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## **How Activated Carbon Influenced the Development of SigmaPure Technology**

*Disclaimer - This document has been prepared to help explain how activated carbon had a positive influence on the conceptual design and development of the SigmaPure System. It is not intended to besmirch any particular product manufactured, or distributed by any particular company, or used by any particular customer of the aforementioned manufacturers or distributors. Further, it is not intended to cause any particular company currently using activated carbon to stop its use or reduce its usage of activated carbon. The facts presented are, in part, drawn from public information, but also include the author's personal experiences and opinions.*

Activated carbon is a wonderful substance. It is a substance, whose function is quite literally full of wonder. Activated carbon is a very general adsorbent. Its adsorptive selectivity is only generally understood, and follows like guidelines. According to the *CRC Handbook of Activated Carbon Adsorption*, Jerry R. Perrich editor, the following general adsorption guidelines govern activated carbon's functionality.

### **Table 3 INFLUENCE OF MOLECULAR STRUCTURE AND OTHER FACTORS OF ADSORBABILITY**

1. An increasing solubility of the solute in the liquid carrier decreases its adsorbability
2. Branched chains are usually more adsorbable than straight chains; an increasing length of the chain decreases solubility
3. Substituent groups affect adsorbability:

*Substituent group* - Nature of influence

*Hydroxyl* - Generally reduces adsorbability; extent of decrease depends on structure of host molecule

*Amino* - Effect similar to that of hydroxyl but somewhat greater; many amino acids are not adsorbed to any appreciable extent

*Carbonyl* - Effect varies according to host molecule; glyoxylic are more adsorbable than acetic but similar increase does not occur when introduced into higher fatty acids

*Double bonds* - Variable effect as with carbonyl

*Halogens* - Variable effect

*Sulfonic* - Usually decreases adsorbability

*Nitro* - Often increases adsorbability

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*Aromatic rings* - Greatly increases adsorbability

4. Generally, strong ionized solutions are not as adsorbable as weakly ionized ones (i.e., undissociated molecules are in general preferentially adsorbed)
5. The amount of hydrolytic adsorption depends on the ability of the hydrolysis to form an adsorbable acid or base
6. Unless the screening action of the carbon pores intervene, large molecules are more sorbable than small molecules of similar chemical nature; this is attributed to more solute carbon chemical bonds being formed, making desorption more difficult
7. Molecules with low polarity are more sorbable than highly polar ones

These general guidelines are based on water as the continuous fluid. They hold true, to varying degrees, for any aqueous solution. Other factors that influence adsorbability include: solubility, ionization, temperature, competing solutes. Increases in each factor inhibit or reduce adsorbability.

So, the physical chemistry of activated carbon demands that its function isn't ill defined. By nature it simply doesn't adsorb any particular chemical compounds specifically, or consistently. Further, its inconsistency varies with fluctuations in the application variables (process and fluid).

Will it remove formic acid, or the acid salt, from a 25% DEA solution that has been being used as a sweetening solvent of 2 years? The answer is: yes, probably, maybe, it might, test it and see, no, or all of the above. If it does and the conditions change, it might stop. If it doesn't and the conditions change, it might start. The length of time it functions will also vary with conditions, the amount, and type of carbon present.

As an adsorbent, it is normally used in a fixed bed format. Fluids are passed up or down through the bed to cause contact between the fluid, the contaminants to be removed, and the carbon. The design of the bed is crucial to its function. General guidelines by major manufacturers are 15 minute residence time or less, and not more than 4.0 gpm/ft<sup>2</sup> fluid superficial approach rate. These guidelines are given with respect to the adsorption of contaminants.

As with any fixed bed reactor, it has mechanical sieving capabilities that depend on the nature of the activated carbon granules, bed design, immiscible contaminant nature, and fluid dynamics. Solid particles tend to migrate through the bed based on size and kinetic energy loss. Deformable particles, i.e., oil droplets, tend to be stopped mechanically, then deform around the granules based on fluid stream lines and interfacial tension. General limits for solids and immiscible liquid contaminants for activated carbon applications is <50 ppm and <10 ppm respectively.

