time required for a fluid to pass through the volume equivalent of the media bed, without the media being present. In a bed of granular activated carbon, the void volume or space between particles is usually about 45 percent. Therefore, the EBCT is about twice the true or actual time of contact between the fluid being treated and the GAC particles.

The EBCT plays an important role in determining the effectiveness and longevity of granular activated carbon (GAC) used to treat liquids in a fixed-bed adsorber. Factors that influence and are influenced by EBCT, and their relationship to GAC performance in a treatment scheme include: adsorption, mass transfer zone, impurity concentration, adsorption affinity, flow rate and system design considerations.

Adsorption

Adsorption is a process in which activated carbon removes an impurity from the liquid stream being treated. Adsorption refers to the accumulation of molecules or atoms on a surface, held there by chemical forces, electrostatic (physical) forces or both. In the case of GAC, the adsorptive surface refers to the walls of the pores which are formed inside the carbon particles during the activation process.

GAC adsorption is a time-related phenomenon that takes place in three steps. Initially, impurities in solution contact the external surface of a carbon particle as the liquid passes through the GAC bed. Secondly, impurities, or adsorbates, diffuse into the pores of the carbon particle. The diffusion step in the process is the adsorption rate determining step. Finally, the impurity is attracted to the pore wall and held by electrostatic or chemical forces.

The process is concentration driven and time dependent. Therefore, the highest loading of the impurity on the GAC, on a weight-percentage basis, will occur in the presence of high-contaminant concentrations and at times sufficient for the carbon to reach equilibrium. As a result, each application may require a different minimum EBCT to achieve treatment objectives.

Real world situations usually deal with influent streams composed of several impurities at various concentrations. Since each application is unique, several factors must be considered in order to design a system that achieves optimum GAC utilization and performance.

Mass transfer zone

The mass transfer zone (MTZ) refers to the area in a bed of activated carbon where adsorption occurs. It also is known as the adsorption wave zone, because it moves through the GAC bed as the carbon becomes spent. As long as the flow rate, impurity composition and concentration remain constant, the length of the MTZ remains fixed as it moves through the GAC bed. Breakthrough occurs when the leading edge of the MTZ, where impurity concentration is lowest, moves beyond the end of the GAC bed and vessel.

The time for fluid flow through the MTZ of an activated carbon bed represents the minimum EBCT required to meet treatment objectives. As stated earlier, the EBCT refers to the total time required for the liquid to flow through the entire GAC bed. In contrast, the time for liquid

Here's Some Applicable Terms

Adsorbate: any substance that is or can be adsorbed, including color bodies, organic compounds and taste and odor.
Adsorbent: any solid having the ability to concentrate significant quantities of other substances on its surface, or in its pore structure, such as actived carbon.
Adsorption: a process in which molecules or atoms are concentrated on a surface by chemical or electrostatic (physical) forces, or both.
Breakpoint/breakthrough: the first appearance of an adsorbate of interest in the effluent.
Channeling: the greater flow of liquid or gas through passages of lower resistance which can occur in fixed beds or columns of particles due to non-uniform packing, irregular sizes and other causes.
Chemisorption/chemical adsorption: the binding of an adsorbate to the surface of a solid by forces whose energy levels approximate those of a chemical bond.
Effluent: fluid flowing out of a treatment system.
Empty bed contact time: the time required for a fluid to pass through the volume equivalent of the carbon bed, but without the carbon being present. It is usually about twice the true or actual contact time.
End point: the occurrence in the effluent of the maximum

to flow through the MTZ represents only that portion of the EBCT when adsorption occurs. If a system is designed and sized correctly, the EBCT will be greater than the time required for liquid to flow through the MTZ.

Impurity concentration

Concentration of the impurities in the influent also can impact the EBCT needed for maximum adsorption of impurities. For example, increases in contaminant concentration in the influent results in greater loading of impurities on the carbon on a percentage by weight basis. However, low impurity concentrations (parts per billion levels) can compromise carbon utilization in two ways. First, the equilibrium loading of impurities on the carbon is proportionately lower. Second, a longer MTZ, and therefore longer EBCT, may be required for the compounds that are present to contact the carbon particles and diffuse into the pore structure where adsorption occurs.

