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VISCOELASTIC OLEOPHILIC FILTERS: PROPERTIES AND APPLICATION IN INDUSTRY AND TERRORIST PROOFING

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Organic compounds are ubiquitous in nature and industry. Many are toxic, mutagenic or carcinogenic in addition to being oil soluble and stable. Compounds such as PCB's, PAH's, POP's, insecticides and nerve gas pose a threat to humans through industrial release or in use as a weapon. In many cases nerve agents are chemically similar to organics used in industry (i.e. insecticides). Technologies capable of treating industrial waste streams such as POP's, PAH's and PCB's are applicable to protection of people and facilities from chemical attack. This paper discusses the characteristics which are required of affinity enhancing surface modification technologies. In particular, use of curable oleophilic viscoelastic polymeric surfactant (PS) filtration systems in treatment of pernicious industrial organic pollutants and their related chemical warfare analogs is discussed and field results reviewed.

Properties Required Of Affinity Enhanced Surface Modifications

Enhancing filter media affinity for organic compounds utilizing surfactants or polymers (*enhancing agent*) has been attempted from time to time but these efforts were mostly unsuccessful due to lack of one or more of the following critical properties required of the enhancing agent.

Affinity - Material must have high affinity (greater than 99% single pass efficiency) for all the types of organic compounds present in crude oil (we use crude oil as a baseline because it is a complex cocktail of the types of organic compounds that are present in organic pollution) with the ability to bind the various components together and not allow phase separation, desorption or dissolution by solvents.

Curability - Affinity enhancing material must have the ability to permanently and integrally cure into the matrix of the filter media with total transfer of properties.

Low-pressure drop - Affinity enhancing material must not swell or otherwise occlude filter to saturation or when exposed to concentrated slugs. In the instant case this is achieved through viscoelasticity.

Binding reaction rate - Binding reaction must be instantaneous or less than 1 second. Reaction rate must be independent of contact time and contact area within operating parameters. This property allows filter units to have fixed footprint in the presence of variable flow rates and/or variable influent concentrations.

Analysis of Field Results

Tables one through three illustrate the above salient properties in typical field applications with the applicable types of pollutants. Table 1 (BTEX) illustrates the ability to permanently bond somewhat water soluble organic compounds and prevent phase separation. Figure 1 demonstrates the ability of PS filters to permanently affix pollutants without desorption. Non-PS filter would appear uniformly oily with the same amount or less pollutant. Slightly soluble compounds including BTEX, MTBE and emulsified oils tend to desorb readily from conventional sorbents such as GAC thereby requiring large volumes for removal of relatively small amounts of pollutant (i.e. 11 grams of MTBE per cubic foot of GAC).

Table 1. BTEX

	Influent	Effluent
Benzene	100ppm	< 5ppb
Toluene	100ppm	< 5ppb
Ethylbenzene	100ppm	< 5ppb
Xylenes	100ppm	< 5ppb

Filter contact time < 1 sec

Figure 1

Table 2 illustrates a very important property the lack of which results in high costs and poor operating time to maintenance time ratios in industrial settings and presents a possible way to breach anti-terrorist devices. Namely the property in question is the ability to process concentrated slugs of organic compounds without clogging, breakthrough or compromising of the filter medium. Membrane filtration devices are readily clogged and shut down when exposed to concentrated slugs of oils. Sorbant filter devices develop high differential pressures while at the same time enabling entrainment through channeling resulting in breakthrough of oily micelles. The ability of PS filters to absorb acute slugs of oil without breakthrough or significant increase of differential pressure is demonstrated by the ability to handle up to 114 g/L with less than .5 psi ΔP and below detectable limit effluent discharge.

