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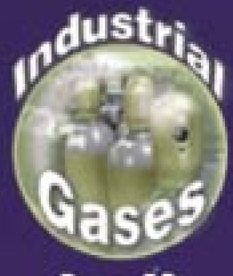

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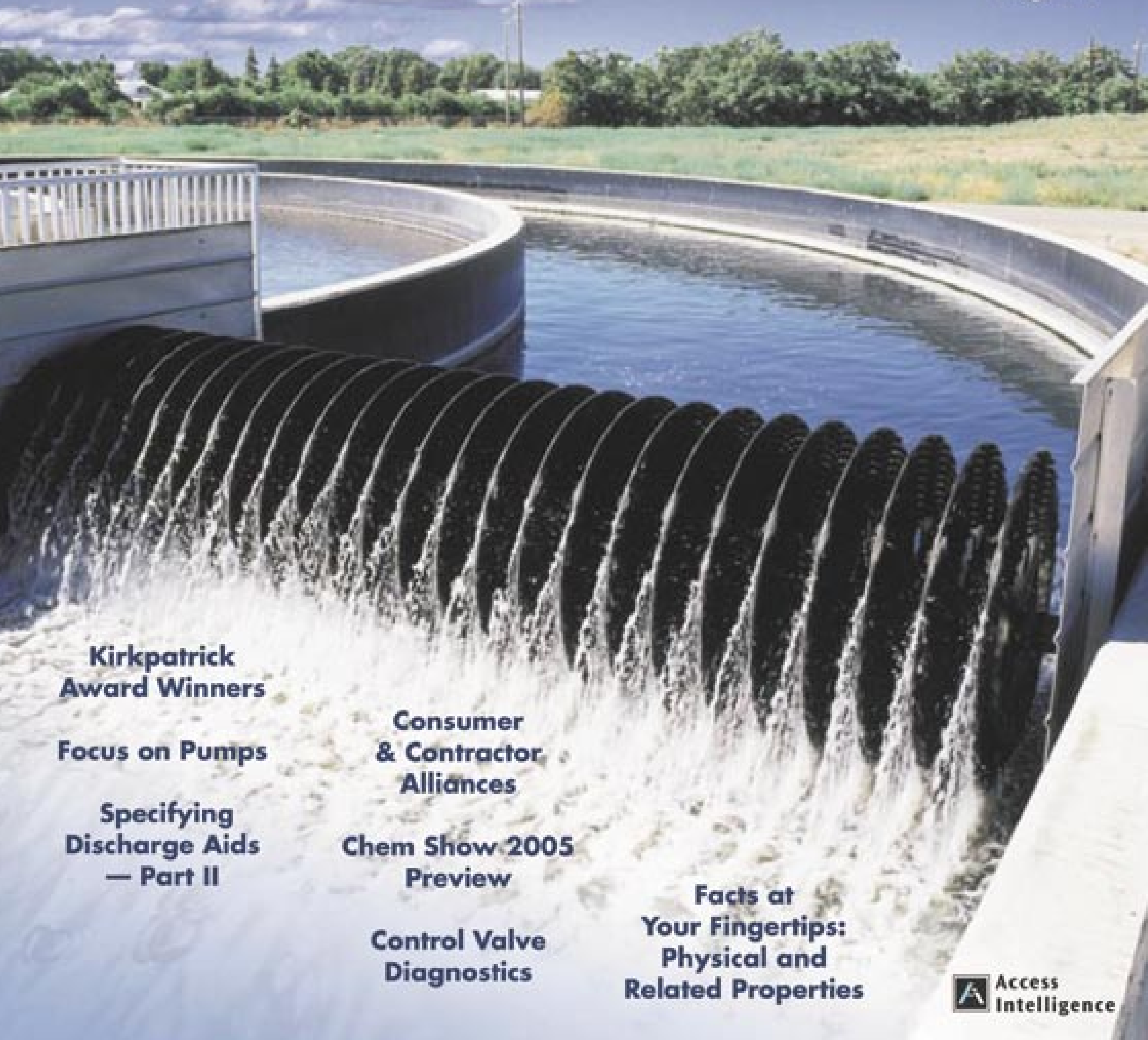

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Biological Wastewater Treatment

