

## **CHOOSING AN ODOR CONTROL TECHNOLOGY – EFFECTIVENESS AND COST CONSIDERATIONS**

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### **ABSTRACT**

When decisions are made on an odor control technology, there are always two determinants that go into the final decision: odor removal effectiveness and cost. The former is one-way manufacturers generate interest in their products. However, it still comes down to cost as to whether a specific technology or product is ultimately approved or rejected. Equal emphasis should be placed on both. While cost is very important, minimum performance criteria should be established. If a system costs less but offers a lower performance as well, it may or may not be cost efficient to save money on the front end. Cost evaluations are performed here to show a method of comparing technologies. Then an example scenario in which the criterion was to remove odorous gases below odor thresholds is presented to show a successful application of technology.

Various odor control systems are cost effective at different airflows and different concentration levels. This paper presents advantages and disadvantages of five odor control technologies (wet scrubbers, biofilters, engineered media, granular activated carbon (GAC), and catalytic/regenerative carbon). Wet scrubbers have been shown to be an effective choice in high air velocity and flow applications. Dry-scrubbing technologies (engineered media, GAC, and catalytic/regenerative carbon) can be very effective at lower air velocities and have the ability to remove contaminant gases with high efficiencies. Biofilters have been shown to be effective at lower air velocity regions with the ability to have long media life.

Cost comparison can be presented in several different ways. Cash Flow Analysis is proposed for determining which technology is the most cost effective. This type of analysis allows the end user to determine the actual cost of a system as a function of time. A comparison of the different technologies by initial cost, utility/maintenance cost, and accumulated cost, allows the customer to make a sound economic decision based upon his present needs and budgetary constraints. The contaminant most frequently cited in odor control applications is hydrogen sulfide and it is used for the Cash Flow Analysis in this paper. Two cash flow analyses were performed, a biofiltration application as a calculation example and a dry-scrubbing application as a comparison of two technologies. The biofiltration analysis showed a low maintenance cost for the system in terms of media replacement. The dry-scrubbing analysis determined engineered media to be more economical than catalytic/regenerative carbon in terms of initial investment and future cost for anywhere from 15 to 27 years. The catalytic/regenerative carbon showed less maintenance cost in terms of media replacement.

## **KEYWORDS**

Odor Control, Cost Effectiveness, Cash Flow Analysis, Gas-Phase Filtration

## **INTRODUCTION**

Odors are a very subjective yet very powerful problem for owners and operators of wastewater treatment facilities. Municipalities experiencing constant complaints from residents neighboring a treatment facility or collection system, face lawsuits unless actions are taken to eliminate or significantly reduce odors. Since odors are something subjective defining if an odor problem has been solved can be a difficult task. First, there is the contaminant gas concentration, which is the concentration of contaminant gases in the ambient air. Second is the odor intensity, which is a measure of detection sensed by the nose. Odor intensity can be the effect of one gas or the combined effect of many gases. It has been shown that odor intensity does have a positive correlation to gas concentration, but reductions in gas concentrations do not always indicate similar reductions in odor intensity (Schmidt, 1995). Therefore, both odor intensity and gas concentration must be taken into account when the effectiveness of an odor control system is evaluated.

There are many ways to approach controlling an odor in wastewater facilities. These different approaches are: dilution, removal of the offending substances, or counteraction or masking (Crocker, 1985). Dilution can be used when the contaminated area is enclosed and there is a source of uncontaminated air nearby to pump into that enclosed area. At wastewater facilities or pump stations, dilution is not generally effective because there is no source of clean air and the odor is not localized to an enclosed space. The technologies left are counteraction and removal of the odor. Counteraction sprays are many times used on large open areas to react with the contaminants, to mask the odor of the contaminants, or keep the odorous contaminants from volatilizing. Removal of the offending substances can be used if the odor source can be captured or focused into a removal system. The technologies that are discussed in this paper concentrate on such systems that remove offending substances from the odorous air.

In choosing an odor control technology, many items need to be evaluated. These items are: collection efficiency, ease of reuse or disposal of recovered material, ability of collection to handle variations in gas flow and loads at required collection efficiencies, equipment reliability and freedom from operational and maintenance attention, and initial investment and operating cost (Crocker, 1985). Of course, removal of the odor should be the ultimate goal of any odor control system. All of these items will not be discussed in depth. Instead, a brief description of each technology with advantages and disadvantages, including some of these evaluation items, will be given. Cash flow analysis will be performed on a couple of scenarios to show how the analysis is performed and how operational costs as well as initial investments can be used to compare systems. Finally, some efficiency and odor intensity data will be given for one successful system to show that odor removal can be achieved.

**ODOR CONTROL TECHNOLOGIES COVERED**

The odor removal technologies that will be discussed here are wet scrubbers, biofilters, and dry-scrubbers (including granular activated carbon, regenerative/catalytic carbon, and engineered media). One key difference between these is the flow capacity. Table I presents a comparison of sample velocities for each of these technologies. It is evident from the information that wet scrubbers can handle the highest flow and then dry-scrubbers and biofilters come consecutively next. A brief overview of each technology will be given for comparison of the technologies themselves. Then cash flow analysis will be performed on an application employing biofiltration and on two proposed dry-scrubbing systems for a headworks application. The emphasis of economic comparison will be given to these two types of dry-scrubbing media: catalytic carbon and engineered media.

**Table I – Sample Velocities for Odor Control Technologies (Duffee, 1991)**

Odor Control Technology	Face Velocity	
	m/s	fpm
Packed Tower Wet Scrubber	1.52 – 2.54	300 - 500
Dry-Scrubber	0.13 – 0.51	25 - 100
Biotower	0.14 – 0.27	27 - 54
In-Soil Biofilter	<0.06	<12

**Wet Scrubbers**

Wet scrubbers use the process of absorption as well as chemical reaction (normally oxidation) to remove gases from contaminated air/gas streams. The contaminated air is intimately contacted by a solvent in which the odorous gases are soluble and they are thus transferred from the gas phase into the liquid phase. Clean air is expelled while the contaminants are oxidized or chemically treated some other way in the solvent medium (McEnhill, 1991).

