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# THE EFFECT OF AN ACTIVATED CARBON (GAC) FILTER ON THE MICROBIAL QUALITY OF WATER

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**Abstract:** Water is a component of the environment, that its quality is influenced by the health of environment. On the other side, improving environmental health is also directly related to the quality and quantity of water. A healthy water resource must be able to supply safe and sufficient water for the society. For this purpose, the resources have to be under monitoring and control of health responsible regularly; so that by being aware of the presence of any potential contaminants in water, control measures should be applied. Provision of safe water and proper management of wastewaters play the major role in reducing water-related infectious diseases. A set of measures on improving the environment and the health, safe and adequate water supply can reduce 40 to 100% of water related communicable diseases. In this study, the effect of active carbon, as an actual absorbent, on the elimination of turbidity, color, taste and smell has been investigated in order to improve the quality of drinking water. The results of the study indicated that active carbon, as a strong absorbent with high porosities and broad lateral surface is effective to eliminate turbidity, color, and smell.

**Keyword:** Water, Activated carbon, Microbial Quality, Drinking Water Treatment, Adsorption processes

## 1 INTRODUCTION

Water is a component of the environment, that its quality is influenced by the health of environment. On the other side, improving environmental health is also directly related to the quality and quantity of water. A healthy water resource must be able to supply safe and sufficient water for the society. For this purpose, the resources have to be under monitoring and control of health responsible regularly; so that by being aware of the presence of any potential contaminants in water, control measures should be applied. Provision of safe water and proper management of wastewaters play the major role in reducing water-related infectious diseases. A set of measures on improving the environment and the health, safe and adequate water supply can reduce 40 to 100% of water related communicable diseases. Seemingly healthy and clear water may contain a variety of pathogenic live microorganisms and therefore we must ensure the health of water before drinking (Crittenden, Weber 1978).

Water treatment is needed to produce drinking water from sources contaminated with pathogenic micro-organisms, anthropogenic chemicals and/or containing an elevated concentration of natural organic matter (NOM) and/or inorganic compounds impacting drinking water quality, both from a public health point of view and/or its aesthetic appreciation, e.g. color, taste, odor and turbidity (Clifford 1983).

Supplying healthy and sufficient water in war zones and emergency situations is also very important; in this regard, proper selection of water resources and making necessary plans to protect water resources and distribution network as well as conducting refinery ways and disinfection methods on water as required process of refinement are among the measures of effective prevention of transferring diseases related to the water and providing the conditions for eliminating possible pathogenic factors (Femogarcia, Utrina 1988).

GAC is typically used in a water treatment plant after the coagulation and sedimentation processes and, commonly, following preliminary disinfection steps during which chemical reactions can occur. Moreover, water is often disinfected before it passes through the GAC adsorbers in order to prevent nuisance biological growths. In many instances, the activated carbon functions as a granular filter medium for removing particulates, although in a few cases in the United States and in most instances in Europe the GAC adsorbers are preceded by filters for particulate removal. Water is usually passed downward through packed beds of GAC. Regeneration of GAC is not generally practiced at water plants in the United States as it is in Europe. If the objective of GAC use is to include the removal of organic compounds in addition to those that cause taste and odor, regeneration is likely to become more common in the United States. The type of contactor selected for the GAC will be influenced by the frequency of regeneration. After treatment of a water supply with GAC, post disinfection is generally used to reduce the total number of bacteria, some of which may be present because of the microbial growths in adsorbers. Sufficient disinfectant is usually applied to ensure a residual in the distribution system to prevent contamination of the water (Hassler 1963).

### 1.1 Problem Statement

Reference to water treatment methods in medical documents of the past times is indicative of the fact that there is a direct relationship between cleanliness of water and human health. Hippocrates who is considered as the father of medical science says: the person who intends to competently investigate and search in medicine must consider the water consumed by residents of an area since water is of high importance in humans' health. Historical resources and images obtained show that since 2000 B.C. water treatment for drinking has been common (Hutton, Cheremision1978).

