Granular Activated Carbon for Drinking Water Treatment

Chemviron Carbon

ACTIVATED CARBON-EQUIPMENT-SERVICES

Granular Activated Carbon for Drinking Water Treatment

Contents

FOR A BETTER QUALITY DRINKING WATER

FILTRASORB® activated carbons.
The world-leading range of granular activated carbons for water treatment.

CHEMVIRON CARBON will select the most appropriate type for you to upgrade your water quality.

We are available to test your water quality and offer the best solution to your problem.

Chemviron Carbon
European Operations of Calgon Carbon Corporation

Chemviron Carbon

Chemviron Carbon is the European Operations of Calgon Carbon Corporation, the world's largest producer of Granular Activated Carbon (GAC). **Chemviron Carbon** has been at the forefront of the development of GAC for drinking water treatment from its first application as a sand replacement for taste and odour removal to more recent developments such as the **GAC Sandwich** for the installation of GAC in slow sand filters. In addition, **Chemviron Carbon** has pioneered the use of large scale reactivation centres to provide a complete service for water works.

Over the last 20 years granular activated carbon has become the standard for the treatment of surface sourced drinking water in Europe. The **Chemviron Carbon FILTRASORB®** range of coal based granular activated carbons are recognised as the standard for drinking water treatment and are installed in nearly 1000 water works in Europe, the United States and Asia.

Activated Carbon

Activated carbon is a porous material made up of a random structure of graphite platelets, produced from a range of raw materials including bituminous coal, peat, wood and coconut shells. Most activated carbon used for drinking water is produced from bituminous coal. The graphite platelet structure has a very large surface area which gives it excellent properties for the adsorption of organic compounds. These are removed from solution and fixed on the activated carbon surface by adsorption forces.

Adsorption

The adsorbability of an organic molecule increases with increasing molecular weight and decreasing solubility and polarity. This means a compound such as ethanol with a low molecular weight and high solubility in water is poorly adsorbed, while high molecular weight compounds with low solubility such as most pesticides are very well adsorbed.

Forms of Activated Carbon

As well as coming in granular form (GAC), activated carbon is also available extruded as a pellet and pulverised as Powdered Activated Carbon (PAC). GAC is utilised in drinking water treatment by installing it in a fixed bed adsorber constructed of concrete or steel. Water is passed through the adsorber containing the activated carbon which adsorbs organic compounds, purifying the water. When it becomes exhausted, the GAC is removed and regenerated by reactivation. PAC is utilised in a totally different way as the powder is added to water, mixed and then removed at the decantation or filtration stage.

Properties and Selection

There are a number of criteria that should be considered in the selection of a GAC.

Adsorption performance

GAC for drinking water treatment needs a pore structure to allow the adsorption of a wide range of organic compounds including specific micropollutants and natural organic matter. The GAC must also possess a suitable amount of transport pores which allow the molecules to be transported to the adsorption site. The adsorption capacity for drinking water applications is very difficult to quantify by laboratory evaluation. Parameters such as the iodine number indicate the overall porosity of the carbon, but cannot be used to estimate the performance in drinking water applications. This is illustrated by the fact that **FILTRASORB® 200** has a higher capacity than **FILTRASORB® 400** for the removal of chlorinated compounds from ground water, even though it is less active. The best way to evaluate the performance of GAC is to carry out on-site pilot tests directly modelling the proposed plant. Alternatively, the design should be based on experience and references.

The pore structure of carbon is strongly influenced by the raw material and the activation process. For example, coconut shell-based activated carbons have very few transport pores. This means the high adsorption capacity of these activated carbons is not utilised very well in drinking water. In contrast, the **Chemviron Carbon FILTRASORB®** range of coal-based GAC have a very good balance of both adsorption and transport pores, making them optimal for the treatment of drinking water.

FILTRASORB® 100, 200 and **TL820** have an adsorption capacity suited to the removal of specific organic compounds in the presence of low concentrations of natural organic matter. In addition, these products are suitable for taste and odour removal.

FILTRASORB® 300, 400 and **TL830** have a pore structure and greater number of transport pores making the GAC suitable for the adsorption of a wide range of organic compounds, both specific micropollutants and natural organic matter.

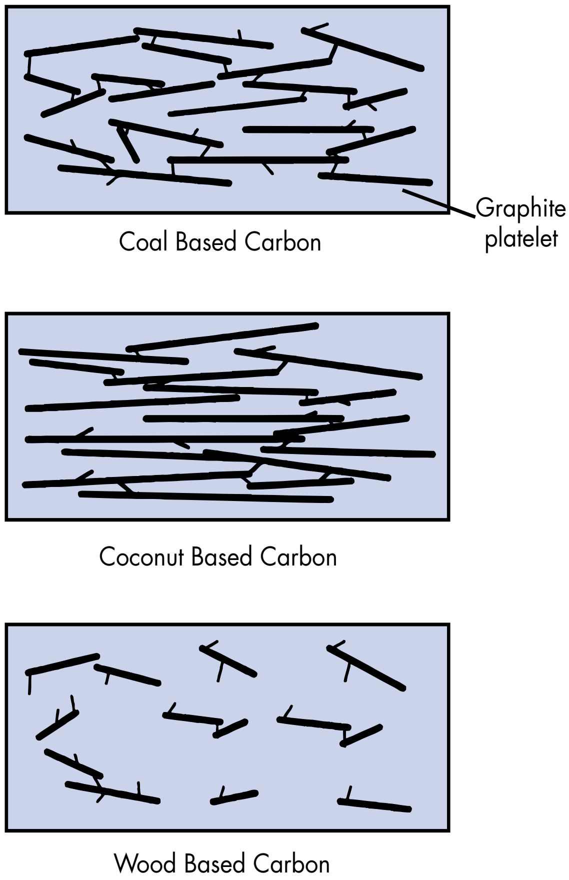


Figure 1: Molecular structure of activated carbons produced from different raw materials.

Granulometry

In general, the smaller the activated carbon granule, the better the adsorption performance due to kinetics. However if a granule becomes too small, hydraulic problems will be encountered with resulting high pressure drop. In addition, as a carbon granule size becomes very small, it becomes difficult to reactivate.

Mesh Size - The granulometry is determined by sieving a sample of GAC. The sieve sizes are based on the US Mesh system, where the number refers to the openings per inch. This means the higher the sieve number, the smaller the granule size.

The sieve sizes between which most of the GAC is retained are often used to describe the carbon. The **Chemviron Carbon FILTRASORB®** range comes in three main sizes: 12x40; 8x30 and 10x20.