There are two basic types of wet scrubbers. One type seeks to promote contact between a liquid solvent and contaminant gases by atomizing the solvent. This provides a large amount of surface area for the gases to contact through the small droplet size of the solvent. A 15 to 30 second contact time is provided for the odorous gases to be transferred into the liquid phase. The second type promotes intimate contact between odorous gases and the liquid solvent by use of packing material. This packing material slows the liquid’s descent through the tower, creates a large liquid surface area, and causes thorough contact between the liquid and gas (Kruse, 1991).

Some disadvantages and advantages of wet scrubbers are shown in Table II. Disadvantages of wet scrubbers are generally on the maintenance side. One common problem is the gradual fouling of the packing surface. In areas with hard water, this is more of a problem because of the tendency to form deposits. Bacterial fouling of the packing can occur in systems operating in the pH range of 3 – 10. However, both of these can be solved and prevented if properly scheduled maintenance is performed (Kruse, 1991). As indicated, frequent preventive maintenance may be needed in various wet scrubber applications and this is a drawback for the technology. Costs of

water addition and disposal of the caustic solution used in a wet scrubber are further items to consider on the disadvantage side (Crocker, 1985).

**Table II – Some Advantages and Disadvantages of Wet Scrubbers**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- chemical costs at high flows</li> <li>- high air flow capabilities</li> <li>- versatility for various gases</li> </ul>	<ul style="list-style-type: none"> <li>- fouling of packing surface</li> <li>- cost of water addition</li> <li>- disposal of caustic solution</li> <li>- maintenance of equipment</li> </ul>

As compared to the other technologies here, wet scrubbers are most generally thought to handle the highest airflows. Table I displays sample face velocities of the different technologies ordered from highest to lowest. Packed tower wet scrubbers can range from approximately 1.5 – 2.5 m/s (300 – 500 fpm). This is 5 times greater than that handled by a dry-scrubber and 9 times greater than the flow handled by a biofilter. In fact, this is what plays into the advantages of a wet scrubber. Although, many times they are not used at lower flows, at high flows there really is not an alternate technology. The chemical cost at these high flows is much less than the required media cost if biofiltration or dry-scrubbing were used. Wet scrubbers can also be very versatile in the types of contaminants treated by the variety of liquid chemicals used.

### **Engineered Dry-Scrubbing Media**

Engineered Media is one of the three types of dry-scrubbing technologies discussed here (engineered media, granular activated carbon, and catalytic carbon). It is distinguished from other dry-scrubbing media in that the manufacturing process forms the media from base materials while impregnating it with specific impregnants. This produces a product in which the chemical reactant is uniformly distributed throughout and which has proper pore structure for capturing the contaminant gases (Muller). The materials used (activated alumina, sodium bicarbonate, etc.) not only provide adsorptive capabilities for contacting contaminants, but also aid in sustaining the chemical properties of the media so that it may react with target gases.

Many times engineered media are designed for specific gases or types of gases. However, the most common impregnant in engineered media is potassium permanganate, which oxidizes a wide range of gases (NAFA, 1996). This is both an advantage and disadvantage of engineered media, because it can have good capacity for gases that are not well adsorbed, but less capacity for high molecular weight gases that are preferentially removed by adsorption (see **Granular Activated Carbon (GAC)** below).

Engineered media utilizes chemisorption to remove contaminants from an air/gas stream. Chemisorption can be thought of as a means of converting an objectionable or hazardous chemical to a less objectionable form. It involves adsorption, absorption, and chemical reaction. These three work together to remove gases that are not removed well by physical adsorption. This is one benefit of engineered media, the chemical reaction of the impregnant is instantaneous and irreversible, resulting in stable organic and inorganic salts which remain bound to the media (NAFA, 1996). Thus, the gases that have been removed by chemisorption cannot desorb back

into the air stream. Chemisorption generally works better at higher temperatures and humidities. This is because higher temperatures allow for the reaction rates to increase and higher humidity allows more of a chance for the adsorbed gas to contact the impregnant (NAFA, 1996).

Some disadvantages as well as advantages of engineered media systems are shown in Table III. Engineered media cannot be regenerated because it removes contaminants by chemical reaction. Once it is spent it must be replaced with new media. The price per pound is not as low as commodity types of dry-scrubbing media (activated carbons). Engineered media also has many properties which give it inherent benefits. Engineered media is generally disposed of in a landfill because the contaminants are converted to non-toxic salts. It is UL Rated for flammability, so it will not spontaneously ignite. Media life analysis can be performed on engineered media to give an indication of how much longer the media should last. As dry-scrubbing media, it can achieve very high efficiencies for properly designed systems (>99.9%, see section entitled **ENGINEERED MEDIA PERFORMANCE DATA**). Lastly, versatility for contaminants can be achieved by varying or blending the media type used.

**Table III – Some Advantages and Disadvantages of Engineered Media**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- chemisorption</li> <li>- high efficiencies can be achieved</li> <li>- media life analysis</li> <li>- UL rated for flammability</li> <li>- versatility</li> </ul>	<ul style="list-style-type: none"> <li>- low capacity for gases purely adsorbed</li> <li>- non-regenerative</li> <li>- price per pound higher than activated carbons</li> </ul>

These high efficiencies are achieved in part by using bulk beds of media. These are typically 12 or more inches deep and handle maximum face velocities of 0.51 m/s (100 fpm). These conditions provide the minimum residence time required for high efficiencies. These air flows are 5 times less than those for wet scrubbers and 2 times greater than those of biofilters (see Table I).

**Granular Activated Carbon (GAC)**

Granular Activated Carbon (GAC) is another of the dry-scrubbing technologies discussed here. It utilizes the process of adsorption to remove contaminant gases from an air stream. Adsorption can be described as the process by which gas molecules (the adsorbates) are attracted and held to the surface of a solid (the adsorbent). As just mentioned, adsorption takes place on the surface of the adsorbent and is therefore related to the surface area of the material. GAC is manufactured to have a very high surface area to mass ratio by permeating the dense material with a system of pores. These pores provide the capacity for the adsorption of contaminant gases. The surface area of activated carbon can be as high as 1,400 m<sup>2</sup>/g (47,500 yd<sup>2</sup>/oz) (NAFA, 1996).

