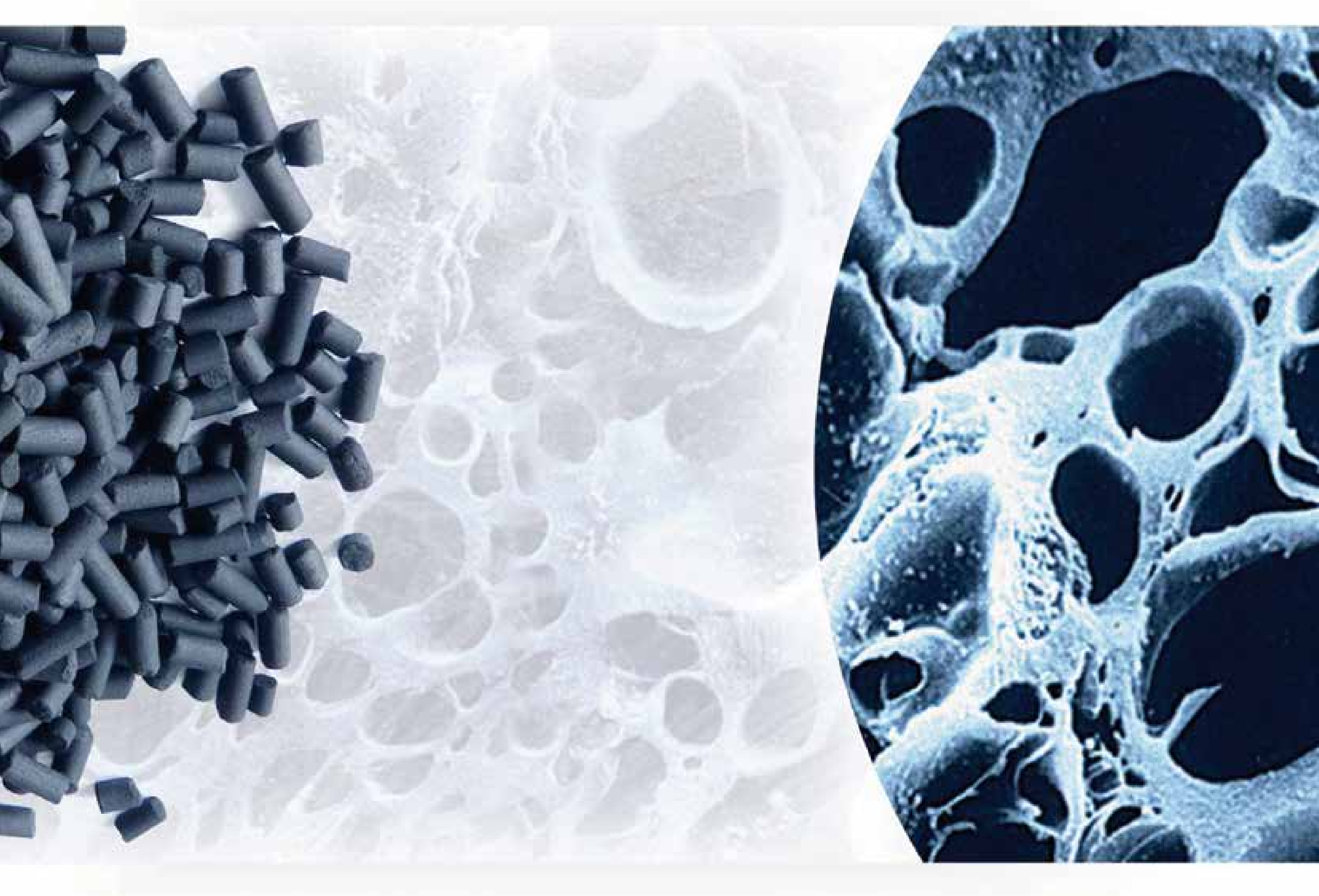
DONAU
CARBON



Activated Carbon and its Applications

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Foreword

Since the early days of 1920 large-scale activated carbon production in the large-scale activated carbon has steadily increased in importance to industry. Continual improvement and optimisation of production processes and new raw materials have led to the advanced level of adsorption technology in use today.

Donau Carbon, which is part of the Donau Chemie Group, has been involved for decades with the development, sale and industrial use of activated carbon and with the construction of plants in which it is used.

Activated carbon lies at the heart of a number of different processes used in the industry. Environmental problems affecting air and water are solved through the use of activated carbon, and new applications are being continually developed in rapid succession.

Of particular interest in the field of environmental protection is the reactivation and subsequent reuse of spent activated carbon and the recycling of activated carbon that is no longer amenable to regeneration or reactivation.

This brochure provides a general overview of the manufacture, characteristics and the potential uses of activated carbon in a variety of fields of application.

Our application engineers and our special laboratory for adsorption technology are available to provide further information and consultation on specific technical problems.

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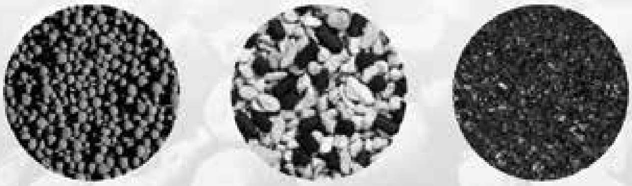


Introduction

The adsorptive properties of charcoal were first observed near the end of the 18th century. It was discovered that charcoal was capable of decolourizing certain liquids. This discovery led to the first industrial use of charcoal in an English sugar refinery in 1794.

Modern activated carbon manufacturing technology dates back to the patent registered by R. v. Ostrejko in 1901.

Today, activated carbon is used in a wide range of industrial **applications**, including **gas and air cleaning** involving traditional reusable substance recovery applications. Heightened environmental awareness and the enactment of strict emissions guidelines have led to the development of new applications, most notably in the area of air pollutant removal. Activated carbon is also being used to an increasing extent in the treatment of water, including drinking water, groundwater, service water and waste water. Its primary role in this context is to adsorb dissolved organic impurities and to eliminate substances affecting odour, taste and colour in halogenized hydrocarbons and other organic pollutants.

Yet another broad field of application for activated carbon is the **treatment, purification and decolourization of liquids**, which is of particular importance in the pharmaceuticals, food, beverage and other industries.

The **selection** of the most suitable type of activated carbon for a specific application depends on the physical and chemical properties of the substances to be adsorbed. Aside from this material data, other processrelated factors also play a role in the adsorption process.

Activated Carbon – Production and Product Forms

Activated carbon is made from carbonaceous **raw materials** such as charcoal, peat, lignite, bituminous coal, fruit stones (e.g. olive pits), coconut shell, etc. These materials are activated using one of two distinct methods.

In the **gas activation process**, previously carbonized material is subjected to the oxidizing action of a stream of gas, such as steam, carbon dioxide, air or a mixture of these. Activation temperatures typically range from 700 to 1.100° C. In the resulting water-gas reaction

$$C + H_2O \rightarrow CO + H_2$$
$$C + 2\,H_2O \rightarrow CO_2 + 2\,H_2$$

the carbon is partially gasified, and a porous, highly activated carbon skeleton is produced.