Effective Size - The effective size is the diameter for which 10% by weight of granules are smaller. It is an indicator of the filtration and pressure drop performance of the GAC. A lower effective size will have a higher pressure drop and filter smaller particles from the influent water.

Uniformity Coefficient - This is an indicator of the range of the grain size. The lower the uniformity coefficient, the more uniform the medium. A uniformity coefficient of 1 indicates all the granules have the same size. Most GAC used in drinking water treatment such as **FILTRASORB® 300,** which is an 8x30 U.S. Mesh, and **FILTRASORB® 400,** which is a 12x40 U.S. Mesh, have a uniformity coefficient of 1.7 to 2.0. **FILTRASORB® TL820** and **TL830** have a low uniformity coefficient of 1.4 and have been specially designed for sand filter conversion, where in-depth filtration is obtained. This allows the frequency of backwashing for filter cleaning to be greatly reduced. The uniformity coefficient of 1.4 still ensures segregation of the bed so the adsorption front is maintained after backwashing which maximises the adsorption capacity.

Density

FILTRASORB® type carbons have a high density, which means a higher capacity per unit volume. This also ensures the granules do not float and therefore minimises the loss of GAC.

Mechanical Strength

GAC in drinking water requires high mechanical strength for:

- backwashing
- air scouring
- reactivation
- handling and transport

If the carbon is not strong enough, it can result in operating losses and the formation of fine carbon particles in the adsorber which can cause high pressure drop. The hard coal base of **FILTRASORB®** carbons ensures good mechanical strength and, in general, the operating losses from a well designed adsorber are negligible.

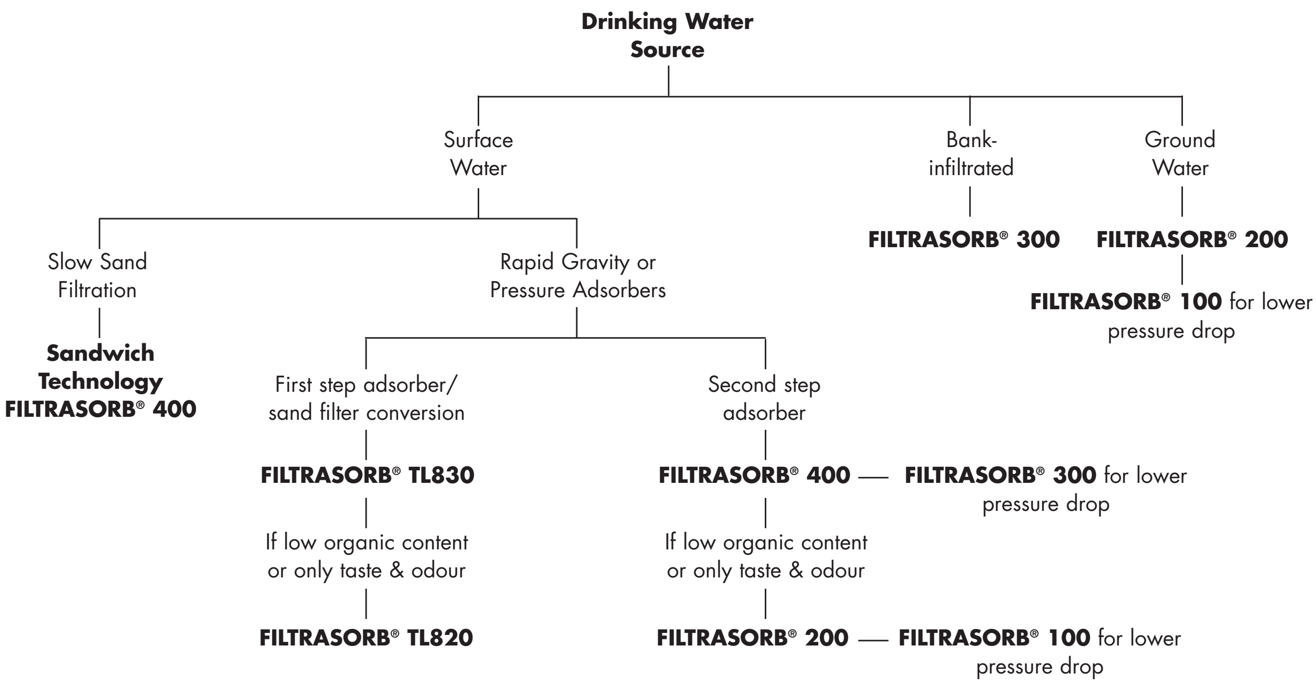


Figure 2: Selection criteria for different drinking water applications.

Removal of Natural Organic Matter

Natural waters contain some Natural Organic Matter (NOM) from the breakdown products of plants, animals, bacteria and algae. These are made up of a large number of different compounds or humic substances of which only a small percentage can be identified. Since they can not be individually identified, they are measured as a group in a number of different ways including total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet adsorption at 254nm (UV_{254}) and oxidisability or permanganate value.

The composition of NOM in water depends on a number of factors including the source of water, geology and industrial and municipal pollution. In particular, ground waters because of the natural purification, have low concentrations of organic matter with typically less than 2mg/l measured as DOC. In contrast, surface waters have generally higher and more variable concentrations of organic matter with a typical DOC of 4mg/l. In addition, water can contain a number of toxic man-made chemicals as a result of pollution.

GAC is widely used to reduce the concentration of NOM in drinking water because:

- NOM is generally the source of taste and odour forming compounds found in drinking water.
- NOM will react with chlorine to form toxic disinfection by-products such as trihalomethanes (THM). By reducing the natural organic matter, or *trihalomethane precursors*, the concentration of trihalomethanes will be reduced in the final water. Trihalomethane formation is further aided by a reduction in the chlorine demand, due to the NOM reduction.
- NOM is a source of food and increases the potential for bacteria to grow in the distribution system.