The strength with which the carbon holds the gas onto its surface is based on the attractive forces between the two (McEnhill, 1991). As adsorption is a surface phenomenon, it is totally reversible (the reverse of adsorption is termed desorption), and this is one of the disadvantages of GAC. The rate at which activated carbon adsorbs or desorbs is affected most by the temperature

and relative humidity of the air stream. Adsorption occurs more readily at lower temperatures and humidities while the opposite is true for desorption. At approximately 60% relative humidity (RH), the water content of activated carbon goes up to 25% by weight (NAFA, 1996). Therefore, quick rises in RH can cause activated carbon to desorb gases in order to adsorb water.

It is well known that activated carbon has a good affinity for high molecular weight (>80) and polar gases. This is an advantage as well as disadvantage for GAC. Other media will not remove higher molecular weight organic compounds with the capacity that GAC will. However, this preference for these chemicals is to the extent that it may prefer them over others in the air stream. Therefore, it may desorb the non-preferred gases in order to adsorb high molecular weight/polar gases (NAFA, 1996).

More disadvantages as well as advantages for GAC are shown in Table IV. It is flammable and therefore can be a source of combustion in the dry-scrubbing system. If one of the gases being removed is a flammable gas or the environment is very dry and hot, a GAC bed may spontaneously combust. Finally, since the workhorse for GAC is adsorption, the chemical nature of the substances removed does not change. Many times this causes the disposal of spent media to be hazardous and special precautions must be taken.

**Table IV – Some Advantages and Disadvantages of GAC**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- capacity for high molecular weight organics</li> <li>- familiar product</li> <li>- high efficiency can be achieved</li> <li>- inexpensive media</li> </ul>	<ul style="list-style-type: none"> <li>- desorption, caused by increase in RH &amp;/or temperature preferential gases</li> <li>- flammability</li> <li>- spent media may be hazardous</li> </ul>

On the other side, it is a very well known product and does not require much technical explanation as to how it operates. It is also one of the most inexpensive dry-scrubbing media, which has made it an attractive choice for multiple applications. A common thread in dry-scrubbing technology is that good efficiency can be achieved if deep bed systems are used. This applies to GAC also. If the media is applied where effective and the system is designed correctly, high efficiencies (>99.9%) can be achieved.

The ability of GAC system to have a high efficiency is also based on the residence time in the media bed. Therefore, bulk media beds of GAC typically handle much lower flows than wet scrubbers, up to 0.51 m/s (100 fpm). This flow is approximately 5 times less than that of wet scrubbers and approximately twice as much as biofilters (see Table I).

### **Catalytic/Regenerative Carbon**

Catalytic/regenerative carbon is the last type of dry-scrubbing technology covered here. It is different from GAC in that it can both adsorb gases as well as catalyze reactions (oxidation). Some of the disadvantages of adsorption with GAC also pertain to catalytic carbon, however the benefit of reacting with gases that are not preferred by the GAC is added. As a brief definition, a

catalyst is a material of which a small percentage significantly affects the rate of a reaction without itself being consumed. This is the advantage of a catalyst material, it is not consumed by the reaction. A typical industrial catalyst may last between 1,000 and 10,000 hours and then need to be disposed of or regenerated. This is because the catalyst can become poisoned by some compound or deposit taking up the surface area of the catalyst, in the same way that lead gasoline poisons a catalytic converter and makes it useless (NAFA, 1996). Similarly, different gaseous compounds may poison the catalytic/regenerative carbon.

Traditional catalysts are normally applied as pure catalyst or on an inert substrate. Catalytic carbon is neither inert nor a pure catalyst. Therefore, it may adsorb some of the reaction products or contaminant gases (NAFA, 1996). This can serve both as an advantage and disadvantage. For odor control, it helps reduce odors by removing more of the contaminants, but it also utilizes surface area on the carbon and reduces the capacity for other compounds to be oxidized. This is one reason that the catalytic carbon must be regenerated, to remove any adsorbed compounds that are taking up surface area.

Some disadvantages and advantages of catalytic carbon are shown in Table V. Desorption is still a possibility if there is an increase in RH or Temperature. However, its probability is lessened from that of GAC by the catalytic reactions. Regeneration does allow the media to have a longer life, but typically also decreases the capacity of the carbon by changing the surface of catalytic sites. Flammability may also still be a concern, especially in dry air streams and high temperatures. Lastly, the initial costs can be high for such systems. Other advantages of catalytic carbon are that it is able to realize a long life for the media, because of the previously mentioned properties and that good efficiencies can be achieved as in GAC applications.

**Table V – Some Advantages and Disadvantages of Catalytic Carbon**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- capacity for high molecular weight organics</li> <li>- adsorption and catalysis</li> <li>- high efficiency can be achieved</li> <li>- long life of media</li> </ul>	<ul style="list-style-type: none"> <li>- desorption possibility</li> <li>- flammability</li> <li>- high initial cost</li> <li>- regeneration negatively impacts capacity</li> </ul>

As with the other dry-scrubbing systems, the ability of a catalytic carbon system to operate at high efficiency is a function of the residence time in the media bed and how much media is in the path of the air stream. Therefore, bulk catalytic carbon beds typically handle much lower flows than wet scrubbers, up to 0.51 m/s (100 fpm). This flow is approximately 5 times less than that of wet scrubbers and approximately twice that of biofilters (see Table I).

**Biofilters**

Biofiltration uses the process of biological degradation to remove odorous gases from a contaminated air/gas stream. The contaminants in the air stream are adsorbed onto the medium or absorbed by the water which is present and then degraded by the biological processes of the media (Duffee, 1991). There are basically two types of biofilters: in-soil filters and biotowers. In-soil filters typically apply the medium to a land surface and distribute the contaminated air

stream underneath it through perforated piping. Biotowers apply the medium in a vessel through which the contaminated air makes its way with a minimum residence time (Duffee, 1991).