In the **chemical activation** process, nonincinerated carbonaceous material is initially mixed with dehydrating or oxidizing chemicals and heated to between 400 and 800° C. The activation agent – zinc chloride, phosphoric acid, sulphuric acid, etc. which may be used – is leached out and recovered.

The activation process itself is carried out in **rotary kilns, multiplehearth, shaft or fluidized bed furnaces or in fluid bed reactors.**

The most common **product forms** of activated carbon include:

- extruded (usually in the form ofcylindrical pellets)
- broken (granular or broken activated carbon)
- powder, in specified particle sizes

Specially manufactured types include:

- spherical activated carbon pellets
- activated carbon fibres and fibre mats and
- honeycombs

The manufacturing and activation processes and the basic raw material used have a determining influence on the adsorptive capacity of activated carbon products in use. The size of the inner surface area and the pore structure are particularly dependent on the activation process used.

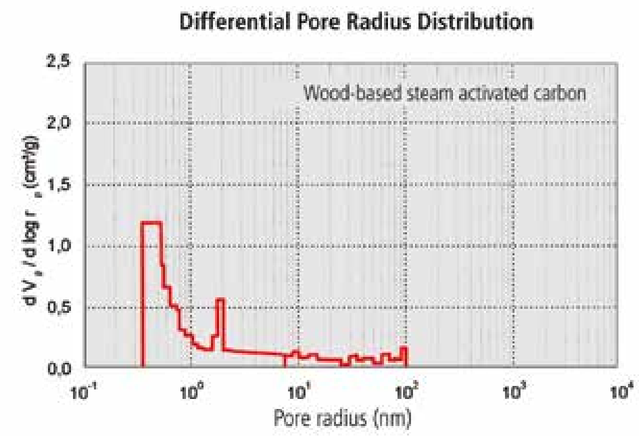


Fig. 1a

Fig. 1a and 1b show the differential pore radius distribution of two different powdered activated carbons. Pore radius distribution is analyzed only within a range of up to 100 nm, as it is not possible to distinguish between pore radius and particle intervals in powdered carbons using mercury porosimetry.

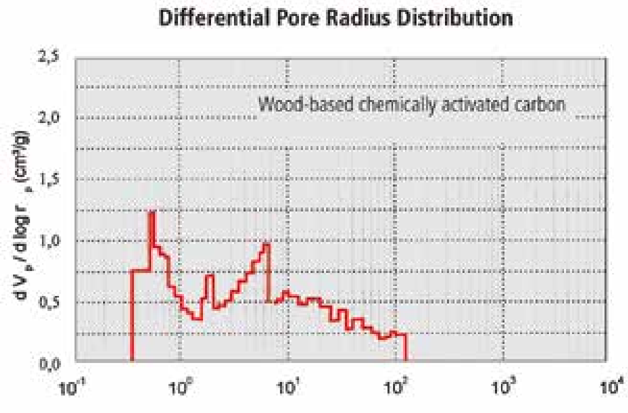


Fig. 1b

Adsorption on Activated Carbon

Adsorption is understood as the accumulation of gaseous compo-nents, or solutes dissolved in liquids, on to the surface of solids. Adsorption is primarily a physical process, i.e. substances deposited on the solid do not undergo any chemical reaction with the adsorbent. The adsorbing solid is referred to as an adsorbent, and the substance to be adsorbed from the liquid or gas phase as an **adsorbate**.

If chemical substances (impregnating agents) are applied to an adsorbent, these agents may react with solutes in a process known as **chemisorption**, in which the deposited substances are chemically altered.

In adsorption, molecular attractions known as van der Waals forces play an active part. One important phenomenon involved in adsorption processes in the gas phase is **capillary condensation**, which triggers condensation of adsorbed vapours as deposits accumulate in the pores of the activated carbon. This effect, which takes place primarily in the micropores, results in much higher adsorbate deposits on the adsorbent than could be achieved through pure adsorption.

Adsorption is always an exothermic process, i.e. **adsorption heat** is released. This physically determined warming effect can be significantly intensified by chemical processes involving the reactive surface oxides of fresh activated carbon and the substances to be adsorbed. As deposits accumulate, adsorption heat diminishes. Nevertheless, the activated carbon may continue to heat as a consequence of the condensation heat produced by capillary condensation.

Adsorption is normally reversible. This reverse adsorption is known as **desorption**. Technically speaking, the regeneration of adsorbate-laden activated carbon is achieved by exposing it to heat, e.g. in water vapour, hot gas or vacuum. The resultingrecovery of adsorbates plays an important role in solvent recovery processes, for example:

If an adsorbent such as activated carbon is brought into contact with an aqueous solution or a gaseous medium containing adsorbates, the adsorbate concentration of the medium is reduced as adsorbates accumulate on the activated carbon. After a sufficient period of time, a stationary balance will be achieved between the adsorbate concentration in the liquid or gaseous medium and the concentration on the adsorbent. This is known as adsorption equilibrium.

The degree of adsorbate accumulation on activated carbon in relation to the concentration of the same substance in the surrounding medium is referred to as adsorption capacity. The maximum achievable accumulation depends primarily on the characteristic properties of the adsorbent, the properties of the adsorbate substance and other physical and chemical conditions affecting the adsorption process.

Adsorption isotherms **(Fig. 2)** can be derived depending on the concentration adsorbate substance and the temperature. This material-specific balance can be calculated for a wide range of substances in both the liquid and gas phases using empirical isothermic equations.

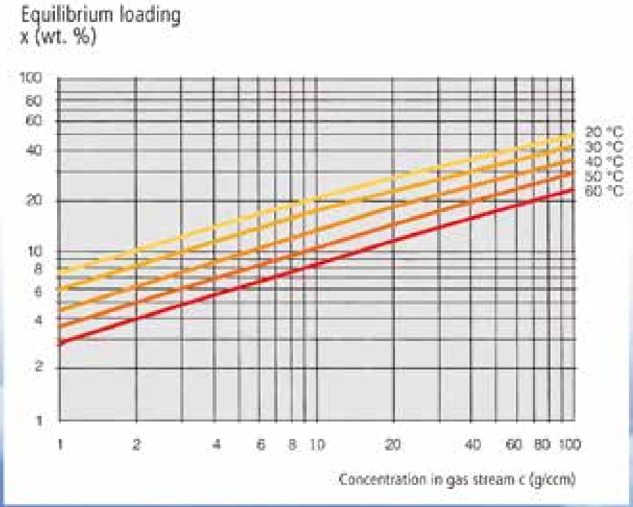


Fig. 2 Loading profile of an adsorber bed

Adsorption velocity depends, among other things, on the type of activated carbon, pore size, pore radius frequency and distribution, the physical and chemical attributes of the adsorbate, the properties of the ambient gas or liquid phase and a number of process-related parameters. Adsorption speed diminishes with progres-sive saturation of the activated carbon.