Unfortunately, the general design guidelines for these reactors work in favor of their mechanical efficiency. Lower flow rates increase the mechanical removal efficiency. Solids plug the bed, while immiscible liquids plug the beds and mask the pores. A

properly applied activated carbon bed, in a perfect world, should never have an appreciable pressure drop increase from start to finish.

The following was taken from the ARCE website. It contains an excellent description of general carbon usage and design criteria. Although more mechanically oriented than the CRC Handbook, it does illustrate some of the application warnings listed above. Following the ARCE section is a table taken from a government study that lists some of the general findings regarding the application of activated carbon.

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### **Amine Purification**

Amine solvents such as Diethanolamine (DEA) are widely used in recirculating loops to remove Carbon Dioxide (CO<sub>2</sub>) and Hydrogen Sulphide (H<sub>2</sub>S) from natural gas. Granular activated carbon is installed to purify the recirculating amine to remove degradation products and dissolved hydrocarbons. **ARCE Systems** can supply one of our standard high pressure adsorption systems for amine purification. Some of the benefits of using this technology include:

- Ensures the gas specifications are met
- Prevention of amine foaming
- Reduced corrosion problems
- Maintains amine efficiency and plant capacity
- Reduced level of amine consumption

## **Physical Properties of Carbon**

### **Pores**

Activated carbon has a large volume of very small pores which creates a large surface area. Typical activated carbons have surface areas from 600 to 1,200 m<sup>2</sup>/g with some reported as high as 3,000 m<sup>2</sup>/g. These internal pores are classified based on size as either micropores (10 to 1,000 Å) or macropores (greater than 1,000 Å). Adsorption occurs primarily in the micropores with the macropores acting as conduits.

### **Iodine and Molasses Number**

The iodine number provides an indication of the amount of small pores in carbon. It is defined as the milligrams of iodine (I<sub>2</sub>) that are adsorbed per gram of carbon when the equilibrium concentration of the bulk saturation (C<sub>eq</sub>) is 0.02 N. It is also correlated with the surface area in pores with diameters less than

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10 Angstroms. Because iodine is a small molecule, it provides an indication of a particular carbon's capacity to adsorb smaller molecules.

The molasses number, in contrast, represents the amount of large pores in carbon. It is calculated from the ratio of the optical densities of the filtrate of a molasses solution treated with a standard activated carbon and one treated with the activated carbon in question. The molasses number can be correlated with the surface area in pores with diameters greater than 10 Angstroms. Because the color pigments in molasses are large molecules, this information provides an indication of a particular carbon's capacity to adsorb larger molecules.

For compounds which do not have published isotherms, the iodine and molasses numbers may be used as a relative guideline (not an adsorption rate) for measuring the capacity of a carbon for larger adsorbate molecules. Both the iodine number and the molasses number decrease with time as adsorption occurs.

### **Apparent Density**

The particle density (dry) increases with time as adsorption fills the particle's pores. An associated increase in apparent density, defined as the mass per unit volume of a container occupied by non stratified dry carbon, will result.

### **Corrosion**

Granular activated carbon is electrically conductive and can set up a galvanic cell which then corrodes carbon steel. The materials of construction can be selected exclusively on the basis of the corrosiveness of the fluid to be treated and the conditions used for regeneration.

## **Interference with the Adsorption Process**

### **Total Organic Carbon**

Total organic carbon (TOC) is the heterogeneous mixture of organic compounds including primarily humic substances as well as humic acid and fulvic acid. These compounds are adsorbable and reduce the capacity of the carbon to adsorb the compounds of interest. However, some of the substances which comprise TOC are non-adsorbable, resulting in the immediate appearance of TOC in the effluent (i.e. breakthrough).

