Advice & Counsel

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That Lump of Coal - Part 6

Dear Advice & Counsel,
My company has asked me to look into recycling our treated wastewater back to our plating lines. While I think I have a handle on the basics, like TDS reduction using ion exchange, I'm not sure I know enough about organics removal using carbon. Can you shed some light on this topic?

Signed,
Fusili Carbonera

Continuing our series of articles on the subject of carbon treatment of wastewater:

Pulsed/moving bed systems

When high wastewater flow rates and/or high organic concentrations need to be treated, a fixed bed system typically uses too much carbon or requires too frequent shut-down and carbon replacement. In such cases, a pulsed or moving bed system is employed instead.

In these systems, the raw wastewater to be treated is pumped into the bottom of the carbon column and then, under pressure, travels upward through the carbon and out at the top of the vessel. A system for adding virgin or regenerated carbon at the top of the vessel and removal of spent carbon from the bottom is part of the technology. If the carbon is removed continuously, the system is called a moving bed system. If a portion of the carbon is removed and replaced periodically (every four to eight hours or daily), the system is termed "pulsed." In either case, the carbon-containing vessel is typically totally filled with carbon (no free-board for expansion of the carbon).

Since the most saturated carbon is removed from the bottom on a continuous or periodic basis, such systems utilize carbon efficiently and come close to a steady state condition, yielding consistent water quality. These types of carbon treatment systems are less prone to fouling by suspended solids/colloids than fixed bed downflow systems because the upward flow tends to expand the carbon bed (while downflow tends to compress it).

Carbon consumption for pulse and moving bed systems can vary significantly based on equipment design and application. Reported usage ranges from 400 to 1800 pounds per million gallons of treated water.

Pulsed systems are undesirable in cases where the raw wastewater may contain organisms that can take "residence" within the chamber (since the median residence time of carbon within the vessel is comparatively long. These systems also do not tolerate solids very well, as the chamber is completely filled with carbon, providing little room for expansion.

Single vs. multiple columns

Carbon columns can be used as solitary systems or can be plumbed for series, parallel or combinations of series plus parallel flow. When carbon usage rates are low and the mass transfer zone is relatively short, a single column is often specified. Sometimes financial constraints force the use of a single column, as the plumbing is less complex and the system is easier to maintain.

In cases where a single column poses too many process interruptions for carbon replacement, or when a single column requires too tall a column to fit in a given space, multiple column systems are specified. Use of multiple columns also allows for flexibility of operation. One column can be off-line for backwashing and/or maintenance, while another is on line. A third may be employed as a stand-by or additional capacity as required. Two columns may be used in series, and then rotated as the carbon is exhausted. Other designs employ parallel columns, with a third off stream and employed during maintenance.

Carbon columns in series

To take full advantage of the adsorption capacity difference between breakthrough and saturation, several carbon beds are often operated in series. This allows the mass transfer zone to pass completely through the first bed prior to its removal from service. Effluent quality is maintained by the subsequent beds in the series.

Carbon columns are best connected in series when the saturation curve is gradual and the system must perform to the lowest levels of organics obtainable with the carbon type used.

A series connection is operated until breakthrough is detected in the first column. At that time, Column #1 is taken off-line and regenerated or re-loaded with fresh carbon. The system is plumbed so that Column #2 can now become the first column and Column #3 takes over as the "safety" column. Once the original Column #1 is re-loaded, it becomes the new Column #3.

Because the carbon is essentially used at 100% capacity, the operational costs tend to be lower for series connected columns.

Carbon columns in parallel

In a parallel column connection, each of the multiple columns takes a partial load or takes the load for part of the time. Parallel connected columns operate with smaller pumps/pipes and operate at lower pressures reducing energy consumption.

The carbon in a parallel connection is not completely consumed before a given column is taken off-line and regenerated or re-loaded. The utilization efficiency for carbon in parallel connections is therefore not as great as for series connections.

