Groundwater Treatment Technologies

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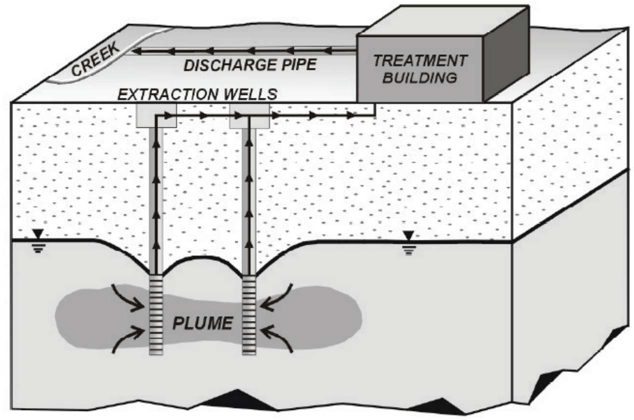
According to a recent EPA report "pump and treat" methods are the most frequently used to clean up contaminants from groundwater with monitored natural attenuation and in-situ methods being used less often.



Most often, the contaminants being cleaned up using pump and treat are volatile organic compounds (VOC's) or chlorinated VOC's. These contaminants include trichloroethene (TCE), tetrachloroethene (PCE), benzene, toluene, vinyl chloride, 1,1,1-trichloroethane, xylene and dichloroethene (DCE).

More than half of the pump and treat systems include air stripping as a treatment technology while approximately one quarter use activated carbon.

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Oil water separators remove free and dispersed, non-emulsified oils from water by exploiting the differences in the specific gravities of the product and the water. The effectiveness of the oil water separator is dependent on this difference and the size of the oil droplets present in the water.

Contaminated water enters through one end of the separator and then passes through a coalescing media. This media provides increased surface area and less turbulent flow, which allows the oil droplets to combine. The media is constructed of an oleophilic (oil-attracting) material that attracts small oil droplets to its surface. Once many droplets have combined, they become large enough that they will float to the surface of the water where they are skimmed off for recycling or disposal. The clean water passes under and over a set of baffles and into the effluent chamber where it is pumped to the next treatment step or gravity drained to a discharge point.

A similar process works for DNAPLs (Dense Non-Aqueous Phase Liquids) which are heavier than water and will sink, such as chlorinated compounds. A "V" shaped section is included in the DNAPL separator and the coalescing media allows the DNAPL droplets to combine and then sink into the V bottom where they can be either gravity drained or pumped out. The remaining water again passes through a series of baffles into the effluent chamber where it can be pumped out or gravity drained.

Advantages

Oil water separators are recommended when free product is present, particularly prior to technologies such as air strippers or adsorption media. This will help to reduce the frequency of cleaning required in an air stripper and will increase the life of the adsorption media.

Different media types are available with spacing to allow for higher sludge loading or for increased removal efficiencies. Some media are single use while others may be cleaned and re-used.

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The oil water separator can be equipped with a sludge containment section to allow for collection of solids and sediment, in some cases removing the need for an additional settling tank.

Limitations

An oil water separator cannot remove chemically emulsified oils from water although it will remove some degree of mechanically emulsified oils.

Significant amounts of solids may clog the media. This problem can be somewhat overcome by the use of a media with larger spacing, although this reduce the removal efficiency and may increase the size of the separator.

If the density of the product is very close to the density of water, a very large separator will be required.

Design Considerations

Several factors affect the design of the oil water separator: specific gravity of the oil, presence of solids, temperature, required removal efficiency and available surface area.

The separator works based on the difference in specific gravity between the contaminant and the water. When sizing an oil water separator, the specific gravity of the contaminant must be specified. Specific gravities of some typical contaminants encountered in groundwater remediation are shown below.

Contaminant	Specific Gravity
Pure gasoline	0.68
Diesel	0.88
BTEX	0.72
Trichloroethylene (TCE)	1.46
Tetrachloroethylene (PCE)	1.62

If high solids loading is expected, a sludge containment section should be included. The solids will collect in the media and fall to the bottom in much the same way that DNAPL does. If the oil and solids are expected to create a very viscous mixture, a media with larger spacing may be required to avoid clogging of the media or very frequent cleanings being required. Depending on the type of media used, it may be cleaned using high pressure water or disposed of and replaced when it becomes clogged.