### **Iron and Manganese**

Iron and manganese are known to cause fouling problems in filtration systems. Both may be oxidized by dissolved O<sub>2</sub> and precipitate within the GAC pores. Capacity loss is expected as pores become filled with oxidized minerals.

Accelerated degeneration of the carbon will also result if inorganic compounds are not removed from the carbon prior to regeneration. During successive GAC regeneration cycles, an increasing ash content may cause an accelerated degradation of the GAC structure, as indicated by decreasing iodine and molasses numbers. These changes may be attributed to the oxidation of the carbon structure which may be catalyzed by inorganic compounds such as Fe<sub>2</sub>O<sub>3</sub>, CaO, and NaO.

## Calcium Carbonate

Lime softened water or water supersaturated with calcium carbonate may result in the deposition of calcium carbonate on the GAC particle which could cement the filter grains together, cause an increase in grain size and a deterioration in water quality, or reduce the adsorptive efficiency of the GAC.

## Turbidity and Coagulants

In some cases where highly turbid water is applied directly to GAC, breakthrough may occur quickly. This has been attributed by some to coating of the GAC particles by the solids, which acts as a barrier against adsorption. It is also possible that other factors in these cases, such as competitive adsorption from background TOC, may have contributed to observed effects in these cases.

## Biological Growth

Biological growth may occur within the filter, and, over time, may plug the filter resulting in increased operating pressures and requiring more frequent backwashing. However, microbial activity may extend the bed life for biodegradable compounds. Degradation of organic substances by microbial growth on carbon may contribute to improved removal of compounds including TOC and benzene.

## Desorption

Adsorption is a dynamic and reversible process, and, as a result, desorption of contaminants may also occur. Desorption may result from:

1. Competition from more strongly adsorbing species.
2. Reduced influent concentrations, causing materials to be desorbed as a new equilibrium is established.
3. Destratification or mixing of the GAC, again causing carbon originally exposed to higher contaminant concentrations to establish a new equilibrium under a lower contaminant concentration.
4. Changes in water quality, such as pH.
5. Increases in temperature.

Desorption also has the effect of leaving additional capacity for periodic high concentrations of contaminants of incoming species.

## LIQUID PHASE CARBON SYSTEMS

### General

Liquid phase granular activated carbon adsorption (GACA) is an effective and reliable treatment method. It is considered a best available control technology (BACT) by the USEPA and is a benchmark for other remediation technologies. In order for carbon adsorption to work well, it is important that the final design incorporate both the physical and adsorption process.

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## Minimum Carbon Bed Mass

The carbon bed must have sufficient mass to remove the contaminants in the water stream. This is a function of many factors, most of important of which is the mass rate of the contaminants (i.e. concentration and flow rate). The mass rate of contaminants may be calculated from Equation 1 as shown:

$$\text{Mass Rate BTEX} \left[ \frac{\text{lbs}}{\text{day}} \right] = \sum \text{Conc.} \left[ \frac{\text{mg}}{\text{L}} \right] \cdot \text{Flow} [\text{gpm}] \cdot 0.012$$

Breakthrough is defined as the point when contaminants are detected in the effluent and generally occurs when the adsorption capacity of the carbon is approached. Equilibrium saturation, or the maximum usable life of a carbon bed, may be determined from the following:

$$\text{Equilibrium Saturation} [\text{days}] = \frac{\text{Carbon Bed} [\text{lbs}] \cdot \text{Loading} \left[ \frac{\text{lb organic}}{\text{lb carbon}} \right]}{\text{Mass Rate (BTEX)} \left[ \frac{\text{lbs}}{\text{day}} \right]}$$

A well-designed GACA vessel should have sufficient contaminant mass removal capacity to allow for continued operation for a significant period of time before a carbon bed replacement is required. Most systems are designed to operate for a minimum of three months between carbon changes. However, several factors must be considered when determining the minimum carbon bed mass such as the travel time to and from the site, the operation and maintenance budget, space constraints on the site and within the equipment shed, the negative consequences of a discharge violation, etc.