GAC filtration is applied in water treatment in the world for the removal of organic micro pollutants and for the reduction of color, and in combination with advanced oxidation for the improvement of the biological stability of finished water. The efficiency of GAC filtration is limited, and GAC regeneration is needed when breakthrough of a target compound is reached22 Microbial activity in GAC filters in drinking water treatment [7]. Thermal regeneration of GAC is expensive, and the costs of the annual regeneration of GAC at location Weesperkarspel of Amsterdam Water Supply comprise 46% of the total operational costs for GAC filtration, and 15% of the drinking water production costs (Mckinny, Roos 2004).

After several decades of research, the relationship between microbial activity in GACFs and the surface characteristics of GAC is still not elucidated. A research project was defined aiming at collecting such knowledge in a series of investigations including observations in full-scale treatment plants, laboratory experiments, and pilot plant studies. For this purpose, both adsorption processes (R. van der Aa, TU Delft) and microbiological processes were studied. The investigations described in this thesis aim at analyzing the microbiological processes occurring in GACFs used in water treatment. In particular the contribution of bacteria to the removal of organic compounds is studied. To elucidate the contribution of the bacterial activity to the effects of GAC filtration on the removal of NOM from the water the study focused on the quantification and the characterization of the bacterial community in GACFs (Nawwar 1989).

The following goals of this investigation have been defined:

1. Development and evaluation of a method for measuring the concentration of active microorganisms in GAC filter beds;
2. Characterization of the bacterial activity in GACFs, which includes:
    a. Isolation and identification of predominating bacterial species;
    b. Elucidation of physiological properties of the predominant species

3. Analysis of the interactions between process conditions and the microbiological processes during GAC filtration.

### 1.2 Characteristics of Activated Carbon

The ability of activated carbon to remove organic compounds from water is based on the properties of this material. These properties include: (i) a high specific surface area and (ii) specific chemical surface characteristics including hydrophobicity and presence of functional groups.

The specific surface area varies between 400 and 1500 m2 g-1 and is a result of the high porosity of GAC. The shape, size, volume and surface area of the pores and their spatial distribution within the carbon particle characterize the porosity of GAC (Sarai, 2006).

### 1.3 Adsorption

Adsorption is a process in which a molecule (adsorbate) from the liquid or gas phase is bound to the surface of a solid phase (adsorber) that is in contact with the liquid or gas. In case of *physical adsorption* van der Waal's and electrostatic interactions are responsible for the partitioning of the adsorbate between two phases. Non-polar compounds or hydrophobic parts of complex molecules are attracted to the lipophilic surface of GAC and regions of molecules with electrostatic charge are attracted to surface oxides with the opposite charge. Although physical adsorption is generally considered a reversible process, desorption of complex molecules is unlikely to occur due to the multiple binding by different mechanisms (Simsek 1970).

### 1.4 Powder of Activated Carbon (PAC)

Manufactured by direct activation, powdered activated carbons have been specifically developed for the removal of a broad range of organic contaminants from potable, waste and process waters. Powdered activated carbon (PAC) has a relatively smaller particle size when compared to granular activated carbons and consequently, presents a large surface to volume ratio.

As such, PAC is not commonly used in a dedicated adsorber vessel, due to the high head loss that would occur. Instead, PAC is generally added directly to other process units, such as raw water intakes, rapid mix basins, clarifiers, and gravity filters.

PAC is made from organic materials with high carbon contents such as wood, lignite and coal. PAC typically has a diameter less than 0.1 mm and an apparent density ranging between 23 and 46 lb/ft3, depending on the material used and manufacturing process. Iodine and molasses numbers are typically used to characterize PAC. These numbers describe the quantity of small and large pore volumes in a sample of PAC. A minimum iodine number of 500 is specified for PAC by AWWA standards.

PAC is used by water treatment plants on either a full time basis or as needed for taste and odor control or removal of organic chemicals. PAC is can be fed as a powder using dry feed equipment or as a slurry using metering pumps. PAC can also be mixed with water and fed as a slurry. Slurry systems are normally used when PAC is frequently added and the required dosages are high. Slurry systems usually include a storage tank, day tank, and a chemical feeder (either a diaphragm pumps or rotary feeders) (Smethurst 1979).