Table VI displays some of the advantages and disadvantages of biofiltration systems. One disadvantage of biofiltration systems in the tower form is that flow channeling can occur. Uniformity of air flow through the system is very important to biofilter performance. Channeling can result in a reduced residence time through the system, which reduces odor removal efficiency. Then the media sections that do not contact as much air suffer from depletion of oxygen, which upsets the microbiological activity. In wet and dry scrubbing, substrate uniformity is not such an issue. This is due to the homogeneity of the media/packing and less fluctuations in moisture levels. In worst case scenarios, channeling can lead to emission of an odor from the media itself. This is due to the drastic upset of the microbiological activity and anaerobic conditions. Other disadvantages are that systems may require a period of gas conditioning and that the bacteria in the microbiological media, can be sensitive to changes in inlet conditions (Duffee, 1991). Although biofilters are capable of versatility, some applications have shown that mercaptan and organic sulfide removal efficiencies decrease over time to unacceptable levels due to pH changes in the media (Greer, 2000).

**Table VI – Some Advantages and Disadvantages of Biofiltration**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- good efficiency can be achieved</li> <li>- high odor removal possible</li> <li>- low operating cost can be achieved</li> <li>- versatility</li> </ul>	<ul style="list-style-type: none"> <li>- gas conditioning may be required</li> <li>- potential for flow channeling</li> <li>- relatively large footprint</li> <li>- removal life for organic sulfides and mercaptans</li> <li>- sensitivity of bacteria to inlet conditions</li> </ul>

Biofilters cover the lower range of air face velocities, 0.06 – 0.27 m/s (12 – 54 fpm), as shown in Table I. Wet scrubbers can handle flows 9 times greater than these and dry-scrubbers can handle flows almost double the amount. At these lower velocities, biofilters can handle some high concentrations of H<sub>2</sub>S (>200 ppm). However, to get greater volume flows, >340 m<sup>3</sup>/hr (>200 cfm), multiple biotowers must be used in parallel or the in-soil biofilter must be used. If each biotower has a diameter of 1.8 m (6 ft), this can make a foot print of more than 2.6 m<sup>2</sup> (57 ft<sup>2</sup>). When compared to the high flow wet scrubbers, this is not very much. However, when compared to a dry-scrubber, which can handle 850 m<sup>3</sup>/hr (500 cfm) at 0.65 m<sup>2</sup> (7 ft<sup>2</sup>), this is a large footprint.

Advantages of biofilters include the previously stated ability to handle high concentrations of H<sub>2</sub>S, (>200 ppm). Another advantage is that low maintenance costs in terms of media replacement can be achieved. These are a result of the media having a long lifetime, typically 3 to 5 years. Other advantages are that high odor removal abilities can be realized in percentage and total amount. There have been cases for which a biotower has reduced average concentration of H<sub>2</sub>S from 220 ppm to 1 ppm (99.4% efficiency) and peak concentrations from 700 ppm to 1 ppm (>99.8% efficiency) (Greer, 2000). Lastly, it has been stated that systems can be versatile by using various strains of bacteria in the media (Duffee, 1991).

## CASH FLOW ANALYSIS

Past history of price changes in the United States suggests that a minimum annual inflation rate of 3% and maximum of 7% can be expected for the near future (Peters, 1991). This inflation factor should always be taken into account when presenting design estimates of cost. Here an inflation factor of 5% is used as an average between the minimum and maximum. The method of using future cost is presented here. The future cost of a value can be determined by the following equation (Peters, 1991):

$$S = PC$$

In this equation  $S$  represents the future cost of the value,  $P$  represents the present value, and  $C$  represents the compound interest factor. The present value ( $P$ ) is a known rate or cost for the present period of time. The compound interest factor ( $C$ ) is calculated from the periodic interest rate ( $i$ ) and the number of periods ( $n$ ) into the future, as shown below (Peters, 1991). In the calculations performed here, the periodic interest rate ( $i$ ) is an annual interest rate and so the periods ( $n$ ) are years in the future.

$$C = (1 + i)^n$$

System cost is estimated by calculating the impact of inflation on the present value of costs (initial cost, replacement media cost, utilities and maintenance expenses). These inflated costs are summed over a certain period of time (expected life of a system, etc.) to provide an estimated system cost. The annual accumulation of this cost can be logged to show a cash flow over time for the system. This accumulation of cost over time is used here to estimate system cost and is thus called the Cash Flow Analysis.

### Cash Flow Analysis for a Biofiltration System: An Example

An installed system for removal of sulfide odors is described in Table VII below (Greer, 2000). This system removed hydrogen sulfide levels of 220 ppm with an air flow of 200 cfm. The total equipment cost was \$32,740 and the media cost was a total of \$2,100. This media was given a life range of 3 to 5 years. The operating cost of the system involves electricity and humidity costs for the system. This was estimated to be \$1,630 per year. The system was definitely chosen for its low economic cost and effectiveness, in the range of contaminants and concentrations to be seen. However, after installation it was discovered that organic sulfides were still causing odor problems. Therefore, a dry-scrubber was added onto the system to take care of organic sulfides. An estimated cost for the dry-scrubber system is also shown in Table VII. The initial cost is \$1,800 and media replacement cost is \$435 with a life estimate of 9 months.

**Table VII – Parameters for Cash Flow Analysis: Biofiltration System**

<b>Biofilter</b>	
Airflow (cfm):	200
H <sub>2</sub> S Conc. (ppm):	220
Equipment Cost:	\$ 32,740
Media Cost:	\$ 2,100
Media Life (months):	36
Operating Cost (\$/yr):	\$ 1,630
<b>Polishing Scrubber</b>	
Initial Cost:	\$ 1,800
Media Replacement:	\$ 435
Media Life (months):	9

A cash flow analysis has been performed on this system as an example of determining the future cost of a system by cash flow analysis. It can also serve as a benchmark cost for similar cases. The cash flow analysis is shown in Table VIII for the total system (biofilter and dry-scrubber). The future cost of this system over the 3-year life is determined to be \$46,272.46.