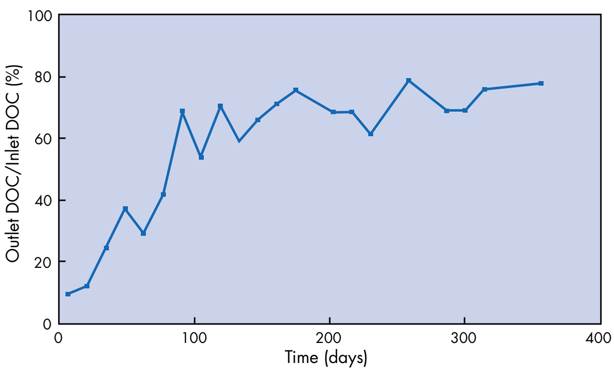


*Figure 3: Reduction of Dissolved Organic Carbon (DOC) from a surface water with an average inlet of 5mg/l using **FILTRASORB® 400** with 15 minutes contact time.*

GAC will initially remove up to 90% of NOM from water and then stabilise after 3 to 6 months at 20 to 30% removal for a single adsorber as illustrated in Figure 3. In practice the removal performance will be significantly enhanced by phased reactivation of the GAC. If for the case illustrated in Figure 3, the adsorbers are reactivated on average once per year, and this commenced after 6 months for the first adsorber so all adsorbers were reactivated after 18 months, the average DOC removal is significantly improved as illustrated in Figure 4. That is because at any one time, there are fresh adsorbers on-line so the average DOC removal in this case was nearly 50%. This point is very important to consider when interpreting pilot data where only the breakthrough from a single adsorber is considered.

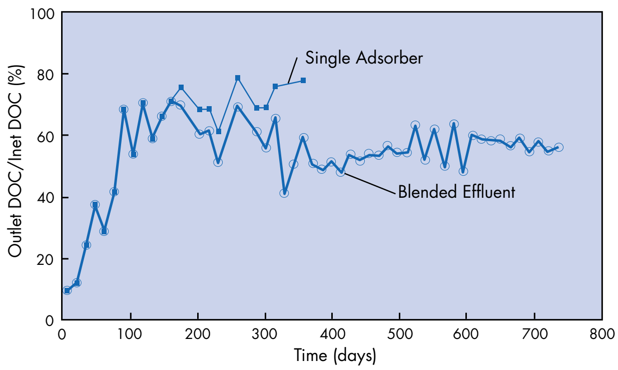


Figure 4: Reduction of Dissolved Organic Carbon (DOC) showing the improvement in performance achieved with blending on the output of the full plant.

Taste and Odour Removal

Tastes and odours in water are due to the presence of very low concentrations of mainly natural compounds. Common sources of these problems include blue-green algae and actinomyces, a type of bacteria found in drinking water reservoirs.

Due to the very low concentration of these products, often in the nanogram per litre (ng/l) concentration range, it has been very difficult to determine which specific molecules are responsible for tastes and odours. The most well known natural compounds are geosmin and 2-methylisoborneol.

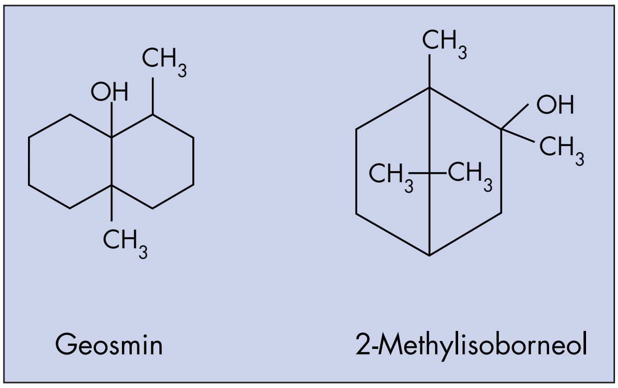


Figure 5: The molecular structure of geosmin and 2- methylisoborneol.

As the compounds forming tastes and odours are difficult to analyse, the dilution number is used. This is the number of times a sample of water is diluted with distilled water until taste and odour can no longer be detected. The European Union drinking water directive specifies a maximum dilution number of 2 at 12°C and 3 at 25°C with a guide level of 0.

FILTRASORB® type activated carbons are very effective for the removal of taste and odour compounds, especially **FILTRASORB® 100, 200** and **TL820**. The typical contact time for GAC required for taste and odour removal is 6 to 10 minutes with a bed life of 2 to 4 years. PAC can also be effective for periodic taste and odour problems.

Removal of Chlorinated Hydrocarbons

GAC is widely used for the removal of chlorinated hydrocarbons such as trichloroethylene and carbon tetrachloride from ground waters. They are poorly biodegradable and will persist in the ground water for long periods of time. They are not normally found in surface waters due to their volatility.

The removal efficiency of GAC for chlorinated hydrocarbons depends on the molecular size, the polarity and number of chlorine atoms. For example, perchloroethylene (CCl_2CCl_2) is better adsorbed than chloroform ($CHCl_3$). Contaminated bore holes used for drinking water typically have concentrations ranging from 50 to 200µg/l. For this concentration range, the typical bed life with a 10 minute contact time for higher molecular weight compounds such as perchloroethylene is over 12 months, while chloroform is less than 6 months. Increasing the contact time will generally increase the bed life proportionally.

FILTRASORB® 200 is the best GAC type for this application and gives better performance than more active carbons such as **FILTRASORB® 400.**

Pesticide Removal

The removal of pesticides from drinking water is one of the largest applications of GAC. Pesticides are found in both ground and surface waters as a result of both agricultural and non-agricultural uses such as crop protection, weed control and wood treatment. In some cases pesticides can be discharged into water courses by the factories where they are produced. The concentration depends on a number of factors including the amount used, pesticide type and the geology and climate of the area.

The European Union Water Regulations have set very low limits close to the detection limit with a maximum of 0.1µg/l for individual pesticides and 0.5µg/l for total pesticides. The World Health Organisation (WHO) has different limits which are guidelines depending on the toxicological data for each pesticide and are generally less strict than the European limits.

The typical inlet concentrations of individual pesticides are between 0.1 and 1µg/l, though peaks of up to 5 or even 10µg/l have occurred. Some common pesticides found in drinking water are shown in Figure 6. Conventional surface water treatment processes such as coagulation, sedimentation and sand filtration are not effective for the removal of pesticides.

FILTRASORB® 400 is the mostly widely used and effective GAC for pesticide removal with excellent performance for a wide range of pesticides. The performance of GAC for pesticide removal depends on the following factors:

- **Type of pesticide** - most pesticides have a similar molecular weight in the range of 200 to 300g/mol, therefore the solubility has a greater influence on absorbability. For example, atrazine is better removed than bentazone which is more soluble.
- **Concentration of pesticide -** the higher the concentration, the shorter the bed life.
- **Concentration of natural organic matter (NOM) -** this competes with the pesticides for the available adsorption sites. The concentration of NOM is 10,000 times greater than that of the pesticides with a typical value of 1 to 5mg/l compared to 0.1 to 0.5µg/l for pesticides.

