United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-81-177 Oct. 1981

Project Summary

Granular Activated Carbon Installations

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Granular activated carbon (GAC) treatment design criteria, performance, and cost data from 22 operating municipal and industrial GAC installations that treat water and wastewater and that process food and beverage products are compiled and summarized. Guidance and an example of how this information can be used to estimate costs for GAC treatment of water supplies is provided. The report should be used in conjunction with a previous series of reports on "Estimating Water Treatment Costs" to obtain project-specific cost estimates. It is not a design manual and does not provide design criteria such as required contact time, probable regeneration frequency, activated carbon reactivation system criteria, or activated carbon transfer guidelines. Rather, the approach to determining such design data for water systems is presented.

This Project Summary was developed by EPA's Municipal Environmental 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

On January 9, 1978, the U.S. Environmental Protection Agency (EPA) proposed the use of GAC as a means of treating drinking water. Since that time, much has been written both for and against using GAC in this manner. Serious challenges and many questions have been raised regarding EPA's cost estimates for GAC use. To respond to some of these questions, EPA's Drinking Water Research Division initiated a carefully designed study to establish water supply unit process cost curves on a consistent and understandable basis.

In an earlier study ("Estimating Water Treatment Costs," EPA-600/2-79-162 a, b, c, and d, performed by Culp/Wesner/Culp under EPA Contract No. 68-03-2516), construction and operation and maintenance cost curves were developed for processes capable of removing those contaminants included in the National Interim Primary Drinking Water Regulations. The final report contains cost curves for 99 different unit processes. These cost curves were divided into two categories: large water treatment systems applicable to flows between 1 and 200 mgd and small water treatment systems applicable to flows between 2,500 gpd and 1 mgd. A computer program for retrieving, updating, and combining the cost data was also developed. During the course of this work, the costs of GAC adsorption and reactivation in municipal water treatment as they relate to the removal of organics from drinking water became a subject of great national interest. Because of this, in 1978, the original project was expanded to include a special study of the unit process costs of GAC adsorption and reactivation in potable water treatment. The special study was directed at visiting as many existing GAC installations as possible to gather and publish data on actual operating experiences, particularly on the costs of building, operating, and maintaining GAC plants.

The report summarized here presents the findings of this special study of GAC installations and the compilation of the information available on the use of GAC in water treatment.

Use of Activated Carbon in Drinking Water

Powdered activated carbon (PAC) has been used, without harmful effects, for more than 50 years to remove taste and odor from public water supplies, but the use of GAC in treating municipal water in the United States is limited to a few facilities. In most cases, GAC is used to remove taste and odor from drinking water. Its use *may* become more common in light of new information on the occurrence of trace organics in water, the recent regulations limiting the concentration of trihalomethanes in public water supplies, and the possibility of requirements for GAC treatment. European water works have had considerable experience over a long period of time with GAC installations.

Although the use of GAC in municipal water treatment has been limited, GAC has been used in industrial and municipal wastewater treatment and in various industrial process applications. The specific uses of GAC are somewhat different with these applications than with water treatment, but much of the information on design and operations will prove useful to water purveyors. In general, the application of GAC adsorption to drinking water is simpler than to wastewater.

Eighteen of the twenty-two GAC installations visited were industrial process or municipal wastewater facilities, whereas four were municipal water treatment plants. Case histories presenting design, operating, performance, and cost information are presented in the report; the pertinent information has been summarized (Table 1). Single page fact sheets for each of these case histories are given in the report.

A principal function of the site visits was to collect construction and operation and maintenance (O&M) cost information on GAC installations. Plant records were used to obtain available construction costs, the dates for these costs, and the most recent O&M costs. The basic data are presented in the individual case study reports, but no attempt was made to update construction or O&M costs to present day prices or to extrapolate the costs to water treatment plants. This report does, however, refer to procedures whereby data from existing GAC projects can be adjusted or modified (based on the results of pilot-plant test results of the water to be treated) so as to be useful to experienced professionals making preliminary estimates of costs for future potable water projects involving GAC adsorption and reactivation or replacement.