Air Stripping

Air stripping transfers organics from the liquid phase to the vapor phase where they can be treated or released to atmosphere depending on local regulations. An air stripper allows the contaminants to move from the liquid to the vapor by maximizing the contact area between the water and the air to allow for mass transfer. Air strippers can consist of a simple tank with a blower bubbling air through it to packed columns and low profile tray strippers. Low profile tray strippers are the most common used in remediation due to their compact size, relative ease of cleaning and the typically low levels of contaminants present.

Low profile tray strippers operate using a counter current flow. This means that the clean air is brought in through the bottom of the stripper and discharged through the top while the contaminated water is introduced through the top of the stripper and flows by gravity through to the sump at the bottom. Each tray is perforated to allow the air to flow up through it. As the air bubbles up through the perforations, the air and water form a frothy mixture, which is where the mass transfer of contaminants from water to air takes place.

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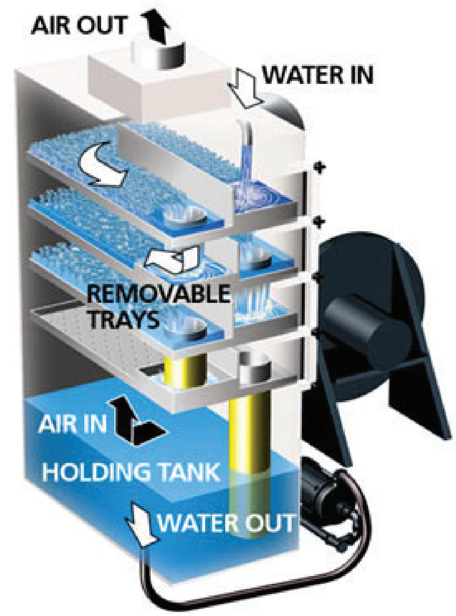
Air strippers can be used in series to improve removal efficiencies. After an air stripper, the treated water can be polished using media such as carbon or discharged. The air from the air stripper may require treatment through carbon or an oxidizer or may be discharged to atmosphere depending on local regulations.

The air stripper efficiency is determined using Henry's constant for the contaminant, which is temperature dependent. An air stripper is typically sized using a software package, such as the QED air stripper modeler.



Typical Counter-Current Air Stripper Configuration (QED EZ-Tray)

Advantages

Air stripping is a very efficient technology for reducing the levels of certain contaminants. With the Henry's Law constant given in units of atmospheres - m3/mol, air stripping is more effective the larger the number. The table below gives some average ranges for common contaminants at 20°C.

Contaminant	Henry's Law Constant (atm-m³/mol)
Benzene	0.0044
Toluene	0.005
Ethylbenzene	0.00588
Xylenes	0.00385- 0.00570
Methyl-t-Butyl ether (MTBE)	0.000503
Tetrachloroethylene	0.013
Tricholorethylene	0.007-0.008
Vinyl Chloride	0.02
Acetone	0.0000313

EPA On-line Tools for Site Assessment Calculation –Estimated Henry's Law Constant

In cases where the Henry's Law Constant is not high enough for air stripping to be completely effective at removing a contaminant, an air stripper can often be used to reduce the concentration to a level where another technology such as activated carbon can be feasible.

Limitations

Several factors can adversely affect the performance of an air stripper by increasing fouling. High levels of inorganic compounds such as iron, manganese and carbonates that are soluble in groundwater become oxidized during air stripping and precipitate out of solution. These precipitates can plug the holes in the trays, which reduces the efficiency of the stripper. The addition of oxygen through the aeration process can also create biological fouling of the stripper if certain types of bacteria are present in the groundwater.

Sequestering agents and pH adjustment techniques can be used to reduce fouling of the trays. Periodic maintenance and cleaning are also required to keep the air stripper functioning at peak performance.

Sediment and solids can also foul the air stripper trays. If significant amounts of solids are expected the influent should be pre-filtered using bag filtration units.