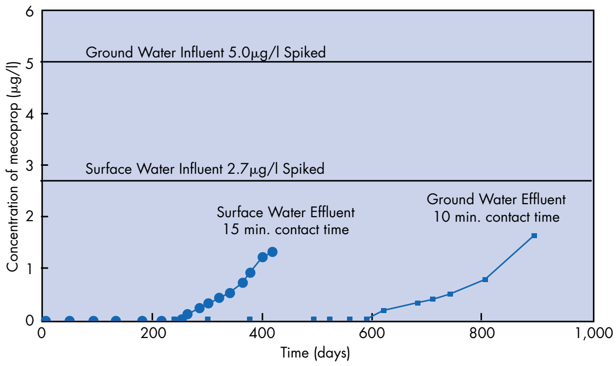


*Figure 7: Comparison of the removal of mecoprop, a pesticide commonly found in drinking water, from ground and surface water with **FILTRASORB® 400**. In this case, the bed life for ground water was twice as long as for the surface water, even though the contact time was shorter and inlet concentration higher because of the higher NOM concentration.*

- **Ozonation -** ozone alone will break down most pesticides to some extent. It will also increase the bed life of GAC for pesticides by both directly oxidising and reducing competitive adsorption with NOM. This is illustrated in Figure 8 for the removal of atrazine. In this case, the atrazine was spiked to the same as the inlet concentration. This doubled the bed life due to reduced competitive adsorption. For ozonation, the amount of removal will depend on a number of factors including the type of pesticide, ozone dose, NOM content, temperature and pH. It is therefore important to install GAC after ozone to ensure removal of the pesticides.

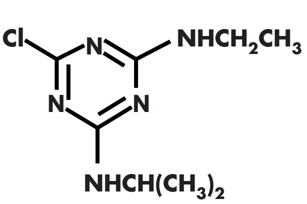
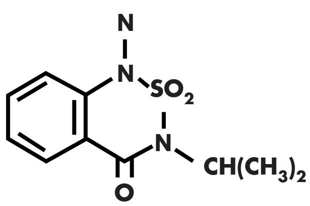
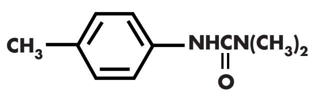
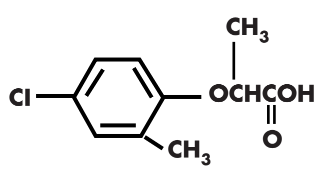
Atrazine Molecular Weight 216g/mol Solubility 28mg/l	Bentazone Molecular Weight 240g/mol Solubility 500mg/l	Chorotoluron Molecular Weight 213g/mol Solubility 70mg/l	Mecoprop (MCPP) Molecular Weight 215g/mol Solubility 620mg/l
			

Figure 6: Common pesticides found in drinking water and removed by activated carbon.

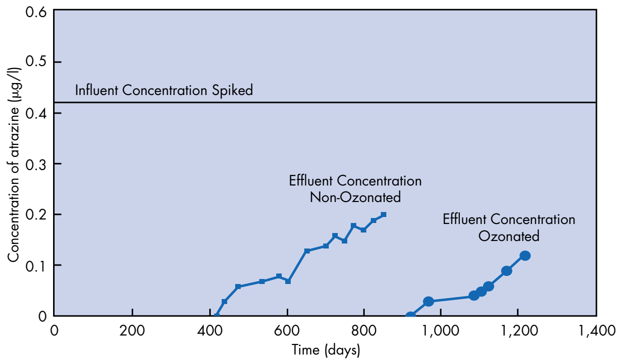


*Figure 8: Comparison of the removal of the pesticide atrazine from ozonated and non-ozonated water with **FILTRASORB® 400**.*

Pesticide Metabolites

The 1998 European Union Drinking Water Directive 98/83/EC requires pesticides metabolites and degradation and reaction products to meet the same limit of 0.1µg/l as for individual pesticides. This includes compounds such as desethylatrazine and desisopropylatrazine which are breakdown products of atrazine and aminomethylphosphonic acid (AMPA) which is a breakdown product of glyphosate. Even though the adsorbability of desethylatrazine is lower than atrazine, tests have demonstrated that this can be effectively removed with **FITRASORB®** activated carbons under typical operating conditions.

Other Applications

Colour Removal

Colour is made up of a wide range of varying molecules, often of very high molecular weight, which will vary in different waters. Activated carbon is normally effective to some extent in reducing the colour of water, but its performance can vary significantly from one water to another. Test work is normally recommended in this application to determine the performance.

Algal Toxins

Algal toxins come from different algal types and include compounds such as Microcystin. These compounds have caused the death of cattle after drinking from algal laden reservoirs. The study of these compounds is quite recent and they have been shown to be adsorbable on activated carbon.

Overall Water Quality Improvement

Although GAC may be installed for one objective, it will also work for other applications. For example, if the GAC is installed for pesticide removal, it will also remove any taste and odour compounds and reduce disinfection by-products.

Security of Water Quality

GAC provides security against accidental pollution spills and a buffer capacity for varying inlet concentrations.

	Contact Time minutes	**Bed Life** years
Taste & odour removal	6 - 12	2 - 4
Pesticide removal	10 - 15	1 - 3
NOM & Trihalomethane reduction	15 - 30	1.5 - 3
Chlorinated Hydrocarbons	10 - 20	0.5 - 1.5

Table 1: Summary of typical contact time and bed life for main applications of GAC.

Chemviron Carbon can provide information on the estimated performance of **FILTRASORB®** type GAC for a wide range specific pesticides, chlorinated hydrocarbons and other organic compounds.

Sand Filter Conversion

For surface water treatment plants, GAC can be installed in a **first or second step adsorber.** This is illustrated in Figure 9. In general, GAC is the final treatment step before disinfection.

First step - this is where the adsorber is located directly after the clarifier, where it is operating as both an adsorption and filtration step. This is the case, for the conversion of existing sand filters to GAC.

Second step - this is where the adsorber is located after sand filtration and used for adsorption only.

The conversion of existing rapid sand or multimedia sand/anthracite filters to GAC is a widely used technique for the application GAC in drinking water treatment which has a number of advantages including:

- the capital cost of separate adsorbers, land and pumping stage are not required
- GAC is as good and often better than sand as a filtration media
- conversion can be carried out very quickly
- it is easy to pilot by installing a trial filter
- GAC from a sand filter conversion can be moved to a second step adsorption system, if that option is taken at a later date.
- it allows GAC to be installed if the space for additional adsorbers is not available.

There is normally a compromise in terms of adsorption performance because only a limited volume of GAC can be installed in existing filters and this will limit the contact time. This makes sand filter conversion especially suited to applications such as taste and odour removal where only a low contact time is normally required.

