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Project Summary

Granular Activated Carbon for Removing Nontrihalomethane Organics from Drinking Water

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A summary is presented of the various aspects of using granular activated carbon (GAC) to adsorb organics other than trihalomethanes from drinking water using surface water sources. Areas of research considered were GAC performance (service life, water quality, and reactivation), microbiological concerns, cost of GAC treatment, and GAC adsorption capacity.

Several large, field-scale research projects were undertaken to evaluate the performance of GAC under varying operating conditions and with different source waters. Most of this GAC research effort has been completed at nine locations (Cincinnati, OH; Manchester, NH; Jefferson Parish, LA; Evansville, IN; Miami, FL; Huntington, WV; Beaver Falls, PA; Passaic, NJ; and Thornton, CO).

Various carbons produced for organics removal were evaluated at the nine locations. From these nine locations, more than 150 organics were detected. In addition to these specific organics, surrogate parameters such as total organic carbon (TOC) and total organic halide (TOX) were used in many cases to determine GAC performance. Most of these compounds were removed by GAC. Low molecular weight compounds such as 1,2-dichloroethane were continuously removed for periods up to 100 days. Higher molecular weight compounds such as the chlorinated herbicide atrazine were removed through 180 days of operation.

Both the post-sand filter adsorber and the sand replacement adsorber were evaluated. The performances of these two systems were found to be comparable. Also, pilot systems at these sites generally predicted the performance of their full-scale counterparts.

After exhaustion, GAC was reactivated onsite at three locations and offsite at one location. Reactivation systems included a fluidized bed furnace and a infrared furnace. Several properties were evaluated to ensure that proper reactivation had occurred.

Actual cost data associated with the construction and operation of full scale research facilities were summarized. In addition, cost estimates for various GAC treatment scenarios were developed to examine the effect of economies of scale and cost tradeoffs between alternative GAC treatment systems.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Granular activated carbon has long been considered a broad-spectrum adsorbent and has been used for many years to remove tastes and odors from drinking water. In the past 10 years, however, some utilities have seriously considered the use of GAC for removing trace organics from their drinking water. With more sophisticated, affordable instrumentation rapidly becoming

available to utilities, more organics are being detected at trace concentrations. Utility managers as well as the general public are becoming more concerned about the health effects of ingesting these trace concentrations of various organics over many years.

GAC was investigated under actual operating conditions to provide adsorption efficiency data that considered the mix of compounds in drinking water sources and the competition for available adsorption sites. Sampling schemes were developed, and analytical methods were used to detect various organics, surrogates for organics, microbiological contaminants, and general operating parameters. Several thousand pieces of data have been generated from this effort and stored in the U.S. Environmental Protection Agency North Carolina Computing Center at Research Triangle Park, North Carolina. These data were used to evaluate the following items:

1. removal or reduction of specific organics and their surrogates by GAC,
2. the positive and negative aspects of GAC reactivation, and
3. the microbiological effects of GAC use and control measures required.

The general characteristics of the following items were also summarized from the research projects and developed from various treatment scenarios:

1. GAC adsorption costs for steel-pressure and concrete gravity contactors,
2. onsite reactivation using fluid bed, infrared, and multihearth furnaces,
3. offsite reactivation costs,
4. behavior of GAC treatment costs with variations in system size, and
5. the cost relationships associated with several GAC treatment alternatives.

Presented here is a summary of the various aspects to consider when using GAC to adsorb organics from drinking water using surface water sources.

GAC Performance

Service Life

Various GACs produced for organics removal were evaluated. Generally, the coal-based GACs resulted in the best removals over the longest time period. Of the carbons evaluated, one coal-based GAC appeared to be the best choice for removal of low-molecular-weight volatile organics such as 1,2-dichlorothane. The higher-molecular-weight organics appeared to be equally well removed by all of the coal-based GACs evaluated.

With steady-state total organic carbon (TOC) as an evaluation criterion, 3 months would generally be expected to be the service life of GAC before replacement or reactivation. Deviations from this norm occurred in both directions, with service lives lasting both more and less than 3 months. High TOC/organic precursor waters can generally expect shorter GAC service times before exhaustion, whereas other water sources have experienced more than 3 months of GAC operation before exhaustion.