The use of microorganisms to remove contaminants from wastewater is effective and widespread. To choose the right system from the many options offered, understand the various techniques available and evaluate them based on your requirements

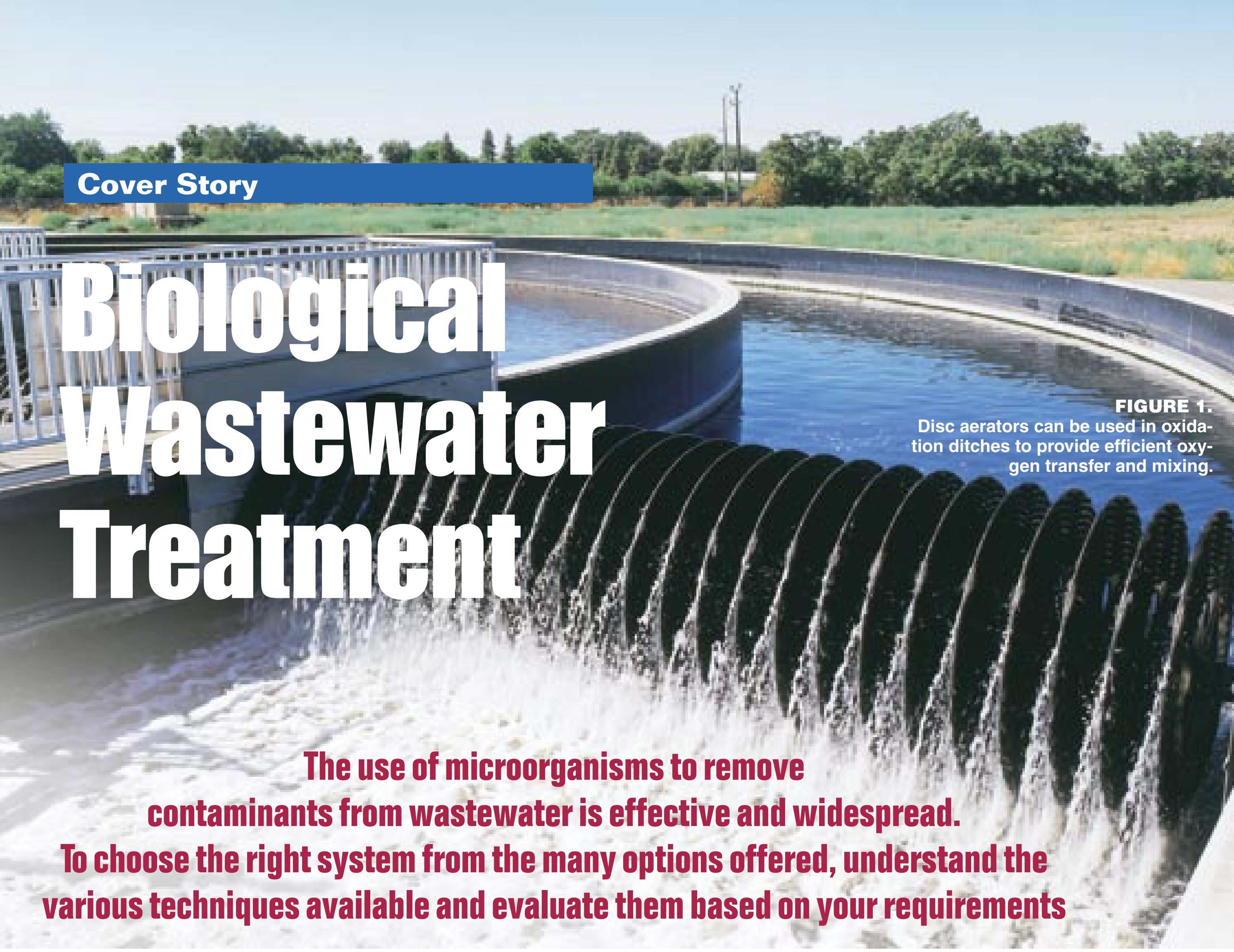

FIGURE 1. Disc aerators can be used in oxidation ditches to provide efficient oxygen transfer and mixing.