In most cases, no or only minor modifications to the existing filters are required. The major operating difference for a GAC filter is the backwash procedure. GAC is lighter than sand and therefore a greater bed expansion is obtained for the same backwash rate. This may cause loss of GAC in the event that insufficient free board is available between the top of the overflow weir and the bed surface. To overcome this, it may be necessary to extend the height of the overflow weir. Generally the existing air scour system used on the sand filters is suitable for use, without modification.

It is preferable to install the GAC directly on the underdrain nozzles as this maximises the volume of GAC and keeps it free of gravel for reactivation.

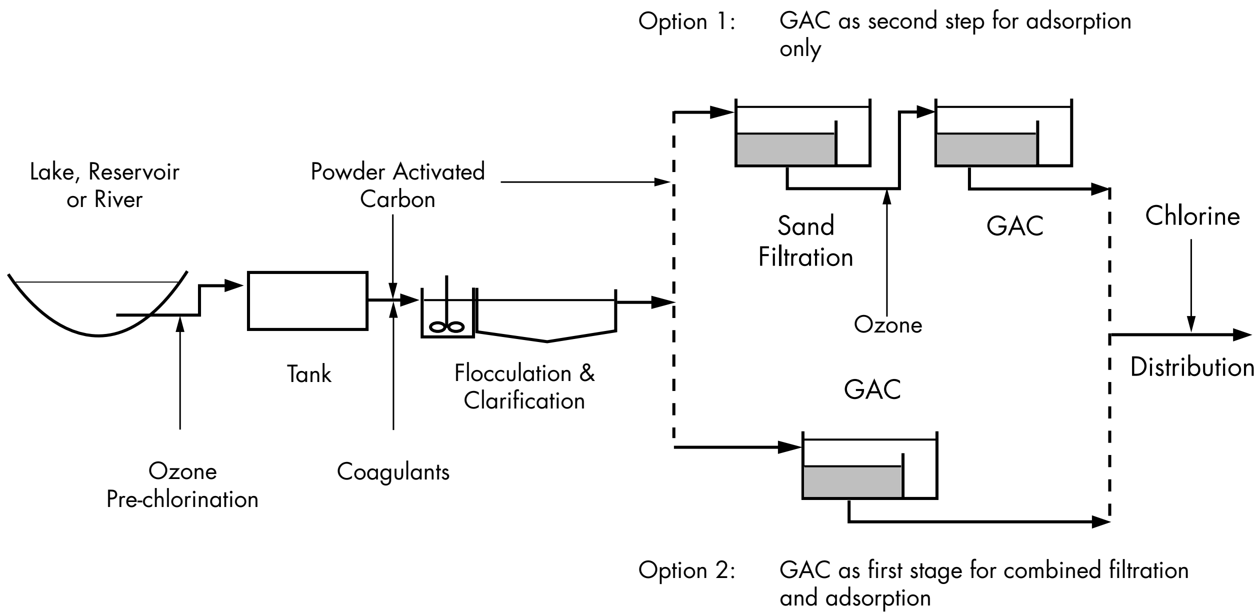


Figure 9: Options for adsorber location in a typical surface water treatment plant.

GAC Sandwich Filter

Chemviron Carbon have developed two special products for this application; **FILTRASORB® TL820** and **FILTRASORB® TL830.** Both of these GAC's have a specially selected narrow particle size range with a 10 x 20 U.S. Mesh (0.85 to 2.00mm) and a low uniformity coefficient of 1.4.

Experience has shown that filters converted to **FILTRASORB® TL820** and **TL830** have longer run times than sand filters and similar to sand/anthracite dual media filters. The rough surface of **FILTRASORB®** type GAC gives them excellent performance for the removal of turbidity.

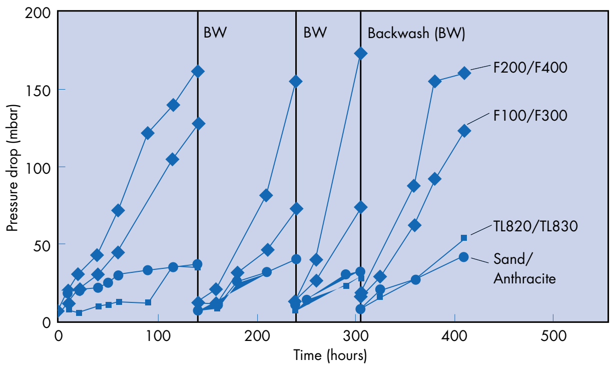


*Figure 10: Comparison of different **FILTRASORB®** grades to sand anthracite filters for pressure drop build up. **FILTRASORB® TL820** and **TL830** are similar to sand/anthracite which allows a lower backwash frequency than normal grades of GAC.*

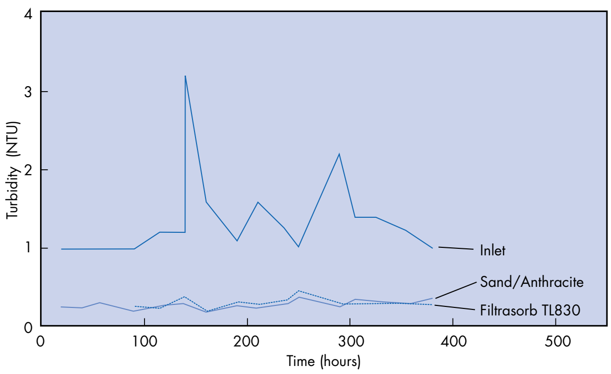


*Figure 11: Comparison of **FILTRASORB® TL830** and sand/anthracite for the removal of turbidity showing similar performance.*

The **GAC Sandwich Filter** was developed for the installation of activated carbon into slow sand filters, one of the oldest forms of water treatment. Compared to a conventional rapid sand filter with a linear velocity around 10m/h, slow sand filters operate around 0.1 to 0.5m/h and are cleaned by mechanical scraping of the surface rather than backwashing. This very slow filtration rate results in excellent particle removal and biological performance due to the low disturbance of the bed.

The **GAC Sandwich Filter** involves installing a small 8 to 15cm layer of **FILTRASORB® 400** within the slow sand filter. Special technology and equipment has been developed to ensure accurate laying and removal of the GAC for reactivation.

This technology is effective for all applications of GAC including pesticide removal, taste and odour removal and reduction of disinfection by-products. At the same time it allows the more economic installation of longer contact times giving better performance or more efficient use of the GAC. In addition, the GAC enhances the already excellent biological performance of the slow sand filter.