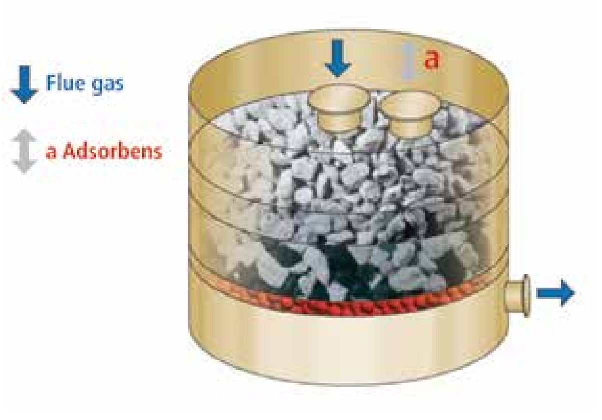
In the fixed bed process, the medium to be purified flows through an adsorber filled with activated carbon and deposits adsorbatea onto the activated carbon. As the adsorbate concentration in the medium decrease, the concentration on the activated carbon increases, forming a concentration profile in the adsorbent bed and a corresponding profile in the interparticle volume of the corresponding activated carbon bed. Within this profile, the concentration falls from the initial inlet concentration value to the effluent value **(Fig. 3)**. The **adsorption zone** is the concentration incline that forms along a layer of activated carbon during the adsorption process, whereby the effluent concentration is reduced to a defined value. The length of the adsorption zone can be influenced by various factors such as humidity, impurities (matrix effects) and displacement effects in use on different adsorbate components.

The activated carbon is loaded in relation to the adsorption equilibrium on the inflow side and is initially free of deposits on the outflow side of the adsorber. The concentration and load profiles shift in the course of adsorber run time in the direction of flow. Once this zone reaches the end of the activated carbon bed, the adsorbate concentration in the filter outlet rises until the effluent concentration ultimately reaches equilibrium with the inlet concentration.

Plotting the **concentration profile** against the length of the column produces a breakthrough curve as depicted in **Fig. 3.** Activated carbon utilization improves in proportion to the thickness of the activated carbon bed relative to the length of the adsorption zone. In other words, the configuration of the adsorption zone is of crucial importance to the efficiency and economy of the percolation process. The longer the adsorption zone, the thicker the activated carbon bed must be. The correlation between effluent concentration and adsorber run time is generally referred to as **breakthrough behaviour**.

The **breakthrough point** in the fixed bed process is the point at which the first traces substance to be adsorbed appear in the purified medium once it has passed through the activated carbon bed. The concentration accumulated on the activated carbon prior to this point is known as the **breakthrough concentration**.

Retention behaviour refers to the capacity of the activated carbon to capture an adsorbed substance. Good retention behaviour makes desorption difficult and is thus desirable where no regeneration is planned.



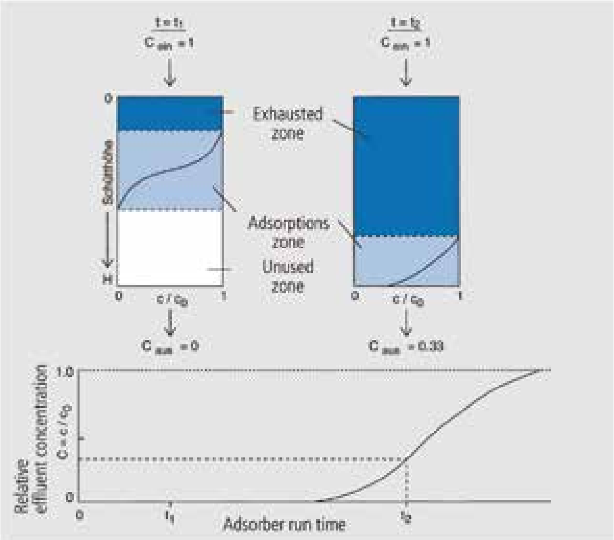


Fig. 3

The **residual load** is the quantity of adsobates that, for reasons of economy (e.g. high steam consumption during regeneration) is not fully removed from the activated carbon during desorption. The adsorption capacity for the subsequent adsorption phase is thus reduced by the residual concentration. The practical available adsorptive capacity remaining in regenerated activated carbon after subtraction of the residual concentration is known as the cyclic capacity.

The time required by the adsorption process is a key factor in the determination of filter dimensions. In addition to diffusion mechanisms, the total dependence of concentration reduction on time and the influence of operating conditions affecting the activated carbon bed through which the medium flows are also of crucial importance.

Mathematical Models for the Description of Adsorption Processes

Single substances

As in all physical-chemical processes, equilibrium is eventually achieved between adsorption and its reversal

adsorption $\rightleftarrows$ desorption,

which is described by the Freundlich Equation. Adsorption equilibrium is a function of temperature and also depends upon the properties of the adsorbate, the pH value and the type of activated carbon used.

In gas phase applications, lower temperatures favour adsorption; in the liquid phase, particularly in the treatment of viscous liquids, elevated temperatures are normally used in order to exploit the advantages of higher diffusion rates and lower viscosities.

The specific correlation between load concentration and residual concentration at a constant temperature for each specific adsorption process forms an isotherm, which is described mathematically in a number of different isothermic equations.

The **Freundlich** isotherm equation is used for virtually all isotherm descriptions of adsorption in liquid solutions:

$$Q = k * C^n$$

where

Q ... quantity adsorbed

C ... residual adsorbate concentration in the liquid solution (mg/l; g/ccm; ml/ccm, etc.)

k, n ... constants

The constant k corresponds as a numerical value to the adsorbate load at a residual concentration of 1.0. The k value is useful only in conjunction with the selected units of adsorbate load and concentration.

In the graphic representation of the adsorption isotherms, the experimentally derived equilibrium loads for various different concentrations are entered in a dual-logarithm coordinate system. If the Freundlich Equation applies, the curve is straight. This is the case for most substances within a given concentration range.
(Fig. 4)

The exponent n expresses the incline of the straight curves.

Multi-substance mixtures

In actual practice, liquids frequently contain several different pollutant substances. During adsorption, the different components compete for adsorption space on the activated carbon, often leading to overlayering and displacement effects. As a result, the load capacity for the separate components is reduced during simultaneous adsorption of other substances. The more adsorbent the other substances are, the greater the reduction factor.

The position of the adsorption isotherm for each separate substance is influenced by the concentration and the adsorbability of the other components of the mixture, which is why the Freundlich Equation used to determine isotherms of single substances does not provide a satisfactory solution. The computation of reciprocal adsorption behaviour influences is very complicated and requires a knowledge of the exact composition of the mixture and the adsorption isotherms of each individual substance.

Adsorption kinetics

Adsorption equilibrium is not generated spontaneously, as absorbate molecules must first be transferred from the solution to the adsorbent particle and then from the surface to the interior of the particle. The progress of adsorption over time until equilibrium is reached is referred to as adsorption kinetics.

Particle size and pore structure have a significant impact on the kinetic properties of activated carbon. The smaller the particle, the shorter the distances travelled by an ad-sorbate from the liquid solution to the point of adsorption and thus the more rapid the adsorption process.

Accordingly, adsorption equilibrium is quickest with powdered activated carbons.

With the granular carbons ordinarily employed in fixed bed adsorbers, the adsorber filtration rate and the pore structure of the activated carbon both have a significant impact on adsorption kinetics.