In year 0, the initial cost of \$36,640 is paid. This is composed of the biofilter equipment cost of \$32,740, the biofilter media cost of \$2,100, and the dry-scrubber initial cost of \$1,800. Since that sum is paid out in year 0, there is no inflation factor. So the inflated cost and the accumulated cost equal the initial cost. During year 1 of operation, the media replacement cost is set aside. This is made up of a biofilter media cost that would be realized at the end of 3 years annualized to \$700 per year (\$2,100/3 years) and the dry-scrubber media cost annualized to \$580 per year ([(\$435/9 months)\*12 months). The utilities and maintenance cost for year 1 are \$1,630, as estimated by the end user. These two costs, media replacement and utilities/maintenance, are summed and multiplied by the inflation factor of 1.05 to equal the inflated cost of \$3,055.50. This inflated cost is added to the previous year's cost to yield a new accumulated cost of \$39,696.50. This same process is performed for the remaining two years to give the final future cost of \$46,272.46

**Table VIII – Biofiltration System Cash Flow Analysis (200 cfm, 220 ppm)**

Year	Inflation Factor (5%)	Initial Cost & Media Replacement	Utilities/ Maintenance	Inflated Cost	Accumulated Cost
0	1.00	\$ 36,640.00	\$ -	\$ 36,640.00	\$ 36,640.00
1	1.05	\$ 1,280.00	\$ 1,630.00	\$ 3,055.50	\$ 39,695.50
2	1.10	\$ 1,280.00	\$ 1,630.00	\$ 3,208.28	\$ 42,903.78
3	1.16	\$ 1,280.00	\$ 1,630.00	\$ 3,368.69	\$ 46,272.46

**Cash Flow Analysis for Dry-Scrubbers: A Comparison**

Displayed in Table IX are the parameters of two dry-scrubbing systems proposed for installation in the headworks area of a plant. The design parameters for these units were an inlet airflow of 6,000 cfm and a H<sub>2</sub>S concentration of 2 ppm. The two types of systems evaluated here are a regenerative/catalytic carbon system and an engineered media system.

The catalytic carbon system had an initial cost of \$200,000 and a media life estimate of 120 months (10 years). It is obvious that the purpose of this system is to pay for itself through a long media life and thereby not having to buy replacement media except every 10 years. The other system displayed utilizes engineered media for the removal of H<sub>2</sub>S. It has a media life estimation of 34 months (2.8 years).

So the question lingers of whether it is more cost effective to use the system that takes benefits from regenerative abilities or the system that has less initial cost, but requires media replacement more often. The only way to truly answer this question is to look at the time value of money. This method allows the end user to evaluate the cost of a system by initial cost, maintenance cost, and accumulated future cost to compare with their budgetary constraints.

**Table IX – Parameters for Cash Flow Analysis: Dry-Scrubbing Systems**

Airflow (cfm):	6,000
H <sub>2</sub> S Conc. (ppm):	2
<b><i>Catalytic/Regenerative Carbon System</i></b>	
Initial cost:	\$ 200,000
Media Life (months):	120
Blower Power (kW):	2.2
Electricity Rate (\$/kW-hr):	\$ 0.077
<b><i>Engineered Media System</i></b>	
Initial cost:	\$ 75,000
Media Replacement:	\$ 23,000
Media Life (months):	34
Blower Power (kW):	2.2
Electricity Rate (\$/kW-hr):	\$ 0.077

A cash flow analysis for each system is displayed in Tables X and XI. The same process as that used for the biofiltration system was used for these calculations. At the end of 10 years, the accumulated cost for the engineered media system is \$201,537.70 and the accumulated cost for the catalytic carbon system is \$219,329.66. So in terms of future cost, the engineered media system is approximately \$18,000 less than the catalytic carbon system. This does not factor in a yearly amount for media replacement on the catalytic carbon system. At the end of this 10<sup>th</sup> year, the catalytic carbon system system’s media would need to be replaced and this would incur another jump in cost. If this media replacement cost is estimated then the cash flow analysis can be extrapolated out further to see where the accumulated costs would cross..

**Table X – Cash Flow Analysis for Catalytic Carbon System (6000 cfm, 2 ppm)**

Year	Inflation Factor (5%)	Initial Cost & Media Replacement	Blower Energy Cost	Inflated Cost	Accumulated Cost
0	1.00	\$ 200,000.00	\$ -	\$ 200,000.00	\$ 200,000.00
1	1.05	\$ -	\$ 1,463.62	\$ 1,536.80	\$ 201,536.80
2	1.10	\$ -	\$ 1,463.62	\$ 1,613.64	\$ 203,150.43
3	1.16	\$ -	\$ 1,463.62	\$ 1,694.32	\$ 204,844.75
4	1.22	\$ -	\$ 1,463.62	\$ 1,779.03	\$ 206,623.79
5	1.28	\$ -	\$ 1,463.62	\$ 1,867.99	\$ 208,491.77
6	1.34	\$ -	\$ 1,463.62	\$ 1,961.39	\$ 210,453.16
7	1.41	\$ -	\$ 1,463.62	\$ 2,059.45	\$ 212,512.61
8	1.48	\$ -	\$ 1,463.62	\$ 2,162.43	\$ 214,675.04
9	1.55	\$ -	\$ 1,463.62	\$ 2,270.55	\$ 216,945.59
10	1.63	\$ -	\$ 1,463.62	\$ 2,384.08	<b>\$ 219,329.66</b>