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USFilter

Biological treatment — the use of bacteria and other microorganisms to remove contaminants by assimilating them — has long been a mainstay of wastewater treatment in the chemical process industries (CPI). Because they are effective and widely used, many biological-treatment options are available today. They are, however, not all created equal, and the decision to install a biological-treatment system requires ample thought.

When considering biological wastewater treatment for a particular application, it is important to understand the sources of the wastewater generated, typical wastewater composition, discharge requirements, events and practices within a facility that can affect the quantity and quality of the wastewater, and pretreatment ramifications. Consideration of these factors will allow you to maximize the benefits your plant gains from effective biological treatment. Those benefits can include:

- Low capital and operating costs compared to those of chemical-oxidation processes
- True destruction of organics, versus mere phase separation, such as with air stripping or carbon adsorption
- Oxidation of a wide variety of organic compounds
- Removal of reduced inorganic compounds, such as sulfides and ammonia, and total nitrogen removal possible through denitrification
- Operational flexibility to handle a wide range of flows and wastewater characteristics
- Reduction of aquatic toxicity

The basics

All biological-treatment processes take advantage of bacteria's remarkable ability to use diverse wastewater constituents to provide the energy for microbial metabolism and the building blocks for cell synthesis. This metabolic activity can remove contaminants that are as varied as the raw materials, byproducts and products generated by the CPI. For a discussion of factors used to determine biodegradability of specific water compounds, see Reference [*1*].

Knowing the composition of the water to be handled is essential for planning a treatment process. In petroleum refineries, for example, excessive amounts of spent caustic can quickly overwhelm a wastewater-treatment system due to the normally high chemical oxygen demand (COD) of the spent caustic. Another issue can be a significant increase in ammonia and sulfide loads that result from upsets in the operation of sour-water strippers. These loads can, in turn, upset a biological-treatment system if it is not designed to handle ammonia and sulfide.

In addition to understanding the source and composition of the wastewa-

SELECTION CRITERIA

Biological-treatment technologies vary greatly in their strengths and weaknesses. The following are application criteria, which are normally relevant in evaluating various biological-treatment options for the CPI:

- ***Bioassay/toxicity control*** — The ability to control and minimize the impact of toxic constituents in wastewater on indicating organisms when the treated water is released
- ***BOD removal efficiency*** — The ability to remove biodegradable, organic compounds
- ***COD removal efficiency*** — The ability to remove chemically oxidizable substances that may or may not be biodegradable
- ***O&M costs*** — The cost to operate and maintain the treatment method
- ***Sludge production*** — The amount of residual biological solids generated by the biological-treatment process
- ***Sludge disposal costs*** — The cost to collect, dewater and dispose of residual sludge from the treatment method, either on-site or off-site
- ***Performance in winter and summer*** — The degree in which high or low ambient-temperatures will affect biological treatment
- ***Performance on high- and low-temperature water*** — The degree in which high and low wastewater temperature will affect biological treatment
- ***Operator attention*** — The relative amount of time required to operate the biological treatment system
- ***Upset recovery*** — The amount of time it takes for a treatment method to recover from upset conditions. Upset conditions are defined as abnormal variations in the flow or characteristics of the wastewater, which can detrimentally affect a biological-treatment system
- ***Expandability*** — The ease of expanding the treatment capacity to accommodate either an overall plant expansion or an increase in loading
- ***Nitrification Efficiency*** — The relative ease of converting ammonia contained in wastewater to nitrates
- ***VOC containment*** — The relative ease with which the biological-treatment equipment can be enclosed to contain and collect VOC emissions
- ***VOC stripping potential*** — The relative ease with which the biological-treatment system will strip volatile organic compounds from the wastewater
- ***Ease of installation*** — The total amount of time and labor required to install the treatment method
- ***Energy efficiency*** — The amount of energy used by a treatment method
- ***Ease of secondary containment*** — The ability and ease with which the treatment system can be provided with secondary containment in case of overflow, spills or leaks
- ***Space requirements*** — The area required by the treatment method ❐