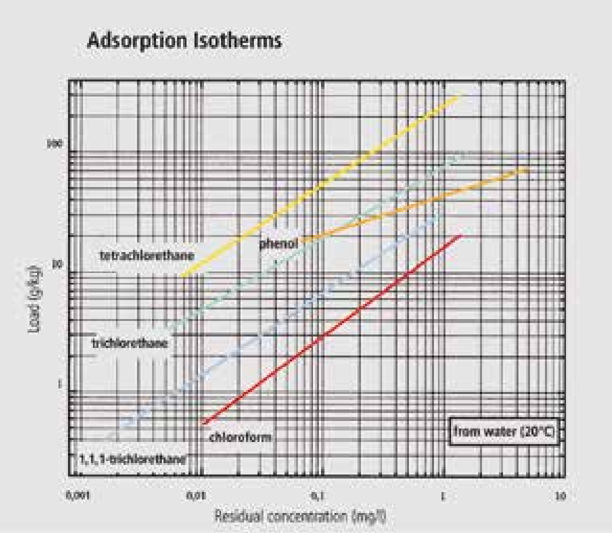


Fig. 4

Factors Influencing Adsorption

Aside from the properties of the substances to be removed, including

- chemical molecular characteristics
- molecule size
- hydrophilic behaviour
- polarity,

the primary factors influencing adsorption are adsorbent characteristics, such as

- the size of interior surface area
- pore structure
- chemical properties

and other physical and chemical conditions, including

- solute adsorbate concentration
- temperature
- composition of the solution or gas mixture
- the pH value of the solution during adsorption in the liquid phase
- relative humidity during adsorption in the gas phase

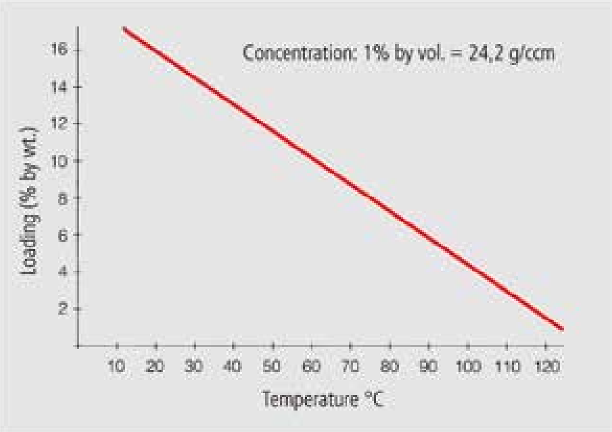


Fig. 5 Influence of temperature on adsorption capacity

Pore Structure and Interior Surface Area

Since adsorption involves the accumulation of molecules on the surface of an adsorbent, the quantity of substance accumulation depends to a significant degree on the size of this surface area. The outside surface plays a limited role in this process. More important is the size of the interior surface, known as the BET surface, which is formed by countless pores and capillaries in the activated carbon.

Photos taken using a scanning electron microscope provide an excellent visual representation of the pore characteristics of activated carbon **(Fig. 7)**.

Activated carbons employed in gas and air treatment ordinarily have a BET surface area within the range of 800 – 1,500 m2/g. Activated carbons used in water purification generally have BET surfaces areas of between 500 and 1,500 m2/g. In adsorption, both interior surface and pore radius distribution play an important role. **Figs. 8a** and **8b** show the pore distribution of two granular carbons made of different raw materials, both steam activated.

Distinction is made in the characterization of pore size between micro-, meso- and macropores. Pores with radii of 1nm or less are classified as micropores. These pores have a determining influence on the total size of the interior surface area. Adsorption takes place primarily in the microand mesopores (1-25 nm). Macropores, with diameters of >25 nm, serving as access pores.

Activated carbons with open pore structures and good desorption characteristics are used in the recovery of solvents with mid- to high boiling points, whereas activated carbon types with higher micropore concentrations are used for highly volatile substances.

In liquid phase adsorption processes, macropores serving as access pores also have a substantial impact on adsorption kinetics.

Characteristic Data and Performance Testing

Depending upon the raw materials and activation methods employed, activated carbons may differ widely with respect to quality and adsorptive properties. These differences are reflected in the characteristic data (quality features) of the various grades of activated carbon.

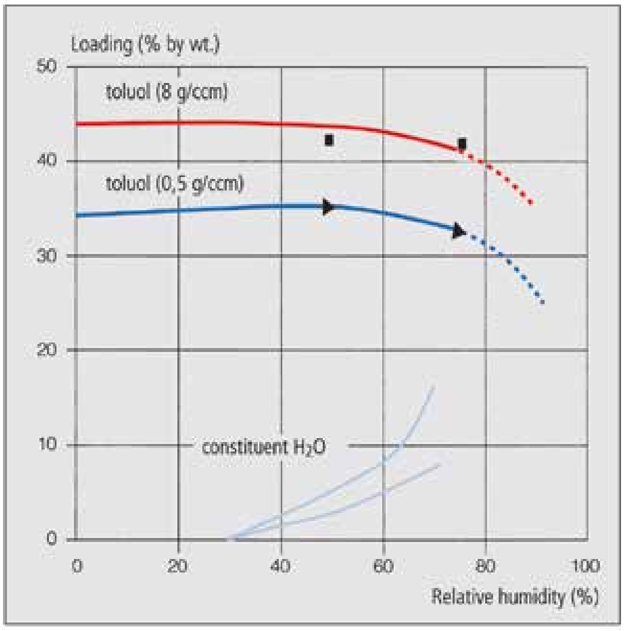


Fig. 6 Influence of relative humidity on adsorption capacity

Fig. 7

In general, carbon properties are described on the basis of characteristic data. Apart from our own laboratory test procedures, international testing standards are given high priority, particularly the methods recommended by such bodies as

- the ASTM (American Society for Testing and Materials),
- the AWWA (American Water Works Association) and
- the CEFIC (Conseil Européen des Fédérations de l'Industrie Chimique).

Also applicable to the grading of carbons used in water purification are the regulations contained in

- European Standard (DIN EN / CEN Comité Européen de Normalisation)

Other standards are employed for special applications, including the International Wine Code and the FCC (Food Chemicals Code).

Depending upon the particular application, different performance characteristics relevant to quality assurance and the issuance of certificates of analysis may also be taken into account.

Typical testing criteria include:

- water content
- ash content
- pH value
- bulk density and vibration density
- iodine adsorption
- molasses decolourization behaviour
- methylene blue adsorption
- tetrachlorocarbon or butane adsorption
- adsorption isotherms of various solvents (e.g. cyclohexane)
- particle distribution / screen analysis
- hardness

In addition, special measurements/tests are performed, including:

- BET surface
- pore radius distribution
- phenol concentration
- chlorine half value length
- water- and acid soluble components
- other purity tests

Substances typically used in the testing of activated carbon for use in water purification include halogenated hydrocarbons or phenol.

