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Project Summary

Granular Activated Carbon Adsorption With On-Site Infrared Furnace Reactivation

Wayne E. Koffskey and Benjamin W. Lykins, Jr.

The costs associated with the design, construction, operation, and maintenance of a 3 million gallons per day (mgd) post-treatment granular activated carbon (GAC) adsorption and reactivation system were evaluated over a 2.4 yr operational period. The adsorption system consisted of three 1-mgd GAC pressure contactors designed with a nozzled plenum plate underdrain, each containing 1,857 ft^3 of granular activated carbon. The reactivation system was comprised of a microprocessor-controlled Shirco infrared reactivation furnace, three GAC storage tanks, and a water slurry GAC transport system. The overall design and construction costs were $2.25 million while operation and maintenance costs,excluding amortized capital costs, were determined to be 20 cents/lb of reactivated GAC or 14 cents/ 1,000 gal of treated water.

The use-related GAC morphological changes, GAC adsorption performance, and GAC loss were evaluated for four GAC lots over 4 to 5 reactivation cycles. While some variability in GAC morphology was indicated, the GAC organics loading data, obtained for various GAC lots over successive reactivation cycles, indicated that the adsorption performance of the reactivated GAC was equal to or greater than that of virgin GAC for all parameters monitored. The GAC loss observed during reactivation averaged 8.6% and was comprised of 7.1% reactivation loss and 1.5% transport loss.

The effluent streams of the infrared reactivation furnace were examined for the presence of polychlorinated dibenzodioxins and polychlorinated dibenzofurans. While trace levels of some of these substances were observed, a risk assessment indicated a maximum lifetime risk of three in 1 billion for the existing facility.

Another objective of this research effort was to obtain bacteriological information at the surface of the GAC within the adsorption system and in the effluent of the adsorption system. The GAC filter effluent contained a mean heterotrophic plate count (HPC) of 3,137 colony forming units (CFU)/mL, which was comprised of approximately 50% *Pseudomonas* and 25% gram positive bacteria. While the HPC on the GAC surface was considerably higher with a geometric mean of 3.5 x 10^6 CFU/mL, similar bacterial species were observed.

This Project Summary was developed by EPA's Risk Reduction Engineering 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

The Mississippi River along with its tributaries drains nearly two-thirds of the continental United States and is used as a drinking water source by many of the cities located along its banks. The waters of the Mississippi River and its tributaries also serve as the receivers of vast quantities of industrial and municipal wastes as well as agricultural run-off, resulting in the occurrence of trace levels of synthetic organic chemicals in this drinking water source. Of equal or sometimes greater concern are those naturally occurring substances that form halogenated by-products during the disinfection process.

Other water sources, besides the Mississippi, also contain many of these contaminants and several drinking water utilities are potentially facing the implementation of GAC adsorption technology to meet impending federal and state regulations. While previous studies have demonstrated the effectiveness of GAC adsorption for reducing the concentrations of organic contaminants in drinking water, only a few of these studies have evaluated the economics of full-scale GAC adsorption with on-site reactivation.

Therefore, objectives for this study were developed to fully document the use of GAC to treat a river water source. These objectives consisted of the following:

- To examine the use-related morphological changes in GAC resulting from reactivation.
- To determine the effects of several thermal reactivation cycles on GAC adsorption performance.
- To perform a material balance on GAC for several thermal reactivation cycles in order to determine the volume of GAC lost across the reactivation furnace and in the GAC transport system.
- To accumulate and evaluate cost information for the design, construction, operation, and maintenance of a full-scale GAC facility with on-site thermal reactivation.
- To determine the presence and significance of polychlorinated dibenzodioxins and polychlorinated dibenzofurans in the effluent streams of the infrared reactivation furnace.
- To obtain bacteriological information at the surface of the carbon within the GAC system and in the effluent water of the system.