Table 2. PCB and Organic Slugs

	Avg. Influent	Max. Influent	Effluent	ΔP (psi)
PCB	34ppm	155ppm	< 1ppb	< 0.5
Oil & Gas	1,000ppm	114,000ppm	< 5ppm	< 0.5

Table 3 illustrates the property which enables PS technology filters to maintain a fixed footprint in the presence of variable concentrations of pollutants and variable flow rates. Conventional sorbents and membrane filtration devices are dependent on time of exposure or obversely amount of surface area available for contact. Generally this means that, for instance an ultra-filtration unit capable of processing ten times the volume of pollutant will generally have to be ten times bigger. A typical example would be a 10 gpm UF unit which would cost about $100,000.00 and take up about 10 cubic feet of space. To get that unit to perform at 100 gpm the price would go up to many hundreds of thousands of dollars and the corresponding space requirement would increase ten-fold. By contrast, PS technology is invariant (within operating parameters) of contact time and its contact area requirement is fixed. Therefore the same unit is able to process 10 gpm or 100 gpm at 10 ppm or 1,000 ppm without any increase in the size of unit. The consequence is that filters must be changed over more frequently in cases of high loading rates.

Table 3 Contact Time Invariance - 500ppm Light Crude Oil

Contact Time	Influent	Effluent
1 second	500ppm	< 1ppm
5 seconds	500ppm	< 1ppm
10 seconds	500ppm	< 1ppm
20 seconds	500ppm	< 1ppm

Anti-Terrorism

Currently there is a trend by public facilities such as hospitals to try to protect themselves from potential nuclear, biological, or chemical attack (NBC). In case of such an emergency, it is critical that such places as hospitals are protected and are able to remain operating in order to respond to the contingency. The properties of PS filters reviewed above are also applicable to potential biological and chemical threats. I will not cover radiological fall-out in this paper.

Biological Attack - There are a variety of vectors through which biological attack can present itself. Here I will primarily address airborne pathogens resulting from aerosolized media. We have all currently had exposure to this type of attack with the anthrax spores which were sent through the mail. The idea behind such materials is to achieve particle size sufficiently small to maintain neutral buoyancy in air while at the same time being large enough to not be exhaled once it has been inhaled. In the case of anthrax, this is generally held to be between 1 and 5 microns. There is also an optimal range within this size range which presents maximum lethal effect. In one sense this is no more complicated than filtering out any other particulate in this size range from an air stream. However, present commercial air filtration devices do not meet the criteria required of filtration systems which can handle this size distribution. Additionally in commercial units, multiple phenomenon are involved simultaneously. Namely at the point where there is an air filter the following occurs:

- water condensation due to △P
- capture and re-release of oil mists
- capture and re-release of particulate matter

Part of the porosity of these filters is simply due to sizing (i.e. 1 micron versus 10 microns). However, even if proper size filters are used, the process of oil mists adsorption and re-micellization acts as a medium to facilitate the transfer of particulate matter through the filter. (Figure 2). Currently, filtration devices utilized to keep biological materials out are HEPA and TETA filters. Although capable in isolation of removing the particle range in question whether biological or not these types of filters are easily compromised by oil mists and other organic compounds in the above manner. Consequently, effective prefiltration of oil mists and higher molecular weight organic compounds is essential in order for biological filtration devices to work properly. The same principals apply to waterborne attack. Membranes are easily capable of removing microbes and chemicals if not compromised by oils and/or other hydrophobic organic compounds. Simulations conducted with organic oil mists similar to nerve agents demonstrate the ability of 1 gram of PS infused filter material to remove 10 grams of oil mist without breakthrough or significant △P. (Figure 3)

Figure 2

Particulate matter captured by PS prefilters

Figure 3

PS prefilter capturing oil mist

Chemical Attack - While working on pesticides in 1934, Gerhardt Schraeder, a German biochemist, discovered the toxic effects of organophosphates. Within days he was blind in one eye, his arms were paralyzed and his breathing was spasmodic. All nerve agents in pure state are colorless liquids. Nerve agents work by inhibiting acetylcholineesterase. Different nerve agents have different modes of entry. The more volatile compounds tend to be inhaled while the oilier compounds tend to form more stable aerosols and are generally absorbed through the skin. Persistent nerve agents are some of the most toxic substances known to man. In addition to conventional nerve agents, less sophisticated compounds such as mustard gas can also cause a threat. Nerve gases are all colorless oily liquids which are sparingly soluble in water and tend to be film-formers. They present an airborne and waterborne threat. Exposure to even very low concentrations is known to cause irreversible damage. Being organophosphates, nerve agents are easily hydrolyzed by alkali which forms the basis of most decontamination procedures.