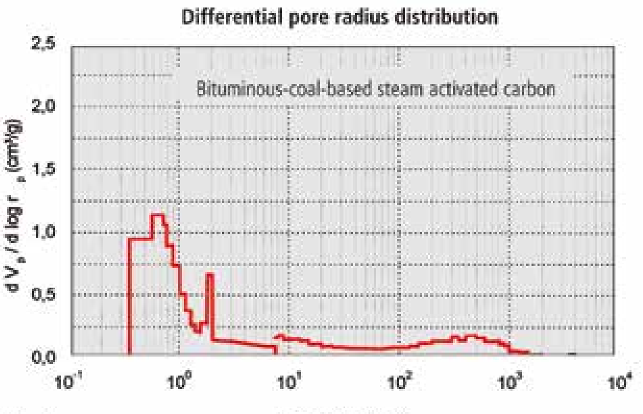


Fig. 8a

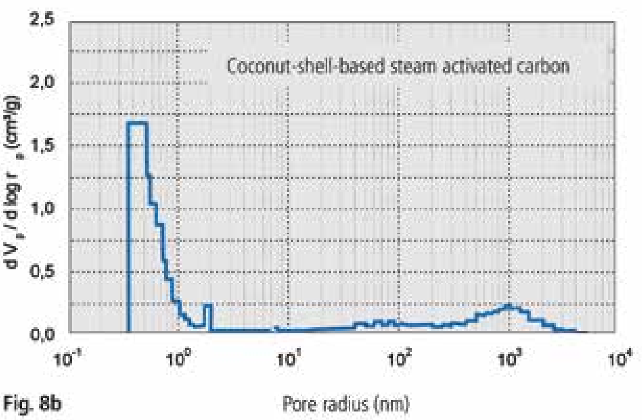


Fig. 8b

BET surface and differential pore radius distribution

The interior surface of activated carbon is measured and evaluated using the BET method (Brunauer-Emmert-Teller). For this purpose, the nitrogen isotherm is measured at – 196° C. Assuming a monomolecular deposit of nitrogen molecules on the interior surface of the activated carbon, the interior surface area is calculated based on the surface required for a single N2 molecule (approx. 0.16 nm2) (DIN 66 131).

To determine the integral pore volume and the differential pore radius distribution, nitrogen adsorption at – 196° C and nitrogen desorption are measured (DIN 66 134; ASTM D 4222). Analysis is performed using the method developed by Barrett, Joyner and Halenda under the assumption of cylindrical pores based on the Kelvin Equation (ASTM D 4641). The determination of pore radius distribution in the macropore range is performed using mercury intrusion (DIN 66 133; ASTM D 4284). Analysis is based on the assumption of cylindrical pore configuration according to the Washburn Equation.

Activated carbon pores are categorized by volume in accordance with the IUPAC Classification System, which distinguishes between micro-, meso- and macropores:

micropores r = 0.2 – 1 nm
mesopores r = 1 – 25 nm
macropores r = > 25 nm

Molasses test

The molasses test is the standard method employed to deter-mine the decolourizing capacity of activated carbon. The decolourization of a standardized molasses solution with activated carbon is determined by colorimetry (photometric extinction measurement) and compared to that of a standard activated carbon.
The rise in the adsorption isotherm determined using the Freundlich Equation provides reliable information on the decolourization behaviour of an activated carbon. **(Fig. 9)**.

Decolourization curves

In order to assess the decolourization capacity of different types of activated carbon under empirical conditions, decolourization curves are ascertained for each solution requiring treatment under the specific conditions prevailing at customer facilities.

In this process, different quantities of solution are treated with the same quantity of each activated carbon tested under defined temperature and contacttime conditions. After filtration, the residual colour is measured photometrically and compared with the control solution which has undergone the same procedure. Colour filters are selected on the basis of the complementary colour for each sample tested. The percentage rate of colour extinction in the individual filtrates is entered in a curve diagram and referenced against the rate of extinction in the control solution. **(Fig. 10)**

Methylene blue titration

This test is used to determine the quantity of a 0.15 % methylene blue solution that can be decolourized by 100 mg of activated carbon (dry substance) within 5 minutes.

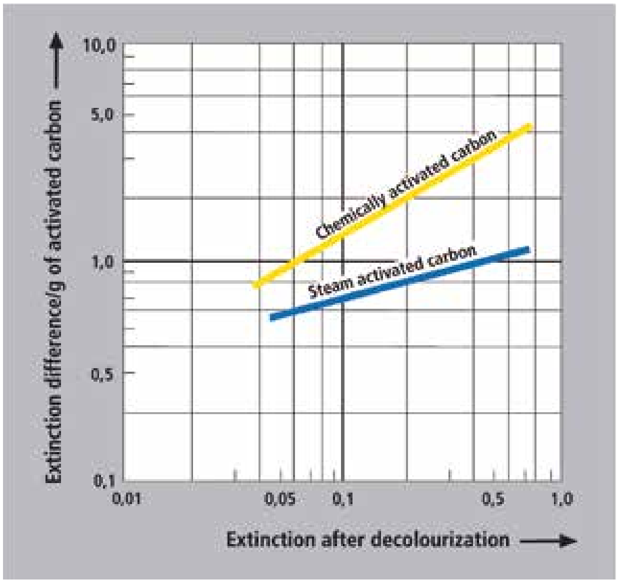


Fig. 9 Molasses Test

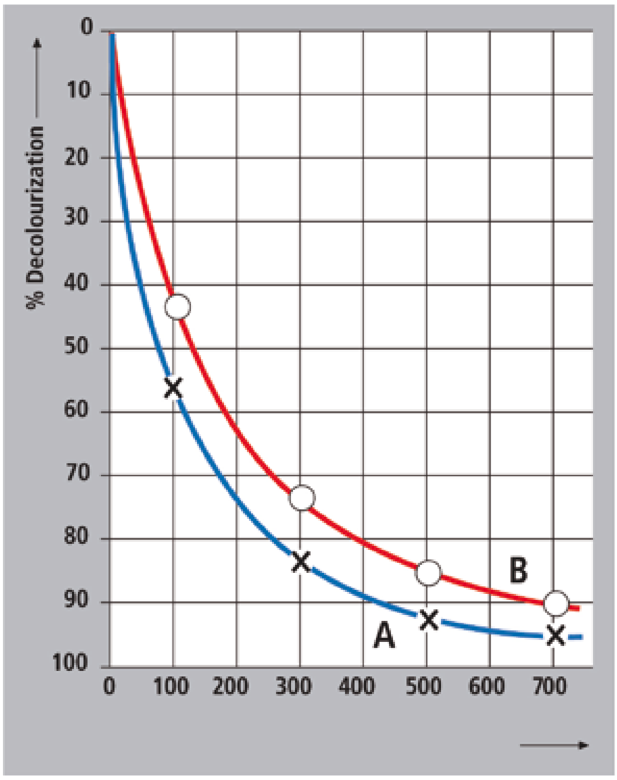


Fig. 10 Decolourization curves of two different activated carbon - Types A and B

Application engineering: gas purification

Granular activated carbon has a wide range of uses in both gas and exhaust air treatment applications:

- Recovery of solvents, e.g. in rotogravure printing operations, from coatings and in the packaging, food and chemicals industries

- natural gas purification; removal of H_2S and BTX
- flue gas cleaning at waste incineration plants for the removal of dioxins and heavy metals
- exhaust air treatment following production processes for the removal of organic impurities
- purification of process gases, e.g. CO_2; scrubbing and separation of oil from compressed air
- removal of pollutants in airconditioning, ventilation and exhaust systems
- removal of odorous substances in kitchen exhaust hoods and refrigerator filters
- emission control, e.g. at filling stations and during tank ventilation for motor vehicle and industrial applications
- pollutant removal in car interior ventilation systems
- in gas masks
- in cigarette and cigar filters
- as a carrier medium for special impregnating agents or catalysts

Donau Carbon supplies special grades of activated carbon for all of the various applications, each designed to meet specific requirements. Product types are Supersorbon, Desorex, Contarbon, Oxorbon, Kombisorb, Sulfacid, Sulfosorbon and Alcarbon.