Loading is a function of many variables including pore size distribution of the carbon, the molecular size and concentration of the contaminants, flow rate, compound solubility in water, and the presence of functional groups such as chlorine substitutions or aromatic structures. The performance of carbon is predicted by the adsorption isotherm. The isotherm is a measure of the amount of soluble organic that is adsorbed per unit weight of carbon at varying concentrations at constant temperature. The data collected from batch tests may be plotted on a log-log graph to form a straight line based on the empirical Freundlich equation:

$$\frac{X}{M} = K C^n$$

or

$$\log \left( \frac{x}{m} \right) = \log k + \left( \frac{1}{n} \right) \log C$$

where,

- x = amount of contaminant adsorbed (mg)
- m = weight of carbon (g)
- c = equilibrium concentration in solution after desorption (mg/l)
- k = constant
- n = constant

Isotherms are available for pure compounds, but these do not take into consideration the dynamics of adsorption when multiple compounds are present. As a result, carbon adsorption modeling is not reliable. However, for the purposes of comparison, pure compound isotherms may be used to calculate the total loading for a system.

After determining the mass of carbon required for the system operating parameters, the volume of the GACA vessel may be calculated. The amount of granular activated carbon required to fill a column may be determined as follows:

$$\text{Carbon Bed [lbs]} = \text{Volume [ft}^3] \cdot AD \left[ \frac{\text{lb}}{\text{ft}^3} \right] \cdot 0.85$$

where AD is the apparent density of the carbon. The above equations may be combined to determine the necessary vessel geometry to allow continued operation of the system before breakthrough as shown in the following equation:

$$\text{Radius}_{\min} = \sqrt{\frac{\text{Equilibrium Saturation} \cdot \text{Conc.} \cdot \text{Flow} \cdot 0.012}{\text{Height} \cdot \pi \cdot AD \cdot 0.85 \cdot \text{Loading}}}$$

## Vessel Flow Configuration

Several adsorption vessel configurations are available including downflow, upflow, fixed-bed, fluidized-bed, pressure, and gravity. The downflow, fixed-bed adsorber is the simplest and most widely utilized design for groundwater treatment applications. The water enters the top of the vessel, is equally distributed across the carbon bed by the packed, flooded bed design, and is collected by slotted screens across the bottom of the vessel. The pressure type adsorber occupies less space and uses higher surface loading rates than gravity types. ARCE Systems offers downflow, fixed-bed, pressure rated carbon adsorption vessels.

## Hydraulic Loading

Hydraulic loading, or flux, is a measure of the volume of water flowing past a given cross-sectional area in a fixed amount of time. It is defined by the following equation:

$$\text{Hydraulic Loading} \left[ \frac{\text{gpm}}{\text{ft}^2} \right] = \frac{\text{Flow [gpm]}}{\text{Area [ft}^2]}}$$

If the hydraulic loading is too high, water will move too rapidly through the GACA vessel and, as a result, the adsorption efficiency will be reduced. Empirical data indicates that the hydraulic loading should not exceed 5 to 7 gpm/ft<sup>2</sup>. As an example, the maximum flow capacity of a 48-inch diameter GACA may be determined by rearranging the above equation and solving for the flow:

$$\text{Flow}_{\max} \text{ [gpm]} = \text{Hydraulic Loading} \left[ \frac{\text{gpm}}{\text{ft}^2} \right] \cdot \text{Area [ft}^2]$$

or

$$Flow_{max} [gpm] = 5 \left[ \frac{gpm}{ft^2} \right] \cdot \pi \cdot (2ft)^2 = 63 [gpm]$$

## Velocity

The velocity is similar to the hydraulic loading; both terms are a measure of flux. To calculate velocity, the following equation may be used:

$$Velocity \left[ \frac{ft}{min} \right] = \frac{Flow [gpm]}{Area [ft^2] \cdot 7.48 \left[ \frac{gallon}{ft^3} \right]}$$

To convert hydraulic loading to velocity:

$$Velocity \left[ \frac{ft}{min} \right] = \frac{Hydraulic \text{ Loading} \left[ \frac{gpm}{ft^2} \right]}{7.48 \left[ \frac{gallon}{ft^3} \right]}$$

Using a maximum hydraulic loading of 7 gpm/ft<sup>2</sup>, the maximum velocity is calculated to be 0.668 ft/min.

