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Wastewater Technology Fact Sheet

Granular Activated Carbon Adsorption and Regeneration

DESCRIPTION

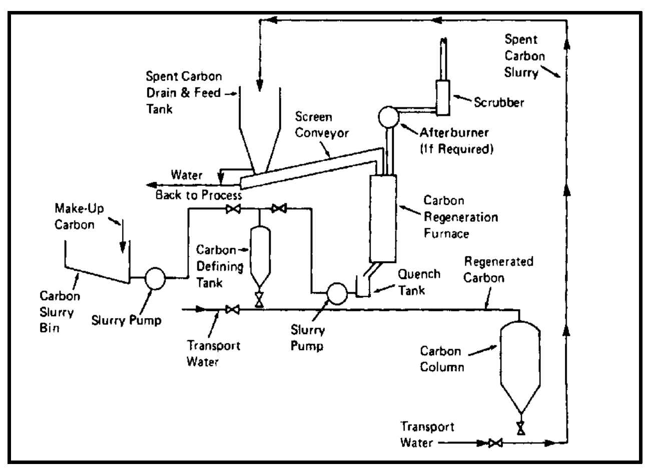
Granular activated carbon (GAC) adsorption has been used successfully for the advanced (tertiary) treatment of municipal and industrial wastewater. GAC is used to adsorb the relatively small quantities of soluble organics (See Table 1) and inorganic compounds such as nitrogen, sulfides, and heavy metals remaining in the wastewater following biological or physical-chemical treatment. Adsorption occurs when molecules adhere to the internal walls of pores in carbon particles produced by thermal activation.

TABLE 1 ORGANIC COMPOUNDS AMENABLE TO ADSORPTION BY GAC

Class	Example
Aromatic solvents	Benzene, toluene, xylene
Polynuclear aromatics	Naphthalene, biphenyl
Chlorinated aromatics	Chlorobenzene, PCBs, endrin, toxaphene, DDT
Phenolics	Phenol, cresol, resorcinol, nitrophenols, chlorophenols, alkyl phenols
Aromatic amines & high molecular weight aliphatic amines	Aniline, toluene diamine
Surfactants	Alkyl benzene sulfonates
Soluble organic dyes	Methylene blue, textiles, dyes
Fuels	Gasoline, kerosene, oil
Chlorinated solvents	Carbon tetrachloride, percholoroethylene
Aliphatic & aromatic acids	Tar acids, benzoic acids
Pesticides/herbicides	2,4-D, atrazine, simazine, aldicarb, alachlor, carbofuran

Source: U.S. EPA, 1984.

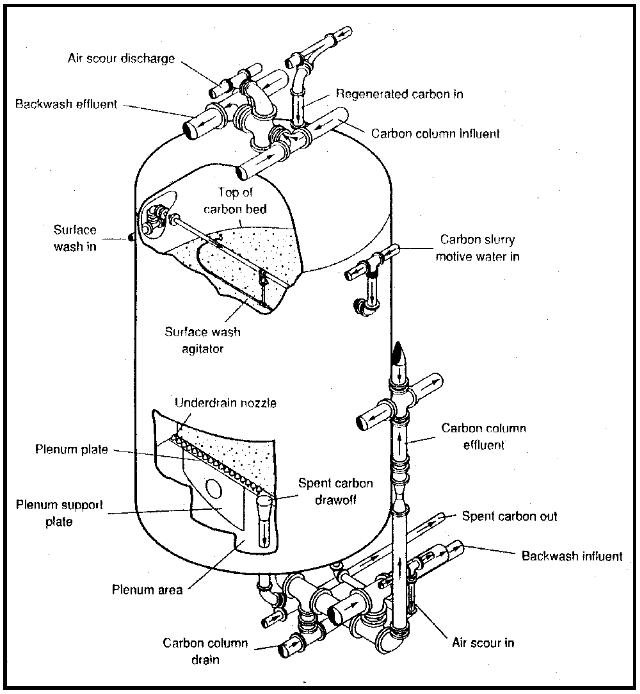
GAC systems are generally composed of carbon contactors, virgin and spent carbon storage, carbon transport systems, and carbon regeneration systems (See Figure 1). The carbon contactor consists of a lined steel column or a steel or concrete rectangular tank in which the carbon is placed to form a "filter" bed. A fixed bed downflow column contactor (See Figure 2) is often used to contact wastewater with GAC. Wastewater is applied at the top of the column, flows downward through the carbon bed, and is withdrawn at the bottom of the column. The carbon is held in place with an underdrain system at the bottom of the contactor. Provisions for backwash and surface wash of the carbon bed are required to prevent buildup of excessive headloss due to accumulation of solids and to prevent the bed surface from clogging.