- **Supersorbon-/Sulfosorbon** types are used for solvent recovery processes in various industries and are steam or heat gas regenerable.
- **Kombisorb** types are used in fixedbed filters to separate dioxins and heavy metals in waste disposal/incineration facilities. These types can be used at higher temperatures.
- **Desorex-/Oxorbon** types are used for the removal of hydrocarbons, BTX etc. in exhaust gas purification systems. Impregnated types are used for the removal of H_2S, Hg, PH_3 and other impurities.
- **Sulfacid** types are suitable for the removal of sulphur dioxide in pigment production, roasting and sintering plants or sulphuric acid production.
- **Contarbon** types are used for catalyst.
- **Alcarbon** types are used for special applications.

Impregnated activated carbon

A number of different pollutants are either partially or totally resistant to separation through adsorption (e.g. chlorine, ammonia, amines, sulphur dioxide, mercury, hydrogen sulphide, mercaptanes, formaldehyde, carbon oxide sulphide, etc.)

These substances can be removed with specially impregnated activated carbons that have a chemisorptive effect. In chemisorption, the substances to be removed are either chemically bonded by the impregnating agent on the activated carbon or converted by these agents into a form that adsorbs on activated carbon. Impregnating agents include metal salts, iodine, sulphur as well as acids and bases.

Ground air treatment

A major area of application in the field of exhaust air treatment is the cleaning of polluted soil. By suctioning off ground air, solvents contained in the soil are removed and can then be adsorbed onto activated carbon. Depending upon solvent concentration in suctioned air, either conventional adsorbers or solvent recovery systems are used.

Donau Carbon supplies compact systems, mobile adsorption units and other solutions for these applications, including all required services.

Application engineering: Water Treatment

Objectives

In the water treatment sector, activated carbon is used either in powdered (suspension process) or granular (fixed bed process), depending upon the specific application and process. The objectives pursued with the use of activated carbon in water treatment have changed significantly in recent decades.

Years ago, activated carbon was employed primarily for the removal of excess chlorine and the elimination of substances affecting odour and taste from relatively good-quality raw water. Increasingly exacting quality requirements for drinking water, coupled with increasing pollution levels in untreated water (groundwater and surface water), have led to the optimization of activated carbon as a means of guaranteeing acceptable drinking water quality. In parallel, changes in treatment processes, such as the reduction of high-strength chorine treatment, have resulted in the elimination of traditional applications.

In recent years, the use of activated carbon processes has become widely established in drinking water treatment, groundwater rehabilitation and the treatment of service water. Likewise, activated carbon is being used to an increasing extent in waste water treatment, whether it be in the systematic treatment of individual effluent streams (e.g. in the chemicals industry), in the removal of substances toxic to bacteria in biological waste water treatment or in tertiary waste water treatment, where effluent restrictions are particularly severe. Yet another application for activated carbon is found in the treatment of landfill seepage.

Donau Carbon's **Hydraffin** grades, available in powdered or granular form, are used for water treatment.

The fixed bed process

In this process, the medium to be treated is passed through layers or beds of granular activated carbon contained in filters or adsorbers. Both open and closed pressure filters are used in water treatment applications. At large water treatment plants, open concrete filter basins are often used. The economic and environmental advantage offered by the fixed bed process is that the granular activated carbon used in the adsorber can be thermally reactivated.

Metering processes

In water purification, powdered activated charcoal is stirred into the medium to be treated. The powdered activated carbon is added either in dry form or as a watery sludge and then, following a specified reaction period, separated by filtration, in most cases supported by the addition of flocculation agents, together with other turbid substances, through gravel, multilayer filters or other filter systems adapted to the specific application. The advantage of the use of powdered carbon is that it provides for timely, optimized and systematic dosage.

Drinking water purification

It is common practice in drinking water purification to use activated carbon in combination with other treatment processes, such as floc-culation, oxidation, filtration, etc. Used in this way, activated carbon can serve a variety of functions. Silverimpregnated grades of activated carbon for drinking water filters are also included in our product program.

Adsorption of solute organic matter

The removal of solute organic substances is accomplished primarily through adsorption processes. If the water to be treated contains biodegradable substances, the purification effect can be enhanced by settling microorganisms on the activated carbon. Organic components in water may come from a number of different sources. Even ground and surface water may occasionally contain such organic substances as humous matter in concentrations high enough to affect taste. Surface water, particularly river water, still contains – even after bank filtration – numerous organic compounds, of which only a fraction are normally identifiable.

It has been determined that groundwater is polluted to an increasing extent by chlorinated hydrocarbons and organic compounds originating from pesticides, herbicides and insecticides used in intensive agriculture.

This man-made water pollution, in particular, not only affects the odour and taste of water but may also have longterm toxic or carcinogenic effects in human beings when consumed over a period of years.

The use of activated carbon makes it possible to remove even the smallest traces of such harmful substances very efficiently from water. Special, highly active, abrasionresistant and easily regeneratable activated carbons have been developed for water purification applications.

Dechlorination, Deozonation

Oxidizing agents such as chlorine, hypochlorine, chlorine dioxide, hydrogen peroxide and ozone are frequently used for disinfection and organic substance removal in water purification systems. In most cases, excess oxidants must then be removed from the water. This can be accomplished effectively through catalytic decomposition of the oxidants on the surfaces of granular activated carbon. The smaller the activated carbon particle, the greater the dechlorination capacity.

Groundwater clean up

Unfortunately, experience has shown that groundwater is often polluted with volatile chlorinated hydrocarbons and other organic solvents or organic substances introduced for agricultural purposes.

The chlorinated hydrocarbons most frequently found in groundwater are tri- and tetrachloroethylene (per), dichloromethane and 1.1.1-trichlorethane. Some of these substances are so stable, that they are still detectable after decades once introduced into groundwater and dispersed over a wide area. The rehabilitation of groundwater contaminated with such dissolved organic substances, e.g. within the scope of groundwater conservation measures or the treatment of groundwater to obtain drinking water, is almost always carried out using activated carbon. At high contaminant concentrations, a stripper unit may be incorporated in advance of the activated carbon filter.

Service water treatment

Basically, service water treatment involves the same problems as are encountered in drinking water treatment. Service water is understood to be used water which must be cleaned prior to re-use. Typical examples of service water are cooling water, boiler feed water, condensate water, swimming pool water and aquarium water.

Boiler feed water treatment

Water used to fill high-pressure boilers must be free of oxygen, as a precaution against corrosion. Oxygen in feed water is converted into nitrogen and water through the addition of hydrazine hydrate ($N_2H_4 - H_2O$). This reaction is accelerated in cold water by filtration through granular activated carbon.

Condensate and contact water treatment

Hot condensate is sometimes contaminated with lubricants. These oils must be eliminated as thoroughly as possible prior to reuse of the condensate, particularly in high-pressure boilers. For high oil concentrations is it advisable to de-oil the condensate using a mechanical oil separator prior to treatment with activated carbon. Fine cleaning can then be accomplished through granular activated carbon.