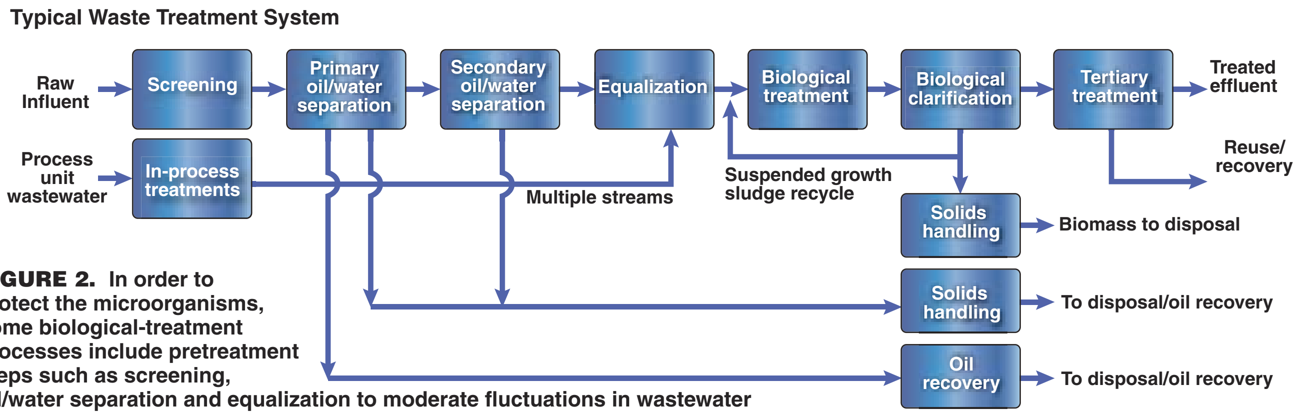

FIGURE 2. In order to protect the microorganisms, some biological-treatment processes include pretreatment steps such as screening, oil/water separation and equalization to moderate fluctuations in wastewater composition. This figure shows a schematic of a wastewater-treatment system which is typical for hydrocarbon related industries.

ter, one must also recognize when pretreatment steps are needed to provide adequate protection for a biological-treatment system. In most petroleum and petrochemical facilities, for example, raw wastewater normally contains free oil, which can have serious, detrimental effects. Oil can coat and kill bacteria, causing the microorganisms to float out of the system, and can interfere with oxygen-transfer efficiency. Another source for concern at refineries is a potential upset in desalter operations that can lead to significant oil/water emulsions in the wastewater and thereby negatively impact the biological-treatment system. To prevent these types of problems in petroleum-industry systems, process steps prior to biological treatment are normally included. Pretreatment for this industry typically includes the use of oil/water separators, an equalization tank to moderate spikes in wastewater composition, and off-spec wastewater storage. Figure 2 shows a typical wastewater-treatment system for a petroleum facility.

Even properly pretreated wastewater can still contain a wide variety of compounds which may or may not be biodegradable. There can also be significant concentrations of sulfides, ammonia, amines, mercaptans and other compounds that require modifications to the treatment process in order to meet discharge objectives. Vendors can be helpful in setting up pilot-plant or bench-scale tests to assist in determining if biotreatment is a viable option for a particular wastewater composition. The types of compounds present, the concentration of each and the ultimate discharge requirements are key to selecting a proper biological-treatment system. This is true whether the wastewater is being discharged directly to the environment or to a publicly owned treatment works (POTW), or if it is to be reused within the facility.

Once the factors discussed above have been resolved, selection from the many available options can begin. Biological-treatment methods vary widely, ranging from fixed-film technologies like rotating and submerged biological contactors to technologies like sequencing batch reactors and continuous-flow activated-sludge systems.