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Design Considerations

Several items are required to properly size an air stripper: water flow rate, air and water temperature, inlet concentrations of contaminants and required discharge concentrations. For sites significantly above sea level, the altitude may also become a factor in the air stripper design.

Because of the temperature dependence of the Henry's Law Constant, heating the water prior to treatment can improve the ability of an air stripper to remove some contaminants. This is usually only practical when there is a source of waste heat such as an oxidizer or steam available on site due to the large amount of energy required to heat the water. The air temperature has a much less significant impact on the effectiveness of the stripper.

Some combinations of inlet concentrations and discharge limits will mean that additional treatment is required after the air stripper. This is usually in the form of carbon adsorbers.

Filtration

Filtration is the process of separating items by size. Filtration can be accomplished using filter bags, sand filters or membrane filters. Most groundwater remediation systems include bag filters to remove sediment and debris while membrane filters are typically used in industrial applications.

Advantages

A bag filter system can be used to protect downstream equipment or achieve required discharge limits for particulates. Bag filters actually become more efficient at filtering as they begin to clog. Once solids start to accumulate in the filter, the remaining holes become smaller. These smaller holes in turn remove smaller particles. Once the filter has trapped a certain amount of solids, the pressure drop across the filter becomes too large and the filter bag must be changed.

Bag filters are often used prior to an air stripper or carbon vessels to protect them from fouling. They may also be used after an air stripper to remove precipitates such as iron, manganese and carbonates which have been oxidized during air stripping. This may be done to reach discharge limits or to protect downstream equipment such as carbon vessels.

Limitations

Bag filters should not be used too early in the treatment system. If free product is present or if the mixture being pumped is too viscous, the filters will quickly clog and frequent change outs will be required. In this situation, the bag filter should be located after an oil water separator to remove the free product and some of the sediment.

Design Considerations

The primary considerations when designing a filtration system are flow rate, expected inlet solids levels and required removal efficiency. Bag filter systems are available in single filter and multi filter configurations and can be installed in parallel or series to achieve the required combination of flow rate and particle size removed. Filters in series usually go from a coarser screen to a finer screen to avoid plugging of filters. Pumps located upstream of the filters must be sized to pump against the backpressure of the clogged filters.

Adsorption – Organo-Clay and Activated Carbon

Adsorption using granular activated carbon is one of the oldest and most trusted means of treating contaminated groundwater. Newer media such as organo-clays are effective at removing organic contaminants not typically treated using carbon.

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In adsorption, contaminants are concentrated on the porous surface of a sorbent (for example, carbon) which reduces the concentration of contaminant that remains in the water. The contaminants stick to the surface and pores of the sorbent, which removes them from the water. This is achieved by pumping water through a media such as carbon in a fixed bed reactor. The amount of contaminant that can be held by a given volume of sorbent is determined by the balance between the forces holding the contaminant to the sorbent surface and the forces keeping the contaminant in the water. Factors such as the type of chemical, the temperature and pH of the water and the type of sorbent all affect this balance.

Activated carbon is manufactured using a two-stage process. The first stage is the “carbonization” which involves heating a material that is high in carbon such as coconut shells, coal or wood to remove the by-products such as tar and other hydrocarbons. This carbonized material is then “activated” using steam at high temperature to burn off any remaining decomposition products and create the porous structure that is needed for adsorption.

Carbon is designated by sizes such as 8x30 or 12x40. A 12x40 carbon consists of particles that will pass through a U.S. Standard Mesh Size No. 12 sieve but be retained on a U.S. Standard Mesh Size No. 40 sieve. This designation determines the particle size, the surface area and the head loss through the bed. 8x30 is the most common size used in remediation applications.

Where high solids loading is expected, the influent stream should be treated through a particulate filter such as a bag filter system prior to carbon treatment. If the solids are not removed prior to the fixed bed reactor, they will be trapped in the carbon causing a high pressure drop through the carbon vessels and necessitating early media changeouts or frequent backwashing.

Carbon and other media are generally used for low concentrations of contaminants due to the cost of replacing or regenerating the media. Vessels can be made larger for higher flow rates or for higher concentrations at low flow rates. Typically, carbon is effective when concentrations are less than 10 mg/L (10 ppm).

In some areas, activated carbon is required by regulating bodies as a final treatment step prior to discharging water.