### 1.5 Removal of Pesticides

Treatment with the activated carbon is the only treatment method effective for removal of pesticides such as aterazin and other artificial organic chemical compounds of water and based on the view of EPA, GAC is the best technology available for removal of fugitive and artificial organic materials from water. Using the 12-18 mg/l dose, the amount of atrazin can be reduced from 8-9 ppb (g/lm) to the amount of 3 ppb (MCL or maximum level of aterazin concentration)

### 1.6 Factors that Affect the Performance of Activated Carbon

#### 1.6.1 Molecular Weight

As the molecular weight increases, the activated carbon adsorbs more effectively because the molecules are lea soluble in water. However, the pore structure of the carbon must be large enough to allow the molecules to migrate within. A mixture of high and low molecular weight molecules should be designed for the removal of the more difficult species.

#### 1.6.2 pH

Most organics are less soluble and more readily adsorbed at a lower PH. As the pH increases, removal decreases. A rule of thumb is to increase the size of the carbon bed by twenty percent for every pH unit above neutral (7.0).

Contaminant concentration: The higher the contaminant concentration, the greater the removal capacity of activated carbon. The contaminant molecule is more likely to diffuse into a pore and become adsorbed. As concentrations increase, however, so do effluent leakages. The upper limit for contaminants is a few hundred parts per million. Higher contaminant concentration may require more contact time with the activated carbon. Also, the removal of organics is enhanced by the presence of hardness in the water, so whenever possible, place activated carbon units upstream of the ion removal units.

#### 1.6.3 Particle Size

Activated carbon is commonly available in 8 by 30 mesh (largest), 12 by 40 mesh (most common), and 20 by 50 mesh (finest). The finer mesh gives the best contact and better removal, but at the expense of higher pressure drop. A rule of thumb here is that the 8 by 30 mesh gives two to three times better removal than the 12 by 40, and 10 to 20 times better kinetic removal than the 8 by 30 mesh.

#### 1.6.4 Flow Rate

Generally, the lower the flow rate, the more time the contaminant will have to diffuse into a pore and be adsorbed. Adsorption by activated carbon is almost always improved by a longer contact time. Again, in general terms, a carbon bed of 20 by 50 mesh can be run at twice the flow rate of a bed of 12 by 40 mesh, and a carbon bed of 12 by 40 mesh can be run at twice the flow rate of a bed of 8 by 30 mesh.

#### 1.6.5 Temperature

Higher water temperatures decrease the solution viscosity and can increase die diffusion rate, thereby increasing adsorption. Higher temperatures can also disrupt the adsorptive bond and slightly decrease adsorption. It depends on the organic compound being removed, but generally, lower temperatures seem to favor adsorption (Snoeyink 1987 ).

## 2 2. MATERIALS AND METHODS

### 2.1 Method Development

Method development was conducted in four phases: (i), determination of the effects of ultrasound on the ATP concentration and cultivability with selected pure cultures of aquatic bacteria (Spirillum sp., strain NOX and Pseudomonas fluorescens, strain P17) and suspensions of mixed bacterial communities detached from GAC samples. The suspensions were treated (10 times) with ultrasound and after each treatment ATP and cultivability were determined. Untreated suspensions served as a control; (ii), determination of the effect of the adsorptive properties of GAC and the release of fines on the concentration of free ATP. Free ATP was added to a suspension of virgin GAC or GAC with developed biomass and incubated for two hours. A solution of free ATP in autoclaved tap water was used as control (iii), testing of the efficiency of the sonication treatment to remove attached bacteria with bacterial biofilms on plasticized polyvinylchloride (PVCp), GAC and sand. The materials were subsequently treated up to 20 times with ultrasound at different

power inputs and after each treatment biomass removal was measured as the ATP concentration. The ATP yield was plotted against the number of treatments; (iv), from the results of these experiments an optimal method for the removal and measurement of active biomass was defined and applied to a series of samples from different filter beds.