Extrapolating Municipal Wastewater Experience to Water Treatment

The first plant-scale use of GAC in a municipal wastewater treatment plant was at South Lake Tahoe, California, in 1965. This plant has operated continuously since that time and now has 15 years of operating experience with GAC; the GAC system has processed more than 12 billion gallons of pretreated municipal wastewater. The reclaimed water COD ranges from 10 to 30 mg/L. The South Tahoe installation was an EPA Demonstration Plant. For 3 years, EPA funded the collection of very detailed and complete plant operating data and cost information.

Other Wastewater Installations

Water reclamation plants constructed at the Orange County (CA) Water District (Water Factory 21), the Upper Occoquan (VA) Sewer Authority, and the Tahoe-Truckee (CA) Sanitation Agency (Nos. 6, 3, and 2, respectively) have the same configuration as the South Tahoe plant both in respect to the type of GAC facilities provided and the high degree of pretreatment afforded. All of these plants operate successfully with few GAC system problems. As might be expected with second and third generation designs, these later plants embody some improvements over the original South Tahoe installation, although no major changes or deviations were initiated.

Although many other successful applications of GAC in advanced waste treatment (AWT) plants exist, the GAC experience in some AWT plants has, unfortunately, been poor. These failures in AWT applications have not stemmed from deficiencies in the basic GAC processes or in organics adsorption and thermal reactivation, but, rather, from mechanical problems.

Operational Problems

In discussing the operational problems encountered with GAC systems, those problems associated specifically with sewage must be distinguished from general problems that might be encountered with any type of GAC system. Many problems with GAC in wastewater treatment will not occur in water purification. For example, in water treatment, few or no problems could be expected with excessive slime growths, hydrogen sulfide gas production, or corrosion from adsorbed organics released during carbon reactivation.

Some of the types of problems encountered with GAC systems in wastewater treatment include:

- inadequate GAC transfer and feed equipment,
- undersized slurry and transfer lines,
- failure to provide for venting air from backwash lines with destruction of filter bottoms and disruption of GAC,
- failure to house or otherwise protect automatic control systems from the weather,
- inadequate means for continuous, uniform feed to furnace; this results in temperature fluctuations, inconsistent reactivation efficiency, and wasted energy,
- location of furnace and auxilliary drive motors in areas of very high ambient temperature (e.g., above top of furnace), and
- the use of nozzles in filter and carbon contactor bottoms; this produces major failures in carbon systems just as they have for many years in water filtration plants. Their use is risky.

The common problems related to wastewater treatment (biological organisms in the activated carbon contactors and development of anaerobic conditions with the production of corrosive hydrogen sulfide) have been successfully circumvented by providing adequate flow through the columns or frequent backwashing. Failure to provide adequate pretreatment has caused column clogging and mud balls with the need for more frequent backwashing.

Corrosion has been a problem with some of the GAC systems. The furnace system, transfer piping, and storage tanks are susceptible components. Many operations require frequent replacement of the rabble arms and teeth and replacement of the hearths every few years. At one installation, titanium or ceramic coated rabble teeth were no more resistant to corrosion than were stainless steel teeth. In one case, the corrosion problem in the furnace was solved by eliminating the use of auxiliary steam during reactivation. In another, corrosion was linked to fluctuating temperatures in the hearths caused by irregular feed to the furnace and frequent startup and shutdown. These problems can be partially remedied by better operation and avoided by better engineering design.

In several industrial applications, the wastewater itself has been highly corrosive. In these cases, the contactors have been subject to corrosion. At Spreckles Sugar, the epoxy linings in the columns must be replaced every 3 years; Republic Steel also replaces its column linings on a regular basis. Public water supply sources would not be expected to consist of corrosive water.

By properly applying the best current engineering design knowledge and practices for GAC systems, these rather serious problems might be avoided. When water works engineers apply GAC to produce high quality drinking water, they should make the most of the experiences of the consultants for industry and wastewater agencies.

