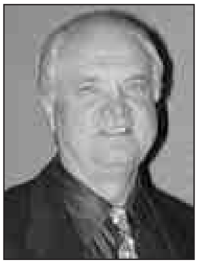

Advice & Counsel

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That Lump of Coal - Part 5

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

Over the summer, I have offered this series on carbon treatment of wastewater. Continuing our discussion:

Continuous adsorption columns

While batch treatment systems, vacuum filtration and systems employing clarifiers may be viable carbon treatment technologies, by far, the most common treatment systems are "columns" that look similar to ion exchange systems and employ granular AC. The efficacy of systems utilizing columns of carbon depends on a number of factors.

Mass transfer

As wastewater to be treated enters a column of AC, a "saturation" gradient is produced with the carbon near the entry in a state of complete exhaustion and the balance of the carbon less and less exhausted as the wastewater travels through the column (down for the down-flow column and up for an upflow column). This zone of variable saturation may be called the adsorption zone (AZ). Eventually, before the wastewater reaches the exit, the saturation level of the carbon is decreased to zero and the concentration of organic impurity removed is decreased to an equilibrium level yielding a very low concentration.

As the inflow of wastewater continues, and in the absence of fresh carbon addition, the AZ, moves through the column. At first the boundary for the AZ is near the entry but as flow continues, the boundary travels down the column of carbon and eventually would approach the exit. At some point the organics would no longer be effectively adsorbed by the column and we would find a higher than desirable level of organics in the treated wastewater (We have "break through."). Going on without regenerating the carbon in the column, we would eventually have the carbon totally saturated, and the organic concentration in the wastewater would be nearly the same at the entry and exit. The saturated capacity is that which is represented by the isotherm for a given carbon and a given set of operational conditions.

Therefore for any given length of a column of carbon, we have a time to break-through and a time to saturation.

The AZ in a given application may be calculated using the equation:

$$AZ = \frac{L\,(t_x - t_b)}{t_s}$$

where L = length of carbon column,
t_s = time to saturation
t_b = time to break-through

Of course, we would like the MTZ to be as short as possible to maximize the capacity of the AC in any given application.

Factors affecting mass transfer

A number of factors determine the shape of the exhaustion curve and the height of the adsorption zone, including column dimensions, flow rate, type of carbon employed, composition and concentration of impurities in the feed liquid, temperature and pH.

Flow rate
As one might imagine, high flow rates have a serious impact on the mass transfer zone, extending it to the point of breakthrough when not controlled to the maximum design gal/min/ft^2 cross section of the column. A typical lab test begins with a flow of 1.0 to 3.0 gal/min/ft^2 of column surface.

AC particle size
The carbon particle size can also have a significant impact. A carbon with a small median particle diameter reduces the size of the adsorption zone, while a larger particle size makes it larger. Typically particle sizes between 0.8 and 1.7 mm median particle diameter work to maintain good hydraulic flow while minimizing the size of the adsorption zone.

Competitive adsorption
In most commonly treated industrial wastewater, there is a range of organics to be removed from the raw water. Since compositions and variations in carbon properties will favor one organic over another, competitive adsorption may increase the size of the adsorption zone. Carbon may also release a previously adsorbed organic in favor of one that offers better matched adsorption characteristics. Desorption can also occur when there is a significant variation in organic concentration.

Temperature
Temperature variations typically have only negligible or mild effect on the adsorption zone in carbon treatment of industrial wastewater. The effect may be positive or negative depending on whether the reduced capacity of the carbon at higher temperature is less than or more than compensated by the increase in diffusion rates.

pH
Variations in pH may only mildly affect the size of the adsorption zone.

Proper laboratory testing of anticipated variations in organic concentrations help to determine the impact from the above parameters.

GAC carbon adsorption systems

Metal finishers typically employ simple up-flow columns or down-flow columns

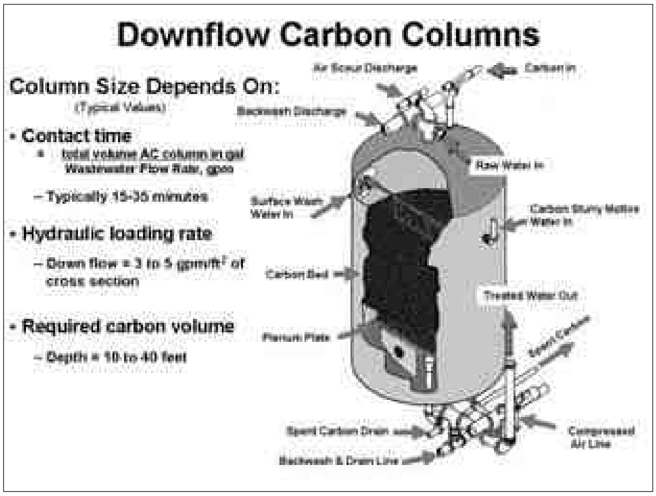

Figure 1—Schematic diagram of a downflow carbon column.