**Table XI – Cash Flow Analysis for Engineered Media System (6000 cfm, 2 ppm)**

Year	Inflation Factor (5%)	Initial Cost & Media Replacement	Blower Energy Cost	Inflated Cost	Accumulated Cost
0	1.00	\$ 75,000.00	\$ -	\$ 75,000.00	\$ 75,000.00
1	1.05	\$ 8,117.65	\$ 1,463.62	\$ 10,060.33	\$ 85,060.33
2	1.10	\$ 8,117.65	\$ 1,463.62	\$ 10,563.34	\$ 95,623.67
3	1.16	\$ 8,117.65	\$ 1,463.62	\$ 11,091.51	\$ 106,715.18
4	1.22	\$ 8,117.65	\$ 1,463.62	\$ 11,646.09	\$ 118,361.26
5	1.28	\$ 8,117.65	\$ 1,463.62	\$ 12,228.39	\$ 130,589.65
6	1.34	\$ 8,117.65	\$ 1,463.62	\$ 12,839.81	\$ 143,429.46
7	1.41	\$ 8,117.65	\$ 1,463.62	\$ 13,481.80	\$ 156,911.26
8	1.48	\$ 8,117.65	\$ 1,463.62	\$ 14,155.89	\$ 171,067.15
9	1.55	\$ 8,117.65	\$ 1,463.62	\$ 14,863.68	\$ 185,930.83
10	1.63	\$ 8,117.65	\$ 1,463.62	\$ 15,606.87	<b>\$ 201,537.70</b>

Such an analysis was performed and is shown in Figure 1. The replacement cost for the catalytic carbon was estimated from the replacement cost of the engineered media system as a percentage of initial cost (\$23,000 = 30% of initial cost). If this same percentage of initial cost (30%) is used for the catalytic carbon replacement media, the figure is \$60,000. If the catalytic carbon replacement cost is only 15% of the initial cost, the figure is \$30,000. These replacement costs can be annualized to provide a yearly impact on the accumulated cost.

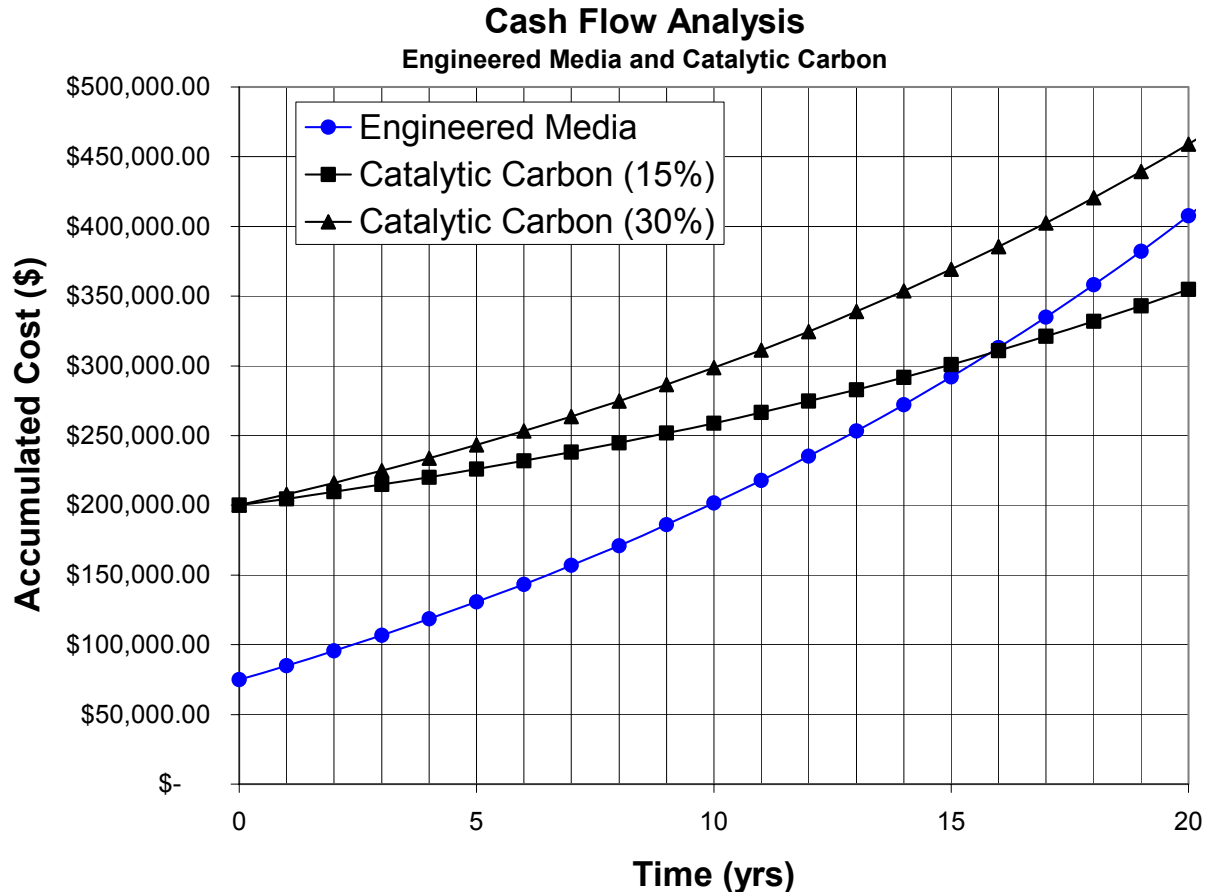
Figure 1 demonstrates that if the catalytic carbon replacement media costs 15% of the initial expense, then the accumulated cost of the engineered media system will not meet that of the

catalytic carbon system until the middle of the 15<sup>th</sup> year. If the catalytic carbon replacement media costs 30% of initial expense, then the accumulated costs do not meet until after year 27 (this point is off the graph). This does not necessarily mean that the catalytic carbon system should be ruled out, but rather these types of results should be considered for proposed systems

The following conclusions can be made purely from economic considerations. If a plant does not have \$200,000 of initial investment capital, but does have approximately \$8,100 in maintenance for annual media replacement, the wiser choice is definitely the engineered media system. If a plant has an abundance of initial investment capital (\$200,000), maintenance savings of approximately \$2,000 to \$5,000 could be realized annually by using the catalytic carbon system. It should be kept in mind that the payback for that investment would be at least 15 to 16 years and may be as long as 27 years.