Extrapolating Industrial and Wastewater Data to Water Supply

Caution must be observed in extrapolating GAC cost data from operating industrial installations and municipal wastewater treatment plants to the design of water works. The purpose for using GAC in each of these types of applications is generally the same — to remove organics. Important differences do exist, however. In industry, the GAC serves to remove a rather narrow band of organics — color molecules — from a viscous liquid. In wastewater treatment, the GAC removes (with or wihout biological activity) a broad spectrum of organic substances from water as measured by BOD, COD, and TOC.* In water treatment, the objectives of GAC treatment are not completely defined at this time. For raw waters with color or taste and odor problems, using GAC unquestionably improves drinking water from an aesthetic standpoint. In many cases, the cost of GAC may be warranted for either of these purposes alone. For the great number of water systems without color or taste and odor problems, the only concern with respect to organics is the possible health effects over long periods of time from ingesting trace quantities of organics that may cause cancer.

Public health officials and water works managers still disagree as to whether the health risks that may be involved in the presence of minute traces of organics in drinking water are sufficient to warrant the cost of GAC treatment. A major problem is that the potentially harmful organics in drinking water have not all been identified at this time, and many of those that have been tagged as suspect have widely different adsorptive characteristics. Some adsorb readily on GAC; others do not.

GAC loading rates at exhaustion of adsorptive capacity vary widely among the different potentially hazardous organics. This affects the length of service life of GAC before reactivation or replacement is necessary — a determining factor in GAC treatment costs. Similarly, the reactivation times and temperatures for thermal reactivation of GAC saturated with different organics also differ, and all are not known at this time. Again, this has an important bearing on GAC treatment costs. Because of the widely varying adsorptive and reactivation characteristics of trace organics on GAC in water supplies, pilot plant tests of both adsorption and reactivation are mandatory preludes to treatment system design at this time.

Over a period of years, general, average design parameters may emerge from the results of pilot plant studies and demonstration projects, but this time is not yet at hand. Once the GAC design parameters for water treatment have been established from pilot tests for a particular water source, then the knowledge and experience from other GAC installations in industry and wastewater plants can be put to good use. GAC dosages, contact times, and spent carbon reactivation times and temperatures can be determined. Contactor sizes can be calculated and furnace sizes and fuel requirements can be determined. Transport facilities for GAC in water treatment can be the same as for other types of GAC installations provided differences are taken into account — differences in quantities and possible differences in the viscosities of activated carbon slurries because of any slime growths. Also, with GAC design parameters pinpointed as a result of pilot plant studies, construction costs can be accurately estimated based on costs of existing installations in AWT and industry. The estimates cannot, however, be based on a million-gallon-per-day capacity basis; rather, they must be based on adsorption and reactivation data applicable to each specific installation.

Selecting the most economical numbers of contactors for a water system of a certain size involves the same principles that are used for other systems. Because of shipping regulations, factory-fabricated contactor vessels are generally limited to about 12-ft maximum diameter. For large capacity installations, a smaller number of field-erected steel vessels or poured-in-place concrete vessles may be less costly.

Because upflow contactors provide all of the advantages of countercurrent operation with respect to GAC savings, they are favored for most types of service. The exception is water treatment. In this case, downflow is used because of the discharge of carbon fines in the effluent (a characteristic of upflow columns) is avoided.

Cost estimates must be evaluated on the same basis as all other estimates of construction cost; there is no reason that they should be more or less accurate than estimates made for the rest of the treatment plant. Fifteen percent is generally accepted as being an allowable difference between costs estimated from construction plans and the best bid received from contactors. With good pilot plant data and with proper application of cost data from existing GAC installations, preliminary cost estimates for GAC treatment of public water supplies should be accurate enough for planning purposes.

The extrapolation of wastewater treatment experience with GAC to the design of water treatment systems is a task for trained, experienced, engineering professionals. Even then, the following discussions are intended to be no more than an introduction to the subject.

Designing GAC Systems for Water Treatment

The following discussion is devoted to some of the procedures and details for developing the design basis and costs for GAC water treatment systems from pilot plant test results and information from full-scale applications.

GAC System Components

Systems utilizing GAC are rather simple. In general, they provide for contact between the GAC and water to be treated for the length of time required to obtain the necessary removal of organics; reactivation or replacement of spent carbon; and transport of makeup or reactivated carbon into the contactors and transport of spent carbon from the contactors to reactivation or hauling facilities.