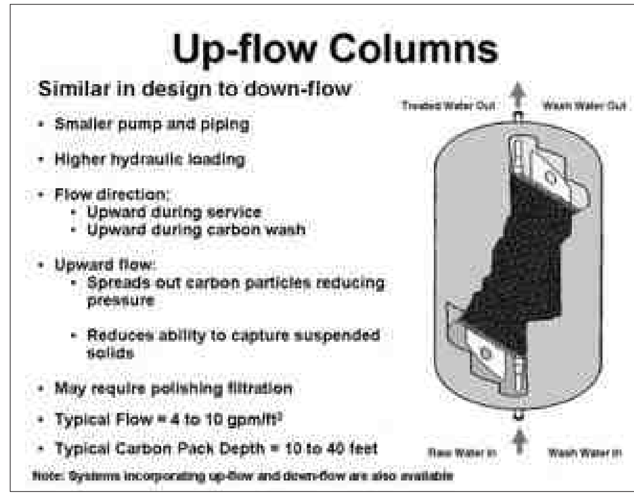

Figure 2—Schematic diagram of an upflow carbon column.

(without regeneration) either in series or parallel. Thermal regeneration systems become economically viable only when carbon consumption is more than 400 lb/day.

The vessel containing the carbon can be made of steel, stainless steel or (preferably) fiberglass. The vessel houses the selected and tested carbon, forming a "filter" bed. Carbon columns may be operated using gravity or under pressure.

In designing or choosing a carbon treatment scheme, variations in flow or concentration, any future changes in requirements and the impact of repeated regeneration upon the performance of the carbon must be taken into account.

Fixed bed down-flow

The hardware used for carbon adsorption falls into two categories, fixed bed and moving bed. A fixed bed down-flow column is the most commonly employed for removal of organics from treated wastewater at metal finishing plants. The carbon in such a column is held in place using a plenum plate (Fig. 1). An underdrain system at the bottom of the column is used to route the treated wastewater out of the column and remove spent carbon as well. Wastewater enters at the top of the column, flows through the carbon bed and is withdrawn at the bottom.

Fixed bed down-flow columns are typically equipped with backwash and surface wash options. Back and surface wash systems allow for the cleaning of suspended solids that can foul the carbon and increase operational pressures to excessive levels. These systems may be pressurized or may flow by gravity. A typical system includes the carbon vessel, plumbing, pumps and a backwash system to clean up fouled carbon.

Down-flow columns can tolerate suspended solids better than upflow units, since the finer carbon tends to reside in the top layer of the carbon bed, and the carbon tends to pack together during service. The pumps and associated plumbing needs to be large enough to provide enough pressure to overcome the added burden of the accumulated solids in the bed. Otherwise the system will backwash too often, creating too large a volume of backwash water and too frequent service interruptions.

All carbon columns must be designed for removal and replacement of spent carbon, unless the system is so small that the columns are taken into and off line for off-site disposal or regeneration. In larger systems such as the one shown schematically in Fig. 1, spent, regenerated and virgin carbon is transported hydraulically as a water slurry.

Should the treated water approach quality limits (TOC analysis or continuous monitoring), the spent carbon is removed and disposed of or regenerated.

The size of downflow carbon columns is based on contact time, hydraulic loading rate, carbon bed depth and the number of columns required. The correct contact time depends on the adsorption rate for the organic-carbon combination in the column. The contact time is calculated by dividing the total volume of the activated carbon bed by the liquid flow rate. Contact time is usually expressed in minutes, and typical values are 10 to 35 minutes.

Downflow columns utilize hydraulic loading rates of around 3 to 5 gal/min/ft^2 of column cross section while upflow columns typically operate at 4 to 10 gal/min/ft^2. The depth of the carbon typically is 10 to 40 feet depending on the designed carbon contact time.

Upflow columns

A typical upflow column (Fig. 2) is similar in design to a downflow column, in that the equipment includes a carbon vessel, plumbing, pumps and a wash system to clean up fouled carbon. Upflow columns utilize smaller pump and piping. Upflow columns operate under pressure and can handle higher flow rates than downflow columns of the same size. The flow direction is upward during service and during the wash cycle. The upward hydraulic flow tends to prevent packing of the carbon, thereby reducing operating pressure but also reducing the ability to capture any suspended solids. When properly employed, upflow systems go into the "wash" cycle fewer times, producing less wash water. When the effluent is too turbid, due to the presence of solids, polishing filtration may need to be added.

Upflow-downflow fixed bed systems

There are proprietary systems designed to take advantage of down-flow and up-flow systems, while minimizing the disadvantages. One example uses a dual upflow "roughing" column and a downflow "polishing" column. As the first column becomes saturated, both are taken off line and the upflow column is regenerated or re-packed with virgin carbon. The column that was used in downflow mode becomes the "new" upflow column.

More next month. *P&SF*