Three 1-mgd GAC pressure filters and a 215 lb/hr infrared reactivation furnace were used during the operational period from March 1985 through February 1988. Morphological data and loading data for the various parameters of interest as well as bacteriological data were collected for virgin GAC through the fifth reactivation. Volumetric GAC losses as well as operational and maintenance costs were determined for five reactivations of four GAC lots totaling approximately 38,000 ft^3 (966,000 lb). Polychlorinated dibenzodioxins and polychlorinated dibenzofuran analyses were performed on the furnace effluent streams along with a risk assessment of the levels found.

Treatment Plant Configuration

Conventional Treatment

Mississippi River raw water is pumped to the East Jefferson Parish water treatment plant where fluosilicic acid (up to 4 mg/L) is added followed by powdered activated carbon (2 mg/L) and cationic polyelectrolyte polymers (up to 8 mg/L) prior to clarification. After clarification, ammonia gas is added to the process stream followed immediately by chlorine at a chlorine to ammonia ratio of 3:1 prior to sand filtration. After sand filtration (2 gpm/ft^2), zinc-sodiumhexametaphosphate (1 mg/L) was added. Prior to entering the distribution system, a portion of the finished water was diverted to the GAC adsorption and reactivation facility.

GAC Research Plant

Conventional treatment plant finished water was pumped into one of the three 1-mgd GAC contactors. Operation of the GAC contactors (20 min EBCT each) was scheduled so that reactivation of exhausted carbon could be done without interrupting GAC adsorption studies. Each of the GAC contactors was designed to withstand a differential pressure of 60 lb/in^2 (psi) with water flowing upward for backwashing and 70 psi in a downward direction. A beam supported underdrain contained 212 stainless steel filter nozzles for passage of the GAC effluent.

A slurry system was used to transport GAC. Four-inch pipe bent to a minimum radius of 2 ft was used for all transport lines except for those between the furnace quench tank and the reactivated GAC tank. These lines were constructed of 1.25-in. pipe to a radius of 1.5 ft.

Thermal reactivation of exhausted GAC by the Shirco infrared reactivation system consisted of three sequential steps: drying, volatilization and pyrolysis of adsorbed organics, and reactivation with flue gas and steam. Exhausted GAC was fed through a rotary valve into the furnace feedhopper and into the furnace by a dewatering screw. From the feed chute in the furnace, GAC was drawn off by a woven wirebelt and leveled to a depth of 0.75 in. Reactivation was accomplished by glowbars placed above the belt.

GAC Performance

Organic Chemicals

Organic chemical analyses performed during the study included: total organic carbon (TOC), total organic halide (TOX), volatile organics (VOA), capillary gas chromatography (CGC) of solvent extractables with electron capture and flame ionization detection, and gas chromatography/mass spectrometry (GC/MS) of both volatile organics and solvent extractables. Extensive data were collected from these analyses.

***Table 1.** Average GAC Performance For A Reactivation Cycle Of 3 Months*

Parameter	*Influent*	*Effluent*	*Percent Removal*
TOC, mg/L	*3.5*	*1.2*	*67*
TOX, µg/L	*114*	*9*	*92*
TOX-FP, µg/L*	*500*	*128*	*74*
TTHM, µg/L	*3.8*	*0.4*	*89*
TTHM-FP, µg/L*	*250*	*70*	*72*
TFIC+, µg/L	*3.6*	*1.2*	*67*
TECC#, µg/L	*0.6*	*0.1*	*89*
Total Alkylbenzenes, ng/L	*251*	*89*	*65*
Total Alkanes, ng/L	*144*	*109*	*24*
Total Phthalates, ng/L	*142*	*78*	*45*
Total PNAHs@, ng/L	*156*	*32*	*79*
Total Nitrobenzenes, ng/L	*59*	*13*	*78*
Total CHIs&, ng/L	*129*	*6*	*95*

** FP - formation potential*
+ TFIC - total flame ionization concentration
 # TECC - total electron capture concentration
@ PNAHs - polynuclear aromatic hydrocarbons
& CHIs - chlorinated hydrocarbon insecticides

Therefore, GAC performance for a reactivation cycle of 3 mo was selected as a typical example. This data as presented in Table 1 shows that GAC with a 3-mo reactivation cycle removed from 24% to 95%, by average, of the groups of compounds evaluated.