Pilot Plant Tests

Despite the simplicity of GAC systems, laboratory and pilot plant tests are needed to select the carbon and the most economical plant design for both water and wastewater treatment projects. Pilot column tests make it possible to determine treatability; select the best carbon for the specific purpose based on performance; determine the required empty bed contact time; establish the required carbon dosage that, together with laboratory tests of reactivation, will determine the capacity of the reactivation furnace; determine the necessary activated carbon replacement costs; and determine the effects of influent water quality variations on plant operation. During pilot plant testing, the influence of longer carbon contact time on reactivation frequency can be measured; these measurements allow costs to be minimized through a proper balance of these two design factors.

Design of Pilot GAC Columns

Detailed information, including a list of materials, on the design and construction of pilot GAC columns is presented in Appendix C of EPA's "Interim Treatment Guide For Controlling Organic Contaminants in Drinking Water Using GAC" (out of print). Appendix B of the "Interim Treatment Guide" describes the analytic methodology for monitoring pilot column tests. Also included are data on the adsorbability of various organic compounds; the performance of GAC in their removal; information on the use of multiple-hearth, infrared, fluidized bed, and rotary kiln furnaces for reactivating spent GAC; and example calculations for balancing added costs of increased contact time versus savings (if any) from less frequent reactivation.

Use of GAC in Water and Wastewater Treatment

Frequency of Reactivation

One of the principle differences in costs between water and wastewater GAC treatment is the more frequent reactivation required in water purification caused by earlier breakthrough of the organics of concern. In wastewater treatment, GAC may be expected to adsorb 0.30 to 0.55 lb COD/lb activated carbon before the GAC is exhausted. From the limited amount of data available from research studies and pilot plant tests (most of it unpublished), some organics of concern in water treatment may breakthrough at carbon loadings as low as 0.05 to 0.25 lb organic/lb carbon. The actual allowable carbon loading or carbon dosage for a given case must be determined from pilot plant tests. Costs taken from wastewater cost curves, which are plots of flow in million gallons per day versus cost (capital or O&M costs), cannot be applied directly to water treatment. Allowance must be made in the capital costs for the different reactivation capacity needed and in the O&M costs for the actual amount of carbon to be reactivated or replaced.

Because the organics adsorbed from water are generally more volatile than those adsorbed from wastewater, the increased reactivation frequency resulting from lighter carbon loading may be partially offset, or more than offset, by the reduced reactivation requirements of the more volatile organics. The times and temperatures required for reactivation may be reduced because of both the greater volatility and the lighter loading of organics on the carbon.

From the experimental reactivation to date, reactivation temperatures *may* be less than the 1,650° to 1,750°F required for wastewater carbons. The shorter reactivation times required for water purification carbons may allow the number of hearths in a multiple hearth reactivation furnace to be reduced. Also, less fuel may be required for reactivation. These factors must be determined on a case-by-case basis.

GAC Contactors

Selection of the general type of contactor to be used for a particular water treatment plant application may be based on several considerations including economics and the judgment and experience of the engineering designer. The choice generally would be made from three types of downflow vessels:

1. Deep-bed, factory-fabricated, steel pressure vessels of 12-ft maximum diameter. The size of these vessels might vary from 2,000 to 50,000 ft^3.
2. Shallow-bed, reinforced-concrete, gravity-filter-type boxes may be used for carbon volumes ranging from 1,000 to 200,000 ft^3. Shallow beds probably will be used only when short contact times are sufficient or when long service cycles between reactivations can be expected from pilot plant test results.
3. Deep-bed, site-fabricated, large (20- to 30-ft) diameter, open concrete or steel, gravity tanks may be used for GAC volumes ranging from 6,000 to 200,000 ft^3, or larger.

These ranges overlap, and the designer may very well make the final selection based on local factors, other than total capacity, that affect efficiency and cost.

The AWT experience with GAC contactors may be applied to water purification if some differences in requirements are taken into account. The required contact time must be determined from pilot plant test results. Although contactors may be designed for a downflow or upflow mode of operation and upflow packed beds or expanded beds provide maximum carbon efficiency through the use of countercurrent flow principles, the leakage of some (1 to 5 mg/L) carbon fines in upflow column effluent make downflow beds the preferred choice in most municipal water treatment applications. At the Orange County Water Factory 21, upflow beds were converted to downflow beds to successfully correct a problem with escaping carbon fines. This full-scale plant operating experience indicates that leakage of carbon fines is not a problem in properly operated downflow GAC contactors.