The treatment of contact water is closely related to that of condensate water. In solvent recovery systems, the steam regeneration process produces a highly solventladen condensate which normally consists of organic and aqueous components. The aqueous phase (contact water) is saturated by solvents and is frequently cleaned by routing it through layers of granular activated carbon.

Swimming pool water treatment

Swimming pool water is cleaned mechanically and chemically in recirculation systems. Several different combinations of processes (described in DIN 19643-1 to 5) are available for swimming and bathing pool water treatment. Filtration through activated carbon removes chlorine-nitrogen compounds, halogenated organic compounds /THM, AOX) and organic compounds with a high degree of efficiency. Residual traces of ozone and chlorine are also eliminated.

Aquarium water treatment

Water used in fresh and salt-water aquaria are contaminated with toxins contained in animal excrement and decomposing food. These pollutants, along with medication residues, can be removed by filtration through activated carbon.

Waste water and sewage treatment

Among the wide range of physical, chemical and biological processes used in waste water treatment, activated carbon adsorption is gaining steadily in importance. The use of activated carbon is especially advisable in cases requiring the removal of toxic substances or pollutants that are not easily biodegradable.

Activated carbon is almost always employed in the treatment of waste water in the paper, textile and petrochemical industries. In practical situations, it is rarely possible to identify the components of mixtures contained in waste water. Consequently, such non-specific parameters as the following are used to determine pollution levels:

- TOC (dissolved organic carbon), DIN EN 1484
- COD (chemical oxygen demand), DIN 38409 Part 41/43
- AOX (absorbable organic halogens), DIN EN 1485

As impurities found in waste water exhibit widely differing adsorption behaviour, tests must be performed for the purpose of obtaining data for adsorption system design and the selection of the most suitable type of activated carbon.

Donau Carbon offers a wide range of powdered and granulated products for the various water and waste water treatment applications.

Landfill seepage treatment

Several different processes are used in the treatment of water seeping from landfills.

In addition to such techniques as biological treatment, precipitation/flocculation, chemical oxidation, reverse osmosis and vapourization, activated carbon adsorption now plays a major role as well.

Powdered activated carbon is seldom used in newer facilities. In most cases, granular activated carbon is used in fixed beds, followed by reactivation.

Adsorption is often employed following other pollutant-reducing treatments, which increases the effectiveness of the activated carbon process. Adsorption removes COD compounds and AOX compounds, which are not readily biodegradable. Achievable pollutant loads depend primarily on the influent concentration.

Application engineering: Liquid treatment and decolourization

A major field of application for adsorption technology is the treatment of liquids of all kinds, including sugar solutions, glucose, vegetable oils and fats, glutamate, spices, wine, beer, fruit concentrates, plant extracts, chemicals, pharmaceuticals, etc.

Apart from simple decolourization, activated carbon also removes other solute organic impurities as well as substances which affect odour and taste.

Ordinarily, powdered activated carbons (**Carbopal** grades) are used instirring/suspension processes or bed filtration.

In many cases, powdered carbon can be used in multiple applications.

Granular activated carbon (**Epibon** grades) is employed in a fix bed system in what is known as a percolation process.

The stirring or suspension technique

In this process, which is probably the most commonly used approach, activated carbon is introduced directly into the solution to be treated or metered in as a liquid suspension (e.g. 15 %). The suspension can be made with water, condensate or a previously purified solution.

The length of exposure to activated carbon depends upon the physical properties of the liquid to be treated, i.e. its viscosity, temperature, pH value, and the specific substances that are to be removed. Contact times ranging from 15 to 30 minutes are ordinarily sufficient.

Layer filtration / percolation

In the less commonly used layer filtration process, a filter layer is built up by accumulating powdered activated carbon on a filter element – with the aid of a filtration enhancer, if necessary – through which the solution to be treated is then filtered.

Layer filtration is similar to the percolation process used in decolourization and liquid purification, in which granular activated carbon is employed in adsorption columns. Typical of both processes is the distribution of solute concentration within the layer or the adsorption column. The highest concentration is found on the influent side/end, the lowest on the effluent side. This pattern of distribution shifts in the direction of flow as deposits accumulate.

Multiple applications

In adsorption, an equilibrium is achieved between solute concentrations in activated carbon and the medium to be treated.

After one-time use in the stirring process, the adsorption capacity of an activated carbon is not exhausted. Its residual adsorption capacity depends, among other things, on the point at which adsorption equilibrium is reached. If this point is low, the residual capacity is larger. The adsorptive capacity of activated carbon can be optimally exploited if the activated carbon used to treat a weaker, pretreated solution is then reused a second or even a third time with progressively „darker" solution. In this multiple use process, the heavily polluted effluent solution is precleaned with previously used activated carbon and then treated again with fresh carbon. **(Fig. 11)**

Guidelines for use

The filtration behaviour of powdered activated carbon depends on both the degree of fineness and, in particular, the particle shape of the ground activated carbon.

The degree of fineness of powdered activated carbon is adapted to ensure optimum filtration characteristics during the production process. Filtration problems may arise in the presence of certain secondary substances in the solution (e.g. colloids). In such cases, we recommend the use of filtration enhancers such as kieselgur, perlite or cellulose fibres.

The first step in this process is to accumulate a precoat of this filtration enhancer on the filter element before the filter is exposed to the solution containing the activated carbon.

In special cases, filtration enhancers can be added directly to the activated carbon suspension. This does not affect the adsorption capacity of the activated carbon.

The powdered activated carbon can then be separated using filter presses, candle filters and rotary vacuum filters.

Applications

Our program of activated carbon products for the purification and decolourization of liquids encompasses a wide range of carbon qualities, each with different adsorption capacities and other characteristics, for a multitude of applications:

- Cleaning and decolourization of softeners, shellac, glycerin, enzymes, paraffin, Vaseline, wax, fine chemicals, organic acids and other products
- Decolourization and deodourization of gelatins
- Cleaning of galvanizing baths
- Decolourization and purification of intermediate and endproducts of the pharmaceuticals industry
- Purification and decolourization of sugar solutions
- Purification and decolourization of solutions used in theproduction of glucose, dextrose and other starch products as well as lactose
- Decolourization of seasonings and glutamate
- Treatment of vegetable oils and fats
- Decolourization and deodourization of juices and fruit extracts; treatment of wine
- Treatment of beer, wort and final runnings of wort for flavour enhancement, colour adjustment and the removal of undesirable compone