Source: WEF MOP 8, 1998.

FIGURE 1 GAC ADSORPTION SCHEMATIC

Expanded bed and moving bed carbon contactors have been developed to overcome problems associated with headloss buildup experienced with fixed bed downflow contactors. In an expanded bed system, wastewater is introduced at the bottom of the contactor and flows upward, expanding the carbon bed, much as the bed expands during backwash of a fixed bed downflow contactor. In the moving bed system, spent carbon is replaced continuously so that the headloss does not build up. Carbon contactors may be operated under either pressure or gravity flow. The choice between pressure and gravity flow generally depends on the available pressure (head) within the wastewater treatment plant and cost.



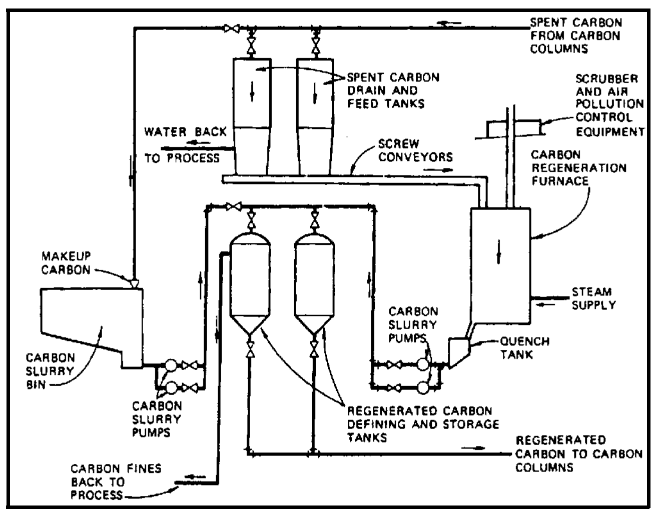
Source: Tchobanoglous and Burton, 1991.

FIGURE 2 TYPICAL DOWNFLOW CARBON CONTACTOR

All carbon contactors must be equipped with carbon removal and loading mechanisms to allow spent carbon to be removed and virgin or regenerated carbon to be added. Spent, regenerated, and virgin carbon is typically transported hydraulically by pumping as a slurry. Carbon slurries may be transported with water or compressed air, centrifugal or diaphragm pumps, or eductors.

When the carbon contactor effluent quality reaches minimum water quality standards, the spent carbon is removed from the contactor for regeneration. Small systems usually find regeneration of their spent carbon at an off-site commercial reactivation facility to be the most convenient and economical method. In this case, the spent carbon is hydraulically transported from the contactor to a waiting truck. Regenerated or virgin carbon is then hydraulically transported from a second truck or from a separate compartment in the first truck to the contactor, then to a commercial reactivation facility. Generally, systems which contain at least one million pounds of carbon find on-site regeneration to be cost effective.

Carbon regeneration is accomplished primarily by thermal means. Organic matter within the pores of the carbon is oxidized and thus removed from the carbon surface. The two most widely used regeneration methods are rotary kiln and multiple hearth furnaces. Approximately 5 to 10 percent of the carbon is destroyed in the regeneration process or lost during transport and must be replaced with virgin carbon. The capacity of the regenerated carbon is slightly less than that of virgin carbon. Repeated regeneration degrades the carbon particles until an equilibrium is eventually reached providing predictable long term system performance. See Figure 3 for a schematic of the carbon regeneration process.