## Superficial Contact Time

Superficial contact time is defined as the volume occupied by the activated carbon divided by the water flow rate. It may be calculated from the following equation:

$$Contact \text{ Time} [min] = \frac{GACA \text{ Volume} [ft^3] \cdot 7.48 \left[ \frac{gallon}{ft^3} \right]}{Flow [gpm]}$$

For a cylindrical GACA vessel, the above equation may be reduced to the following:

$$Contact \text{ Time} [min] = \frac{Height [ft] \cdot \pi \cdot (Radius [ft])^2 \cdot 7.48 \left[ \frac{gallon}{ft^3} \right]}{Flow [gpm]}$$

The actual contact time is difficult to calculate, but is approximately one-half the superficial. Generally a superficial contact time of 10 to 15 minutes is adequate for treatment of contaminated groundwater. Longer times, however, may be required as the types of organic compounds in groundwater increase in number and concentration.

For short contact times (i.e. several minutes or less) the volume of water treated between carbon replacement increases sharply with increasing EBCT as the mass transfer zone occupies smaller and

smaller percentages of the total carbon bed. The carbon usage rate may therefore be reduced by increasing the contact time of the vessel. The incremental changes in bed volumes processed decreases as the contact time increases, so that eventually further increases in contact time yield only marginal increases in the bed volumes processed. For TOC and trihalomethanes the frequency of carbon replacement increases dramatically as the contact time decreases.

## GACA Vessel Geometry

In addition to flux and contact time considerations, the vessel geometry must be considered when designing a GACA system. The contaminant front moves through the GACA vessel in a plug flow manner. The shape of the plug is determined by many factors some of which include the type and number of contaminants, the flow rate, the adsorption rate, and the vessel geometry. If the shape of the vessel negatively alters the shape of the contaminant front, breakthrough may occur sooner than estimated. An API study determined that the optimum carbon bed height (i.e. GACA vessel height) is six feet. Using six feet as the minimum carbon bed height, 15 minutes as the minimum superficial contact time and the equations described above, the minimum cross-sectional area for a given set of conditions may be calculated from the following:

$$Radius_{min} [ft] = \sqrt{\frac{15 [min] \cdot Flow [gpm]}{6 [ft] \cdot \pi \cdot 7.48 \left[ \frac{gallon}{ft^3} \right]}}$$

Using the example of a 48-inch diameter GACA vessel and its maximum flow rate of 63 gpm, this equation indicates that, for a single GACA, the minimum vessel must be 63-inches in diameter. In order to minimize the size of the vessel while still maintaining the minimum contact time, two GACAs may be piped in series. This will double the contact time while keeping the vessel size to a minimum.

## Head Loss

Hydraulic head loss is related directly to the flow rate and inversely to the average size of the carbon particles. This may be seen in the following equation:

$$\Delta P = \frac{K \cdot \nu \cdot Q \cdot L_c}{D_p \cdot D_C}$$

where,

$\Delta P$  = Pressure Drop  $\in$  inches

$k$  = constant

$\nu$  = viscosity  $\in$  centipoise

$Q$  = Flow Rate  $\in$  gpm

$L_c$  = Bed Depth  $\in$  feet

$D_p$  = Mean Particle Diameter  $\in$  mm

$D_C$  = Column Diameter  $\in$  inches

The particle size also has a significant effect on the kinetics of the adsorption process where rates of adsorption increase with a decrease in particle size. A balance must, therefore, be reached between the

optimum particle size for maximum adsorption versus minimum head loss. Commercially available particle sizes include 8 X 16, 8 X 30, 10 X 30, 12 X 40, 14 X 40, and 20 X 40, with effective sizes ranging from 0.55 mm to 1.35 mm. ARCE Systems recommends 8 X 30 mesh carbon for most groundwater treatment applications. This grade provides a reasonable compromise between good hydraulic characteristics and higher adsorption rates. This should be evaluated for sites with unusual conditions such as high TOC, low flow rates, compounds other than BTEX, or the presence of poorly adsorbed compounds.