Water Quality

Direct GAC adsorption after coagulation and settling appeared to produce water quality that was comparable with that from post-sand filtration and GAC adsorption with the same empty bed contact time (EBCT). Water utilities without the capital or available land can replace their sand with GAC and effectively remove turbidity and organics if sufficient EBCT is available. However, if a utility has a choice of GAC filtration/adsorption or post-sand filtration and GAC adsorption, the latter is recommended. Sand filtration provides another barrier for certain microbial contaminants. Turbidity accumulation on the GAC will also require more frequent backwashing if prior sand filtration is not used.

Both GAC pilot columns and pilot plants were used to predict the performance of a full-scale system. EBCT is important for efficient GAC operation, but longer times are not necessarily cost-effective. An optimum EBCT exists for each situation after which a diminishing return can be expected. From the sites evaluated, 15- to 25-minute EBCTs were generally optimum, based on a steady-state TOC removal.

Reactivation

GAC was effectively reactivated. Performance of subsequently reactivated GAC was comparable if not better than virgin GAC. Thermal reactivations did produce volume losses ranging from 5 to 12 percent, depending on the furnace type. Within the 45.4-kg (100-lb)/hr infrared furnace, approximately 5-percent losses can be expected. Ten to 12 percent losses can be expected from the 227-kg (500-lb)/hr fluidized-bed furnace An additional 3-percent loss can also be expected for carbon transport, regardless of furnace type.

Concern always exists that organics in water adsorbed on GAC will be transferred to the air during reactivation. The intent during GAC reactivation was to incinerate the adsorbate, but some organics were detected in the stack gases. The detected organics of major concern were tetrachlorodibenzo-p-dioxin (TCDD) and tetrachlorodibenzo furan (TCDF). Average total concentrations of both chemicals were in the low ppt range (0.14 ppt TCDD and 0.25 ppt TCDF). A major portion (0.13 ppt TCDD and 0.21 ppt TCDF) of the levels found were attached to the particulates in the stack gas. When a dispersion model was applied to the stack discharge, no health hazard was indicated. Dryer off-gas carbon fines contained higher average concentrations than the stack gases (2.2 ppb total TCDD and 1.7 ppb total TCDF). Disposal of these fines is a concern.

The TCDDs and TCDFs appear to be produced during reactivation from precursor compounds, since no detectable concentrations were found in the spent carbon fed to the furnace. Some of these precursors are suspected of being formed during chlorination, and others may be in the natural gas used to fire the furnace. Future research is planned to investigate systems that do not chlorinate water before GAC adsorption and thermal destruction of TCDDs and TCDFs in a furnace afterburner.

Microbiological Concerns

Start-up operations using GAC in several pilot plant and full-scale processes revealed a surprising problem with initial coliform and heterotrophic bacterial contamination. The origin of this contamination may have been the filter basin (which was converted from sand filtration operation), the GAC supplied by the manufacturer, or the water slurry movement of GAC into the filter compartment.

In the first 2 months of operation, influent quality for new GAC beds showed no detectable total coliforms in 100-ml samples containing 1.0 to 2.0 mg/L of free chlorine residual. Filter effluent from each of three different GAC materials contained 46 to 85 total coliforms/100 ml during the first week of operation. The total coliform densities peaked in about 3 weeks and then declined below detectable levels by

week 11 to 14. The heterotrophic bacterial population rose to density levels of 10^4/ml within 4 to 7 weeks and declined below 10^2/ml by the 11th week.

Reactivation of GAC may cause some particle size reduction and change in surface characteristics, but they appear to have little effect on the ability of heterotrophic bacteria to find sites for attachment and colonization. A field study of a full-scale operation using GAC filters showed identical microbial activity on virgin GAC and the same GAC material after reactivation.

The higher velocity of process water passing through pressure contactors or adsorbers does minimize the continued presence of high densities of heterotrophic bacteria in the GAC effluent after these systems are stabilized. Total coliform regrowth also appears to be minimized in these closed devices. Filter adsorbers are affected by floc or silt that coats the carbon particles. This condition contributes to shorter service life for the GAC and to potential colonization by coliforms and their subsequent release into the GAC process effluent. One pilot study with connecting contactors in series indicated that coliform passage from one contactor to another can occur, with releases in the final effluent. However, colonization was not permanently established in any of the four contactors in series.