Source: WEF MOP 8, 1998

FIGURE 3 REGENERATION SCHEMATIC

APPLICABILITY

Typically, GAC adsorption is utilized in wastewater treatment as a tertiary process following conventional secondary treatment or as one of several unit processes composing physical-chemical treatment. In wastewater treatment plants utilizing biological secondary treatment, GAC adsorption is generally located after filtration and prior to disinfection. When utilized in a physical-chemical treatment process, GAC adsorption is generally located following chemical clarification and filtration and prior to disinfection. In addition, GAC adsorption systems have a relatively small footprint making them suitable for facilities with limited land availability.

The successful application of carbon adsorption for municipal wastewater treatment depends on the quality and quantity of the wastewater delivered to the adsorption system. For a carbon contactor to perform effectively, the feed water to the unit should be of uniform quality (suspended solids concentrations less than 20 mg/l) and without surges in flow. Wastewater constituents that may adversely affect carbon adsorption include suspended solids, BOD_5, and organics such as methylene blue active substances or phenol and dissolved oxygen. Environmental factors that must be considered include pH and temperature because they may impact solubility, which affects the adsorption properties of the wastewater components onto carbon (WEF MOP 8, 1998).

ADVANTAGES AND DISADVANTAGES

Before deciding whether carbon adsorption/regeneration meets the needs of a municipality, it is important to understand the advantages and disadvantages of both the adsorption and regeneration process.

Advantages (Adsorption)

C For wastewater flows which contain a significant quantity of industrial flow, GAC adsorption is a proven, reliable technology to remove dissolved organics.

C Space requirements are low.

• GAC adsorption can be easily incorporated into an existing wastewater treatment facility.

Advantages (Regeneration)

C Systems are reliable from a process standpoint.

C Reduces solid waste handling problems caused by the disposal of spent carbon.

C Saves up to 50 percent of the carbon cost.

Disadvantages (Adsorption)

C Under certain conditions, granular carbon beds may generate hydrogen sulfide from bacterial growth, creating odors and corrosion problems.

C Spent carbon, if not regenerated, may present a land disposal problem.

C Wet GAC is highly corrosive and abrasive.

C Requires pretreated wastewater with low suspended solids concentration. Variations in pH, temperature, and flow rate may also adversely affect GAC adsorption.

Disadvantages (Regeneration)

C Air emissions from the furnace contain volatiles stripped from the carbon. Carbon monoxide is formed as a result of incomplete combustion. Therefore, afterburners and scrubbers are usually needed to treat exhaust gases.

C The induced draft fan of a multiple hearth furnace may produce a noise problem.

C The process is most effective when operated on a 24-hour basis, requiring around-the-clock operator attention.

C The process is subject to more mechanical failures than other wastewater treatment processes.

DESIGN CRITERIA

Prior to the design of GAC systems, a pilot plant study should be performed to determine if the technology will meet discharge permit requirements and to quantify optimum flow rate, bed depth, and operating capacity on a particular wastewater. This information is required to determine the dimensions and number of carbon contactors required for continuous treatment.

The sizing of carbon contactors is based on contact time, hydraulic loading rate, carbon bed depth, and number of contactors. The carbon contact time typically ranges from 15 to 35 minutes depending on the application, wastewater constituents and desired effluent quality. Hydraulic loading rates of 4 to 10 gpm/sq.ft are typically used for upflow carbon columns. For downflow carbon columns, hydraulic loading rates of 3 to 5 gpm/sq.ft are used. Carbon bed depth varies typically within a range of 10 to 40 feet depending on carbon contact time (Tchobanoglous, 1991).

The number of contactors should be sufficient to ensure enough carbon contact time to maintain effluent quality while one column is off line during removal of spent carbon or maintenance. The normal practice is either to use two columns in series and rotate them as they become exhausted or to use multiple columns in parallel so that when one column becomes exhausted, the effluent quality will not be significantly affected (WEF MOP 8, 1998).