Reference: [http://www.frtr.gov/matrix2/section4/4\\_51.html](http://www.frtr.gov/matrix2/section4/4_51.html)

**Limitations:**

The following factors may limit the applicability and effectiveness of the process:

- The presence of multiple contaminants can impact process performance. Single component isotherms may not be applicable for mixtures. Bench tests may be conducted to estimate carbon usage for mixtures.
- Streams with high suspended solids (> 50 mg/L) and oil and grease (> 10 mg/L) may cause fouling of the carbon and may require frequent treatment. In such cases, pretreatment is generally required.
- Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels.
- Type, pore size, and quality of the carbon, as well as the operating temperature, will impact process performance. Vendor expertise for carbon selection should be consulted.
- Carbon used for explosives- or metals-contaminated ground water is not regenerated.
- Water-soluble compounds and small molecules are not adsorbed well.
- All spent carbon eventually need to be properly disposed.

**Cost:**

Costs associated with GAC are dependent on waste stream flow rates, type of contaminant, concentration of contaminant, mass loading, required effluent concentration, and site and timing requirements. Costs are lower with lower concentration levels of a contaminant of a given type. Costs are also lower at higher flow rates. At flow rates of 0.4 million liters per day (0.1 mgd), costs increase to \$0.32 to \$1.70 per 1,000 liters (\$1.20 to \$6.30 per 1,000 gallons) treated.

It is no wonder activated carbon fails to consistently remove contaminants, foam causing or not, from amine solvents. This statement is a fact that is supported by literally hundreds of publications that describe the presence, in their solvents, of soluble constituents that should have been removed by activated carbon, i.e., simple and complex amine degradation compounds, other heat stable salt precursors, and whatever the heck it is that is soluble and causes foaming (we know to be organic surfactants). Activated carbon beds are dynamic environments. Chemical compounds are adsorbed and desorbed constantly during its lifetime. Less soluble compounds are constantly taking the place of the more soluble ones. Compounds with more complex structures are doing the same with those with less complex structures. This is not to mention the immiscible liquid contaminants that should have been removed by a functioning activated carbon bed, i.e., antifoam, and free liquid hydrocarbon.

Unfortunately, it doesn't matter how much carbon is used, how slowly the fluid is treated, or how cheap it is, activated carbon will never consistently remove organic contaminants from amine solvents. It isn't the carbon's fault. It is simply the nature of the beast.

This is also simply why the SigmaPure technology was developed. The primary reasons for changing activated carbon in amine plants have been increasing heat stable salts, presence of free liquid hydrocarbon, and foaming. All three are often described, individually, as the sole reason for having carbon in amine plants. Plants have also used these three criteria to tell when the carbon was exhausted. Useable guidelines have never been given to amine plant personnel. It is easy to see why. There are no specific contaminants to test for. It might be saturated for formic acid, but not for an ethoxylated alcohol. Heat stable salts can increase without foaming. Hydrocarbon content can also increase without foaming or heat stable salts. Foaming frequently happens, even with freshly made up amine. Carbon manufacturers couldn't explain it either, they were just happy amine people recognized the need to have it in the plants.

Surfactants are responsible for solvent foaming. They are organic compounds that are soluble or insoluble in amines. They may be very, or only partially polar or ionic. Some are very low molecular weight, and some are huge. Surfactants may be branched and complex or totally aliphatic and simple in structure. They are powerful film producers, and cause foaming at extremely low concentrations. It is easy to see why they don't adsorb with any consistency to activated carbon, and have remained almost invisible to analytical methods. Surface tension studies have shown variations in surface activity in foaming versus non-foaming amines, but nobody knew precisely what was causing it. Some of the compounds that were already recognized as contaminants were identified, i.e., degradation related carboxylic acids as surface active, but not blamed for foaming.