Single beds or two beds in series may be used. Open gravity beds or closed pressure vessels may be used. Structures may be properly protected steel or reinforced concrete. In general, small plants will use steel, and large plants may use steel or reinforced concrete.

Sand in rapid filters has, in some instances, been replaced with GAC. In situations where contact times are short and GAC reactivation or replacement cycles are exceptionally long (several months or years, as may be the case in taste and odor removal), this may be a solution. With the short cycles anticipated for most organics, however, conventional concrete-box-style filter beds may not be well suited to GAC contact. Deeper beds may be more economical in first cost and provide more efficient use of GAC. In converted filter boxes, possible corrosion effects of GAC on existing metals, such as surface wash equipment and metal nozzles in filter bottoms, must be taken into account. Beds deeper than conventional filter boxes, or contactors with greater aspect ratios of depth to area, provide much greater economy in capital costs. The contactor cost for the needed volume of carbon is much less. In a water slurry, carbon can be moved easily and quickly and with virtually no labor from contactors with conical bottoms. Flat-bottomed filters of a type that require labor to move the carbon unnecessarily add to carbon transport costs. The labor required to remove carbon from flat-bottomed beds varies considerably in existing installations from a little labor to a great deal, depending upon the design of the evacuation equipment.

For many GAC installations intended for precursor organic removal or synthetic organic removal, specially designed GAC contactors should be installed. Contactors should be equipped with flow measuring devices. Separate GAC contactors are especially advantageous where GAC treatment is required only part of the time during certain seasons because they then can be bypassed when not needed, possibly saving unnecesary exhaustion and reactivation of GAC.

Tremendous cost savings can be realized in GAC treatment of water through proper selection and design of the contactors. The design of contactor underdrains requires experienced expert attention.

GAC Contactor Underdrains

Although good proven underdrain systems are available, often they have not been used, and there have been numerous underdrain failures due to poor design. Some designs used in the past for conventional filter service have failed in many installations, yet they continue to be misapplied to GAC contactors as well as filters.

GAC Reactivation or Replacement

Spent carbon may be removed from contactors and replaced with virgin carbon, or it may be reactivated either on-site of off-site. The most economical procedures depend on the quantities of GAC involved. For larger volumes, onsite reactivation is the answer. For small quanitites, replacement or off-site reactivation will probably be most economical.

GAC may be thermally reactivated to very near virgin activity. Burning losses may, however, be excessive under these conditions. Experience in industrial and wastewater treatment indicates that carbon losses can be minimized (held to 8 to 10 percent per cycle). To remove certain organics, no decrease in actual organics removal may occur despite a 10 percent drop in iodine number.

Thermal Reactivation Equipment

GAC may be reactivated in a multiple-hearth furnace, a fluidized bed furnace, a rotary kiln, or an electric infrared furnace. Spent GAC is drained dry in a screen-equipped tank (40 percent moisture content) or in a dewatering screw (40 to 50 percent moisture) before being introduced to the reactivation furnace. Dewatered carbon is usually transported by a screw conveyor. Following thermal reactivation, the GAC is cooled in a quench tank. The water-carbon slurry may then be transported by means of diaphragm slurry pumps, eductors, or a blow-tank. The reactivated carbon may contain fines produced during conveyance; these fines should be removed in a wash tank or in the contactor. Maximum furnace temperatures and retention time in the furnace are determined by the amount (lb organics/lb carbon) and nature (molecular weight or volatility) of the organics adsorbed.

Off-gases from reactivation present no air pollution problems provided they are properly scrubbed. In some cases, an afterburn may also be required for odor control.

Despite recent advances in the design area of infrared and fluidized bed reactivation furnaces, the multiple hearth furnace is still the simplest, most reliable, and easiest to operate for GAC reactivation. The infrared and fluid bed units still have problems to be worked out; experience with the multiple hearth equipment has already solved these problems. Still, it is necessary with all four types of furnaces to specify top quality materials to suit the conditions of service and to see that these materials are properly installed. Corrosion resistance is important in the furnace itself and especially in all auxiliaries to the furnace.