Regeneration facilities are typically sized based on carbon dosage or use rate. The dosage rate depends on the strength of the wastewater applied to the carbon and the required effluent quality. Typical dosage rates for filtered, secondary effluent range from 400 to 600 lbs/mil.gall., while typical dosage rates for coagulated, settled and filtered raw wastewater (physical-chemical) range from 600 to 1800 lbs/mil.gall.

PERFORMANCE

Niagara Falls Wastewater Treatment Plant Niagara Falls, New York

The Niagara Falls Wastewater Treatment Plant (NFWTP) has been operating as a physical-chemical activated carbon secondary treatment facility since 1985. With a design average daily flow capacity of 48 mgd, it is the largest municipal physical-chemical activated carbon wastewater treatment plant in operation in the United States. The treatment process consists of chemically assisted primary sedimentation, granular activated carbon adsorption, oxidation, and disinfection. The influent pH can be adjusted to compensate for industrial discharge. The current average daily flow is 35 mgd. Industrial flow to the plant is approximately 17 percent of the total flow.

The activated carbon system at NFWTP includes 28 carbon beds which are 17.3 feet wide by 42 feet long. Each carbon bed is approximately 8.5 feet in depth and contains 180,000 pounds of carbon. Primary effluent percolates downward by gravity through the GAC bed. Each carbon bed provides chemical adsorption of pollutants from the wastewater, physical filtration of solids, and biological degradation from the incidental anaerobic activity that occurs within.

The carbon beds at NFWTP operate in parallel. During dry weather, there are typically 17 carbon beds in operation with a primary effluent application rate of approximately 2.2 gpm/sq.ft. During wet weather, additional beds are placed in operation. All beds are operated at an application rate of approximately 3gpm/sq.ft (Roll, 1996). Backwash of the carbon beds is based on headloss.

Regeneration of the spent carbon is performed on-site in a multiple hearth furnace. Each filter bed is separately removed from service and emptied of carbon. The carbon is fed to the furnace at a rate of about 2,000 lbs/hr. The regenerated carbon is kept in storage until an empty bed becomes available. Normal operating losses, which average 5.5 percent, require the addition of virgin carbon to maintain inventory levels. At present, the four month regeneration process to regenerate all of the carbon is performed once per year.

Three storage tanks are used during on-site regeneration. The spent carbon storage tank has a capacity of 2.5 carbon beds; the regenerated carbon storage tank can hold 1.5 beds of carbon and the virgin carbon storage tank has a capacity of 1 carbon bed. Carbon is moved about the plant in a slurry through an eductor system.

With GAC adsorption, the NFWTP has achieved very low effluent organic compound concentrations. On a daily basis, the facility receives approximately 800 pounds of influent priority pollutants which are reduced by the treatment process to 12 pounds in the effluent to the Niagara River. The effluent discharge permit issued to NFWTP by the New York State Department of Environmental Conservation includes effluent limitations for volatile compounds, acid compounds, base/neutral compounds, pesticides, metals, and cyanide.

Millard H. Robbins Reclamation Facility, Upper Occoquan Sewerage Authority, Centreville, Virginia

The Millard H. Robbins Reclamation Facility (MHRRF) provides biological, tertiary treatment to an average daily wastewater flow of 24 mgd. Industrial flow to the plant is approximately 10 percent of the total flow. The treatment process consists of primary sedimentation, conventional activated sludge with nitrification, lime addition for phosphorous removal, clarification, two-stage recarbonization, flow equalization, multimedia filtration, GAC adsorption, post filtration and disinfection. The MHRRF discharges its effluent to Bull Run which flows into the Occoquan Reservoir. This reservoir serves as raw water storage for the potable water supply to portions of northern Virginia.

The activated carbon system at MHRRF includes 32 upflow carbon columns which are 10 feet in diameter and 40 feet tall. Each column has a capacity of 1mgd and contains approximately 75,000 pounds of carbon. Flow is pumped through the columns by a pump station which also serves the multimedia filters and post filtration system. Post filtration is provided following the GAC columns to remove carbon fines from the effluent to maintain the Virginia Pollutant Discharge Elimination System (VPDES) permit requirement for turbidity of 0.5 NTU.