Economics

Once carbon treatment studies have been completed and bench scale testing is done, the comparative costs for different carbon column configurations and the cost of on-site regeneration versus off-site regeneration must be estimated. Construction costs include the carbon columns and instrumentation, effluent monitoring devices, carbon transport system, carbon storage tanks, carbon regeneration system (if used), influent wastewater pumps (if applicable) and backwash system. Operation and maintenance costs include the purchase of virgin carbon/regenerated carbon, electrical power to operate pumps and controls, flushing of carbon slurry piping and replacement of parts. The operational costs may also include the use of outside laboratories to cross check or monitor the effluent quality on a routine basis.

Effective maintenance of carbon adsorption systems yields well working reliable equipment and efficient removal of soluble organics from the wastewater. A routine O&M schedule following manufacturer's recommendations should be developed and implemented. This includes:

- Maintenance of backwash system as required.
- Flush carbon transport piping periodically.
- Backwash carbon frequently to minimize clogging of backwash nozzles by carbon fines.
- Maintenance of an adequate supply of carbon.
- Testing and calibration of instrumentation and controls on a routine basis.
- Maintenance of effluent quality monitoring system (TOC or COD analyzer)

While chemical regeneration of carbon is commercially available, the most common method of carbon regeneration is via thermal means. While on-site thermal regeneration is not typically performed by metal finishers, commercial facilities that can regenerate spent carbon on a contract basis are available.

Thermal regeneration of carbon

In thermal regeneration, high temperatures (800-1800°F) in the presence of carefully controlled concentrations of water vapor, flue gas or oxygen are used to convert (oxidize) organic matter within the pores of the carbon. The organic matter is converted to a gas that requires scrubbing or thermal oxidation at high temperature to comply with Clean Air Act requirements.

Up to four "stages" may be employed in a conventional thermal oxidation system:

1. In the first stage the wet carbon is dried.
2. In the second stage the bond between the organic and the carbon is broken down.
3. In the third stage, non-volatile organics are either oxidized or converted to carbon (carbonized).
4. At the highest temperatures, carbonized organics and residuals from the carburization from Step 3 are converted to gases (gasification) and expelled from the furnace.

The two most widely used thermal regeneration methods utilize rotary kiln or multiple hearth furnaces (see reference 5 for details). In a multiple hearth furnace, the spent carbon is introduced at the top and is routed through various chambers by a raking system. Each chamber is at a controlled temperature, depending on which stage of the regeneration process is being conducted. The efficiency of the regeneration is dependent on the carbon residence time and temperature at each stage. Steam may be added in certain stages to distribute the temperature more evenly within a given chamber. Steam can also reduce carbon density and increase the iodine number of the carbon.

Approximately 5 to 10% of the carbon is destroyed in the regeneration process or lost during transport and must be replaced with virgin carbon.

Due to the presence of residual ash and combustion products produced by the regeneration process, regenerated granular carbon undergoes changes in the following properties:

- Total surface area
- Pore volume
- Surface area in the small pores is reduced
- Surface area in large pores is relatively unaffected

These changes may affect the performance of an adsorption system. Regenerated carbon has an altered pore structure because it is impossible to have the carbon go through thermal temperatures employed without suffering some level of destruction. In general, the total surface area of the carbon is reduced due to losses of small pores, which typically yield high iodine numbers. As a result, regenerated carbon will typically be lower in efficacy in adsorbing smaller organic molecules.

The population of smaller pores is reduced due to the production of ash from various calcium, magnesium or iron-based mineral salts from the treated water, yielding plugging of pores containing these minerals. Incomplete oxidation of adsorbed organics due to fluctuations in residence time and hearth temperatures can leave residual organics within the smaller pores. Also, some of the small pores are themselves destroyed and converted to gas by the thermal treatment temperatures employed.

The source of carbon can also affect the performance after thermal regeneration. In general, lignite-based carbon is less changed and can be regenerated using lower temperatures and shorter residence times, but losses of carbon are higher for lignite vs. bituminous sources of carbon, yielding higher operational costs. Bituminous sources of carbon may also yield higher adsorption capacities of some organics after regeneration vs. lignite. The advantage(s) of one source over the other may be so cloudy that testing is normally used to confirm a benefit.

If at all possible, laboratory pilot tests should be done with carbon that has undergone several regenerations, not virgin carbon. Even with regenerated carbon, an equilibrium performance level is eventually reached and as long as this performance is taken into account during the design phase a viable system can be built. ***P&SF***

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