Bacteriological

Bacteriological parameters monitored included heterotrophic plate count (HPC), total coliforms, and speciation of gram negative bacteria from the HPC analyses. The geometric mean HPC of the influent water to the GAC facility was 19 CFU/mL with an observed maximum of 330 CFU/mL. The geometric mean increased to 3,137 CFU/mL in the effluent of the GAC facility with an observed maximum of 1.6 x 10^5 CFU/mL. This level of biological activity produced a dissolved oxygen reduction of 3.9 mg/L across the GAC contactors from an average influent level of 8.6 mg/L to an average effluent level of 4.7 mg/L.

Total coliforms were detected in the influent to the GAC facility in 7 samples with a maximum of 5 CFU/100 mL and a non-zero average of 2 CFU/100 mL. In the GAC effluent, total coliforms were observed in 21 samples with a non-zero average of 1 CFU/100 mL and a maximum of 7 CFU/100 mL. Disinfection of the GAC effluent reduced the HPC and coliforms to acceptable levels.

Of the 19 CFU/mL HPC present in the influent water, about 80% were gram positive bacteria occurring in 93% of the samples while *Pseudomonas* accounted for 7% occurring in approximately 20% of the samples. In the GAC plant effluent, the geometric mean of the HPC of 3,137 CFU/mL was composed of approximately 49% *Pseudomonas* in about 95% of the samples and 25% gram positive bacteria in 84% of the samples.

The level of HPC on the surface of the GAC was considerably higher than the plant effluent with a geometric mean of 3.5 x 10^6 CFU/mL. Essentially the same bacteriological trend observed for the plant effluent was also found on the surface of the GAC within each contactor. The number of unknown bacteria did not change significantly across the GAC beds but the number of picked colonies that did not regrow on nutrient agar increased from 3% to 13%.

GAC Reactivation

Morphology

Analyses were performed on both spent and reactivated GAC to determine reactivation quality and to measure any physical changes in the GAC which may result from repeated reactivations. These analyses consisted of apparent density, percent ash, iodine number, sieve (effective size, uniformity, coefficient, and mean particle diameter), molasses number, abrasion number, volatile matter, phenol number, percent moisture, BET surface area, and pore size distribution.

Generally, the reactivated carbon was comparable to virgin GAC. Some variations were observed, as shown in Table 2. These variations are suspected to have occurred from non-representative samples. From all indications, however, the origin GAC lot within each contactor can be continually recycled without any performance deterioration until it is eventually replaced through attrition by makeup GAC.

Losses

One of the most important economic factors in determining the feasibility on on-site reactivation is the amount of GAC loss associated with both GAC transport and GAC reactivation. In order to accurately determine losses, each GAC contactor and storage tank had to be calibrated. After calibration, GAC volume measurements were performed on each vessel after backwashing from 5 to 10 min and draining for approximately 40 min. The contactors were backwashed at 900 gpm (8.2 gpm/ft^2) while the flow rate used for the storage tanks was 300 gpm (2.7 gpm/ft^2) because of their lack of backwash freeboard. Each pressurized GAC contactor had four measuring ports while each storage vessel had ten measuring ports. The backwash/drain/measure sequence was repeated a minimum of three times until the average of three GAC volume measurements were within 0.05 ft of each other. This resulted in the GAC volumes being within 5.5 ft^3 of one another or 0.3% of a full contactor load of 1,857 ft^3. The average total loss was 8.6% with 7.1% loss occurring during reactivation and 1.5% during GAC transport.

Byproducts

Each effluent stream of the reactivation furnace was sampled for polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) during reactivation of virgin and exhausted GAC. No PCDDs or PCDFs were detected during reactivation of virgin GAC indicating that the GAC did not produce or contain these compounds. However, during the reactivation of exhausted GAC, PCDDs and PCDFs were observed in the stack gas of the reactivation furnace.