The carbon columns at MHRRF are operated in parallel. During average daily flow periods, approximately 24 columns are in operation with the remaining eight columns brought on line during daily peak flow periods. During wet weather, flows in excess of 32 mgd are stored in a 90 million gallon pond.

Regeneration of the spent carbon is performed on-site in a multiple hearth furnace. The regeneration process takes approximately 8 to 10 weeks to regenerate approximately one-third of the carbon in all 32 columns and is performed twice each year. Consequently, it takes approximately 18 months (three regeneration cycles) to regenerate the total quantity of carbon in the columns. Spent carbon is removed from the bottom of each column and transported to the regeneration furnace through an eductor system. The regenerated carbon is then added at the top of each column. The cost for on-site regeneration at MHRRF is approximately $0.35 per pound. Normal operating losses, which average 5 to 7 percent of the total quantity of GAC in use, require the addition of virgin carbon to maintain inventory levels. Most of the carbon attrition occurs during regeneration with approximately 10 to 12 percent of the total carbon regenerated lost during the regeneration process. Carbon is moved about the plant in a slurry through an eductor system.

GAC adsorption is utilized at MHRRF to remove non-biodegradable, soluble organics. COD is used as the surrogate indicator of non-biodegradable organics removal by the GAC columns. Currently, the Virginia Pollutant Discharge Elimination System (VPDES) discharge permit limit for COD is 10 mg/l. Following GAC regeneration, effluent COD concentrations range from 6 to 7 mg/l, which corresponds to approximately 50 percent removal of COD. As the GAC in the columns becomes exhausted, the percentage removal of COD declines to approximately 25 percent. When the effluent COD concentration has increased to 9 mg/l, GAC regeneration is initiated.

OPERATION AND MAINTENANCE

The proper operation and maintenance of GAC adsorption and regeneration systems ensures the efficient removal of soluble organics from secondary effluent. A routine O&M schedule following manufacturer's recommendations should be developed and implemented for any GAC adsorption and regeneration system. Regular O&M includes the following:

- Backwash of carbon contactor based on headloss or flow.
- Flush carbon transport piping to prevent clogging.
- Backwash frequently after loading carbon to minimize clogging of backwash nozzles by carbon fines.
- Store an adequate supply of spent carbon to allow continuous operation of the regeneration furnace.
- Test and calibrate instrumentation and controls on a routine basis.

COSTS

The construction and operation and maintenance costs of carbon adsorption and regeneration depend on the characteristics of the wastewater to be treated, the capacity of the plant, and the plant site. Therefore, the designer is responsible for selecting a system that will meet the National Pollutant Discharge Elimination System NPDES permit requirements at the lowest cost possible. Once the optimum flow rate, bed depth, and operating capacity of GAC for a particular wastewater are determined, comparative costs for different carbon contactor configurations and the cost of on-site regeneration versus off-site regeneration can be estimated. Following a thorough engineering and economic analysis of alternatives, the final equipment configuration can be selected.

Construction costs include the carbon contactors, carbon transport system, carbon storage tanks, carbon regeneration system (if applicable), influent wastewater pumps (if applicable) and contactor backwash system. Operation and maintenance costs include the purchase of virgin carbon, on-site regeneration or purchase of regenerated carbon, electrical power to operate pumps and controls, flushing of carbon slurry piping, and replacement of parts. Currently, the cost of virgin carbon ranges from $0.70 to $1.20 per pound and the cost to purchase regenerated carbon ranges from $0.50 to $0.78 per pound.

Operational costs depend on the characteristics of the influent wastewater and the adsorption capacity of the GAC. For example, influent wastewater which contains suspended solids concentrations greater than 20 mg/l will require more frequent backwashing of the contactor to prevent clogging of the carbon bed.

REFERENCES

Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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