Required Furnace Capacity

The principal cost differences between GAC treatment of water and wastewater may lie in the capital cost of the furnace and in the O&M cost for carbon reactivation. As already explained, the two principal differences between carbon exhausted in wastewater treatment and carbon exhausted in water purification are that water purification carbons are likely to be easier to reactivate (less time in furnace and lower furnace temperatures) and more lightly loaded (greater volume of carbon to be reactivated per pound or organics removed). Accurate estimates of GAC costs require knowledge and consideration of these two factors. To repeat, it is not possible to use AWT cost curves based on million gallons per day throughput or plant capacity to obtain costs for water treatment. Differences in reactivation requirements must be taken into account.

GAC Transport and GAC Process Auxiliaries

The large differences in O&M costs for GAC systems depend on the method selected for carbon transport. Hydraulic transport of GAC in water slurry by gravity or water pressure uses very little labor and is simple, easy, and rapid. Moving dry or dewatered activated carbon manually or with mechanical means involving labor can be very difficult, time consuming, and costly.

Cost of GAC in Water Treatment

Developing Cost Curves

Little information is available concerning the cost and performance of GAC for drinking water treatment. As discussed in the previous sections, most of the data available on GAC performance have been acquired from wastewater and industrial applications. An attempt has been made, however, to extrapolate from these existing systems and to develop standardized and flexible cost data that can be used to prepare cost estimates for GAC systems that treat drinking water.

Design Cost Information —

Much of the analysis and cost information contained in this section of the full report are based on the four-

Table 1. *Summary of GAC System Characteristics*

Case No.	Owner	Type of Facility	Flow, mgd	Pretreatment	Carbon Contactors		Rated Capacity, lb/carbon/da
					Contact Time, min	Hydraulic Loading, gpm/ft	
1	South Tahoe	Municipal wastewater	7.5 (max)	Extensive	17	6.5	6,000
2	Tahow-Truckee	Municipal wastewater	4.83 (max)	Extensive	20		3,840
3	Upper Occoquan	Municipal wastewater	15.0 (avg)	Extensive	22	8.4	12,000
4	American Cyanamid	Chemprocess	20.0 (avg)	Extensive	30	8.0	122,000
5	Vallejo	Municipal wastewater	13.0 (avg)	Moderate	25	6.0	29,000
6	Orange County	Secondary effluent	15.0 (max)	Extensive	34	5.8	12,000
7	Niagara Falls	Municipal w/ significant industrial	48.0 (avg)	Moderate	40	1.67	—
8	Fitchburg[c]	Municipal w/ significant industrial	15.0 (avg)	Moderate	15	8.00	—
9	Arco Petroleum	Process waters w/significant industrial	4.32 (max)	Minimal	56	1.74	8,500
10	Rhone-Poulenic	Herbicide production wastes	0.15 (max)	None	87	2.00	8,500
11	Reichhold Chemicals	Chemical production wastes	1.0 (max)	Moderate	100	1.55	32,500
12	Stepan Chemicals	Surfactant production wastes	0.015 (max)	None	500	—	6,480
13	Republic Steel	Coke process wastes	0.95 (max)	Minimal	116/58	2.3/4.6	68,000
14	LeRoy	Municipal	1.0 (max)	Extensive	12	—	12,000
15	Manchester	Water supply	40.0 (max)	Moderate	14	—	12,000[d]
16	Passaic Valley[a]	Water supply	2.2 (max)	Extensive	8	—	2,400
17	Colorado Springs	Secondary effluent	2.0 (max)	Extensive	17	4.5	1,800
18	Hercules	Chemical production wastes	3.25 (max)	Moderate	48	6.6	33,600
19	Industrial Sugar	Decoloring sugar	—	Minimal	1080	—	12,000
20	Hopewell	Water supply	3.0 (mg)	Moderate	—	2.0	None
21	Davenport	Water supply	30.0 (max)	Moderate	7.5	2.0	None
22	Sprekles Sugar	Sugar thick juice	—	None	20	—	15,000

[a] Not available.

[b] Data not collected.

[c] Facility under construction.

[d] Fluidized bed.