There are also benefits and shortcomings of each technology that should be evaluated for the specific application. These are given above in the section entitled **Odor Control Technologies Covered**. All factors including budgetary constraints, cash flow analyses, technology benefits and disadvantages, and how these work together for the specific application should be considered in making a decision on the technology. As it usually comes down to cost of a system and ease of employing that system, these two factors should be carefully considered.

**Figure 1 – Cash Flow Analysis of Two Dry Scrubbing Systems**



**ENGINEERED MEDIA PERFORMANCE DATA**

There are several ways to evaluate whether a system will work in a given application. Many topics have been discussed so far as to technical aspects of different odor control technologies and how to compare costs on a cash flow/future cost basis. These should all be considered in choosing a technology for a specific application and budgetary constraint. The last piece of information that can be given is data where a technology has proven to be effective.

Data is presented here for the performance of a system using engineered media. The objective was to remove contaminants below the odor threshold and to qualify this by use of an odor panel to measure odor intensity. The odor thresholds used here are 0.47 – 130 ppb for H<sub>2</sub>S and 2.1 – 41 ppb for methyl mercaptan (Purafil, 2001). This system fulfilled the objectives of removing the odor intensity down to acceptable intensity levels, showing removal efficiencies at peak concentrations of more than 99.9%. The location, setup, and data for this system employing engineered media are shown below.

**Waites Pump Station - Charleston, South Carolina**

The Waites Pump Station in Charleston, SC, is located very close to (actually across the street from) a fairly high-density residential neighborhood. Discharge from the pump station had caused severe odor problems in the past and resulted in complaints from the homeowners.

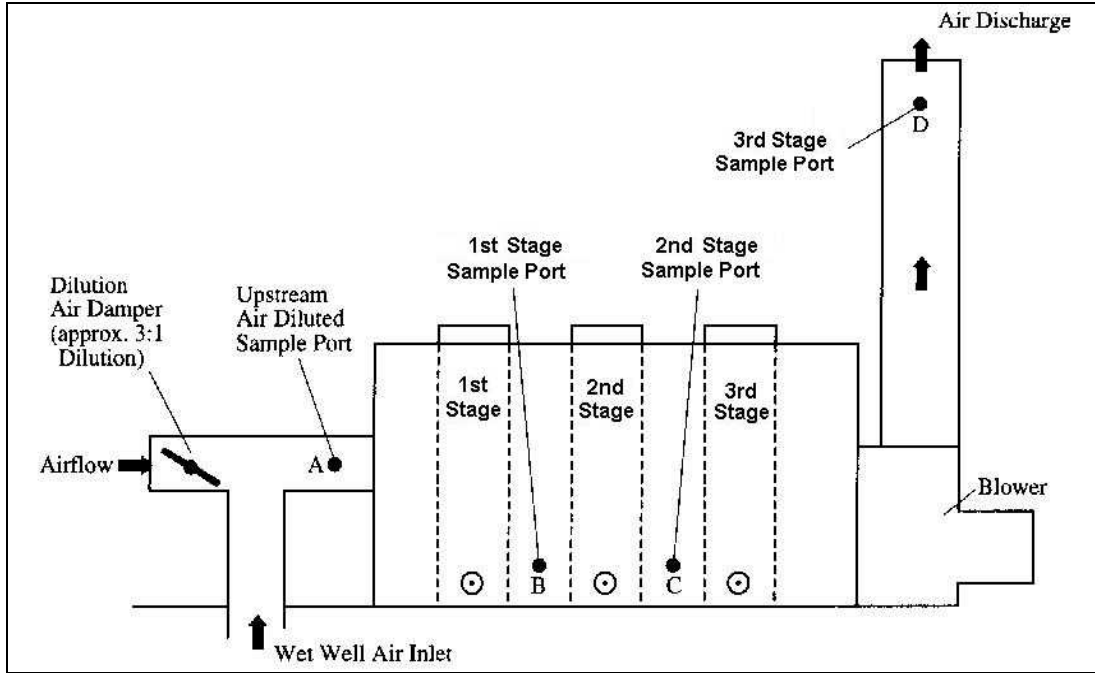
At this pump station, a small deep bed system was installed to remove the odors. The system’s media was changed as scheduled in early summer, and then ran continuously up to September. In September, the system was subjected to independent performance testing performed by Hurst Engineering, Research & Testing Laboratories of Winder, GA. It was noted that the system ran at 0.75 m/s (148 fpm), this is 48% over the recommended face velocity of 0.51 m/s (100 fpm). So this test will show how a system that is designed properly can work above recommended parameters. The test protocol is shown in Table XII. H<sub>2</sub>S was continuously monitored. Grab samples were also taken of H<sub>2</sub>S, methyl mercaptan, and ethyl sulfide and concentrations were measured using analysis by a gas chromatogram. Discharge odor dilution to threshold (D/T) ratios were determined by use of grab samples and a forced choice odor panel.

**Table XII – Testing Protocol for Engineered Media System at Waites Pump Station**

Contaminant	Sampling Points	Sampling Protocol	Analysis Method
H <sub>2</sub> S	Scrubber Inlet Bed Discharge Scrubber Outlet	Continuous	Meloy Sulfur Analyzer
H <sub>2</sub> S Methyl Mercaptan Ethyl Sulfide	Scrubber Outlet	3 "Grab" Samples	Gas Chromatogram
Discharge Odor D/T Ratios	Scrubber Outlet	"Grab" Sample	Eight-Person, Forced Choice Odor Panel

The setup of the deep bed system is shown in Figure 2. The engineered media system consisted of three beds of height 4 ft, width 2 ft, and depth 1 ft. The first two stages employed media targeting H<sub>2</sub>S and other sulfur containing compounds (organic and non-organic). The third stage contained an engineered media impregnated with KMnO<sub>4</sub>, which targets a wide range of gases.