### 2.2 Samples from Filter Beds

Samples of GAC, sand and anthracite were obtained from nine water treatment plants in The Netherlands. Filter material (10-100 g) was collected from below the filter bed surface (2-10 cm) with a properly cleaned multisampler (Eijkelkamp) and stored in 100 cm3 screw-capped borosilicate flasks in the filtrate of the sampled unit at 4°C for a maximum period of 36 hours before the analysis. The specific density of the filter material was calculated from the weight of 50 cm3 of GAC, sand or anthracite that had been dried for four hours at 105° C. The volume is determined with a measuring cylinder (100 cm3).

### 2.3 Calculation of External Surface of GAC

Data for the external surface of the GAC particles assuming spherical shapes were derived from the literature 1The estimation of the surface of the pores with a diameter > 1 µm is based on data provided by the manufacturer about GAC porosity as based on penetration of butan at increasing pressure and the assumption that pores had a cylindrical shape.

### 2.4 Test Strains, Mixed GAC Community, and Stationary Bioflm

Spirillum sp. strain NOX and Pseudomonas fluorescens strain P17 were obtained from the stationary growth phase of AOC tests in treated water as described earlier (Snoeyink 1987).

A mixed microbial community as present on GAC was obtained with a two minutes low energy Optimisation and significance of ATP analysis 35 sonication (LES) treatment of a GAC sample (2 g wet weight) in 50 cm3 autoclaved tap water. Subsequently, the suspended bacteria were separated from the GAC particles and kept in autoclaved tap water for 4 hours at 20°C to allow adaptation to the new environment. A biofilm was grown on pieces (20 cm2) of plasticized PVC (PVC-P) incubated for 10 days at 15 °C in 600 cm3 of tap water inoculated with 1 cm3 of filtered river water (1.2 µm membrane filter) and enriched with nitrogen and phosphorus to prevent growth limitation (Sontheimer, Crittenden 1988).

### 2.5 Ultrasonic Treatment

A total of two to five gram of wet filter material was added to 50 cm3 of autoclaved tap water (pH 8.4±0.2) in a 100 cm3 screw-capped borosilicate flask. Sonication was applied for two minutes. A volume of five cm3 of the obtained suspension was collected and kept on ice for examination. The surplus liquid was decanted, 50 cm3 autoclaved tap water was added and sonication was repeated. This procedure was repeated several times depending on the objective of the experiment. Low-energy sonication (LES) was applied with a Branson sonication unit 5050 at a constant frequency of 43 kHz and 180 W power output. Samples contained in 50 cm3 of autoclaved tap water were placed in the sonication chamber with 10 L of demineralised water. High-energy sonication (HES) was applied with a Sonifier II W-250 at a constant frequency of 20 kHz and an adjustable power output. Ultrasound was applied to the sample via a titanium microtip (D = 5 mm), with power inputs ranging from 10 to 40 W.

### 2.6 ATP Measurement

The measurement of ATP is based on the production of light in the luciferine-luciferase assay. ATP was released from suspended cells with nucleotide-releasing buffer (NRB, Celsis). The intensity of the emitted light was measured in a luminometer (Celsis AdvanceTM) calibrated with solutions of free ATP (Celsis) in autoclaved tap water following the procedure as given by the manufacturer. The detection limit was 1 ng ATP L-1 of sample. Standard additions of free ATP dissolved in autoclaved tap water were used for recovery experiments. The influence of the adsorptive properties of GAC on the ATP measurement was tested by addition of free ATP to suspensions of virgin and preloaded GAC in autoclaved tap water (0.04 - 0.1 g GAC cm-3, dry weight). The concentrations of added ATP were of 2, 100, 600 and 3000 ng L-1 respectively.

Autoclaved tap water with similar concentrations of free ATP was used as control. Recovery of added ATP was calculated from the measured ATP concentrations in the controls and in samples, which were corrected for the concentration of autochthonous ATP.

### 2.7 Total Direct Cell Count (TDC)

A defined volume of the microbial suspension as obtained by sonication of GAC samples was filtered through a 0.22 µm polycarbonate filter, stained with acridine orange as described by36 Microbial activity in GAC filters in drinking water treatment [15] and observed with epifluorescence microscopy.