Capital costs for a carbon system are typically low, however the operating costs can be high for systems with high flow rates or high contaminant levels.

Advantages

Activated carbon is one of the oldest and most trusted groundwater treatment technologies. It is very effective in removing contaminants such as benzene, ethylbenzene, naphthalene, toluene and xylenes.

Organo-clay is a newer media, which is most effective in removing oil, grease and other low solubility organics. Organo-clay is often used prior to carbon and can significantly increase the life of a carbon bed in applications involving oil and grease.

Media filtration systems are typically very simple requiring only the vessels, media and a pump to work. Only simple pressure monitoring and effluent testing is required to ensure the system is functioning correctly.

Limitations

In applications with high contaminant concentrations or very high flow rates, the costs of using carbon become very high as the media is spent quickly requiring replacement or regeneration.

Multiple contaminants can make the modeling of carbon usage rates difficult due to the interactions of the contaminants. If several contaminants are present, bench scale trials are often a more effective predictor of usage rates.

High levels of suspended solids (over 50 mg/L or 50 ppm) can cause fouling of the carbon and the need for frequent backwashing or changeouts. The solids should be removed using filtration prior to the carbon vessel if possible.

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Highly water-soluble contaminants such as acetone and MTBE are not easily removed using carbon and alternate means should be used to remove these compounds.

Design Considerations

When designing a media filtration system, the key components are the contaminants and the contact time needed to remove them. Contact time is determined using the size of the media vessel and the flow rate of the water to be treated and can be increased through larger vessels, series installation or splitting the flow rate through parallel vessels.

Modeling of systems is possible if there are limited contaminants. Mixtures of components can make usage calculations inaccurate and in these cases bench scale trials are a much more effective predictor of actual breakthrough times.

Carbon systems typically include two or more vessels in series allowing contaminants to continue to be removed after saturation of the lead vessel. If additional flow is required, vessels can also be configured in parallel.

Materials of construction may include poly drums, steel or fiberglass rated pressure vessels depending on the size and pressure rating required.

Metals Treatment - Activated Alumina

Originally designed for removal of arsenic from drinking water, activated alumina is an economical choice for metals removal. It is made from a highly porous form of aluminum oxide which gives it the ability to adsorb a large number of contaminants.

Activated alumina is used for the removal of contaminants such as arsenic, lead, fluoride, chromium, zinc, iron and phosphates.

Activated alumina is placed in the same vessels as carbon and can be used after carbon in a water treatment system. Activated alumina vessels may also be placed in series or in parallel depending on the needs of the system.

Advantages

Activated alumina is an effective way to reduce metals concentration for specific contaminants as shown in the table below. The media can be disposed of in landfill.

Parameter	Units	EQL	Outlet of OWS (Influent)	After Filtral Vessel
Dissolved Trace Metals				
Barium	mg/L	0.003	0.232	0.0865
Beryllium	mg/L	0.0002	<0.0002	<0.0002
Cadmium	mg/L	0.001	<0.002	<0.002
Cobalt	mg/L	0.003	0.011	0.003
Chromium	mg/L	0.0007	0.002	0.0007
Copper	mg/L	0.0005	0.0012	<0.0005
Molybdenum	mg/L	0.006	0.016	0.012
Nickel	mg/L	0.002	0.008	0.002
Lead	mg/L	0.006	<0.006	<0.006
Titanium	mg/L	0.006	<0.008	<0.008
Thallium	mg/L	0.05	<0.05	<0.05
Vanadium	mg/L	0.002	<0.001	<0.001
Zinc	mg/L	0.006	0.218	<0.006
Dissolved Major Metals				
Iron	mg/L	0.002	0.748	0.157
Manganese	mg/L	0.0008	2.73	1.91

Limitations

Bench scale testing is the most effective method of determining the effectiveness of activated alumina. Typical contaminants can be ranked based on selectivity of the activated alumina, however the concentrations and characteristics of the water significantly affect the driving forces of adsorption. This reduces the ability to predict the actual performance of the media.

Activated alumina will adsorb VOC's and should therefore be placed after carbon in a system.

Design Considerations

Design considerations of an activated alumina system are similar to those of other media described above.

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