When evaluating the options, one

TABLE 1. EVALUATION OF BIOLOGICAL TREATMENT AND AERATION TECHNOLOGIES FOR THE CPI											
Evaluation Parameter	Trickling Filter	Rotating Biological Contactor	Submerged Biological Contactor	Disc Aeration	Surface Aeration	Fine Bubble Aeration	Coarse Bubble Aeration	Jet Aeration	Sequencing Batch Reactor *	Membrane Bio-reactor*	PACT*
Effective Bioassay/Toxicity Control				✓	✓	✓	✓	✓	✓	✓	✓
Effective BOD Removal Efficiency				✓	✓	✓	✓	✓	✓	✓	✓
Effective COD Removal Efficiency				✓	✓	✓	✓	✓	✓	✓	✓
Low O&M Costs		✓	✓								
Low Sludge Production	✓	✓	✓							✓	
Low Sludge Disposal Costs	✓	✓	✓							✓	✓
Good Operability: Winter								✓	✓	✓	
Good Operability: Summer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Good Performance: High Water Temperature	✓			✓	✓					✓	✓
Good Performance: Low Water Temperature								✓	✓	✓	✓
Minimal Operator Attention		✓	✓								
Quick Upset Recovery	✓	✓	✓						✓		✓
Easy Expandability		✓	✓								
Efficient Nitrification				✓		✓	✓	✓	✓	✓	✓
Easy to Enclose for VOC Containment		✓	✓								
Low VOC Stripping Potential	✓					✓			✓	✓	✓
Easy Installation		✓	✓		✓						
Energy Efficient	✓	✓	✓			✓					
Ease to Secondary Containment		✓	✓								
Minimal Space Requirements						✓	✓	✓	✓	✓	✓

Comparisons are made based on wastewater with a COD of 600 mg/l and BOD of 250 mg/l
* All listed technologies are products, except for sequencing batch reactors (SBRs), membrane bioreactors (MBRs) and powdered activated-carbon treatment (PACT), which are processes that can incorporate the remaining listed products. SBRs can incorporate fine-bubble, coarse-bubble and jet aeration. PACT can potentially incorporate all listed products except for trickling filters. MBRs can incorporate all listed products except for fixed-film treatment technologies like trickling filters, RBCs and SBCs.

needs to consider their effectiveness in the presence of constraints such as toxicity, COD, biochemical oxygen demand (BOD), and levels of nitrogen and sulfur compounds. Perhaps less obvious, but equally important, is to answer questions such as these:

- How will the treatment method operate in cold or warm climates?
- Can the system treat low- and high-temperature wastewaters?
- How much sludge will the treatment method produce?
- Can the system recover from upsets?
- How much will the system cost to operate and maintain, and does it require extensive operator attention?

All of these factors affect a company's bottom line and the quality of its end product. When evaluating treatment methods, it is essential to examine all of these criteria before making a technology selection (see box, p.3).

Evaluation guidelines

Table 1 is an application guide to help determine which biological-treatment technologies are most applicable for typical wastewater applications in the CPI. This table will assist in identifying the top two or three biological-treatment technologies to investigate first. Subsequent detailed applications engineering is still critical to the process, but the guide is meant to prioritize potential technologies for further analysis.

The parameters listed in Table 1 and explained in the box on selection criteria are those typically encountered when evaluating the addition or upgrade of a wastewater biological-treatment system in the CPI. Influent conditions used in the product/process evaluation are 600 mg/l COD and 250 mg/l BOD, amounts most commonly found in CPI wastewaters after appropriate pretreatment. For applications in which the influent conditions fall substantially outside of these criteria, the results in the table may not apply. In such cases, other biological processes such as anaerobic treatment and a fixed-film, fluidized-bed of activated carbon, should also be considered.

Biological treatment options

There are three basic categories of biological treatment: aerobic, anaerobic and anoxic. Aerobic biological treatment, which may follow some form of pretreatment such as oil removal, involves contacting wastewater with microbes and oxygen in a reactor to optimize the growth and efficiency of the biomass. The microorganisms act to catalyze the oxidation of biodegradable organics and other contaminants such as ammonia, generating innocuous by-products such as carbon dioxide, water, and excess biomass (sludge).

Anaerobic (without oxygen) and anoxic (oxygen deficient) treatments are similar to aerobic treatment, but use microorganisms that do not require the addition of oxygen. These microorganisms use the compounds other than oxygen to catalyze the oxidation of biodegradable organics and other contaminants, resulting in innocuous by-products.

The three individual types of biological-treatment technologies — aerobic, anaerobic or anoxic — can be run in combination or in sequence to offer

FIGURE 3. Jet aerators provide microorganisms with the necessary aeration while maintaining the suspension of biological solids without the need for additional equipment.

greater levels of treatment. Regardless of the type of system selected, one of the keys to effective biological treatment is to develop and maintain an acclimated, healthy biomass, sufficient in quantity to handle maximum flows and the organic loads to be treated. Maintaining the required population of "workers" in a bioreactor is accomplished in one of two general ways:

- Fixed film processes — microorganisms are held on a surface, the fixed film, which may be mobile or stationary with wastewater flowing past the surface/media. These processes are designed to actively contact the biofilm with the wastewater and with oxygen, when needed
- Suspended growth processes — biomass is freely suspended in the wastewater and is mixed and can be aerated by a variety of devices that transfer oxygen to the bioreactor contents

It is also possible to combine both methods in a single reactor for more effective treatment.