### 2.8 Heterotrophic Plate Counts (HPC)

Volumes of 0.05 cm3 of appropriate decimal dilutions of microbial suspensions obtained by sonication of GAC, sand or anthracite in autoclaved tap water were spread in triplicate over the surface of R2A agar (Oxoid Ltd.) plates, which were incubated during 10 days at 25° C.

### 2.9 Statistical Analysis

The statistical significance of the effects of ultrasonic treatment on microbial ATP and cultivability was determined by a t-test after correction of the data for the values measured in the controls.

## 3 3. RESULTS AND DISCUSSION

### 3.1 Interaction Between Microbial Activity and Adsorption

**Biodegradability of Organic Compounds**

For the purposes of discussing the interactions between biological and physicochemical processes occurring on the GAC surface, it is convenient to divide organics into the following four categories:

1. nonadsorbable, nonbiodegradable
2. nonadsorbable, biodegradable
3. adsorbable, nonbiodegradable
4. adsorbable, biodegradable

While simple, this classification scheme is ambiguous because the term nonbiodegradable is not easily defined. Instead, Alexander has adopted the adjective recalcitrant to describe substances that persist for extended periods under all environmental conditions thus far tested. Recalcitrant organics include those that are degraded slowly or not at all in nature. Occasionally, some organics that are usually biodegradable are recalcitrant due to specific environmental causes. Alexander outlined the conditions required for biodegradation and listed 15 possible mechanisms to explain recalcitrance. While some of these may be overcome by the environment in a GAC bed, others, such as accessibility of substrate and low concentration of substrate, may not. Attempts have been made to relate biodegradability to chemical structure. However, general rules are difficult to propose. Of all of the organic chemicals that are potentially harmful to health, only benzene was included in an extensive review of biodegradability studies made by Ludzack and Ettinger, who concluded that benzene was resistant to biodegradation. Helfgott et al. (1977) prepared a relative index for organics that are tested. Included were some organics with potential health effects, i.e., benzene, chloroform, DDT, and vinyl chloride. They considered all four compounds to be resistant to biodegradation, but benzene has subsequently been shown to be biodegradable (Weber 1970).

Pitter evaluated 123 organics in the aliphatic, cycloaliphatic, and aromatic classes. Of these, 21 organics were described as "biologically hard to decompose," and all were in the aromatic class. Included among these organics were dinitrobenzene's and phenols, phenyldiamines, trichlorophenol, nitroanilines, and naphthylamines. In all of the studies that were found in the literature, the experimental conditions were not those to be expected in treatment of drinking water. Most important, the concentrations of organics were in

milligrams per liter rather than in micrograms per liter, and the concentrations of biomass were more consistent with biological waste treatment. The organics that are most likely to be attacked microbially fall in the nonadsorbable, biodegradable category. In treatment with GAC, these organics could be removed by the biofilm surrounding the carbon granules without affecting the adsorption process. The absorbable, biodegradable category of organics is of more interest because of the strong interaction expected between biological and adsorption processes. This sets GAC apart from sand or other inert media. Various researchers describe the removal mechanism as biodegradation in the biofilm, followed by adsorption of remaining substrate in the internal pore structure. Ying and Weber have adopted the term bio sorption to describe this process. The resulting mathematical model, which has been applied to concentrations of organics as high as those found in wastewater, indicates that adsorption is responsible for removal of biodegradable organics during the initial period of GAC operation. Later, the biofilm develops enough so that biodegradation predominates. This provides for continued, steady-state removals and can explain extended bed life, particularly in wastewater treatment applications of GAC.

In water treatment, the removal of adsorbable, biodegradable organics by microbial activity, rather than by adsorption, enhances the opportunity for the GAC bed to remove the adsorbable, nonbiodegradable organics. This latter category is generally of more concern because it contains many of the synthetic organics that may be suspected carcinogens.