Furnace			Activated Carbon Dose		Costs		
					Capital		
Carbon Loss, %	Fuel Type	Use, Btu/lb carbon	lb/mil gal	lb organic/ lb carbon	Capital, $1000 (year)	$/lb/day of capacity	O&M, $/mil gal year
8	Gas	2,900	207	0.38	849 (1969)	141.50	36.07 (1979)
5	Propane	3,840		0.33	1,569 (1976)	408.59	N/A[a]
10	LPG	2,750	250	0.33	3,880 (N/A)	323.33	50.00 (1979)
9	—[b]	—	—	—	N/A	—	N/A
7.5	—	—	1,410	0.50	4,359 (1974)	150.31	N/A
6	Natural gas	5,600	—	1.70	3,307 (1972)	275.58	90.49 (1979)
—	—	—	—	—	N/A	—	N/A
5	—	—	—	—	N/A	—	N/A
5	Natural gas	—	1,000	0.26	1,000 (1971)	117.65	490.00 (1973)
8.8	Natural gas	6,500	43,000	0.38	300 (1969)	35.69	319.00 (1973)
5	Natural gas	6,200	79,000	0.26	N/A	—	N/A
6	LPG	6,000	500,000	—	225 (1973)	34.72	25,000 (1978)
8	Natural gas	—	35,000	—	N/A	—	N/A
—	Fuel Oil	—	—	—	2,500 (1975)	208.33	N/A
10	Fuel Oil	—	—	—	N/A	—	N/A
10	Electricity	0.7	—	—	N/A	—	N/A
7.5	—	—	160	0.50	N/A	—	89.59
5	Natural gas	7,000	9,500	0.44	1,622 (1973)	48.27	1,470.00
2.5	Natural gas	—	—	—	N/A	—	N/A
—	—	—	—	—	N/A	—	30.00 (1980)
—	—	—	—	—	N/A	—	20.00 (1980)
4.8	Natural gas	1,785	—	—	238 (1958)	15.67	N/A

GAC test facility.

volume report "Estimating Water Treatment Costs" cited earlier. Twelve cost curves, discussed in detail in this report, were developed specifically for GAC applications.

Derivation of Cost Curves —

The construction cost for each unit process was presented as a function of the process design parameter. This parameter was determined to be the most useful and flexible under varying conditions, such as loading rate, detention time, or other conditions that vary because of designers preference or regulatory agency requirements. For example, the contactor construction cost curves were presented in terms of cubic feet of contactor volume, an approach that allows various empty bed contact times (EBCT) to be used. Contactor O&M curves were presented in terms of square feet of surface area, because O&M requirements are more appropriately related to surface area rather than contactor volume. Reactivation facility cost curves were presented in terms of square feet of hearth area for the multiple hearth furnace and pounds per day of reactivation capacity for the other reactivation variables. This allows the loading per square foot of hearth area to be varied for the multiple hearth furnace and for design of reactivation furnaces at rates less than the reactivation capacity. This approach provides greater flexibility in the use of the cost curves than if the costs were related to water flow through the treatment plant.

For the majority of the unit processes, three separate figures were used to present construction and O&M curves. The first graph presented the construction cost; the second graph, energy (electrical, natural gas, and diesel fuel) and maintenance material requirements; and the third graph, labor requirements and total O&M cost.

Treating water with GAC involves two major and separate process operations: filtration and reactivation. The water comes in contact with GAC by passing through a structure filled with activated carbon granules. Impurities are removed from the water by adsorption when sufficient time is provided for this process. The structure can be either a water treatment filter shell in which the filter media has been replaced with GAC, or in independent carbon adsorption system. A separate adsorption system usually consists of a number of columns or basins, used as contactors, that are connected to a reactivation system. After a period of use, the GAC's adsorptive capacity is exhausted, and it must then be taken out of service, either by replacement with new carbon or by being reactivated by combustion of the organic adsorbate. Carbon is routinely added to the system to replace that lost during hydraulic transport and reactivation. These losses include both losses caused by physical deterioration and by burning during the reactivation process.

In the report, cost estimates have been prepared for the use of GAC as a replacement for existing filtration media (sand replacement) and as a separate adsorption system (post-filter adsorption). On-site multiple hearth reactivation was assumed. Standard levels of key design parameters were set at predetermined levels and then one variable at a time is changed to determine its effect on system cost. Figure 1 shows the cost of both sand replacement and post-filter adsorption systems versus plant capacity.