Concentrations for each isomer detected were multiplied by their respective 2,3,7,8-tetrachlorodibenzodioxin (TCDD) toxic equivalence factor to determine 2,3,7,8-TCDD equivalent concentrations. The total average 2,3,7,8-TCDD equivalent concentration was 0.68 ng/dscm. At a gas flow rate of approximately 200 dscm and a 7,000 hr operating year, an annual emission of 100 µg/yr resulted. The associated maximum lifetime risk for this level of emission was 3 x 10^{-9} (three in 1 billion).

In addition to the PCDD and PCDF analyses, scrubber water, quench tank water, spent GAC, and reactivated GAC were also analyzed for the presence of halogenated and nonhalogenated organics and other byproducts using liquid extraction and soxhlet extraction techniques. The organic content of the scrubber effluent water was generally lower than that of the GAC plant influent water. While TOC showed essentially no change from the influent water, TOX exhibited an average reduction of 42% from 118 µg/L to 69 µg/L. Similarly, the total amount of volatile organics measured was reduced 48% from 6.7 µg/L to 3.2 µg/L. Pentane extractable hydrocarbons and chlorinated hydrocarbon insecticides also exhibited general reductions of 37% with TFIC reduced from 4.2 µg/L to 2.7 µg/L and TECC reduced from 0.50 µg/L to 0.31 µg/L. For the quench tank effluent water, general reduc-

Table 2. *Reactivated GAC Morphology Over Successive Thermal Reactivations*

		Reactivation Number				
	Virgin	*1*	*2*	*3*	*4*	*5*
Apparent Density (g/mL)	0.54	0.49	0.54	0.57	0.56	0.57
Iodine Number (mg/g)	872	1070	897	777	864	846
Molasses Number	237	303	224	220	228	235
Effective Size (mm)	0.80	NA*	0.57	0.69	0.66	0.67
Uniformity Coefficient	1.72	NA*	1.86	1.66	1.69	1.76
Mean Particle Diameter (mm)	1.2	0.56	1.12	1.11	1.06	1.13
Abrasion Number	77.1	71.0	74.4	77.0	76.2	70.2
Ash (%)	8.9	11.4	10.0	8.7	9.1	8.7
BET Surface Area (m^2/g)	892	1066	777	714	1183	751
AWWA Phenol (g/100g)	16.7	22.1	18.5	15.6	13.6	16.5
Volatile Matter (%)	5.6	5.7	6.8	NA*	26.2	4.0

**NA - not analyzed*

tions were observed in the organic content of the GAC plant influent water.

Infrared reactivation removed 90% of the organics adsorbed on the GAC, based on chloroform soxhlet extraction residues. For the 3-mo reactivation cycles, chloroform residues were reduced from an average of 1.79 g/kg of GAC to 0.17 g/kg of GAC. The chloroform extracts were also analyzed for specific halogenated and nonhalogenated semivolatile organics. The results of these analyses, which were summarized by TFIC and TECC, indicated that there was only a small difference between spent GAC and reactivated GAC for those semivolatiles analyzed. The TFIC was reduced by an average of 27% from 0.059 g/kg to 0.043 g/kg while the TECC was reduced by only 9% from 0.0079 g/kg to 0.0072 g/kg. Other substances, such as PNAHs, were formed during the reactivation process.

Costs

The average operation and maintenance (O&M) GAC transport and reactivation cost was 20.4 cents/lb. The O&M GAC transport cost was 1.6 cents/lb and was comprised of 1.1 cents/lb for GAC loss, 0.3 cents/lb for operating labor, and 0.2 cents/lb for water. The cost associated with GAC loss was determined using an average transport loss of 1.5% while that for water consumption was derived from an average figure of 372,000 gal/reactivation, which included three backwashes per vessel for volume measurement. The operating labor cost for GAC transport was estimated on 12.5 hr/reactivation and included 2.5 hr of transport time, 0.5 hr for paperwork, and 9.5 hr for drain and volume measurements per vessel.