Fixed-film options

Biotowers (trickling filters). Biotowers, or trickling filters as they are often called, consist of a layer of media in a tank. Wastewater flowing into the biotower may have gone through an earlier treatment step to remove oil and coarse or settleable solids. Rotary distributor arms or fixed nozzles are used to spray the pretreated wastewater over the surface of the media. The water then trickles downward through the bed. Air circulates upward through the media as treated water is removed by an underdrain system. As the wastewater trickles downward through the bed, a biological slime of microbes develops on the surface of the media. Continuous flow provides the needed contact between the microbes and the organics. As the slime layer gets thicker, it occasionally sloughs off of the media surface, requiring settling to remove the sloughed biosolids.

While biotowers generally are less efficient at removal of BOD and COD than other technologies, they do generate very little sludge and have a very low potential for stripping volatile organic compounds (VOC). Low VOC stripping potential can be an advantage for environmental reasons.

Rotating biological contactors. Rotating biological contactors (RBCs) consist of vertically arranged, plastic media on a horizontal, rotating shaft. The biomass-coated media are alternately exposed to wastewater and atmospheric oxygen as the shaft slowly rotates at 1–1.5 rpm, with about 40% of the media submerged. High surface area allows a large, stable biomass population to develop, with excess growth continuously and automatically shed and removed in a downstream clarifier.

RBC systems have been installed in many petroleum facilities because of their ability to quickly recover from upset conditions. The RBC system is easily expandable should the need arise, and RBCs are also very easy to enclose should VOC containment become necessary.

Submerged biological contactors. Submerged biological contactors (SBCs), big brothers of the RBC, operate at nearly 90% submergence with coarse-bubble diffused aeration providing a means of both aeration and motive force for rotation. Because of greater submergence, the load on the shaft is significantly less than that of an RBC. The SBC also provides nearly three times the surface area of a conventional RBC per foot of shaft length.

With its compact design, the SBC is very easy to cover for VOC and odor containment. Unlike the RBC, the SBC system is driven completely by air, making it one of lowest maintenance and lowest operation-intensive, biological-treatment systems available. Like the RBC, the SBC is modular and can easily be expanded.

Suspended-growth options

Diffused aeration. Diffused aerators add air to wastewater, increasing dissolved oxygen content and supplying microorganisms with oxygen necessary for aerobic biological treatment. Fine-bubble diffused-aeration systems are available in various types including ceramic and membranes, and are highly efficient. More reliable, but less efficient, coarse-bubble aeration systems are also available, and are normally manufactured of corrosion-resistant, stainless-steel components. Both systems are compatible with new installations and replacement of existing gas-aeration equipment. Fine-bubble aerators offer very low VOC stripping potential, and both fine and coarse diffusers provide good BOD and COD removal efficiency.

Jet aeration. The jet-aeration system (Figure 3) is designed to provide required aeration as well as maintain suspension of biological solids, with the flexibility to either aerate or mix independently without the need for additional equipment. Air flowrates to the system can be varied. When aeration requirements decrease and air is completely shut off, pumps provide the required mixing action to enhance process control and save energy. The subsurface discharge leads to smooth and quiet operation, with no misting, splashing or spray from the basin. This also translates to low VOC release to the atmosphere. Since jet aeration requires no moving parts in the basin, the system offers long life with no in-basin routine maintenance required.

Surface aeration. For efficient surface aeration, high- and low-speed floating aerators provide pumping action that transfers oxygen by breaking up the wastewater into a spray of droplets. The large surface area of the spray allows oxygen to enter the wastewater from the atmosphere. At the same time, the oxygen-enriched water is dispersed and mixed, resulting in effective oxygen delivery.

High- and low-speed surface aerators offer excellent oxygen transfer and low operating costs. They are able to handle environmental extremes such as high temperatures.