This process was developed by Thames Water and is now used to treat over 2,000,000m^3 of water a day to 7 million people in the London region. This technology has now been sold to a number of water utilities both in Europe and the United States. **Chemviron Carbon** has worldwide marketing rights for this process which has been successfully employed at a wide range of water works, where there are existing slow sand filters.

GAC and Ozone

The use of GAC in combination with ozone has been utilised for many years for improving the quality of drinking water. Ozonation was originally used as a replacement for pre-chlorination for disinfection to reduce by-product formation. GAC is also used for the removal of residual ozone. Ozone will react with NOM, breaking down some of the larger compounds and increasing the biodegradability of the NOM. This NOM can then be removed by using GAC as a biological media. This process is called ***Biological Activated Carbon***.

The biodegradability of a water can be measured as Assimilable Organic Carbon (AOC) and Biodegradable Organic Carbon (BDOC) and indicates its stability within the distribution system.

Biological activated carbon is an aerobic process represented by the equation below:

$$\text{Organic Matter} + O_2 \xrightarrow{\text{Bacteria}} CO_2 + H_2O + \text{energy}$$

It is a biofilm process, where the bacteria attach to the carbon surface. The rough structure of activated carbon provides a good surface for attachment and shelter from fluid shear forces. Bacteria populations of over 150 million per ml of GAC can be achieved. The benefits of this process are:

- a further reduction in the concentration of NOM, compared to adsorption alone. The steady state removal can be up to 50%
- improved reduction of trihalomethane precursors
- production of biologically stable water by removal of biodegradable organic matter
- reduction in chlorine demand
- removal of ozonation by-products such as aldehydes, and ketones

This application requires a GAC with good adsorption capacity to:

- remove non-biodegradable compounds such as pesticides and ozonation by-products such as deethylatrazine
- concentrate the biodegradable organic matter near the GAC surface by adsorption so it can be utilised by the bacteria.

The **FILTRASORB®** range are the most widely used GAC in this application because of their excellent adsorption properties and as a surface for attachment of bacteria.

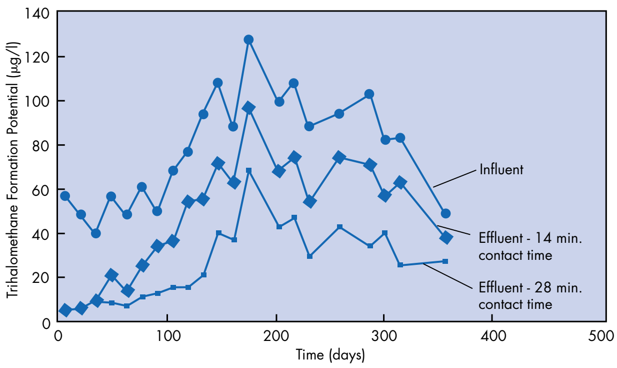


*Figure 12: Reduction of trihalomethane formation potential, a laboratory test to determine the likely concentration of these compounds at the customer's tap, by the combination of ozone and **FILTRASORB® 400**.*

Powdered Activated Carbon (PAC)

In general GAC is more effective than PAC, both because lower treatment objectives can be obtained and the overall consumption of activated carbon is lower. PAC is useful for short or periodic problems such as seasonal taste and odour or as an interim measure before GAC is installed. The dose rate ranges from 5 to 20mg/l with a typical level of 10mg/l.

A comparison of the carbon consumption of **FILTRASORB® TL830** with a contact time of 8 minutes to the use of PAC is given in Table 2. This is the configuration used in the case of the conversion of sand filters to GAC. After one year of operation, the carbon consumption is less than a PAC use rate of 10mg/l.

Bed Life	GAC Consumption (mg/l)
6 months	13.1
1 year	6.5
2 years	3.3
4 years	1.6

*Table 2: Overall carbon consumption of an adsorber containing **FILTRASORB® TL830** with a contact time of 8 minutes.*

	GAC	PAC
Overall use rate	lower	higher
Removal to low limits	yes	with difficulty
Handle changing conc.	yes	with difficulty
Biological activity	yes	no
Reactivation	yes	no
Increased sludge	no	yes
Dosage control required	no	yes
Dust	no	yes

Table 3: Different aspects of the use of Powder Activated Carbon (PAC) in comparison to Granular Activated Carbon (GAC).

Adsorption Systems

Design Parameters

The main design parameters of a system are the contact time and linear velocity.

$$\text{Contact Time (minute)} = \frac{\text{Carbon Volume (m}^3\text{) * 60 (min/h)}}{\text{Flow Rate (m}^3\text{/h)}}$$

$$\text{Linear Velocity (m/h)} = \frac{\text{Flow Rate (m}^3\text{/h)}}{\text{Surface Area (m}^2\text{))}}$$

The superficial contact time is typically between 6 and 30 minutes, though lower and higher contact times are utilised in some cases. For a fixed flow, the volume of GAC and therefore size of the adsorbers can be calculated. That is, if you double the contact time, you double the volume of GAC.

For a certain flow rate, contact time and bed depth, the linear velocity is fixed. This has a large influence on the pressure drop. If bed depth is too deep and the linear velocity is too high, the pressure drop may be excessive. The selection of a carbon with a larger granulometry may help. In some cases this may be the difference between requiring an additional pumping stage or not.

When determining the number of adsorbers and contact time, the number of adsorbers out of service for backwashing and reactivation needs to be considered.

Backwashing & Air Scouring

Most GAC beds will require backwashing at the beginning and from time to time during operation. Backwashing is an upward flow of water through the adsorber causing an expansion in the GAC bed. The bed expansion ranges from 15 to 30% with a typical recommendation of 20%. The upward linear velocity to achieve this is given by a bed expansion graph. There are two types of backwash:

Initial Backwash - this is required after the delivery of virgin or reactivated GAC to remove air, fine particles and segregate the bed. This procedure should be started at slow rate and normally takes 30 to 45 minutes.

Operational Backwash - this is normally required due to an increased pressure drop across the bed brought about by the build-up of filtered particles. The frequency of backwash will depend on the level of turbidity in the influent and the throughput of the adsorber. This is usually dependent on the source of raw water, treatment processes and whether it is a primary or secondary filter. For example, when treating high quality ground water sources, the backwashing may be less than once per month where as a primary filter at a surface water treatment works may be backwashed several times a week. It is recommended to backwash an adsorber treating surface water every one to two weeks. For biological activated carbon, backwashing is an effective method of controlling the build up of biomass within the carbon bed. Typically, the backwash operation takes 10 to 15 minutes.