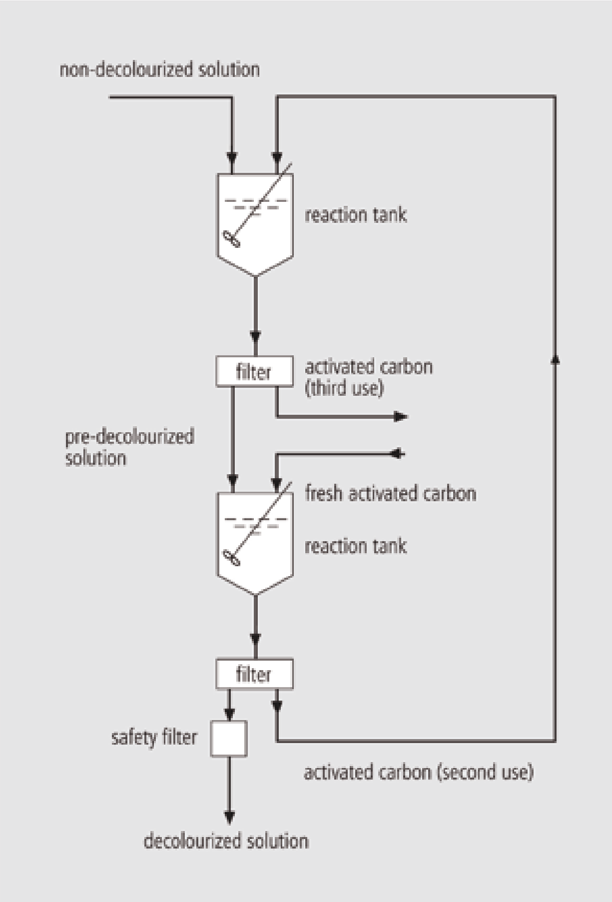
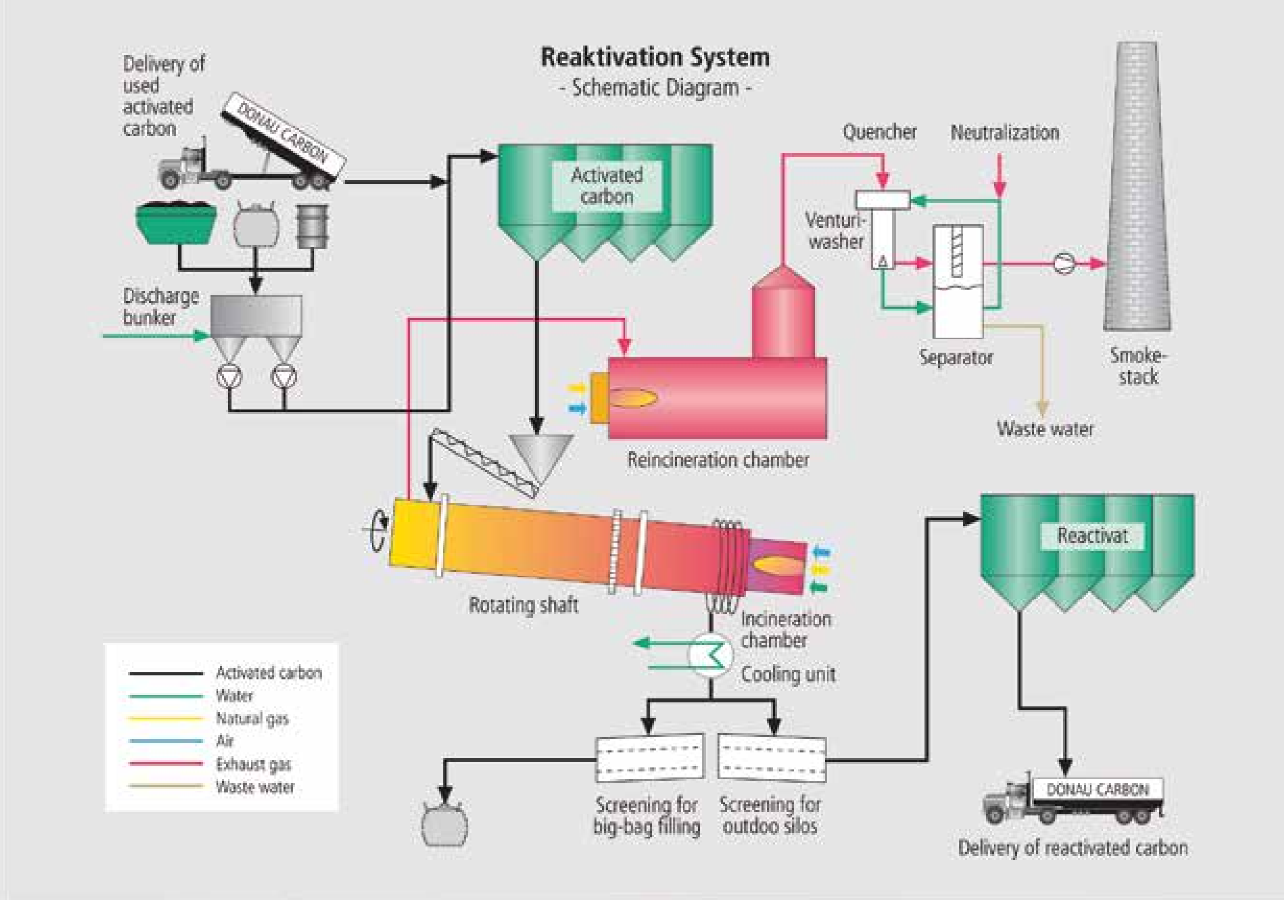


Fig. 11 Two-stage applications of powdered activated carbon



(Fig. 12)

Reactivation

Charged or exhausted granular activated carbon can often be reactivated using a thermal process that is very similar to the original activation process. The activated carbon can then be reused. Thus reactivation is an economical and environmentally sound alternative to disposal.

A number of different technical systems can be used in the reactivation of activated carbon, including:

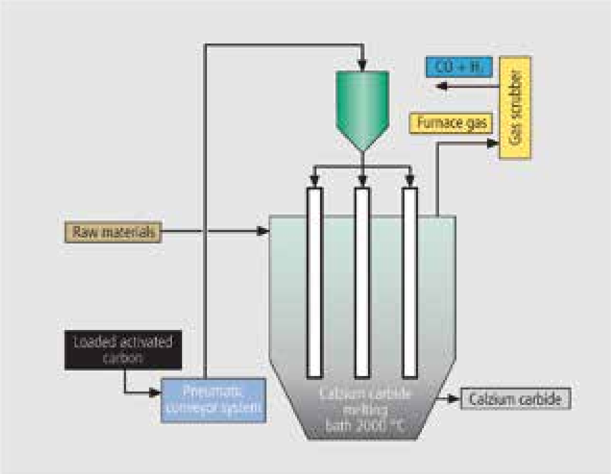
- rotary kilns
- multiple-hearth furnaces
- fluidized bed furnaces

Activated carbon passes through the following steps in the reactivation process:

- drying (up to 100° C)
- desorption and pollutant pyrolysis (100 – 700° C)
- activated carbon reactivation (watergas reaction) (above 700° C)

$C + H_2O \rightarrow CO + H_2$

The pollutants released during the reactivation process are then incinerated at temperatures of up to 1.200° C. The flue gas is then scrubbed. The process sequence, which is adapted to specific application requirements and types of activated carbon, guarantees high reactivate quality. In most cases it is possible to restore the original adsorption capacity of the activated carbon. **(Fig. 12)**



(Fig. 13)

Recycling

It is not always possible to regenerate or reactivate used activated carbon. Through intensive development efforts, Donau Carbon has created an environmentally safe method for recycling such activated carbon using a carbide process.

In this process, the used, exhausted activated carbon is introduced through hollow electrodes directly into the molten carbide, where all of the pollutants attached to the activated carbon are thermally decomposed at a temperature of roughly 2000° C. In the process, the activated carbon is converted along with the burnt lime into carbide. **(Fig. 13)**

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