Another alternative for surface aeration is the use of horizontally mounted aeration discs or rotors. These disc or rotor aerators (Figure 1) can be used in oxidation ditches known as looped, "race track" reactor configurations. They provide stable operation with resulting high-quality effluent. The aerators are above water for easy maintenance and are energy efficient. Other multichannel processes use a concentric arrangement of looped reactors, which is particularly energy efficient and designed to achieve total nitrogen removal through simultaneous nitrification/denitrification. Disc and rotor surface aerators offer good BOD and COD removal efficiencies, and are very easy to replace if necessary.

Reactors in a vertical-loop configuration are also available for surface aeration. They are essentially oxidation ditches flipped on their sides. Upper and lower compartments separated by a horizontal baffle run the length of the tank. Surface-mounted discs or rotors provide mixing and deliver oxygen. Typically, two or more basins make up the system. The first basin operates as an aerated anoxic reactor and the second basin is operated under aerobic conditions. These types of reactors also have high BOD/COD removal efficiency.

Biological treatment processes

All of the previously noted aeration technologies, both fixed film and suspended growth, can be considered treatment products. However, there are some technologies that are actually processes because they can incorporate a number of different aeration technologies in their design. These processes include sequencing batch reactors, membrane bioreactors and powdered activated-carbon treatment (PACT) systems.

Sequencing batch reactors. A variation of the conventional activated-sludge system (in such systems, a clarifier is used to settle and recycle biomass back to an aeration basin) is the sequencing batch reactor (SBR). The SBR is a fill-and-draw, non-steady-state, activated-sludge process in which one or more reactor basins are filled with wastewater during a discrete time period and then operated in batch mode. In a single reactor basin, the SBR accomplishes equalization, aeration and clarification in a timed sequence. Depending upon desired treatment objectives, the SBR can be operated in aerobic, anoxic or anaerobic conditions to encourage the growth of desirable microorganisms. Aeration in this system is typically achieved with jet aeration, fine-bubble diffused aeration or coarse-bubble diffused aeration.

One of the advantages of SBRs is good operability in the winter, making them well suited for installations in colder climates. SBRs also take up little space because all of the treatment steps take place in a single reactor basin. Additionally, since the process is controlled by microprocessors, the plant operator is given tremendous flexibility to modify the treatment scheme to match changes in influent flow and loading characteristics.

PACT systems. When conventional biological treatment alone does not meet desired treatment requirements, powdered activated carbon can be added to enhance treatment efficiency. Activated carbon can be used in most suspended-growth, biological-treatment systems. The addition of carbon allows both physical adsorption and biological assimilation to occur simultaneously. PACT systems can be operated either aerobically or anaerobically.

Using powdered activated carbon in conjunction with traditional biological treatment provides excellent effluent bioassay results, provides for toxicity control within the bioreactor, and promotes higher nitrification efficiency than that of a conventional activated-sludge system. PACT systems also provide a buffering effect to shock or upset conditions, allowing the treatment system to recover quickly or even continue treatment with little or no detrimental effects. The use of activated carbon also decreases VOC emissions and improves COD removal efficiency.

Membrane bioreactors. In addition to the traditional types of biological treatment, specialty products have also been introduced to perform more than just one treatment step. Membrane bioreactor (MBR) systems are unique processes, which combine anoxic- and aerobic-biological treatment with an integrated membrane system that can be used with most suspended-growth, biological wastewater-treatment systems.

In the MBR, wastewater is screened before entering the biological treatment tank. Aeration within the aerobic-reactor zone provides oxygen for biological respiration and maintains solids in suspension. To retain active biomass in the process, the MBR relies on submerged membranes rather than clarifiers, eliminating sludge-settling issues. This allows the biological process to operate at longer than normal sludge ages (typically 20-100 days for a MBR) and to increase mixed-liquor, suspended-solids (MLSS) concentrations (typically 8,000-15,000 mg/l in a MBR) for more effective removal of pollutants.

High MLSS concentrations and long-solids retention time promote numerous process benefits including stable operation, complete nitrification and reduced biosolids production. High MLSS concentrations also reduce biological-volume requirements and the associated space needed to only 20–30% of conventional biological processes. ■

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