Air Scouring

GAC can be air scoured, but due to the abrasiveness of this technique, its use should be minimised. The suspended solids liberated by the air scour are removed from the filter by the subsequent backwash cycle.

Linear velocity	50Nm/h
Time	1 minute
Water level	20cm above the bed

Table 5: Typical conditions for air scouring GAC.

Adsorber Types

There are two main adsorber types used in the treatment of drinking water; the open gravity adsorber, normally constructed in concrete, and the steel pressure adsorber. The selection of the adsorber type will depend on the different requirements of the site.

In addition, the closed pressure vessels will prevent residual ozone escaping into the atmosphere.

	Open Gravity Adsorbers	Pressure Vessel Adsorbers
Cost	better for larger installations	better for small installations
Linear velocity	5 - 15m/h	5 - 25m/h
Carbon removal	more difficult	very good
Head loss available	limited	large
Visual inspection	good	poor

Table 6: Items to be considered in selecting adsorber type.

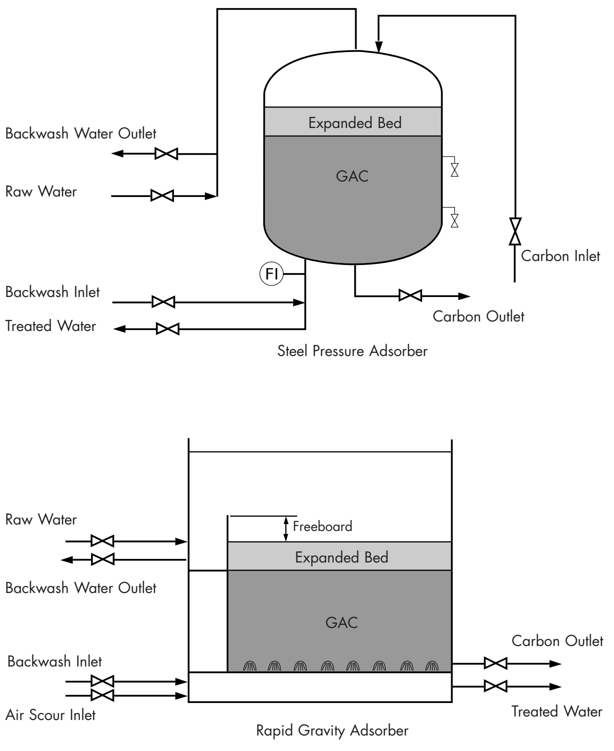


Figure 13: Types of GAC Adsorber.

GAC Delivery and Installation

In general carbon installation into adsorbers is a very simple process. The GAC can be delivered in bulk tankers containing up to 55m^3 of GAC. The bulk tanker can be pressurised up to 1.8 to 2 bar and GAC transferred up to a height of 10 to 14m and a horizontal distance of up to 200m. The carbon is transferred at around 40m^3/h.

GAC Removal

The removal of carbon from adsorbers can be more difficult. For steel pressure adsorbers incorporating carbon removal pipework, the carbon can be transferred easily in a similar way to transfer from a bulk tanker at 40m^3/h. For systems that can not be pressurised such as concrete open gravity adsorbers, it is necessary to pump the carbon. The most common way of achieving this is by an eductor or a slurry pump.

GAC can be removed from a gravity adsorber by eductor at approximately 10m^3/h. It requires motive water of at least 30m^3/h and 5 bar working pressure. Slurry pumps will be faster and reduce the water required. Backwashing of the bed is required to ensure removal. This is especially difficult for ground water sites where there are limitations on the quantity of backwash water. This makes steel pressure adsorbers an attractive option in these cases.

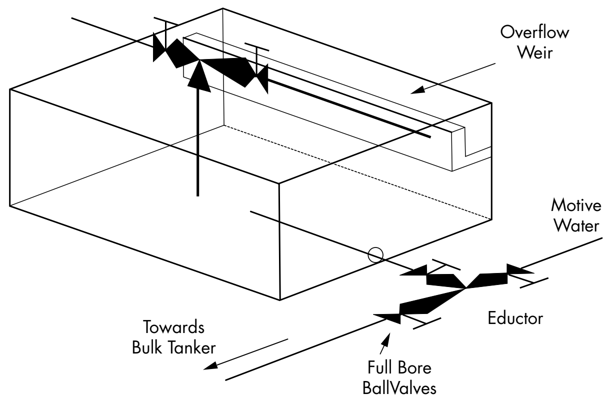


Figure 14: Options for GAC removal from rapid gravity type adsorbers.

Chemviron Carbon can provide technical information on adsorbers and carbon handling including on-site assistance for GAC deliveries and removal. This can include complete engineering packages for carbon handling systems.

Reactivation

Reactivation is a process to restore the adsorption capacity of a GAC. Thermal reactivation involves removing the GAC from an adsorber and processing it in a special furnace to over 800°C. It involves four main stages:

- drying of the GAC to remove water
- thermal evaporation at up to 250°C which involves the physical desorption of volatile adsorbed organic compounds
- char formation which occurs between 200 and 750°C and involves the pyrolysis and carbonisation of non-volatile organics
- gasification of the char at around 800°C which is the most critical stage where the objective is selective gasification of the char from the adsorbed organic compounds, without burning away the carbon structure or altering the pore structure

There will be some loss of GAC during reactivation. This is typically 10% which is made-up with virgin GAC. The GAC is then returned to the adsorber using the same procedure as for virgin GAC.

The two main types of reactivation furnaces are the multiple hearth furnace and direct fired rotary kiln. Off-gas treatment is required to ensure complete destruction of the adsorbed organics.

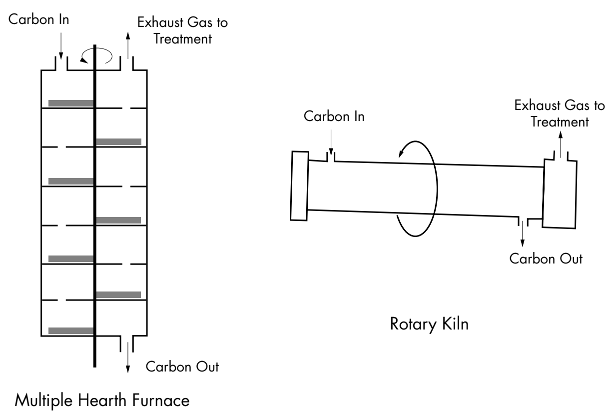


Figure 15: Types of reactivation furnace.