**Figure 2 – Engineered System Setup and Sampling Ports**



Results of the H<sub>2</sub>S monitoring are shown in Table XIII. At the peak inlet concentration of 108.0 ppm, the scrubber discharge concentration was 0.061 ppm. This is greater than a 99.94% removal efficiency, showing how efficient these systems can be and how they can handle load swings. Keeping in mind that the system was operated above the maximum recommended face velocity, the average concentration values show a removal efficiency of still 99.8%. All of the discharge concentrations shown are under the maximum odor threshold concentration for H<sub>2</sub>S (0.130 ppm). The odor intensity of these streams will later be shown through the results of the odor panel.

**Table XIII – Results from H<sub>2</sub>S Monitoring**

Value Type	Port A	Port B	Port C	Port D <sup>a</sup>
Peak Values	108.0 ppm	62.0 ppm	1.6 ppm	0.061 ppm
Low Values	5.3 ppm	3.1 ppm	0.3 ppm	0.017 ppm
Average Values	15.0 ppm	10.9 ppm	0.6 ppm	0.031 ppm

<sup>a</sup> Downstream bags used for D port values, measured with a Meloy H<sub>2</sub>S Analyzer, Model SA285E.

Table XIV shows the results from monitoring for mercaptans and organics. The bag numbers shown correlate with the inlet H<sub>2</sub>S concentration. So bag number 1 correlates to the time when the H<sub>2</sub>S concentration was the average value of 37. This gave the results shown for the mercaptans and organics. All the methyl mercaptan levels shown are also below the maximum odor threshold value (41 ppb). The impact of this removal will also be shown by the odor panel results.

**Table XIV – Results from Mercaptans and Organics Monitoring**

Bag No.	H <sub>2</sub> S Inlet, ppm <sup>a</sup>	Total Sulfur, ppb <sup>b</sup>	Methyl Mercaptan, ppb <sup>b</sup>	Higher Mercaptans, ppb <sup>b</sup>	Ethyl Sulfide <sup>c</sup> , ppb <sup>b</sup>
1	37 (avg.)	31	5	n.d. <sup>d</sup>	22
2	108 (peak)	61	11	n.d.	51
3	15 (low)	17	1	n.d.	15

<sup>a</sup> Bag number was taken at time of shown H<sub>2</sub>S concentration

<sup>b</sup> GC analysis of downstream bag samples.

<sup>c</sup> Tentatively identified and standardized by calibration with ethyl mercaptan.

<sup>d</sup> n.d. = none detected.

Odor panel analysis was performed from the scrubber discharge by a bag air sample, taken at a time when the H<sub>2</sub>S inlet concentration was measured at 37 ppm. The panel test indicated a discharge D/T ratio of 8 odor units. This sensory analysis utilized an older ASTM methodology. However, it does indicate a virtually odor-free discharge from the scrubber. This outcome from the odor panel indicates that this system did meet its goal of removing below odor thresholds and producing acceptable air quality near the pump station.

## CONCLUSIONS

There are many odor control technologies available in the marketplace. All have applications in which they have inherent advantages and cost benefits. What has been presented here are advantages and disadvantages of five odor control technologies (wet scrubbers, biofilters, engineered media, granular activated carbon (GAC), and catalytic/regenerative carbon). Wet scrubbers have been shown to be an effective choice in high air velocity and flow applications. This is because the technology can handle higher face velocities (up to 2.54 m/s). This is also due to the low chemical replacement cost when compared to other media that would be required for these flows. Dry-scrubbing technologies (engineered media, GAC, and catalytic/regenerative carbon) can be very effective at lower air velocities and have the ability to remove contaminant gases with high efficiencies. Engineered media have the advantage of being one of the lower initial cost technologies and other properties relating to their manufacture (capacities, disposal, media life analysis, UL Rating, versatility). GAC has the advantages of being a low priced media and having good affinity for high molecular weight compounds as well as being a very familiar product. Catalytic carbon has the advantages of GAC as well as the ability to be regenerated and react with some compounds that are not readily adsorbed. Biofilters have been

shown to be effective at lower air velocity regions with the ability to have long media life. They have the advantage being able to handle high loads and have a long lifetime and be versatile in application.

Cash flow analysis was performed on one biofilter application and one dry-scrubbing application. The biofilter application also employed a dry-scrubber on the outlet to take care of some organic odors. The biofiltration case was used as an example of how to perform a cash flow analysis to determine future cost of a system. It can also serve as a benchmark for cost of biofiltration on applications similar to 200 cfm and 220 ppm of H<sub>2</sub>S along with mercaptans and organic sulfides. The dry-scrubbing cash flow analysis compared two technologies that were proposed for the same application. The catalytic carbon proposal was shown to have a higher accumulated cost after 10 years than the engineered media system. This would indicate that the initial investment may not be cost effective when compared to the engineered media system. However, final choices should be based on the budgetary constraints of the plant.

Lastly, an example of how a properly designed system can work was given. Performance data on an engineered media system at a residential pump station was presented. Its ability to remove odors below the odor threshold was shown and high efficiencies were achieved.

When looking at an odor control system, many factors have to be analyzed. These are the appropriateness of the technology, the budgetary constraints of the plant, and the final ability to remove the odors. If these are determined to be acceptable, then the highest probability of odor removal success can be achieved.

## ABBREVIATIONS USED

**Table XV – Brief Definitions of Abbreviations Used**

Abbreviation	Definition
cfm:	measure of volumetric flow, cubic feet per minute.
D/T:	measure of odor intensity, dilution to threshold.
fpm:	measure of face velocity, feet per minute.
ft:	measure of length, feet.
GAC:	media type, granular activated carbon.
H <sub>2</sub> S:	hydrogen sulfide.
m:	measure of length, meter.
m/s:	measure of face velocity, meters per second.
m <sup>2</sup> /g:	measure of surface area, square meters per gram.
m <sup>3</sup> /hr:	measure of volumetric flow, cubic meter per hour.
ppb:	measure of gas concentration, parts per billion.
ppm:	measure of gas concentration, parts per million.
yd <sup>2</sup> /oz:	measure of surface area, square yards per ounce.

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