One of the most dangerous of these compounds is so-called VX gas which forms a persistent aerosol micelle and has low vapor pressure. The droplets are extremely long-lived and present a persistent film which can remain on material, equipment and terrain for long periods. Mode of entry primarily dermal but inhalation of aerosol or gas also occurs. Industrially generated insecticides and other organophosphates behave physiochemically similar to nerve agents with the primary difference that oxygen is generally substituted for by sulfur in insecticides and less reactive groups than -F, -CN are used.

Polymeric surfactant filters are able to remove oily film-forming organic compounds from air and water. The properties reviewed earlier are critical in both types of applications in forming an effective barrier to protect downstream filtration and treatment devices and end users. I will review some of these properties as they relate to stopping terroristic chemical attacks.

1. Affinity - ability to permanently affix organic compound without desorption or phase separation. (liquid concentric circle and air pictures) This property maximizes effectiveness per unit weight. Even small amounts of filter material can absorb significant amounts of organic

compound without allowing any breakthrough due to lack of desorption. This is true in the case of both PS water and PS air filters.

2. $\triangle$P - the ability to absorb concentrated slugs without desorption or significant $\triangle$P is critical. Any system is likely to encounter a concentrated slug especially in the case of purposeful discharge. System shut down and maintenance is not always a desirable option.

3. Fixed Footprint - as it is difficult to gage the scale of pollutant concentration, it is important for the protective device to be able to handle a range of concentrations and flow rates without requiring additional contact time or space.

Discussion

Air - Air filtration systems must be capable of removing aerosolized particulate matter in addition to aerosolized oily micelles. These classes of materials have analogs in industry and military settings. Something not discussed in this paper of a less sinister nature certainly involves the filtration of airborne fungal spores which are ubiquitous in car and home HVAC units. Effective particulate filtration is hindered by the presence of oily organic compounds and therefore effective oil mist filtration is a requisite part of effective air filtration. Oil mist is ubiquitous whenever one moves air using air compressors or other mechanical devices which utilize oily lubricants. Effective oily mist filtration is necessary for proper operation for all downstream filtration devices. Even conventional oily mists cause significant damage and contribute to operating expenses. (Figure 5)

Figure 4

PS Water System Prefilter

Figure 5

Corroded heat exchanger from oil mist breakthrough

Water - Waterborne biologicals can be treated effectively utilizing a variety of filtration devices with the primary requisite that they be discriminating at .1 micron. These types of water filtration systems can be overwhelmed by organic compounds which can swell, dissolve or otherwise compromise the membrane or substrate allowing microbes to pass through. An inability to handle concentrated slugs or lower concentrations of corrosive organic material is an impediment to effective biological filtration. Effective prefiltration of organics enhances downstream biological and chemical filter performance.

As mentioned earlier, chemical agents tend to be film-formers and to be sparingly soluble in water. Due to their high toxicity, desorption from filter media is not an option. Nerve agents are very similar in behavior in water to materials ranging in properties from PCB's and PAH's to MTBE. A filtration device can be presented with acute slugs or with chronic low levels of pollutants and must be able to handle both without breakthrough and remain operating. PS prefilters like the one depicted in Figure 6 have extremely high affinity for organic compounds and are currently in use in secure water systems.

Conclusion

The requirements for air and water filtration devices have changed since September 11. Polymeric surfactant technology is one of many technologies being investigated to meet post-September 11 challenges.