Conclusions

Some conclusions resulting from the inspection of 22 operating GAC absorption and reactivation systems and a study of the costs involved are:

1. A substantial number of GAC installations have been operating sucessfully for many years. These installations include facilities that treat water and wastewater and that process food and beverage products.
2. Although long-term use of GAC and PAC by municipal waterworks and industries has been widespread, no adverse health effects have been reported.
3. GAC treatment of public water supplies to remove trace organics is fairly new. Only limited direct design data or cost information are available.
4. GAC treatment of public water supplies for taste and odor control or for color removal is practiced in about 46 cities in the United States. In this application of GAC, however, little need for reactivation and little experience with on-site reactivation exists.
5. The four reactivation studies that EPA presently sponsors concern installations in Cincinnati, OH; Manchester, NH; Jefferson Parish, LA; and Passaic Valley, NJ.

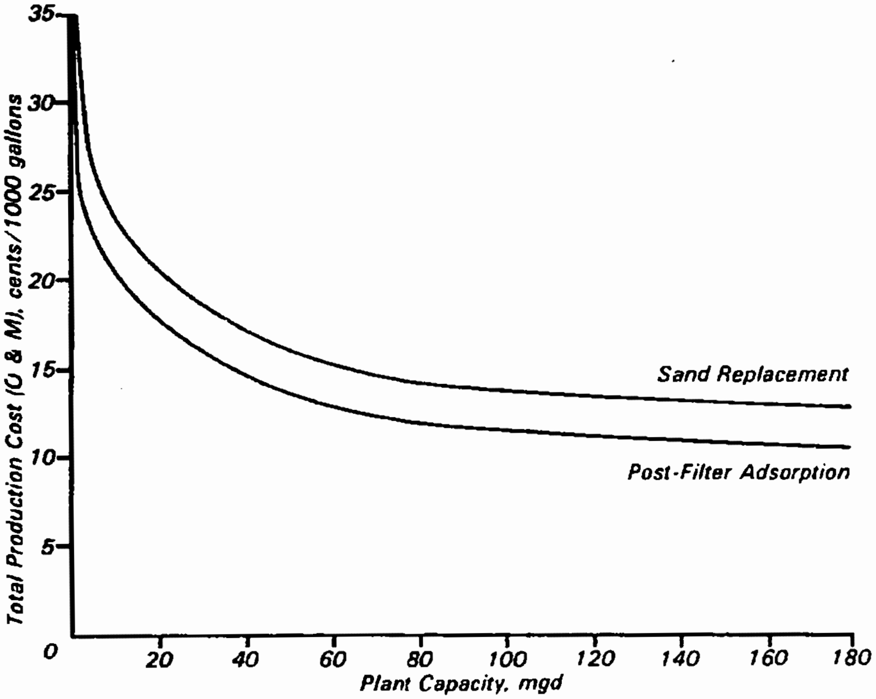

Figure 1. *Total production cost versus plant capacity for post-filter adsorption and sand replacement systems.*

6. Twenty to thirty GAC installations in food processing plants (corn syrup and beet sugar) give insight concerning the safety of GAC but add little need to the available cost data. Some design ideas and information can be obtained from these sources.
7. Twenty to thirty GAC reactivation furnaces in industrial water pollution control plants yield some information on operation and cost of GAC systems.
8. The best sources of detailed cost information and equipment design data are the 20 or so operating municipal advanced waste treatment (AWT) plants using GAC.
9. Pilot plant testing of GAC adsorptive and reactivation characteristics in municipal water treatment plants can be combined properly with the known costs of GAC systems in wastewater treatment to yield a design basis and preliminary cost estimates that are satisfactory for developing water treatment projects. Designers should take full advantage or applicable GAC use and experience available from:
   - municipal water treatment for taste and odor control,
   - municipal AWT,
   - industrial wastewater treatment, and
   - food and pharmaceutical production.

The full report was submitted in fulfillment of Contract No. CI-76-0288 by Culp/Wesner/Culp, Cameron Park, CA, under the sponsorship of the U.S. Environmental Protection Agency.

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