Reactivation Options

Reactivation of GAC can be carried out ***on-site*** or by utilising a ***Reactivation Centre***. The reactivation process is complex and is more suited to large scale continuous operation. Therefore reactivation is normally better handled in a Reactivation Centre. This choice is influenced by a number of factors including location, as transport costs can be significant, availability of space and environmental sensitivity of the area.

The conditions of the reactivation process are very important to ensure the optimum reactivation of the GAC. It is best to consider reactivation at the time of the initial design of a GAC adsorption system. This includes the number of adsorbers off-line for reactivation and backwashing and carbon handling for installation and removal of the GAC.

Alternatives to thermal reactivation are replacement of the GAC with virgin or chemical regeneration. Replacement with virgin GAC is generally more costly than regeneration and also requires removal and disposal of the exhausted material. Chemical regeneration with sodium hydroxide or other chemicals is not very effective in restoring the capacity of GAC in this application and will require disposal of the used regeneration chemicals.

When to Reactivate?

In theory, a GAC adsorber is reactivated when the outlet concentration of the compound to be removed, such as pesticides, is nearing the treatment objective. In practice, the reactivation frequency is also influenced by the following factors:

- estimated performance based on pilot work and previous experience
- security - having capacity remaining for possible peak concentrations
- logistics of removing and replacing the GAC
- the rate at which it can be reactivated
- the time period of the year for factors such as peak plant output.

The GAC in an adsorber can be monitored by taking samples from a bed in operation to assess the condition of the GAC. During reactivation, the iodine number of GAC can normally be increased by over 300mg/g, though not normally higher than the level of the virgin GAC. **FILTRASORB®** type carbons are typically reactivated when they have an iodine number of 500 to 650mg/g, though they are often successfully reactivated when the iodine number is as low as 400mg/g.

Though there is no clear cut-off point where GAC can no longer be reactivated, there comes a point where, because of very high loading of both organic and inorganic compounds, reactivation losses due to burning away the structure of the GAC become excessive.

Quality of Reactivated GAC

The quality of reactivated **FILTRASORB®** activated carbons in terms of operating performance is generally similar to virgin GAC for drinking water treatment because of their bituminous coal base and high mechanical strength. There is generally no limit to the number of times a GAC can be reactivated. In other applications, such as sugar decolorisation, the reactivation frequency can be more than once a week.

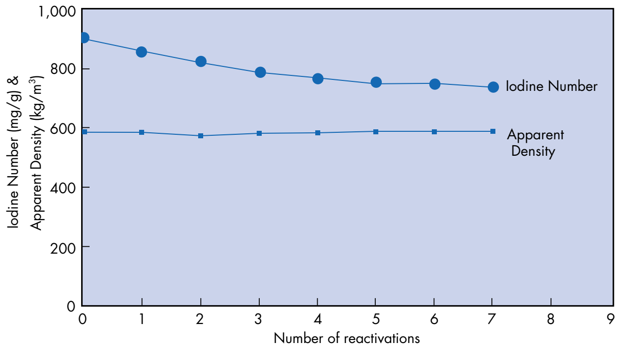


*Figure 16: The evolution of the iodine number and apparent density for reactivated GAC that has been installed over a period of 7 years and has been reactivated 7 times. This is **FILTRASORB®** type GAC that is installed in a sand filter converted to GAC at a conventional water works treating a surface water. With well controlled reactivation conditions and the addition of virgin GAC to make up for reactivation losses, the iodine number remains very stable.*

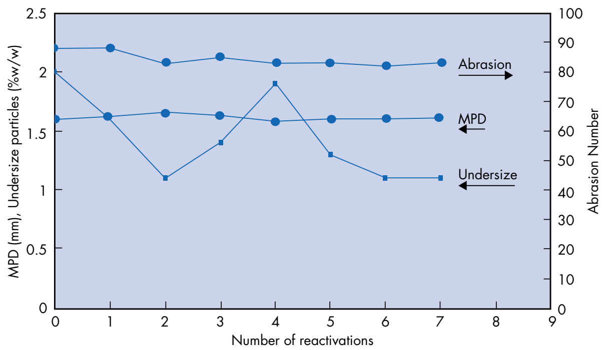


Figure 17: The evolution of mean particle diameter, weight of undersize particles and abrasion. Again these properties are very consistent and show that hydraulic properties and mechanical strength of the reactivated carbon are constant.

A test has been carried out comparing this reactivated GAC to virgin **FILTRASORB®** for the removal of the pesticide atrazine. The breakthrough curve for this test is shown in Figure 18. Figure 19 shows the breakthrough of natural organic matter measured as UV absorbance at 254nm. In both cases, the reactivated GAC had equivalent performance to virgin. In addition, these tests were carried out in conditions that were more extreme than would be normally expected in terms of the continuously high inlet concentration of atrazine.

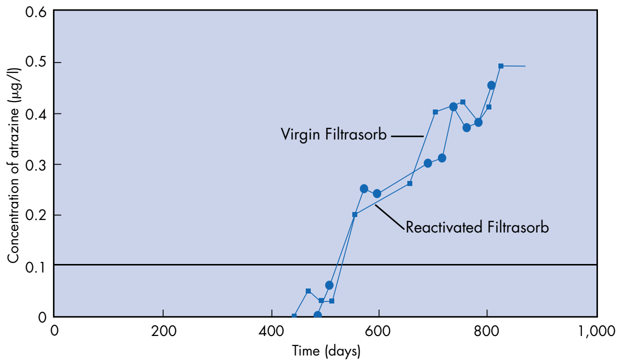


*Figure 18: Breakthrough curve comparing virgin and 7 times reactivated **FILTRASORB®** for the removal of the pesticide atrazine.*

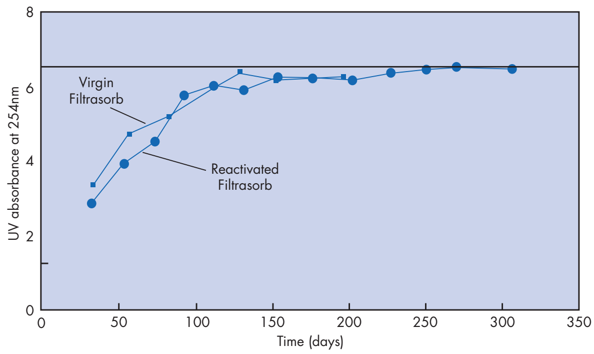


*Figure 19: Breakthrough curve comparing virgin and 7 times reactivated **FILTRASORB®** for the removal of organic matter, measured as UV absorbance at 254nm.*

Chemviron Carbon can provide a complete reactivation service from its central facilities as well as engineering assistance for the design of on-site facilities.

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