Adsorption affinity

Adsorbability, the affinity of activated carbon for a given compound, also plays a major role in the effectiveness of the carbon in a given application, and consequently, affects the EBCT requirements. If there is marginal to low affinity for the impurities to be removed, then the ultimate loading on the carbon will be proportionately lower. Carbon will adsorb compounds of moderate to low affinity, but a longer EBCT may be required to achieve the desired treatment goal because the MTZ is lengthened.

In most applications, the influent stream contains a variety of impurities with different adsorbabilities. The only way to accurately assess GAC's performance in these situations is to perform a pilot column field evaluation, or on-site plant test on the influent to be treated. Although many alternate methods have been tried in laboratory settings, such as mini-column and isotherm tests, these laboratory test methods do not accurately predict the performance of full-scale GAC adsorbers. Laboratory tests can be used to determine if GAC will remove the desired impurities, but they do not accurately predict the minimum EBCT or GAC usage rate, which is based on carbon loading.

Flow rate

Influent flow rate across the bed is one of the factors that determines EBCT. At a given bed volume, the EBCT can be lengthened or shortened by altering the rate at which the influent stream enters the contactor. As the flow rate into the carbon bed increases, the liquid spends less time in contact with the carbon. Additionally, the normally tortuous path through the GAC that would ensure the greatest degree of intimate contact may be short circuited if the stream passes though straits in the bed, a phenomenon referred to as channeling.

In general, the shorter the MTZ, and the greater the EBCT, the more completely the carbon bed is being used or loaded. If the linear velocity is increased, the MTZ begins to stretch out as a greater depth of the GAC bed is now required to achieve the same level of impurity removal. The effect of an increased flowrate can be minimized if the adsorber is designed to distribute the influent uniformly over the entire cross-sectional area of the bed. Usually, there is an economic tradeoff between throughput (capital costs from vessel sizing) and effective carbon use (flowrate).

System design considerations

At a given process flowrate, the system sizing parameters that determine EBCT are the cross-sectional area of the bed and its depth. Contact time with the GAC is determined from the influent flow rate in gpm/ft^2 and the depth of the bed using the following formula.

$$EBCT = \frac{5.87 * D^2 * H}{gpm}$$

where: D = diameter of the carbon bed in feet
H = height or depth of the carbon bed in feet
gpm = influent flow rate in gallons per minute

For water treatment applications, EBCTs ranging from 10 to 30 minutes are typical. The larger the carbon bed volume, the longer the EBCT and run time between changeouts. Increases in carbon volume and EBCT can be achieved via single or multiple vessel systems in parallel or series configurations. There are specific considerations which should be addressed in every different application.

Custom-built GAC systems are available, but in most applications they probably are not required. GAC treatment system manufacturers usually offer several off-the-shelf vessels that can be used in a variety of configurations to meet treatment goals. It is preferable to use systems available from OEMs familiar with activated carbon as the vessels will have been specially designed to ensure optimum service life and GAC utilization with a minimum of maintenance.

Summary

The primary factors that determine adequate EBCT are the type and concentration of the impurities to be removed, the desired effluent or discharge purity and the desired frequency of GAC changeout. EBCT requirements must be evaluated on a case-by-case basis. The only way to accurately assess GAC capabilities and longevity in any application is by on-site testing of the influent stream.

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permissible concentration of an adsorbate of interest.
Influent: fluid flowing into a treatment system.
Mass transfer zone: the area in a bed of activated carbon in which adsorption occurs. It is the region where influent adsorbate concentration is reduced from influent levels to the lowest concentration possible by the activated carbon.
Physical adsorption/van der Waals adsorption: the binding of an adsorbate to the surface of a solid by forces whose energy levels approximate those of condensation.
Service time/service life: the lifespan of a granular activated carbon bed starting from the time fluid flow passes into the bed and ending when the activated carbon is no longer capable of removing adsorbates per the application requirements.