The effects that GAC treatment has on distribution water quality are largely unknown from field operations. Provided the GAC is replaced or reactivated frequently, the theoretical long-term benefit would be to improve the microbial quality of water in distribution and thereby reduce available nutrients (organics) to support bacterial regrowth in the pipe sediments and tubercles. However, investigation of bacterial quality in a water system using GAC treatment did on one occasion reveal evidence of a protected pathway for coliform passage from carbon effluent, through final disinfection, and out into the distribution system. These coliform occurrences were based on three replicate examinations of 1-liter samples. They illustrate how very low densities of coliforms go undetected when only 100-ml sample volumes are analyzed.

Cost of GAC Treatment

Concrete gravity GAC contactor systems appear to exhibit lower water production costs than steel-pressure GAC contactor systems, given the same water treatment goal. The concrete systems have greater economy of scale since they use a few large contactors as opposed to many small steel contactors.

Research conducted at the Cincinnati Water Works indicates, however, that a full-scale, deep-bed, steel-pressure GAC contactor system is more economical than a conventional-depth, sand-replacement GAC filter adsorber system, given the same water treatment goal. The filter adsorber system with a shorter EBCT would require more frequent reactivation and incur significantly higher costs.

Infrared reactivation is more economical than fluid bed and multi-hearth reactivation for small quantities of carbon. However, for quantities greater than about 908,000-kg (2 million lb)/yr, fluid bed reactivation is the most cost-effective alternative evaluated. Onsite reactivation is more economical than replacement of spent carbon with virgin GAC for amounts of carbon as small as 136,200-kg (300,000-lb)/yr using a 22.7-kg (50-lb)/hr infrared furnace. For larger quantities of carbon, onsite reactivation becomes increasingly more cost effective. If the amounts of carbon are too small for economical onsite reactivation, off-site regional reactivation may be a cost-effective alternative for replacing spent carbon with virgin GAC. Process costs for GAC adsorption and reactivation can exhibit significant economies of scale. Total water production unit costs (adsorption plus reactivation) for 113,555-m^3/day (3-mgd) and 662,375-m^3/day (175-mgd) plants ranged, respectively, from about 13.2 ¢ to 6.1 ¢/m^3 (50¢ to 23¢/1000 gal) for steel-pressure contactor systems and from about 10.8¢ to 4.5¢/m^3 (41¢ to 17¢/1000 gal) for the concrete gravity contactor systems.

GAC Adsorption Capacity Model

The adsorption capacity characteristics of three full scale GAC systems (Evansville, IN; Manchester, NH; and Cincinnati, OH) were modeled over 3 to 4 months of operation. The GAC systems were reactivated several times so that capacity renewal or reduction could be investigated in addition to variation in carbon type and physical properties. The total GAC loading was calculated over time, and a model function was subsequently fit to the loading curves by a nonlinear, least squares regression procedure for each operation phase of a particular GAC system. The model function is in the following form:

$$Y(t) = \frac{c}{1 + Ke^{-Rt}}$$

where:

- $Y(t)$ = mg of solute adsorbed/kg carbon
- t = run time in days
- c = limiting value for GAC capacity (mg solute adsorbed/kg GAC per day)
- K,R = calculated values

Reasonably accurate estimates of TOC loading capacity can be made in a full-scale GAC system given iodine number, molasses number, rate of TOC applied, EBCT, mesh size, mean particle diameter, and bed depth for a particular GAC sample and contactor system. The modeling procedure requires a straightforward calculation of the GAC loading based on TOC influent and effluent concentrations, total mass and volume of carbon, and flow data in conjunction with regression-derived values of the three parameters K, C, and R. The overall accuracy of the model equations will no doubt improve as more physiochemical GAC data are collected to increase the total number of model study cases.

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The complete report, entitled "Granular Activated Carbon for Removing Nontrihalomethane Organics from Drinking Water," (Order No. PB 85-120 970; Cost: $22.00, subject to change) will be available only from:

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