The O&M GAC reactivation cost was estimated at 18.8 cents/lb and included 5.8 cents/lb for electricity, 5.3 cents/lb for GAC loss, 3.6 cents/lb for maintenance labor, 1.7 cents/lb for maintenance material, 1.5 cents/lb for operating labor, 0.7 cents/lb for water, and 0.2 cents/lb for laboratory. The cost of electricity was based on an average usage of 46,508 kwh/reactivation determined over 11 reactivations with the afterburner in operation. The cost for GAC loss was determined using an average 7.1% loss per reactivation. The cost of operating labor was estimated at 63 hr/reactivation, which included an estimated 15 min/hr for taking readings and observing system operation over an average period of 10.5 days.

The cost of maintenance labor was based on the actual maintenance hours used for the last 15 reactivations, which averaged 136 hr/reactivation. A total maintenance material cost of $16,876 incurred over 20 reactivations along with an average reactivated GAC volume of 1,789 ft^3 was used to determine the O&M maintenance material cost for GAC reactivation. The figure of 1.7 cents/lb does not reflect any materials replaced under warranty, the cost of the eventual repair or replacement of the corroding duct between the furnace and the afterburner, or the cost of eventual belt replacement at approximately $10,000. The cost for water consumption was derived using the average water consumption over 15 reactivations of 1,280,500 gal/reactivation.

The overall O&M cost for the GAC adsorption and reactivation facility for a 3-mo reactivation cycle with a 20 min EBCT was estimated at 13.7 cents/l,000 gal. This cost was comprised of 2.8 cents/1,000 gal for GAC contactor operation, 0.9 cents/1,000 gal for GAC transport, and 10.0 cents/1,000 gal for GAC reactivation. The O&M cost for the GAC contactors was further broken down to 2.0 cents/l,000 gal for electricity, 0.6 cents/1,000 gal for operation labor, and 0.2 cents/1,000 gal for laboratory.

Conclusions

- Loading curves for all parameters monitored indicated that reactivated GAC adsorption performance was equal to or greater than that of virgin GAC.
- While coliforms were detected in both the influent and the effluent of the GAC contactors, the levels found were not statistically different indicating essentially no change in coliform density across the GAC contactors.
- The overall magnitude of morphological changes observed after repeated reactivations was minimal indicating that the original GAC lot within each contactor can be continually recycled until it is eventually replaced through attrition by make-up GAC.
- The average total GAC loss observed for the reactivation and transport of 20 GAC lots was 8.6%. This total GAC loss was comprised of 7.1% reactivation loss across the infrared reactivation furnace and 1.5% GAC transport loss.
- While some polychlorinated dibenzodioxin and dibenzofuran isomers were observed in the infrared reactivation furnace stack gas equivalent to a 2,3,7,8-tetrachlorodibenzodioxin emission of 0.68 ng/dscm, the lifetime risk level assessed for this level of emission at the Jefferson Parish site was 3×10^{-9} or three in 1 billion.
- No polychlorinated dibenzodioxins or dibenzofurans were found in any of the process streams of the reactivation furnace during the reactivation of virgin GAC indicating that these substances originated from the organic substances and chlorine species adsorbed onto the spent GAC as opposed to being inherent in the infrared reactivation process.
- All plumbing inside the contactors and storage vessels should be made of 316L stainless steel to prevent an eventual failure from the rapid corrosion produced by GAC fines on carbon steel.
- The average O&M GAC transport and reactivation cost was 20.4 cents/lb. Transport cost was 1.6 cents/lb and reactivation cost was 18.8 cents/lb. Overall O&M cost for a 3-mo reactivation cycle with a 20 min EBCT was 13.7 cents/1,000 gal.

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Wayne E. Koffskey is with the Jefferson Parish, Louisiana Department of Public Utilities, Jefferson Parish, LA 70121.
***Benjamin W. Lykins, Jr.** is the EPA Project Officer (see below).*
The complete report, entitled "Granular Activated Carbon Adsorption With On-Site Infrared Furnace Reactivation" (Order no. PB89-110 134/AS; Cost: $19.95, cost subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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