A consistent device had to take advantage of the surfactants' tendency to form surface films. It's their way of reaching physical and thermodynamic equilibrium. Hydrophobic ends interact to form micelles in an aqueous environment. The same micelles combine at vapor liquid interfaces to form films. Turbulence at the interface or gas bubbles breaking

the surface encapsulates gas in the film and foam is formed. Unlike activated carbon's ability to adsorb these compounds, the surfactant's tendency to film is absolutely consistent. Even better, where activated carbon will waste its surface area on compounds you don't want necessarily to remove, surfactants only naturally interact with other surface active compounds and particles.

An added benefit to taking advantage of surfactants' natural tendency to film at vapor liquid interfaces is the fact that they like to stay there. This means that once carried to an interface, they will remain and concentrate.

A consistent device would provide significant vapor liquid interfacial area on which the surfactants could adsorb and film. If the vapor liquid interfaces happen to be gas bubbles moving through a sump filled with surfactant contaminated solvent, the bubbles would readily form foam at the bulk liquid surface. The only problem to overcome was providing enough area to cause intimate contact between the existing surfactant molecules and the interface. At low surfactant concentrations, actual contact between the surfactant molecules and a gas bubble would be difficult if not impossible. Surfactant concentrations that low weren't sufficient to form stable films for foam development.

The SigmaPure System takes advantage of the natural tendency for surface active molecules to film at vapor liquid interfaces by bubbling gas through a reservoir of surfactant contaminated solvent. The gas bubbles provide area for adsorption (mass transfer area). The reservoir is gently mixed to increase the probability of surfactant – interface contact. To further increase the contact probability, a continuously recirculating loop was established that provides motive fluid for an eductor. The probability of contact is further enhanced when the solvent that creates the vacuum mixes with the gas pulled in from the stripping column's vapor space. The gas bubbles are then introduced toward the bottom of the sump and cascade up through the liquid to the bulk liquid interface. The total sump volume is exposed to the cascading bubbles for a period of at least 3 minutes, and is introduced through the eductor at least twice.

Once adsorbed to the settling gas bubbles, the surfactants are deposited at the bulk liquid interface where they continue to encapsulate the gas in the form of foam, or are deposited on the surface as disassociated film. They remain at the interface until the concentration is high enough to form stable foam. In either event, the contaminating surfactants are separated from the solvent.

The surface active nature of a surfactant molecule is completely dependent on its ability to form polymeric films in order to produce foam, either in the SigmaPure System or in the plant. If they don't interact with each other, or with gas liquid interfaces, they aren't surfactants and won't produce foam.

Fortunately, most of the contaminating compounds that are targeted by users of activated carbon in amine systems are also surface active, i.e., degradation products like carboxylic acids. The compounds that inadvertently adsorb to, and waste carbon surface area are not. Those compounds are not affected by, nor do they affect the nature of the

surfactants. The SigmaPure System selectively removes only the surfactants, and doesn't waste mass transfer area on other compounds in the solvent.

The drying section of the system separates the liquid fraction of the foam from the encapsulated gas. The gas is then recycled back to the foaming column. The same gas that produced the original mass transfer area is reused to produce more mass transfer area. In effect, it is self regenerating.

In conclusion, the study of activated carbon's use in amine systems has demonstrated serious deficiencies in its ability to perform consistently. One positive aspect of these deficiencies has been a series of explanations for why field experience has been so inconsistent. Probably the most positive aspect of activated carbon's short falls in amine systems has been the recognition of the actual foam causing culprits, and the development of a system to remove them.

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Questions and comments are invited, and should be sent, in care of the author, to the addresses listed below.