### 3.2 Microbial Activity on GAC in Wastewater Treatment

From pilot plant studies at Pomona, California, determined that adsorption capacity could not be completely exhausted even after very long service times. More detailed investigations of microbial degradation on GAC were provided by Weber et al. (1970, 1972) in other pilot plant studies that addressed the benefits of microbial activity more directly. Comparison studies of GAC and nonsorptive, bituminous coal clearly showed that more TOC removal and microbial growth occurred on GAC. This suggested that microbial activity was in some way interrelated with the adsorption process. Proposed that the rate of microbial activity in a GAC bed should be even higher than that in a conventional biological treatment process because the substrate adsorbed on the activated carbon is much higher than in the liquid (Weber 1970).

## 4 CONCLUSIONS AND RECOMMENDATIONS

1. No direct evidence has been given for removal of specific organics of potential harm to health by microbial activity. Only one study implied that precursors to THM formation were removed by microbial action. An indirect benefit of microbial activity may be the lengthening of GAC service time by removing organics that would otherwise occupy adsorption sites; but this in itself does not imply more effective removal of organics of health concern.
2. While operation of GAC beds for 6 months to 2 yr without regeneration has shown that microbial activity removes organics, as measured by group parameters such as TOC, potassium permanganate demand, COD, and UV absorbance, the efficiency of biodegradation is less than that of adsorption, i.e., biodegradation to remove approximately 1.5 mg/liter TOC requires about 30 min of GAC contact (Benedek, 1977; Eberhardt et al., 1974; Jekel, 1977), while adsorption only requires approximately 10 to 15 min.
3. Pilot and full-scale tests of preozonization have shown that organics are efficiently removed through the total system, including the flocculation and adsorption steps; however, the ability of microbial action to aid in removal of specific organics of potential harm to health has not been reported. Thus far, one study, at the EPA Cincinnati pilot plant (U.S. Environmental Protection Agency, 1978c), implied that precursors to THM formation were somehow altered by ozonization in such a manner that their removal was made more effective.
4. The role of ozone in promoting microbial activity remains unclear. Conversion of organics to more biodegradable forms and addition of oxygen to the biofilm are two possibilities. On the negative side, evidence shows that ozone may decrease the adsorbability of some organics.

5. While prechlorination does not stop microbial growth on GAC, there is some evidence to suggest that it results in formation of organics that are much more resistant to biodegradation on the GAC surface.
6. The bacteria that have been reported to grow on GAC beds are considered nonpathogenic. Increases in bacteria in the effluent may be controlled by backwashing.
7. Microorganisms can generate a variety of highly potent, low-molecular-weight toxicants in culture. Studies of models of several environments and some natural systems indicate that toxicants may be, or are indeed, formed. Such products may also be produced on GAC. However, there is a lack of information regarding the identification of organics in the effluent of GAC beds. Thus, while no evidence exists, the possibility that microbial end products of concern enter the finished water cannot be ruled out.
8. The endotoxin content of water that has been filtered through GAC is either not increased or not significantly increased. The measured levels are very low and should pose no risk.

Thus far, evidence of microbial activity in GAC beds has largely been indirect. Of special importance is the identification of organics that are biodegraded. If these are not potentially harmful to health, then more investigation is needed to determine whether microbial action has actually extended or improved the adsorption of other organics that are potentially harmful to health. This may result if fewer of the internal adsorption sites are occupied because of biodegradation at the surface. Related to this concern about extended removal of organics is the unresolved question of bioregeneration. More careful investigation is needed to determine if adsorbed organics, which are more resistant to biodegradation, can be acted upon by microbes. The role of ozonization in promoting microbial action needs much further elucidation. This would involve studies to determine the changes in biodegradability and adsorbability that are brought about by ozonization of specific organics that could affect public health. There are similar concerns regarding the practice of prechlorination. If the use of GAC is to become widespread, research is necessary to identify the factors that are responsible for the initiation of microbial growth on the GAC surface and the microbiological generation of organic compounds on the carbon. Attention should be given not only to the compounds that are present and retained in the bed, but also to those that are released and could appear in the effluent. Research should be directed toward compounds generated from innocuous, natural precursors, as well as toward those that may be formed as a result of microbial action on synthetic industrial waste, agricultural pesticides, household effluents, and compounds that are formed as a result of chlorination of water. The investigations should identify the specific organic molecules thus formed and not simply the quantity of organic carbon that is emitted from GAC.

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